Final Report

Stream Stabilization in Western Iowa

Iowa DOT HR-352

Submitted to:

Iowa Department of Transportation, Highway Division
Iowa Highway Research Board
USDA Natural Resources Conservation Service
Hungry Canyons Alliance

Submitted by:

Golden Hills Resource Conservation and Development, Oakland Iowa

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Stream Stabilization in Western Iowa

Sponsored by:

Iowa Department of Transportation, Highway Division
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Hungry Canyons Alliance

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ABSTRACT

Stream channel erosion in the deep loess soils region of western Iowa causes severe damage along hundreds of miles of streams in twenty-two counties. The loess-derived alluvial soils in the stream channels are highly susceptible to erosion resulting in bed-level degradation and subsequent bank widening. Stream channel depths and bank widths have eroded from five to ten times greater than at the beginning of the twentieth century, thus threatening the structural safety of thousands of bridges, damaging pipelines and communication lines, and resulting in the loss of productive agricultural land.

Section two of this report presents an assessment of stream channel conditions from aerial and field reconnaissance conducted in 1993 and 1994 and a classification of the streams based on a six stage model of stream channel evolution. A Geographic Information System is discussed that has been developed to store and analyze data on the stream conditions and affected infrastructure and assist in the planning of stabilization measures.

Section three of this report presents an evaluation of two methods for predicting the extent of channel degradation. The first method is a geomorphic approach that identifies the stable reach of a stream and graphically projects the longitudinal profile upstream into the degrading reach to estimate the future amount of degradation. The second method evaluated is an analytical iterative process of balancing applied tractive force with erosion resistance.

Section three also discusses the application of grade control structures; a counter measure to the threat of damage to infrastructure from channel erosion. A planning procedure for identifying the most effective location for and height of grade control structures is presented along with an economic analysis of currently used grade control structures.

Section four of this report presents an estimate of costs associated with damages from stream channel erosion since the time of channelization until 1992. The estimated damage costs to highway and railroad bridges, pipelines, telephone, electric, and rural water lines, and lost agricultural land of five streams were used to estimate the total costs of 155 eroding streams in western Iowa. The estimated time neutral cost of the 155 streams is $174.9 million. The estimated time value cost, which recognizes the time value of money, is $1.1 billion. Damage to highway bridges represent the highest costs associated with channel erosion, followed by railroad bridges and right-of-way; loss of agricultural land represents the third highest cost.

An estimate of costs associated with future channel erosion on western Iowa streams is also presented in section four. Four streams and their tributaries were examined in detail. A predictive model together with field data were used to estimate future stream widening. The costs associated with future damages to public and private infrastructure and land voiding resulting from predicted stream widening were then estimated. The results from these four streams were generalized to 102 actively

eroding streams and their tributaries. The time neutral future costs are estimated at $177.3 million. The time value future costs are estimated at $70.1 million.

Section four also presents a procedure to estimate the benefits and costs of implementing stream stabilization measures. The procedure is applied to evaluate the benefits and costs of installing a grade control structure on Keg Creek in Pottawattamie County. The procedure uses models to predict future stream-bed degradation and widening. Benefits of channel stabilization are estimated in terms of the avoidance of damages to infrastructure and lost farmland which would have occurred due to continued channel erosion. The estimated costs are those associated with installation of the selected stabilization measure. The analysis of the Keg Creek site resulted in a benefit-cost ratio of 1.49.

Section five of this report presents information on the development of the organizational structure and administrative procedures which are being used to plan, coordinate, and implement stream stabilization projects and programs in western Iowa. The Degrading Streams Task Force, comprised of representatives from eight counties in southwest Iowa, provided the initial structure and procedures to address the problem of stream channel erosion. Efforts of the Task Force led to the formation of a non-profit organization called the Hungry Canyons Alliance in 1992. The Alliance, which consists of 21 western Iowa counties, formalized the structure and procedures established by the Task Force. They worked successfully to achieve authorization of the Loess Hills Development & Conservation Authority in the Iowa Legislature in 1993. Membership in the Authority is comprised of county supervisors, county engineers, soil and water conservation district commissioners, and interested people from a twenty-two county area. The Authority plans and carries out projects related to stream channel erosion with technical and financial support from federal, state, and local agencies.

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1.0 INTRODUCTION

1.1 Goal and Objectives

The stream channels of the deep loess soils region of western Iowa are undergoing dramatic changes. The loess-derived alluvial soils in the stream channels are highly susceptible to erosion resulting in bed-level degradation and subsequent bank widening. Since the turn of the century many western Iowa streams have deepened and widened many times their original channel dimensions. A portion of Walnut Creek in eastern Pottawattamie County has increased in depth from 2.1 meters (7 ft) in 1945 to 9 meters (30 ft) in 1993. Bank widths along this reach have widen from 6.3 meters (21 ft) in 1945 to 30 meters (100 ft) in 1993. Similar erosion is occurring along hundreds of miles of streams in twenty-two counties in the region. The channel erosion has resulted in severe damage to the transportation and communication infrastructure including bridges, pipelines, and fiber-optic lines; and the loss of productive agricultural land. Due to the extent and severity of damages there has been an unprecedented willingness of people and organizations to work together to address stream channel erosion in western Iowa.

The goal of this project is to develop information, systems, and procedures for use in making resource allocation decisions related to the protection of transportation facilities and farmland from damages caused by stream channel erosion. The objectives established to meet this goal were to: 1) develop a system that integrates information on stream conditions and infrastructure in the region, 2) develop technical guidelines for preliminary planning and cost forecasting of channel erosion countermeasures, 3) develop information on the past and potential region-wide economic impact of stream channel erosion, and 4) develop administrative procedures for the allocation of technical and financial resources for channel erosion countermeasures. The research project was begun in August of 1992, and concluded in December of 1994.

1.2 Report Organization

This report is presented in sections that address the project objectives. Section two of this report presents an assessment of stream channel conditions from aerial and field reconnaissance conducted by Golden Hills Resource Conservation and Development (RC&D) in 1993 and 1994. The development of a Geographic Information System (GIS) RC&D is discussed. The GIS is being developed to store and analyze data on the stream conditions and affected infrastructure and assist in the planning of stabilization measures. GIS maps are presented showing the classification of the aerial reconnaissance based on a six stage model of stream channel evolution.

Section three of this report presents the findings of stream stabilization research conducted by Robert Lohnes of the Iowa State University Department of Civil and Construction Engineering. An evaluation of two methods for predicting the extent of channel degradation for use in preliminary planning of countermeasures is presented. A procedure for identifying the most effective location for and height of grade control structures and an economic analysis of currently used grade control structures is also presented.

Section four of this report presents the findings of economic analysis research conducted by C. Philip Baumel of Iowa State University Department of Economics. The first part of this section presents an estimate of costs associated with damages from stream channel erosion since the time of channelization until 1992. The second part of this section (by Baumel and Lohnes) provides an estimate of costs associated with future channel erosion on western Iowa streams. The third part of this section (by Baumel and Lohnes) presents a procedure to estimate the benefits and costs of implementing stream stabilization measures. The procedure is applied to evaluate the benefits and costs of installing a grade control structure on Keg Creek in Pottawattamie County

Section five of this report presents information on the development of the organizational structure and administrative procedures which are being used to plan, coordinate, and implement stream stabilization projects and programs in western Iowa. The final section provides recommendations for future activities related to stream channel erosion in western Iowa.

1.3 Background and Study Area

Several factors appear to contribute to the severity of channel erosion in the region. Bettis (1990) reports that the western Iowa fluvial system has undergone gully and entrenched stream development followed by bed and bank stabilization several times during the Holocene (about 10,500 years ago until present). Widespread stream channelization (dredging and straightening) during this century appears to be contributing to a shortened time frame over which channel erosion is occurring. Simon (1989) reports that large scale channel modifications from 1959 to 1978 in the deep loess soils region of western Tennessee resulted in a drastic change in energy conditions and a sudden shock to the fluvial system that caused migrating knickpoints and observable morphologic changes; compared with natural stream channel adjustments that may be exceedingly slow and practically imperceptible by human standards.

The entrenched stream systems in western Iowa where channel erosion is most severe corresponds generally to the 4 meter (13.34 ft) upland loess depth contour (Bettis, 1993) on the east boundary, to the Missouri River floodplain on the west boundary. These loess depths are concentrated in three landform regions of western Iowa: Southern Iowa Drift Plain, Loess Hills, and a portion of the Northwest Iowa Plains (Prior, 1991).

Figure 1.1 shows the upland loess depth contour derived from Lohnes (1980), in combination with the landform regions of Iowa map from the Iowa Department of Natural Resources GIS data layer from 1992. Information provided by Bettis (1993), field and aerial reconnaissance conducted by Golden Hills RC&D as a part of this project, and information provided by county engineer and soil and water conservation district offices was utilized to develop an approximate area map where significant stream channel erosion is occurring in western Iowa (Figure 1.2). Exceptions may occur outside of the defined boundary.

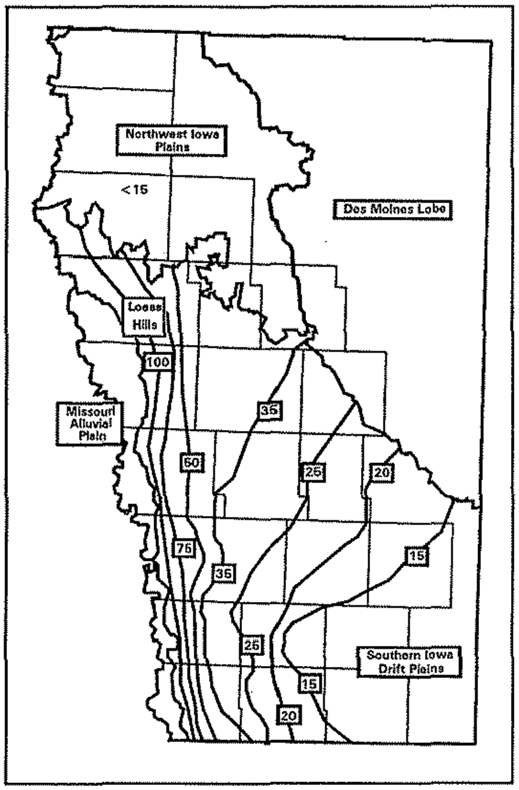

Figure 1.1. Upland loess depth contours (ft) and landform regions of Iowa after Lohnes (1980), IDNR (1992).

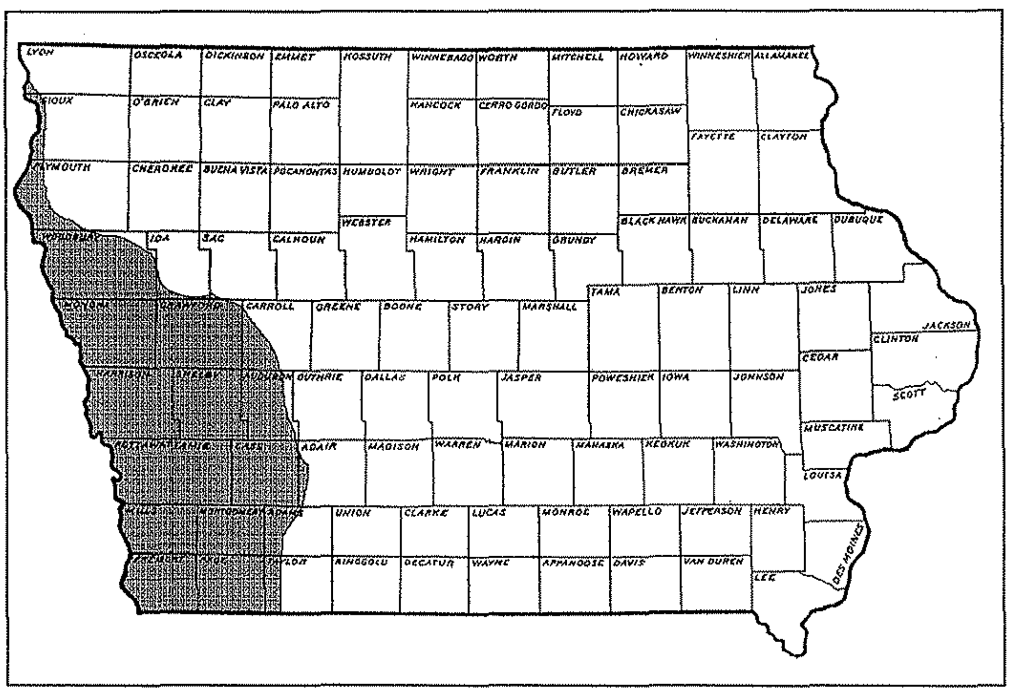

Figure 1.2. Approximate area where significant stream channel erosion is occurring in western Iowa.

1.4 Acknowledgments

Golden Hills Resource Conservation and Development wishes to express its gratitude to the following entities and individuals for their support and assistance with the research project Stream Stabilization in Western Iowa: member counties, directors, and supporters of the Hungry Canyons Alliance and Loess Hills Development and Conservation Authority, especially Russ Brandes, Bernie Bolton, Darrel Driftmier, Jerry Hare, Hubert Houser, J. Munson, Eldo Schornhorst, and Dale Wight; the Iowa Department of Natural Resources, especially Art Bettis; the Iowa Department of Transportation, especially Brad Barrett, Vernon Marks, Marlee Walton, Roger Walton; Iowa State University, especially Paul Anderson, Phil Baumel, Bob Lohnes, and Brad Levich, Jeff Magner, Landon Morris; the U.S. Army Corps of Engineers Omaha District; the USDA Natural Resources Conservation Service, especially Marty Adkins, Lyle Asell, Paul Assman, Ernie Aust, Dale Bruce, Dale Ceolla, Shelly Coon, Jeff Godwin, Mark Jensen, John Littke, Linda McVey, Dennis Miller, Jim Reel, Dave Rohlf, Jim Schneider; Roger Schnoor; and the U.S. Geological Survey, especially Andrew Simon;

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The opinions, findings, and conclusions expressed in this publication are those of the authors and not necessarily those of the Highway Division of the Iowa Department of Transportation.

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2.0 RECOMMENDATIONS FOR FUTURE ACTIVITIES

During completion of this research project, several ideas for future projects related to channel erosion in western Iowa were discussed. These include:

1. Development of a design manual for use by county engineers for stream stabilization structures.

2. Testing of the geomorphic and tractive force methods for predicting depth of degradation.

3. Modify the widening model to account for rotational as well as planar slope failures.

4. Conduct detailed field research on channel adjustment processes to verify and tie in with the reconnaissance investigation in this research project.

5. Conduct detailed studies of channel adjustment processes as related to bridges, as channel adjustment processes tend to be more severe than problems associated with local scour.

6. Conduct detailed study of existing grade control structures in the region to determine their performance and effect on stream channel erosion. Test hydrodynamic and empirical methods for predicting upstream aggradation.

7. Test recently developed widening models on the loess-derived alluvial channels of the region.

8. Compare construction of extended bridges with implementation of grade control.

SECTION TWO

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1.0 AERIAL RECONNAISSANCE

1.1 Purpose and Scope

Aerial reconnaissance was conducted in the early spring 1993 and again in spring of 1994. The purpose of the reconnaissance was to collect a video tape inventory of streams where severe channel erosion was known to be occurring and to provide a regional assessment of stream conditions. Aerial reconnaissance was conducted on 34 streams covering approximately 550 stream miles in 1993 (table 1.1). Aerial reconnaissance was conducted on 73 streams covering approximately 990 stream miles in 1994 (table 1.2). 21 of the 34 streams flown in 1993 were flown again in 1994 to provide a two year record of potential changes that may have occurred.

The reconnaissance was conducted over a wide geographic area covering the major landform regions of western Iowa, including the Missouri Alluvial Plain, Loess Hills, Southern Iowa Drift Plain, and Northwest Iowa Plains. This was done to note any significant differences in stream channel erosion in the various regions. Figure 1.1 shows the location of the streams where aerial reconnaissance was conducted in 1993. Figure 1.2 shows the location of the streams where aerial reconnaissance was conducted in 1994. Reconnaissance was conducted in 15 counties in 1993, and 17 counties in 1994.

1.2 Methods

A helicopter service from Omaha was contracted to fly the streams. Golden Hills RC&D personnel conducted the videography using a hand-held VHS video camera. The streams were videotaped through the window in the door of the helicopter. The height of the helicopter varied from 75 to 200 feet above the ground, depending on the height of obstructions such as trees and power lines. The camera was framed to capture video of the streambed, streambanks, and a portion of the adjacent floodplain.

Some streams were videotaped beginning at their mouth then upstream to the headwaters; others were videotaped beginning at a road crossing in their headwaters then downstream to their mouth. The direction of the videography was based on covering as many of the selected streams as possible on a given day.

Following completion of the aerial reconnaissance, the location of streams reaches covered by the videography were compiled on 1:100,000-scale topographic maps and then digitized for the Geographic Information System (GIS). The streams were then classified based on a six-stage model of stream channel evolution discussed in section 2.0.

Table 1.1. List of streams videotaped during 1993 aerial reconnaissance.

Aerial Reconnaissance Video Database, 1993			
Stream	**Tape #**	**Counties**	**Date**
East Boyer River	6	Craw	4.9.93
East Soldier River	3	Mono, Craw	4.8.93
East Tarkio Creek	1	Page	4.6.93
Elk Creek	3	Shel, Craw	4.8.93
Indian Creek	5	Mills, Mont	4.9.93
Indian Creek	5	Cass, Shel, Audu	4.9.93
Jordan Creek	8	Mono	5.2.93
Keg Creek	4	Shel, Pott	4.8.93
Koker Creek	6	Wood	4.9.93
Little Sioux River	6	Wood	4.9.93
Long Branch	3	Shel	4.8.93
M. Nodaway River	9	Adam, Adai	5.2.93
McElhaney Creek	6	Wood	4.9.93
Middle Silver Creek	8	Pott	5.2.93
Middle Soldier River	4	Craw, Mono	4.8.93
Middle Willow Creek	7	Craw	5.2.93
Moser Creek	3	Shel, Craw	4.8.93
Mosquito Creek	3	Pott, Harr, Shel	4.8.93
Ninemile Creek	9	Adai	5.2.93
Plum Creek	1	Frem	4.6.93
Reynolds Creek	6	Wood	4.9.93
Rocky Run	6	Craw	4.9.93
Silver Creek	2	Mills, Pott, Shel	4.6.93
Soldier River Trib	8	Mono	5.2.93
Soldier River Trib	8	Mono	5.2.93
Tarkio River	2	Page	4.6.93
W. Fk. 102 River	9	Tayl, Adam	5.2.93
W. Fk. Little Sioux R.	6	Wood	4.9.93
W. Fk. Mid Nodaway	9	Adai	5.2.93
Walnut Cr. Tributary	1	Frem, Page	4.6.93
Walnut Creek	5	Pott, Mont, Page, Frem	4.9.93
West Tarkio Creek	2	Page	4.6.93
Willow Creek	7	Harr, Mono, Craw	5.2.93
Wolf Creek	6	Wood	4.9.93

Table 1.2. List of streams videotaped during 1994 aerial reconnaissance.

Aerial Reconnaissance Video Database, 1994			
Stream	**Tape #**	**Counties**	**Date**
Allen Creek	10	Harr	4.1.94
Battle Creek	11	Ida	4.1.94
Big Creek	11	Wood	4.1.94
Big Whiskey Creek	11	Wood	4.1.94
Boyer River	7	Craw	3.23.94
Brushy Creek	9	Carr	3.31.94
Buck Creek	9	Cass	3.31.94
Coon Creek	11	Wood	4.1.94
Cooper Creek	6	Frem	3.18.94
Davids Creek	9	Audu	3.31.94
Deer Creek	6	Frem, Mill	3.18.94
East Boyer River	8	Craw, Carr	3.23.94
E. Br. W Nishnabotna	9	Pott, Shel	3.31.94
E. Fk. Wolf Cr.	11	Wood	4.1.94
E. Nishnabotna River	9	Carr, Audu, Cass	3.31.94
E. Nodaway River	4	Page, Tayl, Adam	3.16.94
E. Soldier River	10	Mono, Craw	4.1.94
E. Tarkio Creek	4	Page	3.16.94
Elk Creek	7	Harr	3.23.94
Elk Creek	8	Shel	3.23.94
Elk Creek	10	Mono	4.1.94
Elliot Creek	11	Plym, Wood	4.1.94
Elm Creek	11	Burt Co. Ne.	4.1.94
Emigrant Creek	10	Craw	4.1.94
Farm Creek	1	Mill, Pott	3.15.94
Fisher Creek	6	Frem	3.18.94
Graybill Creek	2	Pott	3.15.94
Honey Creek	6	Frem	3.18.94
Indian Creek	2	Mill, Mont	3.15.94
Indian Creek	10	Shel, Cass	3.31.94
Jordan Creek	1	Pott	3.15.94
Jordan Creek	10	Mono	4.1.94
Keg Creek	1	Mills, Pott	3.15.94
Little Walnut Creek	2	Pott	3.15.94
Long Branch	9	Shel	3.31.94
M. Br. W. Fk 102 River	4	Tayl	3.16.94
Maple River	11	Mono, Wood, Ida	4.1.94

Table 1.2. List of streams videotaped during 1994 aerial reconnaissance (cont.).

Stream	Tape #	Counties	Date
McElhaney Creek	11	Wood	4.1.94
Middle Silver Creek	1	Pott	3.15.94
Middle Soldier River	10	Craw	4.1.94
Mill Creek	6	Frem	3.18.94
Mill Creek	7	Shel, Harr	3.23.94
Moser Creek	7	Shel	3.23.94
Mosquito Creek	3	Harr, Pott, Shel	3.15.94
Mud Creek	3	Mill	3.16.94
Mud Creek	11	Wood, Plym	4.1.94
Neele Branch	4	Page	3.16.94
North Picayune Creek	7	Harr	3.23.94
Paradise Creek	7	Craw	3.23.94
Picayune Creek	7	Harr	3.23.94
Pigeon Creek	10	Harr, Pott	3.31.94
Pony Creek	6	Mill	3.18.94
Rush Creek	10	Mono	4.1.94
Sevenmile Creek	5	Mont, Cass	3.16.94
Silver Creek	1	Pott, Mills	3.15.94
Snake Creek	4	Page	3.16.94
Soldier River	10	Mono	4.1.94
Tarkio River	4	Page, Mont	3.16.94
Troublesome Creek	9	Cass, Audu	3.31.94
Turkey Creek	5	Cass	3.16.94
W. Br. W. Fk.102 River	4	Tayl	3.16.94
W. Fk. 102 River	4	Tayl	3.16.94
W. Fk. Little Sioux	11	Wood	4.1.94
W. Fk. W. Nishnabotna	8	Pott, Shel	3.23.94
W. Mill Creek	3	Page	3.16.94
W. Nishnabotna River	8	Carr, Shel	3.23.94
W. Tarkio Tributary	3	Page	3.16.94
Walnut Creek	2	Pott, Mont,	3.15.94
Waubonsie Creek	6	Mill, Frem	3.18.94
West Tarkio Creek	3	Mont, Page	3.16.94
Willow Creek	7	Harr, Mono	3.23.94
Willow Creek	8	Shel	3.23.94
Wolf Creek	11	Wood	4.1.94

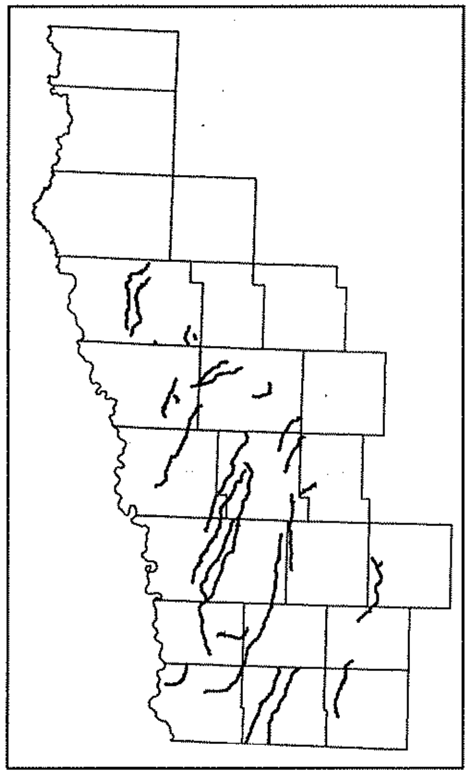


Figure 1.1. Streams covered by aerial reconnaissance in 1993.

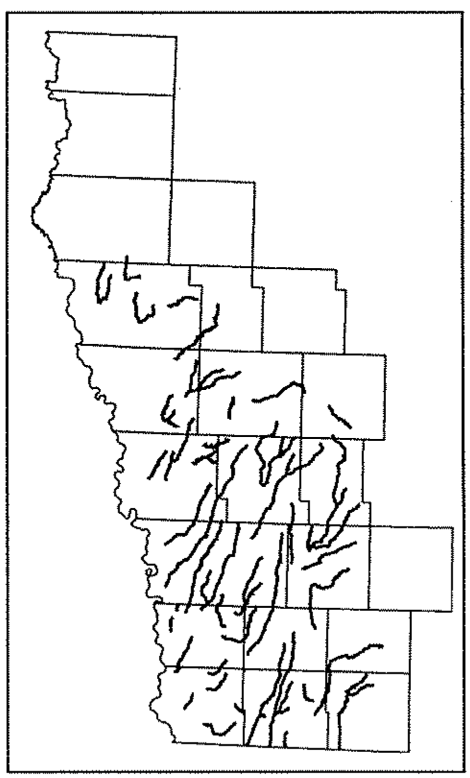


Figure 1.2. Streams covered by aerial reconnaissance in 1994.

2.0 ASSESSMENT OF CHANNEL STABILITY

2.1 Stream Channel Evolution Model

A method of classifying the aerial reconnaissance video was needed to help interpret the processes occurring in the stream channels. This information would be useful in planning potential channel erosion countermeasures. Several models have been developed to describe the stages of channel adjustment that occur in entrenched fluvial systems, including Watson, et. al., (1988), Schumm, et. al., (1984), and Simon, (1989). These models were based on studies conducted in the deep loess region of Mississippi (Watson, et. al., 1988, Schumm et. al., 1984), and Tennessee (Simon, 1989). The adjustment processes of the fluvial systems of these regions are very similar to those occurring in western Iowa (Bettis, 1993, Simon, 1994). Therefore the use of these models is appropriate in classifying western Iowa's streams.

During review of the aerial reconnaissance video tape, Simon's (1989) six stage model of channel evolution was selected for classifying the streams. The model seemed to most appropriately describe the dominant channel processes occurring in the stream channels of western Iowa.

2.2 Simon's Six Stage Model of Channel Evolution

Simon (1989) noted that the channelization of alluvial channels in western Tennessee caused a series of morphologic changes along the modified reaches and tributaries. The model Simon (1989) developed to describe the adjustment phases following modification of the channels is characterized by six process-orientated stages of morphologic development: premodified, constructed, degradation, threshold, aggradation, and restabilization. Table 2.1 describes the dominant processes, characteristic forms, and geobotanical evidence of the six stage model of channel evolution.

Bank slope development during the specific stages provide visual clues of the dominant channel processes occurring in the channel. Figure 2.1 provides a visual representation of bank slope development occurring during the specific channel evolution stages. These visual clues were an important component during the classification of the aerial reconnaissance video.

2.3 Classification of Aerial Reconnaissance Video

Following completion of the aerial reconnaissance and digitizing of the stream reaches covered by the reconnaissance (described in section 1.2), the streams were classified based on the six-stage channel evolution model described above. Other characteristics of the stream channels were also noted including location of bedrock outcrops, significant knickpoints, and grade control structure locations.

Table 2.1. Stages of channel evolution from Simon (1989).

No.	Stage Name	Dominant processes: Fluvial	Dominant processes: Hillslope	Characteristic forms	Geobotanical evidence
I	Premodified	Sediment transport-mild aggradation; basal erosion on outside bends; deposition on inside bends.	—	Stable, alternate channel bars; convex top-bank shape; flow line high relative to top bank; channel straight or meandering.	Vegetated banks to low-flow line
II	Constructed	—	—	Trapezoidal cross section; linear bank surfaces; flow line lower relative to top bank.	Removal of vegetation (?)
III	Degradation	Degradation; basal erosion on banks.	Pop-out failures	Heightening and steepening of banks; alternate bars eroded; flow line lower relative to top bank.	Riparian vegetation high relative to flow line and may lean towards channel.
IV	Threshold	Degradation; basal erosion on banks.	Slab, rotational and pop-out failures.	Large scallops and bank retreat; vertical-face and upper-bank surfaces; failure blocks on upper bank; some reduction in bank angles; flow line very low relative to top bank.	Tilted and fallen riparian vegetation.
V	Aggradation	Aggradation; development of meandering thalweg; initial deposition of alternate bars; reworking of failed material on lower banks.	Slab, rotational and pop-out failures; low-angle slides of previously failed material.	Large scallops and bank retreat; vertical face, upper bank, and slough line; flattening of bank angles; flow line low relative to top bank; development of new flood plain (?).	Tilted and fallen riparian vegetation; reestablishing vegetation on slough line; deposition of material above root collars of slough-line vegetation.
VI	Restabilization	Aggradation; further development of meandering thalweg; further deposition of alternate bars; reworking of failed material; some basal erosion on outside bends deposition on flood plain and bank surfaces.	Low-angle slides; some pop-out failures near flow line.	Stable, alternate channel bars; convex-short vertical face, on top bank; flattening of bank angles; development of new flood plain (?); flow line high relative to top bank.	Reestablishing vegetation extends up slough line and upper bank; deposition of material above root collars of slough-line and upper-bank vegetation; some vegetation establishing on bars.

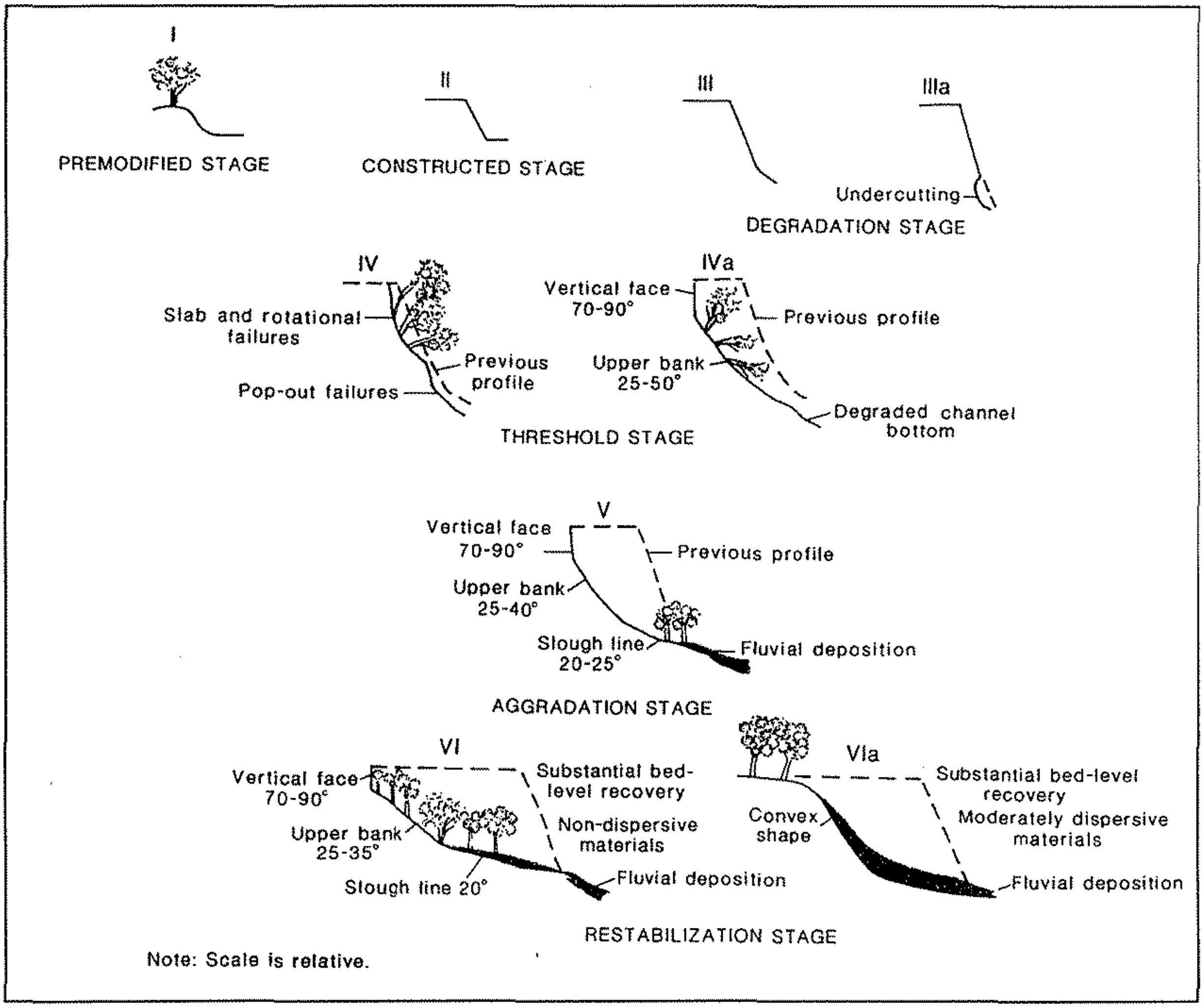


Figure 2.1. The six-stages of bank-slope development from Simon (1989).

The stream reaches covered in the video were classified based on evidence of what appeared to be the dominant channel process as outlined by the model. The video of each half-mile to one-mile stream segment was reviewed and assigned to one of the six stages of channel evolution. The stages of channel evolution were color coded and drawn on acetate overlays over U.S. Geological Survey 1:100,000-scale county topographic maps. The data was later digitized for use in the GIS. The videos were reviewed multiple times to confirm the classification in the context of the entire stream system. Field reconnaissance conducted during the course of the research project was also used to verify the classification on various streams.

2.3.1 Induced stages

During classification of the reconnaissance video it was noted that the banks along the stream reaches upstream of major grade control structures were stable with herbaceous and woody plants reestablishing. This was the result of flat water and siltation above the structures that mimicked a stage

V or stage VI of the channel evolution model. These stream segments did not appropriately fit into the natural adjustment process of the six-stage model of channel evolution, and were therefore classified as "Induced Stage V", or "Induced Stage VI". The reaches above grade control structures classified as Induced Stage V had primarily herbaceous plant growth on the banks and some minor bank erosion; reaches classified as Induced Stage VI had well developed herbaceous and woody plant growth and little evidence of bank erosion. The length of these induced stable reaches varied probably because of the varying heights of the grade control structures, length of time in place, stream slope, and other factors.

2.3.2 Key indicators during classification procedure

During the classification procedure certain key indicators in the video footage were used to identify of the stages of channel evolution (table 2.2). The bank morphologic and botanical evidence was used primarily in the classification along with evidence of damage or modification of bridges, pipelines, and other infrastructure. For example, a single span bridge with one or more added approach spans provided an indication that there had been significant channel widening since the bridge was initially installed. Based on the bridge evidence along with the other morphologic and botanical evidence, the stream reach at this location may be in a stage IV or V of channel evolution. Other bridge-related indicators were bridges that had failed because of undermined abutments and piers. Exposed pipelines were another infrastructure-related indicator. The pipeline crossings were originally installed below the streambed, however because of bed-level channel degradation (Stage III, and Stage IV), some pipelines have been exposed. The bridge-related indicators were taken in the context of the overall channel adjustment processes of the stream reach because the stream channel at a bridge crossing may be affected by local scour or other factors not related to the stage of channel evolution.

Table 2.2. Key indicators used in the classification of the aerial video.

Stage	Key indicators
I. Premodified	Meandering channel geometry; shallow bank to bed depth; alternate channel bars; herbaceous and or woody vegetation to the flow line; no evidence of channel modification.
II. Constructed	Evidence of recent channel modifications including spoil material; linear bank surface; lack of vegetation, or herbaceous vegetation to the flow line.
III. Degradation	Linear bank surface similar to II, but with pop-out failures at the base of the banks; knickpoints and riffle zones; bank to bank widths without appearance of major retreat. Tilted vegetation, raw banks; exposed pipelines.

Table 2.2. Key indicators used in the classification of the aerial video (cont.)..

Stage	Key indicators
IV. Threshold	Obvious major bank retreat, slab and rotational bank failures, knickpoints and riffle zones; linear flow line; tilted and fallen vegetation, damaged infrastructure, approaches added to original bridge lengths.
V. Aggradation	Major bank retreat and bank failures similar to IV, but with development of a meandering flow line, and initial deposition of alternate bars; sands and/or gravels apparent on alternate bars; re-establishment of vegetation at the slough line; similar bridge-related damages as in IV.
VI. Restabilization	Meandering thalweg, stable alternate channel bars, minor bank failures on outside bends; woody vegetation on banks and alternate bars; shallower bank to bed depth than V; evidence of out-of-bank events with deposition of sand on floodplain.
V-i Induced stage V	Stable stream reach upstream of grade control structure; primarily herbaceous plant growth on the banks; minor bank erosion
VI-i Induced stage VI	Stable stream reach upstream of grade control structure; well developed herbaceous and woody plant growth little evidence of bank erosion.

2.4 Results of Classification Procedure

The county-by-county results of the classification of the aerial reconnaissance video are presented in tables 2.3, and 2.4 for 1993 and 1994 respectively. The combined totals of all counties are presented in tables 2.5, and 2.6 for 1993, and 1994 respectively. GIS maps representing the classification of each county are presented in Appendix A . The dominant channel process recorded where reconnaissance was conducted was Stage IV-Threshold with over 55% of the total for both years; followed by Stage V-Aggradation with 16.52% in 1993, and 23.31% in 1994; followed by Stage III-Degradation with 16.37% in 1993, and 10.29% in 1994. Figures 2.2, 2.3, and 2.4 show examples of the Stages III, IV, and V from ground level reconnaissance photos of streams in western Iowa.

Table 2.3. Results by county of the classification of the 1993 reconnaissance video.

Stages of Stream Channel Evolution 1993			
Adair County	*Miles*	*Kilometers*	*% of Total*
stage 3	1.05	1.69	4.93%
stage 4	17.98	28.93	84.41%
stage 5	2.27	3.65	10.66%
Totals	21.30	34.27	100%
Adams County	*Miles*	*Kilometers*	*% of Total*
stage 4	7.46	12.00	73.79%
stage 5	2.65	4.26	26.21%
Totals	10.11	16.27	100%
Audubon County	*Miles*	*Kilometers*	*% of Total*
stage 2	1.03	1.66	13.12%
stage 3	6.82	10.97	86.88%
Totals	7.85	12.63	100%
Cass County	*Miles*	*Kilometers*	*% of Total*
stage 5	15.59	25.08	100%
Totals	15.59	25.08	100%
Crawford County	*Miles*	*Kilometers*	*% of Total*
stage 1	0.60	0.97	1.44%
stage 2	2.83	4.55	6.78%
stage 3	7.84	12.61	18.79%
stage 4	20.88	33.60	50.05%
stage 5	9.57	15.40	22.94%
Totals	41.72	18.13	100%
Fremont County	*Miles*	*Kilometers*	*% of Total*
stage 4	3.78	6.08	16.36%
stage 5	15.16	24.39	65.60%
stage 6i	4.17	6.71	18.04%
Totals	23.11	37.18	100%
Harrison County	*Miles*	*Kilometers*	*% of Total*
stage 3	6.02	9.69	17.38%
stage 4	6.05	9.73	17.47%
stage 5	9.56	15.38	27.61%
stage 5i	6.56	10.56	18.94%
stage 6i	6.44	10.36	18.60%
Totals	34.63	55.72	100%

Table 2.3. Results by county of the classification of the 1993 reconnaissance video (cont.).

Mills County	*Miles*	*Kilometers*	*% of Total*
stage 4	24.03	38.66	88.02%
stage 5	3.27	5.26	11.98%
Totals	27.30	43.93	100%
Monona County	*Miles*	*Kilometers*	*% of Total*
stage 4	21.53	34.64	73.21%
stage 5	2.60	4.18	8.84%
stage 5i	3.15	5.07	10.71%
stage 6i	2.13	3.43	7.24%
Totals	29.41	47.32	100%
Montgomery County	*Miles*	*Kilometers*	*% of Total*
stage 3	3.83	6.16	15.52%
stage 4	11.35	18.26	46.01%
stage 5	9.49	15.27	38.47%
Totals	24.67	39.69	100%
Page County	*Miles*	*Kilometers*	*% of Total*
stage 3	1.87	3.01	3.47%
stage 4	51.95	83.59	96.53%
Totals	53.82	86.60	100%
Pottawattamie County	*Miles*	*Kilometers*	*% of Total*
stage 1	0.22	0.35	0.21%
stage 2	9.08	14.61	8.75%
stage 3	14.60	23.49	14.07%
stage 4	69.53	111.87	67.01%
stage 5	7.58	12.20	7.31%
stage 5i	2.75	4.42	2.65%
Totals	103.76	166.95	100%
Shelby County	*Miles*	*Kilometers*	*% of Total*
stage 2	2.33	3.75	2.88%
stage 3	40.92	65.84	50.66%
stage 4	36.72	59.08	45.46%
stage 5i	0.8	1.29	0.99%
Totals	80.77	129.96	100%

Table 2.3. Results by county of the classification of the 1993 reconnaissance video (cont.)

Taylor County	*Miles*	*Kilometers*	*% of Total*
stage 3	1.07	1.72	6.43%
stage 4	15.56	25.04	93.57%
Totals	16.63	26.76	100%
Woodbury County	*Miles*	*Kilometers*	*% of Total*
stage 1	18.40	29.61	30.61%
stage 2	1.55	2.49	2.58%
stage 3	6.14	9.88	10.21%
stage 4	20.77	33.42	34.55%
stage 5	13.25	21.32	22.04%
Totals	60.11	75.40	100%

Table 2.4. Results by county of the classification of the 1994 reconnaissance video.

Stages of Stream Channel Evolution 1994			
Adams County	*Miles*	*Kilometers*	*% of Total*
stage 4	3.09	4.97	13.24%
stage 5	20.25	32.58	86.76%
Totals	23.34	37.55	100%
Audubon County	*Miles*	*Kilometers*	*% of Total*
stage 1	1.00	1.61	1.78%
stage 3	14.6	23.49	25.96%
stage 4	28.76	46.27	51.14%
stage 5	11.88	19.11	21.12%
Totals	56.24	90.49	100%
Carroll County	*Miles*	*Kilometers*	*% of Total*
stage 1	5.22	8.40	22.27%
stage 3	9.92	15.96	42.32%
stage 4	8.01	12.89	34.17%
stage 5	0.29	0.47	1.24%
Totals	23.44	37.71	100%
Cass County	*Miles*	*Kilometers*	*% of Total*
stage 4	48.83	78.57	55.84%
stage 5	37.04	59.60	42.36%
stage 5i	1.57	2.53	1.80%
Totals	87.44	140.69	100%

Table 2.4. Results by county of the classification of the 1994 reconnaissance video (cont.).

Crawford County	*Miles*	*Kilometers*	*% of Total*
stage 1	0.54	0.87	0.93%
stage 3	3.87	6.23	6.66%
stage 4	26.38	42.45	45.42%
stage 5	27.29	43.91	46.99%
Totals	58.08	93.45	100%
Fremont County	*Miles*	*Kilometers*	*% of Total*
stage 1	6.84	11.01	16.89%
stage 3	5.03	8.09	12.42%
stage 4	14.93	24.02	36.87%
stage 5	4.15	6.68	10.25%
stage 6i	9.54	15.35	23.56%
Totals	40.49	65.15	100%
Harrison County	*Miles*	*Kilometers*	*% of Total*
stage 1	1.57	2.53	2.29%
stage 4	41.19	66.27	60.07%
stage 5	7.32	11.78	10.68%
stage 5i	9.70	15.61	14.15%
stage 6i	8.79	14.14	12.82%
Totals	68.57	110.33	100%
Ida County	*Miles*	*Kilometers*	*% of Total*
stage 1	4.68	7.53	30.53%
stage 3	2.76	4.44	18.00%
stage 5	0.89	1.43	5.81%
stage 6	7.00	11.26	45.66%
Totals	15.33	24.67	100%
Mills County	*Miles*	*Kilometers*	*% of Total*
stage 1	2.27	3.65	5.06%
stage 3	3.08	4.96	6.86%
stage 4	22.93	36.89	51.07%
stage 5	8.1	13.03	18.04%
stage 5i	4.25	6.84	9.47%
stage 6i	4.27	6.87	9.51%
Totals	44.90	72.24	100%

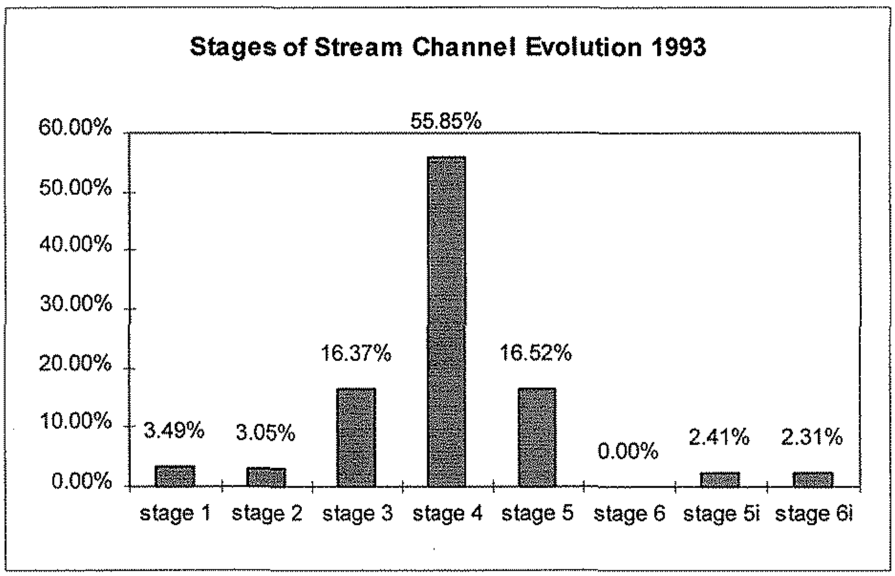
Table 2.4. Results by county of the classification of the 1994 reconnaissance video (cont.).

Monona County	*Miles*	*Kilometers*	*% of Total*
stage 1	1.03	1.66	2.37%
stage 4	34.86	56.09	80.27%
stage 5	1.14	1.83	2.62%
stage 6	3.27	5.26	7.53%
stage 5i	2.58	4.15	5.94%
stage 6i	0.55	0.88	1.27%
Totals	43.43	69.88	100%
Montgomery County	*Miles*	*Kilometers*	*% of Total*
stage 1	6.25	10.06	11.62%
stage 2	0.78	1.26	1.45%
stage 3	13.9	22.37	25.85%
stage 4	25.65	41.27	47.70%
stage 5	6.48	10.43	12.05%
stage 5i	0.71	1.14	1.32%
Totals	53.77	86.52	100%
Page County	*Miles*	*Kilometers*	*% of Total*
stage 1	3.46	5.57	3.94%
stage 3	7.23	11.63	8.23%
stage 4	63.44	102.07	72.18%
stage 5	13.76	22.14	15.66%
Totals	87.89	141.42	100%
Plymouth County	*Miles*	*Kilometers*	*% of Total*
stage 3	2.04	3.28	100%
Totals	2.04	3.28	100%
Pottawattamie County	*Miles*	*Kilometers*	*% of Total*
stage 1	2.82	4.54	1.69%
stage 3	18.54	29.83	11.12%
stage 4	106.26	170.97	63.71%
stage 5	35.46	57.06	21.26%
stage 5i	3.72	5.99	2.23%
Totals	166.80	268.38	100%
Shelby County	*Miles*	*Kilometers*	*% of Total*
stage 1	2.17	3.49	2.07%
stage 3	3.87	6.23	3.70%
stage 4	68.85	110.78	65.83%
stage 5	28.9	46.50	27.63%
stage 5i	0.8	1.29	0.76%
Totals	104.59	168.29	100%

Table 2.4. Results by county of the classification of the 1994 reconnaissance video (cont.).

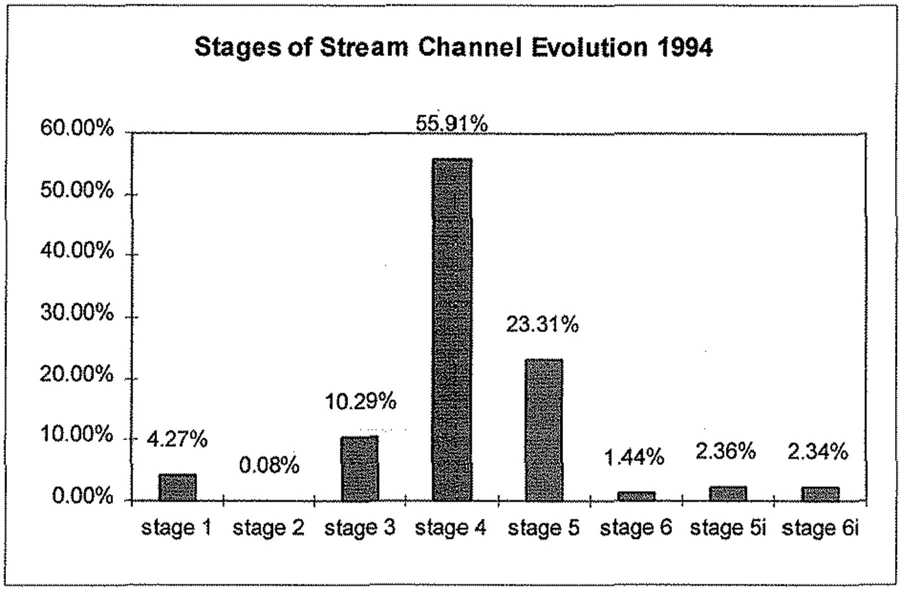
Taylor County	*Miles*	*Kilometers*	*% of Total*
stage 3	1.49	2.40	3.57%
stage 4	34.73	55.88	83.11%
stage 5	5.57	8.96	13.33%
Totals	41.79	67.24	100%
Woodbury County	*Miles*	*Kilometers*	*% of Total*
stage 1	4.40	7.08	6.19%
stage 3	15.51	24.96	21.82%
stage 4	25.14	40.45	35.37%
stage 5	22.07	35.51	31.05%
stage 6	3.96	6.37	5.57%
Totals	71.08	114.37	100%

Table 2.5. Results of the classification of the 1993 reconnaissance video (combined county totals).



1993 Totals	*Miles*	*Kilometers*	*% of Total*
stage 1	19.22	30.92	3.49%
stage 2	16.82	27.06	3.05%
stage 3	90.16	145.07	16.37%
stage 4	307.59	494.91	55.85%
stage 5	90.99	146.40	16.52%
stage 6	0.00	0.00	0.00%
stage 5i	13.26	21.34	2.41%
stage 6i	12.74	20.50	2.31%
Totals	550.78	886.21	100%

Table 2.6. Results of the classification of the 1994 reconnaissance video (combined county totals).



1994 Totals	*Miles*	*Kilometers*	*% of Total*
stage 1	42.25	67.98	4.27%
stage 2	0.78	1.26	0.08%
stage 3	101.84	163.86	10.29%
stage 4	553.05	889.86	55.91%
stage 5	230.59	371.02	23.31%
stage 6	14.23	22.90	1.44%
stage 5i	23.33	37.54	2.36%
stage 6i	23.15	37.25	2.34%
Totals	989.22	1591.65	100%

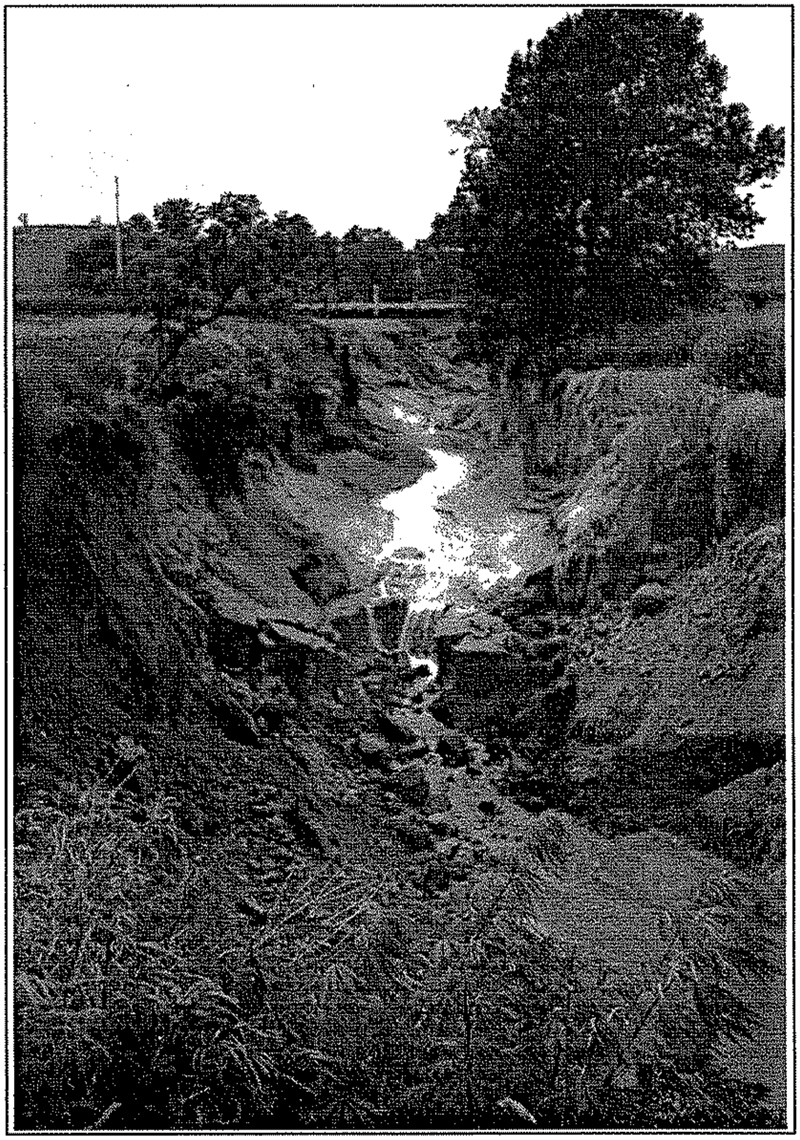


Figure 2.2. Example of stage III stream reach, East Soldier River Tributary, Crawford County.

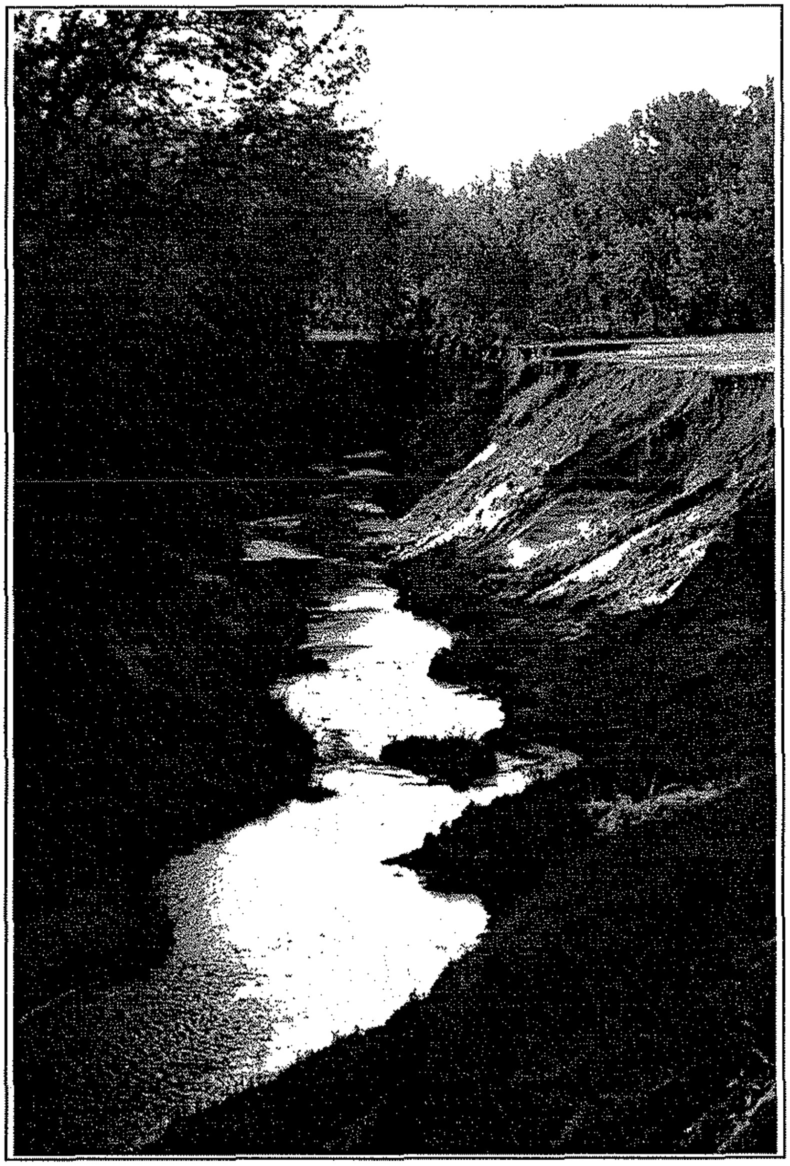


Figure 2.3. Example of a stage IV-threshold stream reach, Walnut Creek at Hwy 6, Pottawattamie County.

Figure 2.4. Example of Stage V-Aggradation stream reach, Willow Creek, Harrison County.

2.5. Stream Bed Sampling

The composition of the stream bed material plays an important role in the channel adjustment process. Simon and Downs (1994) point out that in channels devoid of sand or coarser-sized material for downstream aggradation and gradient reduction, channel widening could be the only means available to the stream to reduce flow energy. Without a coarse bed material, the time needed for a stream to aggrade is greatly increased. Simon (1989) notes that highly disturbed channels (in western Tennessee) which are cut through loess derived sediments and lack a coarse sediment-load for aggradation tend to aggrade extremely slow following degradation. He notes that because of this, Stage V represents the final stage of bank-slope development of these channels.

Three streams in the project area were selected for the collection of bed material samples: West Tarkio Creek in Page, Montgomery Counties, and Atchison County in Missouri; Willow Creek in Harrison, and Monona Counties; Keg Creek in Mills and Pottawattamie Counties (see figures 2.5, 2.6, and 2.7). The purpose of collecting the samples was to see if, 1)the composition of the bed material correlated with the identified stage of channel evolution, 2) to note changes in the composition of the bed material throughout the stream system.

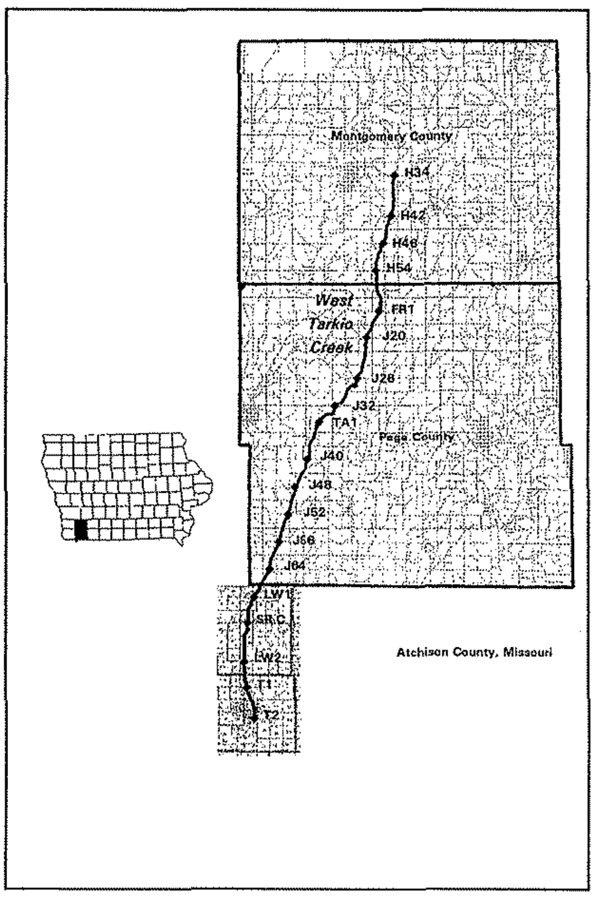


Figure 2.5. Streambed sample collection sites on West Tarkio Creek.

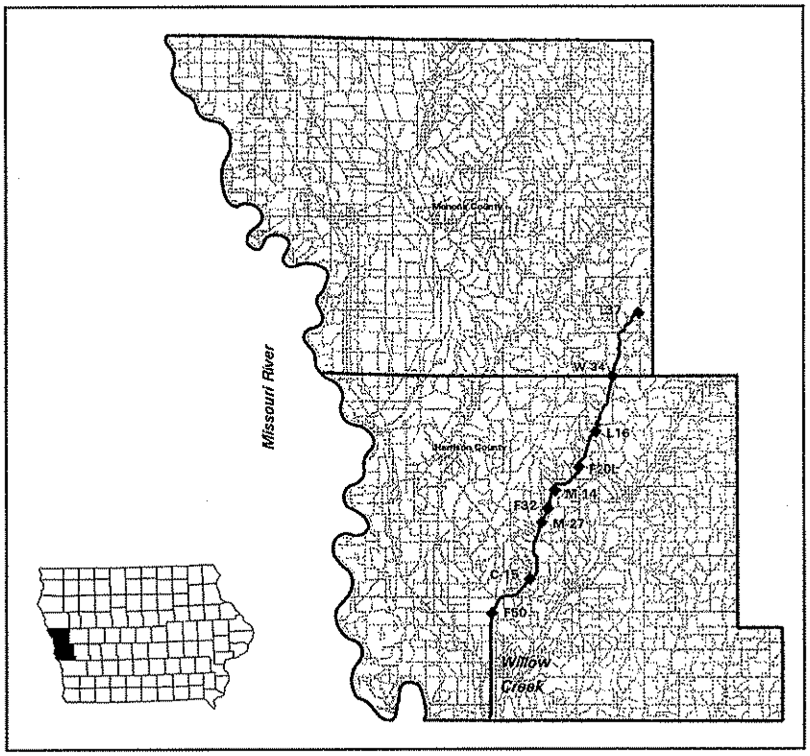


Figure 2.6. Streambed sample collection sites on Willow Creek.

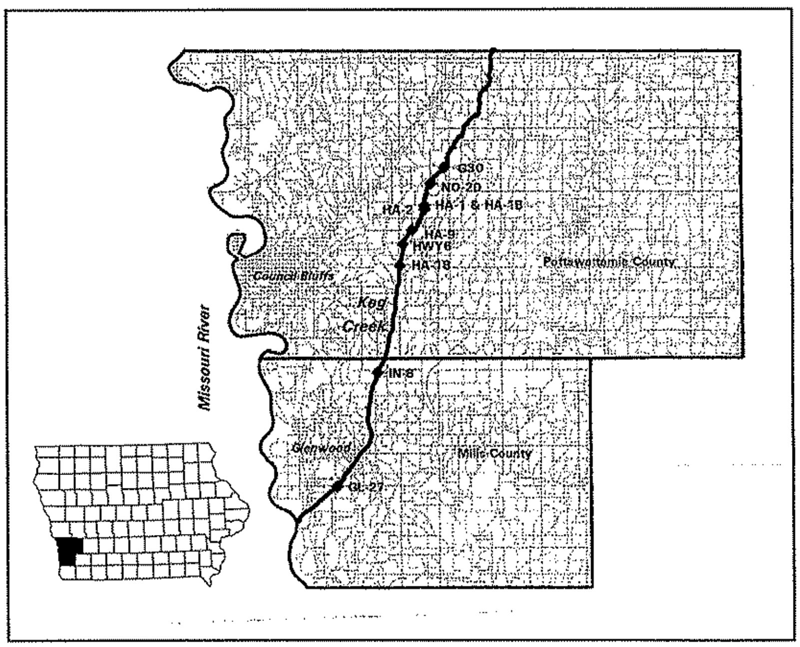


Figure 2.7. Streambed sample collection sites on Keg Creek.

2.5.1 Methods

Bed samples were collected at each site using one of two tools provided by the U.S. Geological Survey, Nebraska District: 1) a hand-held sampling tool that was driven up to eight inches into the stream bed and then withdrawn, and 2) a stream bed sampling device lowered down from a bridge that was released at the point of contact with the stream bed; a spring-loaded device would then collect the sample. The hand held tool was used on all but two sampling sites where it was too difficult to climb down the banks to reach the streambed.

2.5.2 Results

The bed samples were then analyzed by the U.S. Geological Survey in Iowa City and Raleigh, NC. Data on the bed samples are presented in tables 2.7, 2.8, and 2.9. The analysis data for the stream bed samples including the particle size and size class was provided by Andrew Simon of the U.S. Geological Survey, NC. The streambed data was correlated with the stage of channel evolution data (tables 2.10, 2.11, and 2.12). The occurrence of the coarser bed material (sand and gravel) appears to correlate well with Stage V-aggradation, and Stage IV-threshold. As pointed out above, the coarse material is needed for the streams to begin aggradation. The Stage IV sites where sand was sampled may be in a late stage IV or early stage V. The samples on West Tarkio Creek show that aggradation appears to be moving upstream from the mouth into southern Page County. The finer bed material (silt) correlates with Stage II-constructed, Stage III-degradation, and Stage IV-threshold.

2.6 Discussion of Channel Stability Assessment

The aerial reconnaissance has provided the most comprehensive view to date of the channel adjustment processes occurring in the deep loess region of western Iowa. The view of extended stream reaches at low altitude allowed for the interpretation of key indicators of the stages of channel evolution. This information is vital in determining the dominant channel process of a given stream. The classification of the streams based on the six-stage model of channel evolution can be used as a first step in planning of potential erosion countermeasures. Stream reaches that were identified as Stage III, may be the most appropriate areas to concentrate grade control measures. These reaches have yet to experience the severe widening associated with Stages IV, and V, and therefore would likely be less costly to construct grade control measures.

The channel evolution model data show that the overall channel adjustment process occurring in western Iowa is Stage IV-threshold. This may indicate that the streams covered in the reconnaissance the dominant process in the future will be channel widening, while major bed-level degradation has already occurred. However it was noted during the reconnaissance that many of the small tributaries are experiencing major bed-level degradation.

Table 2.7. Bed material data for West Tarkio Creek

Approximate estimates of the d50 of the bed material					
Collections by Golden Hills RC&D; 7/18/94 collections by USGS.					
Analysis by U.S. Geological Survey, Iowa City, and Raleigh, NC.					
ID#	**Location**	**Date**	**Particle size (mm)**	**Size class**	**Notes**
Montgomery County , Iowa					
H34	County Road H34 section 24/25 Red Oak Twp.	8.19.94	0.012	silt	
H42	County Road H42 section 1/12 Grant Twp.	8.19.94	0.011	silt	
H46	County Road H46 section 14/23 Grant Twp.	8.19.94	0.200	sand	
H54	County Road H54 section 26/35 Grant Twp.	8.19.94	0.020	silt	
Page County, Iowa					
FR1	County Road at section 11/14 Fremont Twp.	8.19.94	0.015	silt	
J20	County Road J20 section 22/27 Fremont Twp.	7.18.94	0.480	sand	
J28	County Road J28 section 4/8 Tarkio Twp.	8.19.94	0.270	sand	
J32	County Road J32 section 17/20 Tarkio Twp.	8.23.94	0.032	silt	
TA1	County Road at section 30 Tarkio Twp/25 Grant Twp.	8.23.94	0.014	silt	
J40	County Road J40 section 11/14 Morton Twp.	8.23.94	0.027	silt	
J48	County Road J48 section 22/27 Morton Twp.	8.23.94	0.220	sand	
J52	County Road J52 section 4 Washington Twp.	7.18.94	1.400	sand-gravel	Sample from streambed
J52	County Road J52 section 4 Washington Twp.	7.18.94	0.800	sand	Sample from sand bar
J56	County Road J56 section 9/16 Washington Twp.	8.23.94	0.200	sand	
J64	County Road J64 section 20/29 Washington Twp.	7.18.94	0.800	sand	
Atchison County, Missouri					
LW1	County Road at section 31/6 Lincoln West Twp.	8.23.94	1.000	sand	
SR C	State Rte. C section 12/13 Lincoln West Twp.	7.18.94	1.200	sand-gravel	
LW2	County Road at section 25/36 Lincoln West Twp.	8.23.94	0.800	sand	
T1	County Road at section 2/11 Tarkio Twp.	8.23.94	0.800	sand	
T2	Confluence with Tarkio River section 23 Tarkio Twp.	7.18.94	1.600	sand-gravel	

Table 2.8. Bed material data for Willow Creek.

Approximate estimates of the d50 of the bed material					
Collections by Golden Hills RC&D					
Analysis by U.S. Geological Survey, Iowa City, and Raleigh, NC.					
ID#	**Location**	**Date**	**Particle size**	**Size class**	**Notes**
			(mm)		
Monona County, Iowa					
L37	County bridge section 11/12 Willow Twp.	9.7.94	0.014	silt	
W-34	County bridge SW 1/4 section 34 Willow Twp.	9.7.94	0.380	sand	
Harrison County , Iowa					
L16	County bridge on L16 section 20/29 Lincoln Twp.	9.7.94	0.032	silt	below flume outlet
F20L	County bridge on F20L section 6 Boyer Twp.	9.7.94	1.500	sand-gravel	
M-14	County bridge NE 1/4 section 14 Magnolia Twp.	9.7.94	0.800	sand	
F32	County bridge on F32 section 23 Magnolia Twp.	9.7.94	0.018	silt	upstream of flume
M-27	County bridge in section 27 Magnolia Twp.	9.7.94	2.200	sand-gravel	
C-15	County bridge in section 15 Calhoun Twp.	9.7.94	0.750	sand	
F50	County bridge on F50 section 30/31 Calhoun Twp.	9.7.94	0.375	sand	Mo. River floodplain

Table 2.9. Bed material data for Keg Creek.

Approximate estimates of the d50 of the bed material					
Collections by Golden Hills RC&D					
Analysis by U.S. Geological Survey, Iowa City					
ID#	**Location**	**Date**	**Particle**	**Size class**	**Notes**
			Size(mm)		
Pottawattamie County , Iowa					
G30	County bridge on G30 section 18/19 York Twp.	9.7.94	0.040	silt	
NO-20	County bridge NO-20 section 25 Norwalk Twp.	9.7.94	0.012	silt	
HA-1	County bridge NE 1/4 section 1 Hardin Twp.	9.7.94	0.040	silt	25m d/s of flume outlet
HA-1B	County bridge NE 1/4 section 1 Hardin Twp.	9.7.94	0.045	silt	upstream of gabion flume
HA-2	County bridge section 1/2 Hardin Twp.	9.7.94	0.062	sand-silt	
HA-9	County bridge at section 10/11 Hardin Twp.	9.7.94	0.380	sand	
HWY6	U.S. Hwy 6 bridge section 15/22 Hardin Twp.	9.7.94	0.230	sand	
HA-18	Co. bridge H-18 on L52 section 27 Hardin Twp.	9.7.94	0.060	sand-silt	
Mills County, Iowa					
IN-8	County bridge NL section 8 (west) Ingraham Twp.	9.7.94	0.750	sand	
GL-27	County bridge NW 1/4 section 27 Glenwood Twp.	9.7.94	0.750	sand	

Table 2.10. Correlation of stream bed data with stage of channel evolution, West Tarkio Creek.

ID#	Date	Particle size (mm)	Size class	Stage of Channel Evolution
Montgomery County , Iowa				
H34	8.19.94	0.012	silt	II-constructed*
H42	8.19.94	0.011	silt	III-degradation
H46	8.19.94	0.200	sand	III-degradation
H54	8.19.94	0.020	silt	III-degradation
Page County, Iowa				
FR1	8.19.94	0.015	silt	IV-threshold
J20	7.18.94	0.480	sand	IV-threshold
J28	8.19.94	0.270	sand	IV-threshold
J32	8.23.94	0.032	silt	IV-threshold
TA1	8.23.94	0.014	silt	IV-threshold
J40	8.23.94	0.027	silt	IV-threshold
J48	8.23.94	0.220	sand	IV-threshold
J52	7.18.94	1.400	sand-gravel	IV-threshold
J52	7.18.94	0.800	sand	IV-threshold
J56	8.23.94	0.200	sand	IV-threshold
J64	7.18.94	0.800	sand	IV-threshold
Atchison County, Missouri				
LW1	8.23.94	1.000	sand	V-aggradation*
SR C	7.18.94	1.200	sand-gravel	V-aggradation*
LW2	8.23.94	0.800	sand	V-aggradation*
T1	8.23.94	0.800	sand	V-aggradation*
T2	7.18.94	1.600	sand-gravel	V-aggradation*

* Stage of channel evolution identified from field reconnaissance

Table 2.11. Correlation of stream bed data with stage of channel evolution, Willow Creek.

ID#	Particle size (mm)	Size class	Stage of Channel Evolution
Monona County, Iowa			
L37	0.014	silt	IV-threshold
W-34	0.380	sand	V-i Induced
Harrison County , Iowa			
L16	0.032	silt	IV-threshold
F20L	1.500	sand-gravel	V-aggradation
M-14	0.800	sand	V-i Induced
F32	0.018	silt	VI-i Induced
M-27	2.200	sand-gravel	V-aggradation
C-15	0.750	sand	V-aggradation
F50	0.375	sand	V-aggradation

Table 2.12. Correlation of stream bed data with stage of channel evolution, Keg Creek.

ID#	Particle Size(mm)	Size class	Stage of channel evolution
Pottawattamie County , Iowa			
G30	0.040	silt	IV-threshold
NO-20	0.012	silt	IV-threshold
HA-1	0.040	silt	IV-threshold
HA-1B	0.045	silt	V-i Induced
HA-2	0.062	sand-silt	IV-threshold
HA-9	0.380	sand	IV-threshold
HWY6	0.230	sand	IV-threshold
HA-18	0.060	sand-silt	IV-threshold
Mills County, Iowa			
IN-8	0.750	sand	IV-threshold
GL-27	0.750	sand	V-aggradation*

*stage of channel evolution identified from field reconnaissance.

2.6 Discussion of Channel Stability Assessment (cont.)

Only a minor percentage of the stream miles covered in the reconnaissance were classified as Stage I, II, or VI. Simon (1989) points out that the six-stage model does not suggest that each adjusting reach will undergo all six stages but implies that specific trends of bed-level response will result in a series of mass wasting processes and definable bank and channel forms. Only the Maple River in Monona, Woodbury, and Ida Counties had reaches classified as stage VI-restabilization. Morphologically this stream is more characteristic of streams east of the project area. One major difference of Maple River than other streams reviewed in the reconnaissance is that its head waters are in an area near late Wisconsinan glacial advance (in Cherokee and Ida County); and therefore has as its dominant bed material sands and gravels.

Coarse bed material, as noted in section 2.5, plays an important role in the channel adjustment process. Other data including depth of loess-alluvium above glacial till would be beneficial in helping predict the future adjustment of the channels.

The stream evolution data may be indicating that the final stage of channel development, at least on a human time-scale, will be stage V for the majority of the streams covered in the reconnaissance, i.e., the stream channels will form a new meandering system within the existing entrenched gullies. However as Bettis (1990) points out, the geologic record shows that the western Iowa fluvial system has undergone gully and entrenched stream development several times during the Holocene; therefore reaching a final form of stage VI.

3.0 GEOGRAPHIC INFORMATION SYSTEM DEVELOPMENT

3.1 Objectives

This report describes the development of a Geographic Information System (GIS) begun in March 1993 for the Stream Stabilization in Western Iowa (Hungry Canyons) project at Golden Hills RC&D. A large amount of data related to stream channel erosion in western Iowa has been collected at Golden Hills RC&D over the past four years. This data has been in the form of maps and written material from county engineers and soil and water conservation districts in the 22 county area. A system was needed to organize, store, digitize, and analyze this and other recently collected data. A computer based Geographic Information System (GIS) was chosen as the tool to meet these system needs. The following four objectives were defined for the development of the GIS for the Hungry Canyons project:

A. Determine the benefits of establishing a GIS

   Work on developing the GIS database and use of the GIS storage, retrieval and analysis programs has shown that a GIS can provide the needed tool for the Hungry Canyons project. The GIS can manage the large amount of spatial and attribute data associated with natural resources, transportation infrastructure and stream channel erosion in western Iowa. The GIS can also be used to help plan natural resource, rural development, and infrastructure projects in the region.

B. Evaluate GRASS/GIS software

   Geographic Resources Analysis Support System (GRASS) software is a public domain GIS software that was chosen for the Hungry Canyons project

C. Develop GIS database for selected pilot study area

   GIS data layers were developed for the pilot study area through existing digital data and digitizing analog data.

D. Implement the GIS for the entire project area

   Following implementation of the GIS for the pilot area, GIS development progressed to include a 22 county area.

3.2 Background

3.2.1 Hungry Canyons project background

The Hungry Canyons project addresses the severe loss of land and damage to transportation infrastructure caused by stream channel erosion in a 22 county area of the deep loess soils region of western Iowa. Significant stream channel erosion (channel deepening and widening) has been identified on 155 streams in the region, causing damage to bridges, pipelines, telephone lines, and loss of agricultural land through land voiding.

3.2.2 Golden Hills RC&D GIS

Golden Hills RC&D began developing its GIS capabilities in March 1993. The Natural Resources Conservation Service (NRCS) has provided the computer hardware for the GIS consisting of an EVEREX 6386/33, 170mb and 500mb hard drives, Pinnacle Micro REO-650 optical storage drive, CTX 14" color monitor, AT&T "dumb" terminal, ALTEK model AC31 Digitizing Table, and TEKTRONIX 4696 color printer. GIS software is the NRCS version of Geographic Resources Analysis Support System (GRASS) 4.0, and 4.1. The software is run on AT&T UNIX SYSTEM V release 3.2.3 operating system.

3.2.3 GIS staff and background

Gregg Hadish is the GIS and Project Director for the Hungry Canyons Project. He is an employee of the Golden Hills RC&D Council. Gregg received his Bachelor of Landscape Architecture from Iowa State University in May 1992. He served as research assistant to Paul Anderson in the ISU Department of Landscape Architecture from June 1991 to June 1992, developing a GIS database and analysis techniques for natural resource and recreation master planning for the Dallas County Conservation Board's Raccoon River Greenbelt project. Gregg served as Golden Hills RC&D project specialist from June to September 1992 for the Loess Hills Landscape Resource Study, and has served as RC&D project director since September 1992.

Diane Whited is the GIS technician for the Hungry Canyons Project. Diane received her Bachelor of Landscape Architecture from Iowa State University in May 1993. She is currently working on her Master of Science in Landscape Architecture at the University of Minnesota with a minor in Water Resources. Her thesis work involves an integrated approach to watershed management and water quality and the use of GIS (Arc/INFO) and AGNPS (Agricultural Non Point Source) programs to evaluate management scenarios. Diane has worked as GIS technician at Golden Hills RC&D during winter break 1993 and summer 1994.

3.2.4 Learning GRASS/GIS

Gregg and Diane have learned features of GRASS/GIS without the benefit of software training. The GRASS User's Reference Manual (USACERL, 1991, 1993) has been the primary learning tool. A GRASS 3.0 Tutorial (USACERL, 1988) covering several commands was also referred to, however this was of limited value since command names were completely reorganized with the release of GRASS 4.0. Technical support concerning the use of GRASS has been received from Dale Ceolla and Shelly Coon from the NRCS, Des Moines, and Ken Sibley and Jim Carrington from the NRCS National Cartography and GIS Center in Ft. Worth.

3.3 Procedure

3.3.1 Pilot study area for GIS development

Pottawattamie County was selected as the pilot study area to begin the GIS development. The county is 616,000 acres in size, with over 30 named streams and numerous tributaries. The county is bounded on the west by the Missouri River where its flood plain meets the steep bluffs of the loess hills land form region. The area west of the land form consists of rolling hills with thick loess deposits. The major streams in the county include the West Nishnabotna River, Silver Creek, Walnut Creek, Mosquito Creek, and Keg Creek. These and other streams have experienced severe channel erosion that has impacted the county's highway bridges, pipelines, and other infrastructure and agricultural land. Pottawattamie County was selected as the pilot county for GIS development because the size, stream conditions, and complexity well represent the other 21 counties in the project area.

3.3.2 Digital data sources

A priority during the establishment of the GIS was to identify sources of digital data that could be acquired for free or at minimal cost, and were in a format that could be readily converted into GRASS map layers. Data has been acquired at no cost from several sources including the Iowa Department of Transportation (IDOT), NRCS, U.S. Geological Survey EROS Data Center, Iowa Department of Natural Resource (IDNR), U.S. Army Corps of Engineers, and Iowa State University. Many of these agencies are now providing digital GIS data via File Transfer Protocol (FTP) sites on the Internet. Golden Hills RC&D has acquired data from these sources through an Internet gateway service.

In addition to data acquired from other agencies, digital data layers have been created at the RC&D using the ALTEK digitizing table and GRASS digitizing programs

3.3.3 GIS data layer development (Note: GRASS 4.0 programs used appear in *italics.*)

GIS data layers were developed for Pottawattamie County using existing digital data from IDOT Drawing eXchange Format (DXF) files, NRCS Digital Line Graphs (DLG's), U.S. Department of Census TIGER files, and Defense Mapping Agency Digital Elevation Models (DEM). Conversion routines and data descriptions of the various digital data are described in Appendix B. Other data layers were developed by digitizing analog data and creating files from written material. A spread sheet in Appendix B lists the map layers developed for Pottwattamie County. Included are a description of the map layer and listing of the original source of the data.

Six file types were generated using GRASS/GIS including raster files, vector files, site list files, paint label files, paint icon files, and region definition files. An example of a raster file is the DEM map layer from Defense Mapping Agency data. The file produced a general elevation map layer and a derived slope map layer using *r.slope.aspect*. The elevation data is an important base layer that is used in combination with other raster and vector files. Map layers were generated from the slope classification data derived from the DEM in combination with the Hydrologic Unit (watershed boundary) raster file, and the stream vector file. The elevation map layer was also used in combination with other raster files to display three-dimensional images using *d.3d*. Raster files were also created from converted vector files using *v.to.rast*.

Vector files were another type of file generated in GRASS including the road map layer and county boundary derived from the U.S. Department of Census TIGER files (see conversion routine in Appendix B). Several vector map layers were developed from the Iowa DOT Highway and Transportation DXF files, including streams, pipelines, railroads, secondary roads, primary roads, and federal and interstate roads (see conversion routine in Appendix B). Other vector map layers were digitized from analog data using *v.digit* and ALTEK digitizing table.

GRASS "site list" or point data files were generated from analog data that was first digitized to create a vector file and then converted to create a site file. The data was digitized using the ALTEK digitizing table and the various digitizing and editing tools in *v.digit* , the resultant vector file was then converted to a site file using *v.to.sites*. A planned bridge construction site file was generated from analog data from the Pottawattamie County five year Secondary Road Construction Program that was first digitized and then converted to a site file. A similar file was generated showing the planned culvert construction projects. Other site files were generated following interpretation of the aerial reconnaissance video tape, including stream knickpoint locations, and stabilization sites.

Paint label files were generated in *d.labels* a GRASS Display Program that allows text labels to be placed and displayed on the graphics monitor or printed using *p.map*. Paint icon files were created using the UNIX text editor program "vi" and stored under the user's $LOCATION/icons directory. The resultant icon file can be displayed on the graphics monitor using *d.icons*, or printed as site symbols in *p.map*.

Region definition files were generated in *g.region*, a GRASS File Management Program. The program is used to manage the boundary definitions for the geographic region; the files are stored under the user's $LOCATION/windows directory. A region definition file is used to define the area that is displayed on the graphics monitor or printed using *p.map*.

3.3.4 GIS data layer evaluation

The data layers generated for the GIS have been evaluated based on their level of detail and completeness and applicability to the needs of the Hungry Canyons project. An example is the IDOT Highway and Transportation files and the USDC TIGER files. Although both datasets were originally generated from USGS DLG's, the map layers did not have the same level of detail. For example the stream map layer generated from "level 36" of the IDOT file more completely shows the main and tributary streams for Pottawattamie County, compared to the stream map layer generated from the TIGER file (figure 3.1).

Other data layers from the TIGER data set were complete such as roads and county boundaries, these were included in the GIS database for Pottawattamie County. Several coverages from the TIGER dataset have been reviewed for other counties in the project area. Some of the stream coverages are incomplete for these counties and others are complete. The IDOT dataset has provided good vector base layers, however, the conversion to UTM-referenced GRASS vector files takes several steps (see conversion routine in Appendix B).

The DEM data layer provides a coarse-scale elevation map that can be used to generate a general picture of the topography of a county or region, however the data does not provide adequate detail for many applications that would be useful to the Hungry Canyons project. For example more detailed elevation data could be used to determine stream slope percentages that could in turn be used in preliminary planning of grade control structure location.

3.3.5 GIS analysis

GRASS analysis capabilities are generally limited to use of raster files and GRASS raster commands where cells of a file are reclassified or combined with other files to create derived map layers. The derived map layers can then be used as an analysis tool. Raster commands that have been used in the process of developing the GIS include: *r.cross* which was used to generate a slope classification map. *r.slope.aspect* was used to derive a map layer from the Digital Elevation Model data that defines slope percentages, *r.reclass* was used to derive map layers with reclassified category values, e.g., to show specific slope categories. *r.combine* was used to combine category values from two raster files, using Boolean logic (AND, OR, NOT) which is useful in site selection analysis. *r.mapcalc* was used to perform arithmetic expressions on one or more raster files. A simple operation was to convert an elevation file referenced in meters to one referenced in feet by use of a division command.

GRASS vector commands have also been used to analyze data. For example *d.measure* and *v.report* were used to measure pre-channelized lengths and channelized lengths of Walnut Creek from the stream vector map layer. These programs were also used to measure lengths of video-taped stream reaches covered by the aerial reconnaissance.

3.3.6 Implementation of 22 county GIS

In addition to the map layers developed for Pottwattamie County, data layers have been developed for the other 21 counties in the project area. These counties are: Adair, Adams, Audubon, Carroll, Cass, Cherokee, Crawford, Fremont, Harrison, Ida, Lyon, Mills, Monona, Montgomery, Page, Plymouth, Sac, Shelby, Sioux, Taylor, and Woodbury. Associated attribute databases have also been developed including an integrated database containing the bridge and culvert repair and replacement portions of the IDOT and county secondary 5-year plans; a stream attribute database; and databases related to field and aerial reconnaissance activities.

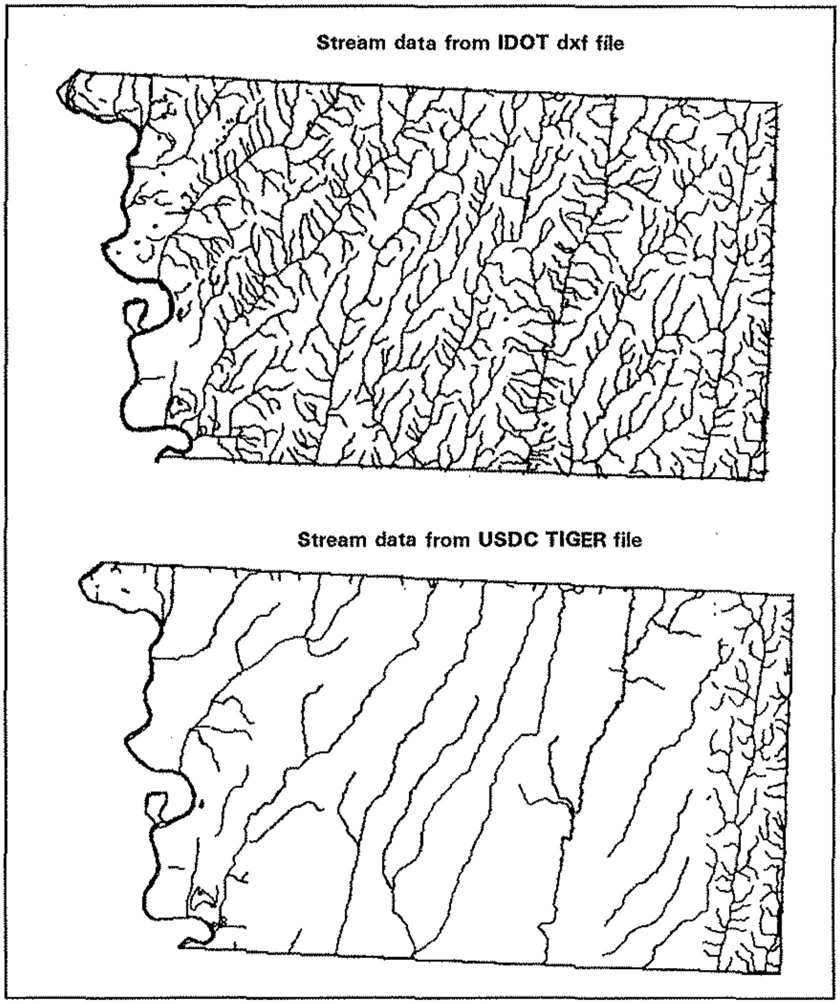


Figure 3.1. Comparison of IDOT and USDC stream data layer for Pottawattamie County.

3.3.7 PONTIS management system

The project director worked with Marlee and Roger Walton of the IDOT in investigating the possibility of acquiring data developed by the IDOT's PONTIS bridge management system for incorporation into the RC&D database. Currently the PONTIS system is not operational.

3.4 Application of GIS

The GIS been has been utilized for several different components of the Hungry Canyons project. The GIS has been used to assist the Iowa State University research teams working on the Hungry Canyons research project. Dr. Philip Baumel has utilized the stream stages, and stream status data layers for the economic analysis component of the project.

The GIS output capabilities have been used to generate hard copy maps and transparencies for presentations at Hungry Canyons meetings. The GIS has been used by counties that are planning demonstration stream stabilization projects funded through the NRCS. The planned culvert and bridge construction map layers have been used to find opportunities to combine stream stabilization projects with other planned construction projects.

The GIS data derived from the two years of aerial reconnaissance video tape has been particularly useful to counties who are planning bank and channel stabilization projects through the NRCS Emergency Watershed Protection Program. The data has been used to identify potential EWP sites, and provides a view of stream channel evolution which is important in planning stabilization projects.

3.5 Evaluation of GIS

3.5.1 Hardware evaluation

During the development of the GIS database and in analyzing data, it became apparent that the 386 processor in the EVEREX 6386 was inefficient in processing the larger data files. For example, the computer processed data for 65 minutes to generate the Digital Elevation Model map layer for a portion of Pottawattamie County. Extended processing times were also needed when using GRASS analysis programs. These programs included: *r.mapcalc, r.combine, r.cross, r.stats,* and *r.report*. The 386 processor can not efficiently process multi-county data files or analysis of those files.

The computer's hard-drive was found to be inadequate during the development of the GIS database. A 170mb drive included with the Everex 6386 was not large enough to store the necessary data files, particularly when the county-wide raster files were being generated. An additional 500mb hard-drive, and optical storage device was added to the system and provides adequate storage space.

3.5.2 GRASS/GIS evaluation

GRASS/GIS has been relatively easy to learn compared with other GIS software such as ARC/Info that Gregg and Diane have previously used. GRASS was found to be a useful tool in the storage, retrieval and analysis of data for the Hungry Canyons project. Several of the GRASS 4.0 programs were found to have bugs. For example, *v.report* calculated inaccurate length measurements; producing length calculations that were several miles too long. Some "Main" programs that were listed in the GRASS 4.0 manual were not included with the software, including *r.thin*, and *r.line*. Other GRASS programs were simply cumbersome to use including: color interact in *d.display*; the need to restart the display monitor in *d.mon* when switching to a different Mapset Location; and the need to exit and restart *v.digit* to access another data layer. Many of the problems listed above were corrected with the release of GRASS 4.1 which is now in use at the RC&D.

3.6 Recommendations

3.6.1 Hardware recommendations

The future development of Golden Hills RC&D GIS capabilities should include the acquisition of a more powerful computer. As mentioned above, the 386 processor in the EVEREX computer could not efficiently process county-wide data files or analysis of the files in GRASS. A PC with a 486, or Pentium processor or a SUN workstation is needed to effectively process and analyze multi-county and regional data files for the Hungry Canyons and other projects underway at the RC&D.

3.6.2 Software recommendations

A geo-relational database system is needed to efficiently store and query attribute data. GRASS/GIS software does not provide these capabilities. GRASS interface programs that link the GIS to a database such as INFORMIX should be tested for use at the RC&D. This interface is excepted to be available with the release of GRASS 4.1.

3.6.3 Data Recommendations

It has become obvious that there is no one source of digital data that can be used to develop an adequate GIS database. Various data sets from multiple sources should continue to be evaluated and compared and then the most appropriate chosen for inclusion in the GIS database. Some recommended data layers that should be acquired are soil mapping units, land cover/ land use, and more detailed elevation (such as 1:100,000 scale). These are important base data layers that can be used in many analysis and GIS modeling applications.

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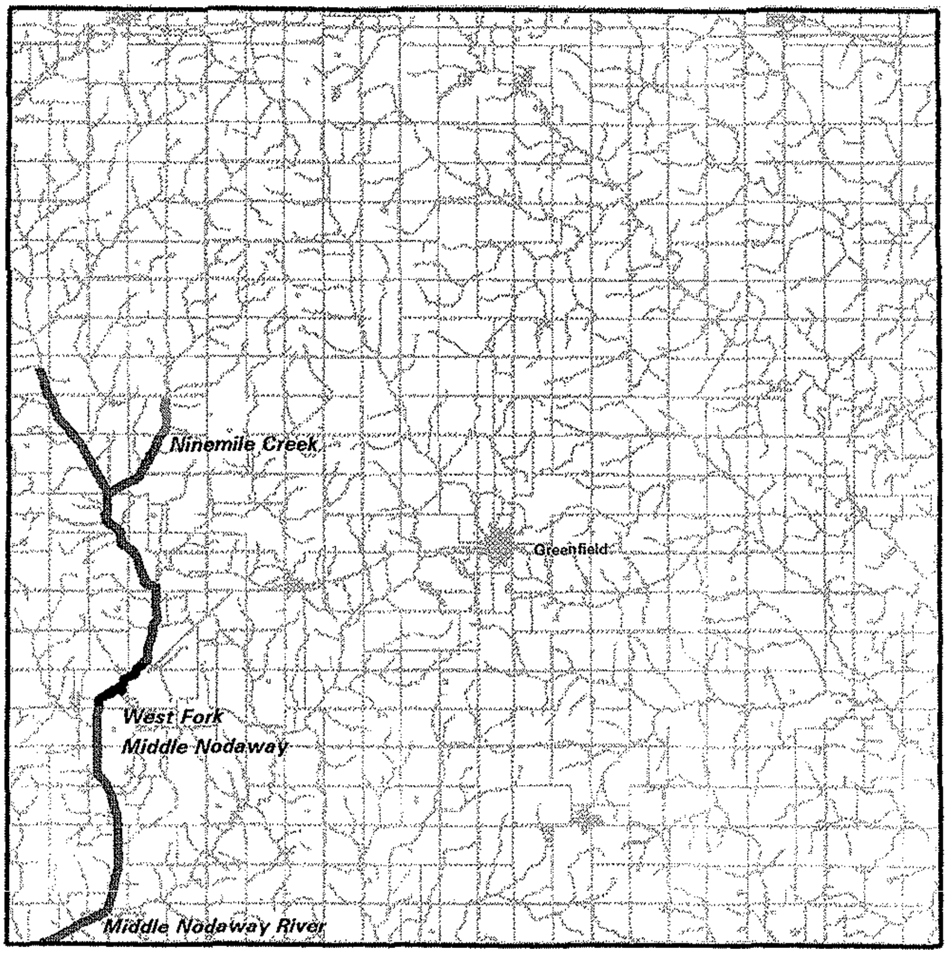
Appendix A



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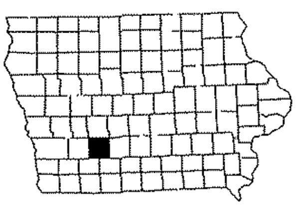
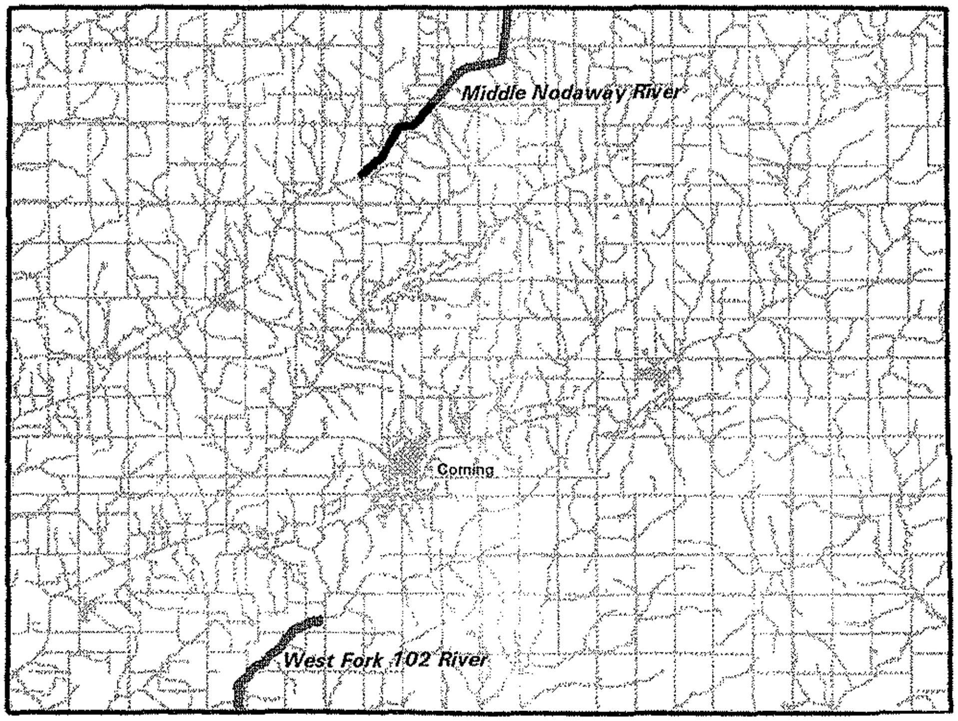


Adair County 1993	*Miles*	*Kilometers*	*% of Total*
stage 3	1.05	1.69	4.93%
stage 4	17.98	28.93	84.41%
stage 5	2.27	3.65	10.66%
Totals	21.30	34.27	100%

Stages of Stream Channel Evolution
classified from April 1993 aerial reconnaissance video
by Golden Hills RC&D, Oakland, Iowa



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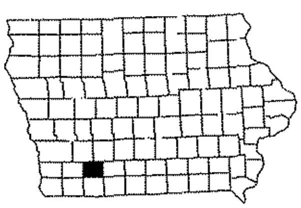

Adams County 1993	*Miles*	*Kilometers*	*% of Total*
stage 4	7.46	12.00	73.79%
stage 5	2.65	4.26	26.21%
Totals	10.11	16.27	100%

Stages of Stream Channel Evolution
classified from April 1993 aerial reconnaissance video
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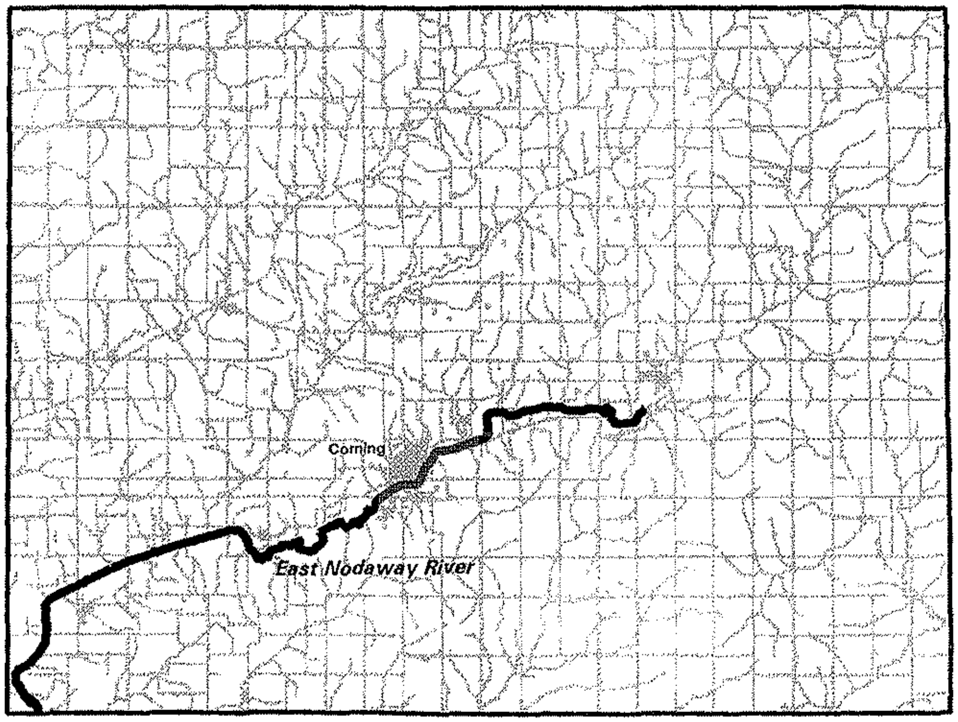

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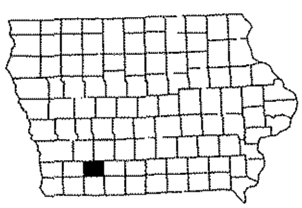

Adams County 1994	Miles	Kilometers	% of Total
stage 4	3.09	4.97	13.24%
stage 5	20.25	32.58	86.76%
Totals	23.34	37.55	100%

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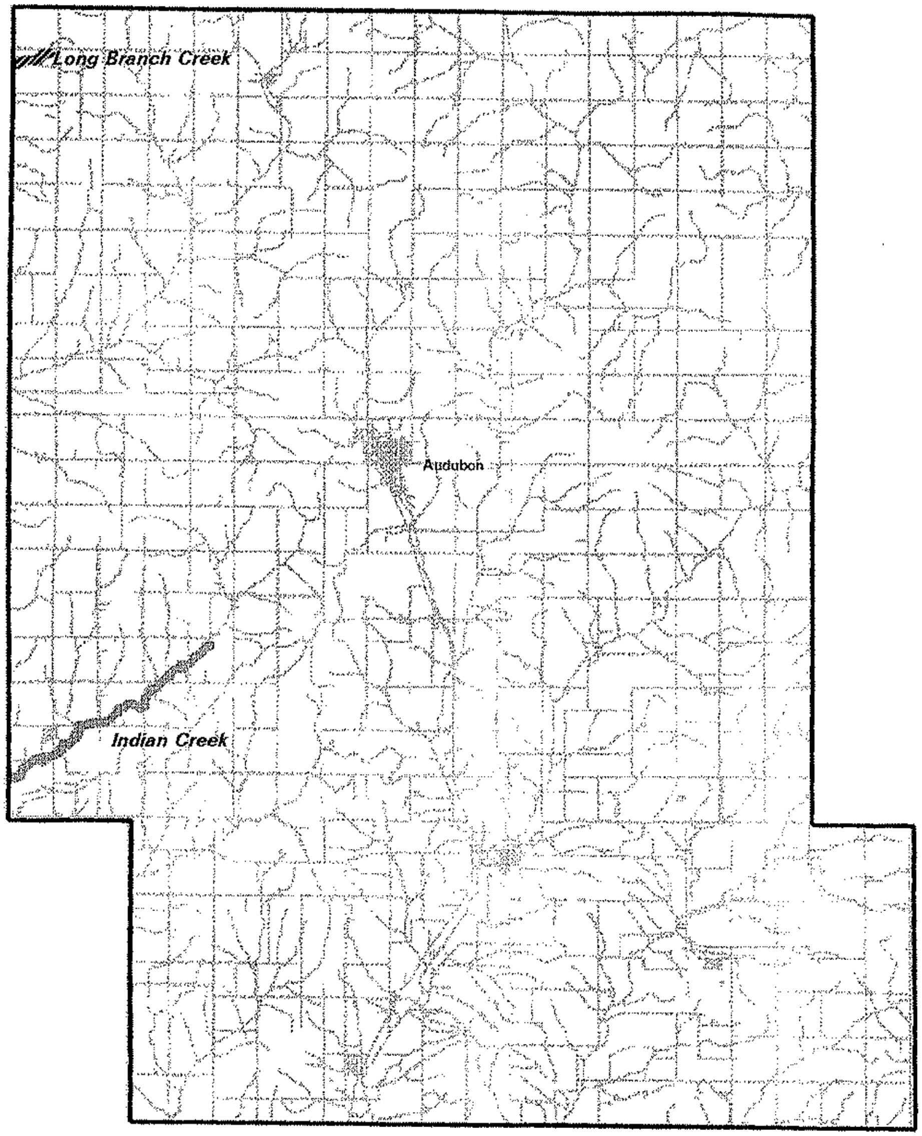

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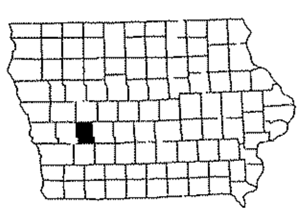
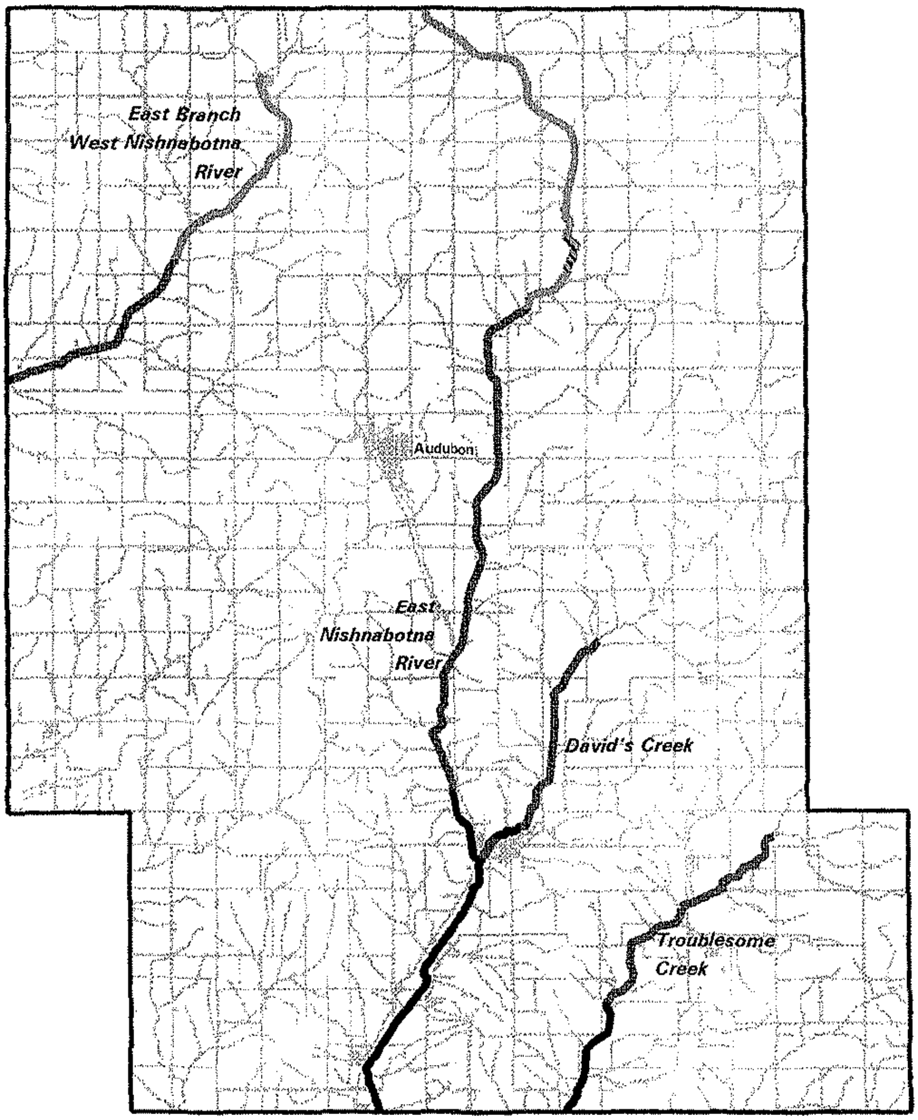


Audubon County 1993	*Miles*	*Kilometers*	*% of Total*
stage 2	1.03	1.66	13.12%
stage 3	6.82	10.97	86.88%
Totals	7.85	12.63	100%

Stages of Stream Channel Evolution
classified from April 1993 aerial reconnaissance video
by Golden Hills RC&D, Oakland, Iowa



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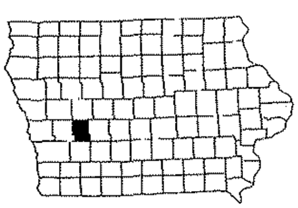
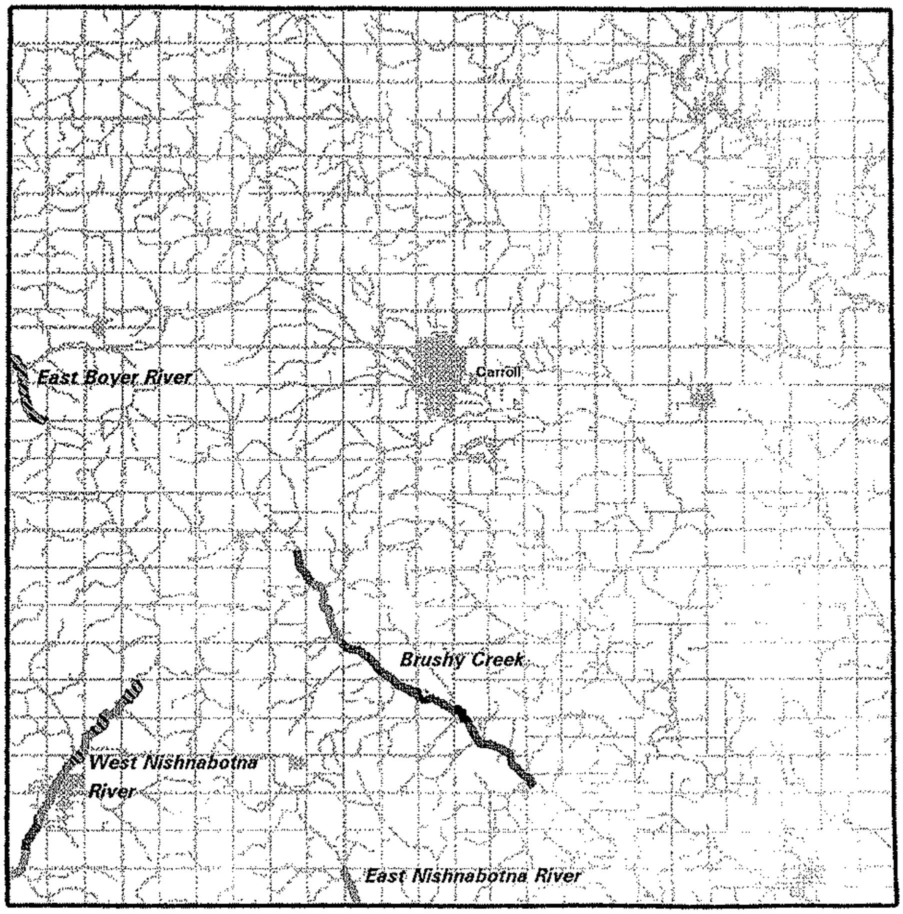


Audubon County 1994	*Miles*	*Kilometers*	*% of Total*
stage 1	1.00	1.61	1.78%
stage 3	14.6	23.49	25.96%
stage 4	28.76	46.27	51.14%
stage 5	11.88	19.11	21.12%
Totals	56.24	90.49	100%

Stages of Stream Channel Evolution
classified from March 1994 aerial reconnaissance video
by Golden Hills RC&D, Oakland, Iowa



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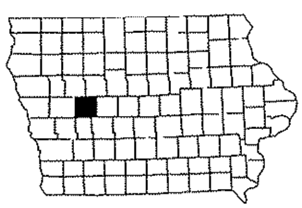
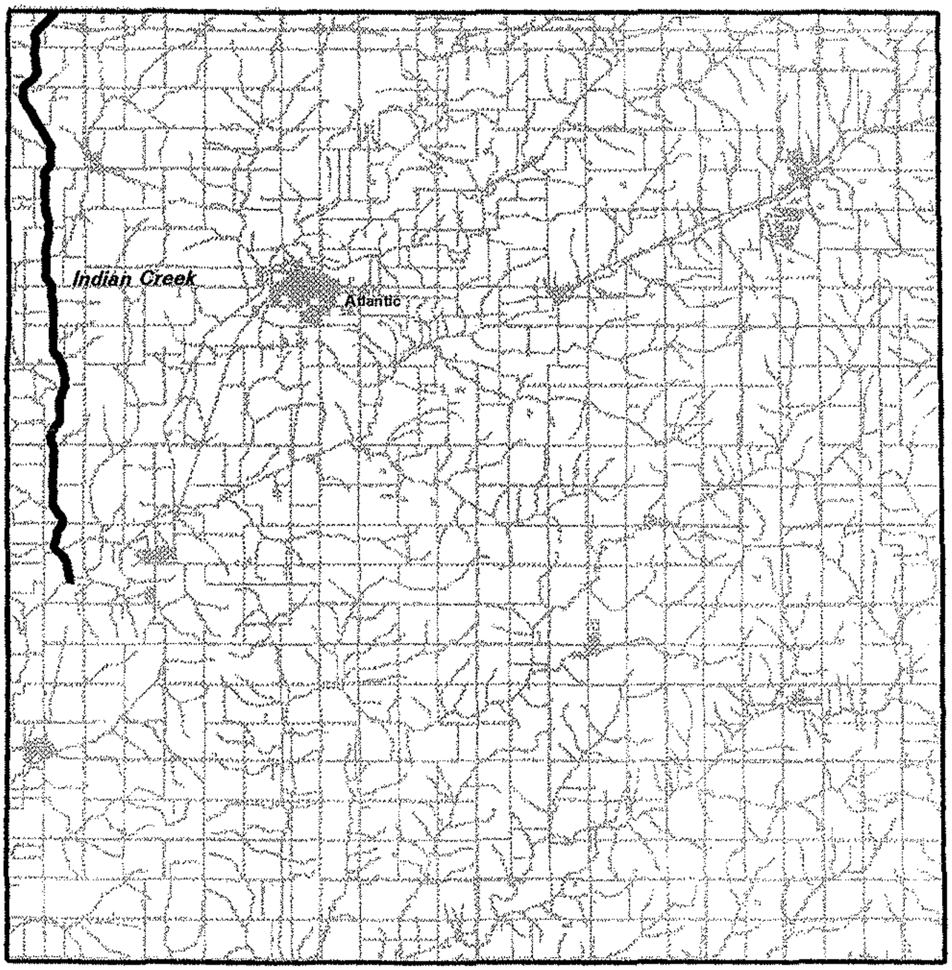


Carroll County 1994	*Miles*	*Kilometers*	*% of Total*
stage 1	5.22	8.40	22.27%
stage 3	9.92	15.96	42.32%
stage 4	8.01	12.89	34.17%
stage 5	0.29	0.47	1.24%
Totals	23.44	37.71	100%

Stages of Stream Channel Evolution
classified from March 1994 aerial reconnaissance video
by Golden Hills RC&D, Oakland, Iowa



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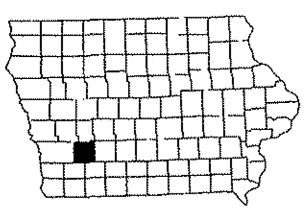
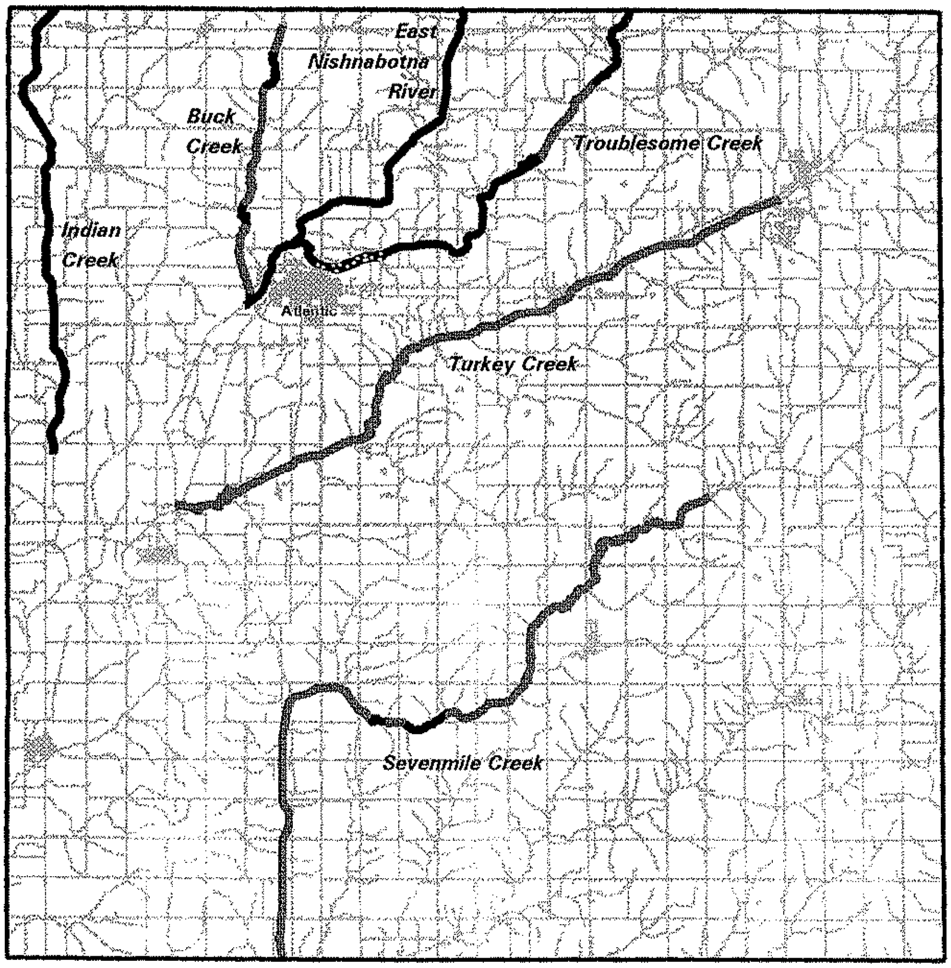


Cass County 1993	*Miles*	*Kilometers*	*% of Total*
stage 5	15.59	25.08	100%
Totals	15.59	25.08	100%

Stages of Stream Channel Evolution
classified from April 1993 aerial reconnaissance video
by Golden Hills RC&D, Oakland, Iowa



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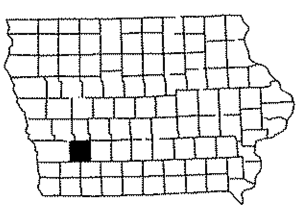
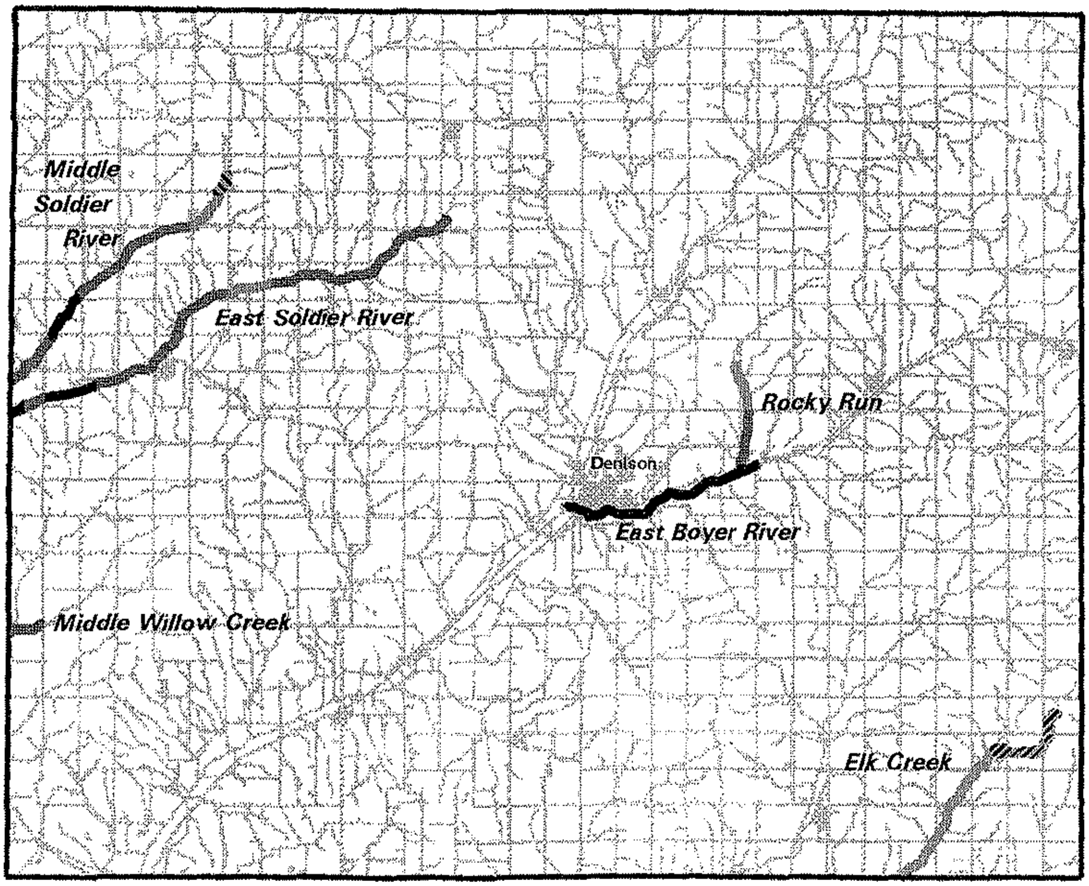
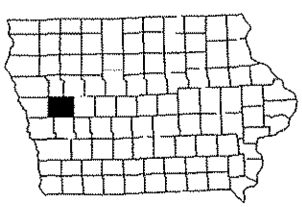


Cass County 1994	Miles	Kilometers	% of Total
stage 4	48.83	78.57	55.84%
stage 5	37.04	59.60	42.36%
stage 5i	1.57	2.53	1.80%
Totals	87.44	140.69	100%

Stages of Stream Channel Evolution
classified from March 1994 aerial reconnaissance video
by Golden Hills RC&D, Oakland, Iowa



Approximate scale 1"=5 miles



Crawford County 1993	*Miles*	*Kilometers*	*% of Total*
stage 1	0.60	0.97	1.44%
stage 2	2.83	4.55	6.78%
stage 3	7.84	12.61	18.79%
stage 4	20.88	33.60	50.05%
stage 5	9.57	15.40	22.94%
Totals	41.72	18.13	100%

Stages of Stream Channel Evolution
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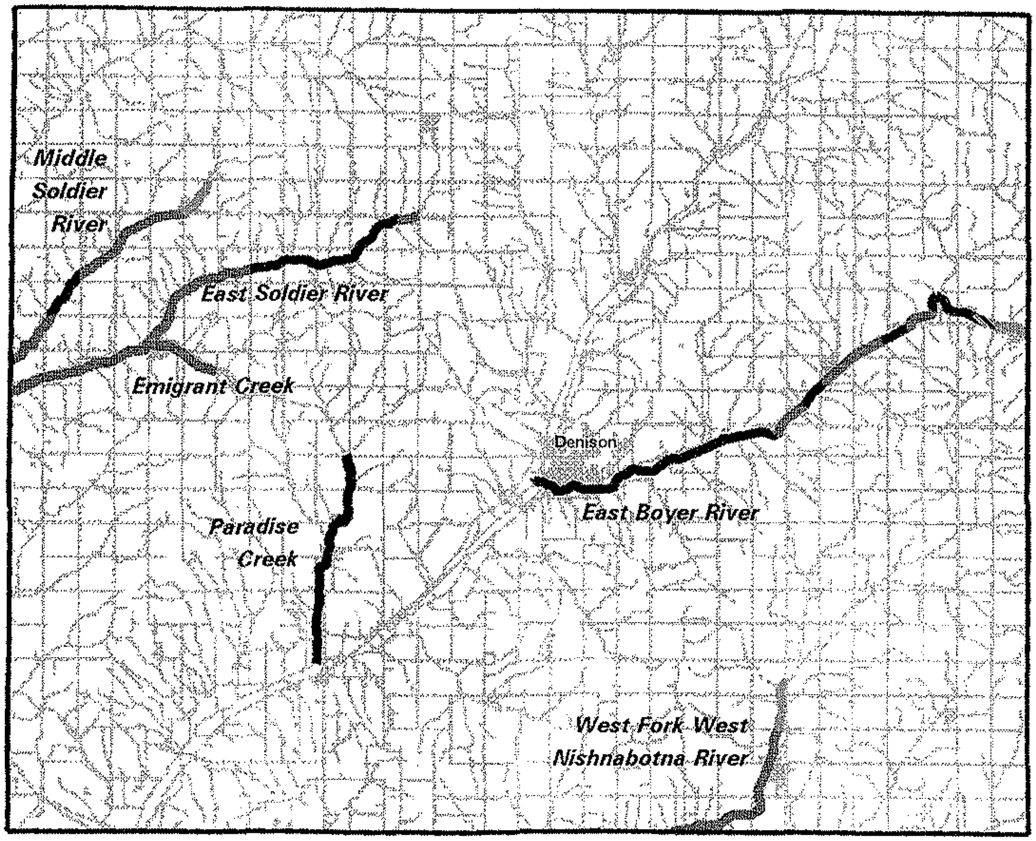

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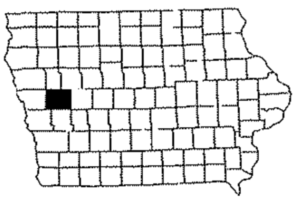

Crawford County 1994	*Miles*	*Kilometers*	*% of Total*
stage 1	0.54	0.87	0.93%
stage 3	3.87	6.23	6.66%
stage 4	26.38	42.45	45.42%
stage 5	27.29	43.91	46.99%
Totals	58.08	93.45	100%

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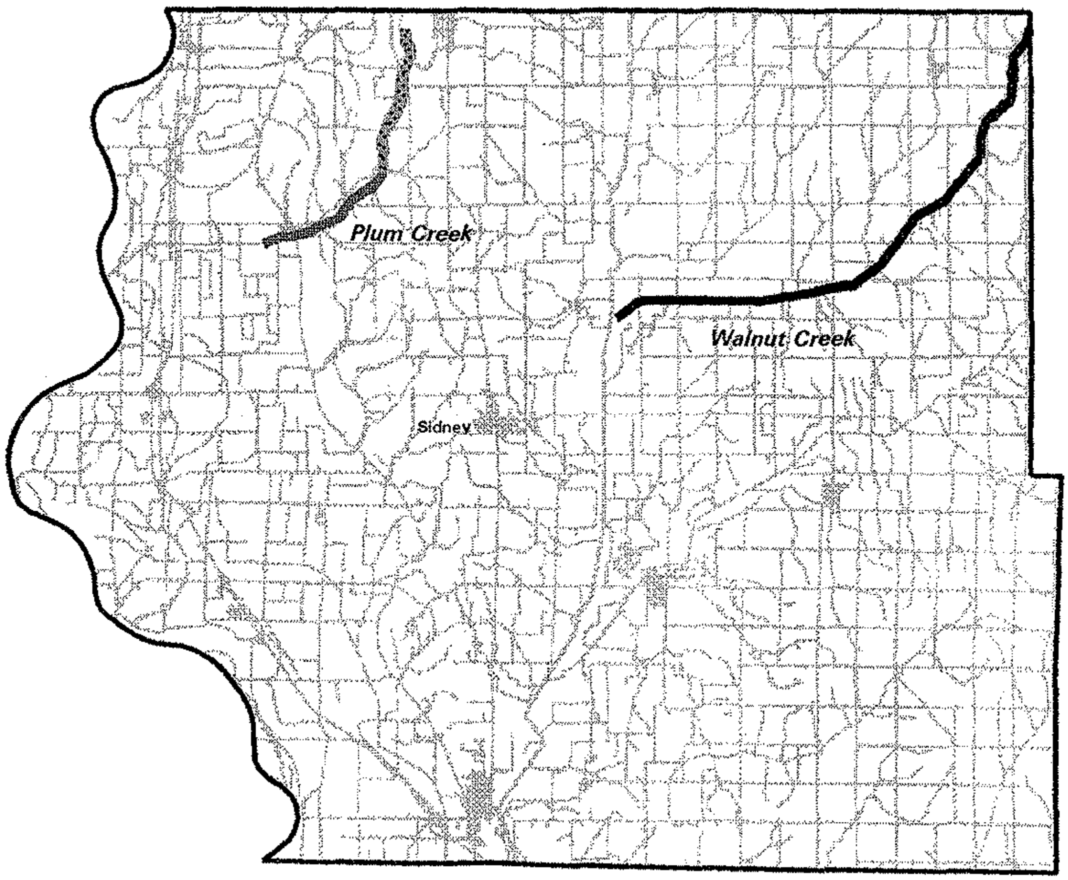

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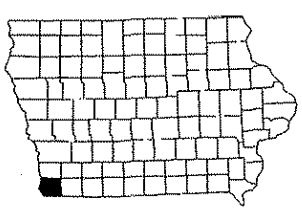

Fremont County 1993	*Miles*	*Kilometers*	*% of Total*
stage 4	3.78	6.08	16.36%
stage 5	15.16	24.39	65.60%
stage 6i	4.17	6.71	18.04%
Totals	23.11	37.18	100%

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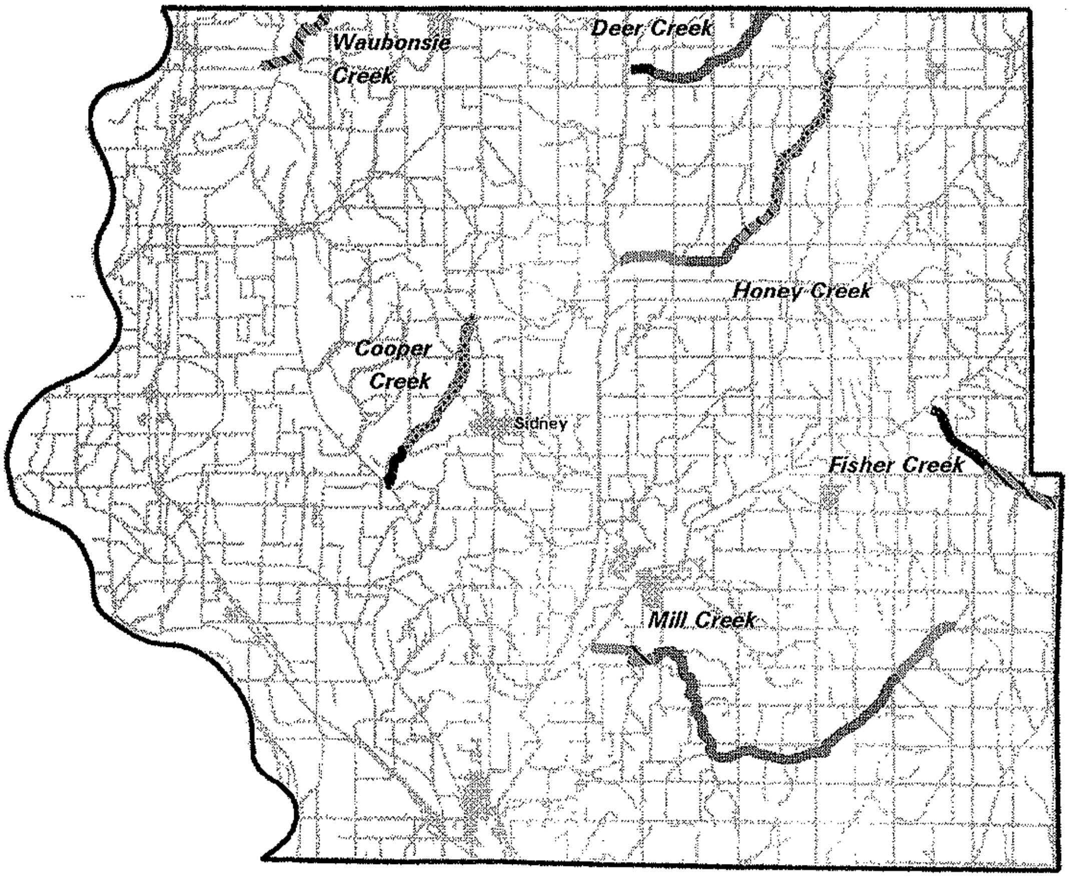

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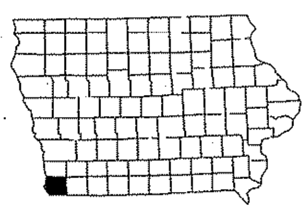

Fremont County 1994	*Miles*	*Kilometers*	*% of Total*
stage 1	6.84	11.01	16.89%
stage 3	5.03	8.09	12.42%
stage 4	14.93	24.02	36.87%
stage 5	4.15	6.68	10.25%
stage 6i	9.54	15.35	23.56%
Totals	40.49	65.15	100%

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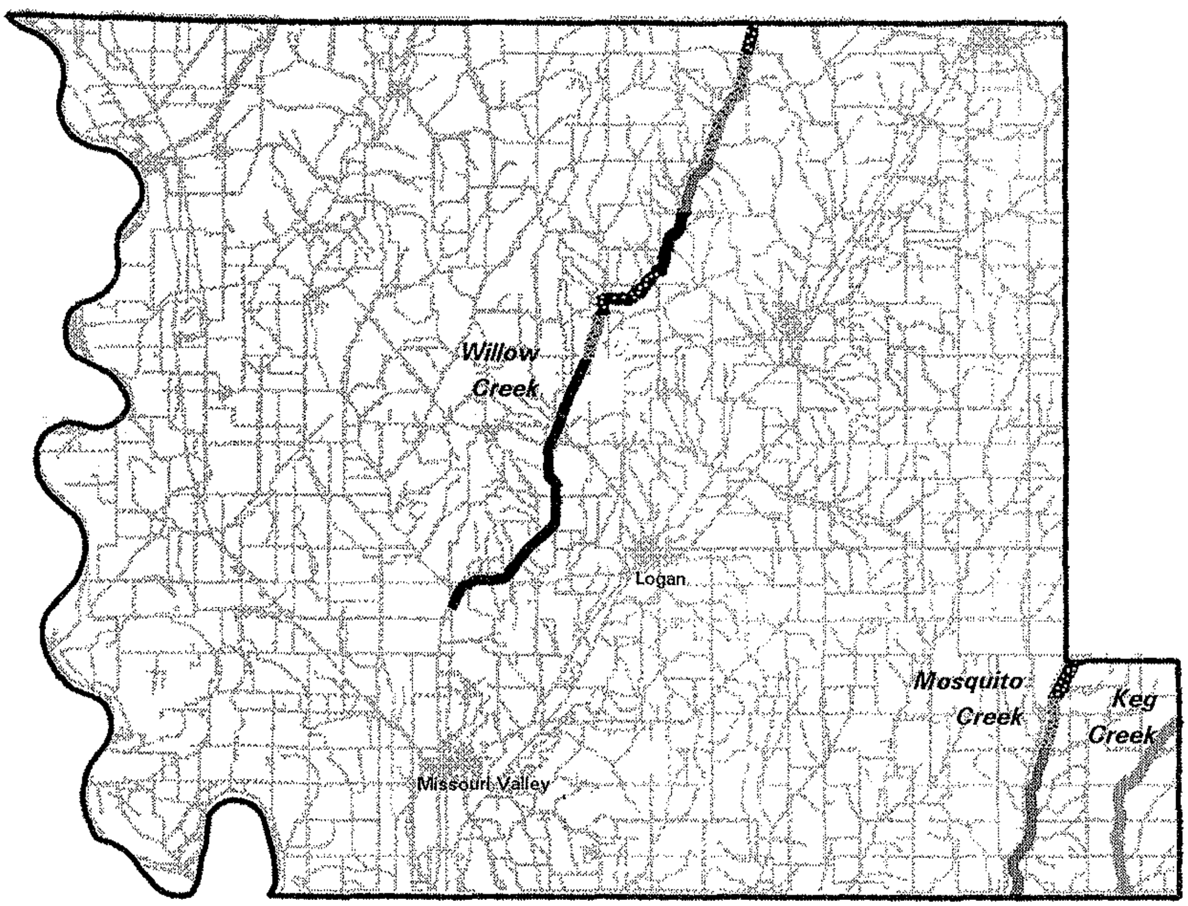

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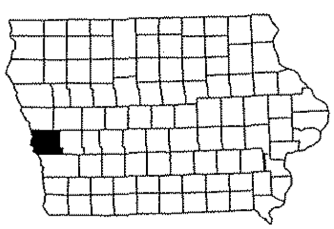

Harrison County 1993	*Miles*	*Kilometers*	*% of Total*
stage 3	6.02	9.69	17.38%
stage 4	6.05	9.73	17.47%
stage 5	9.56	15.38	27.61%
stage 5i	6.56	10.56	18.94%
stage 6i	6.44	10.36	18.60%
Totals	34.63	55.72	100%

Stages of Stream Channel Evolution
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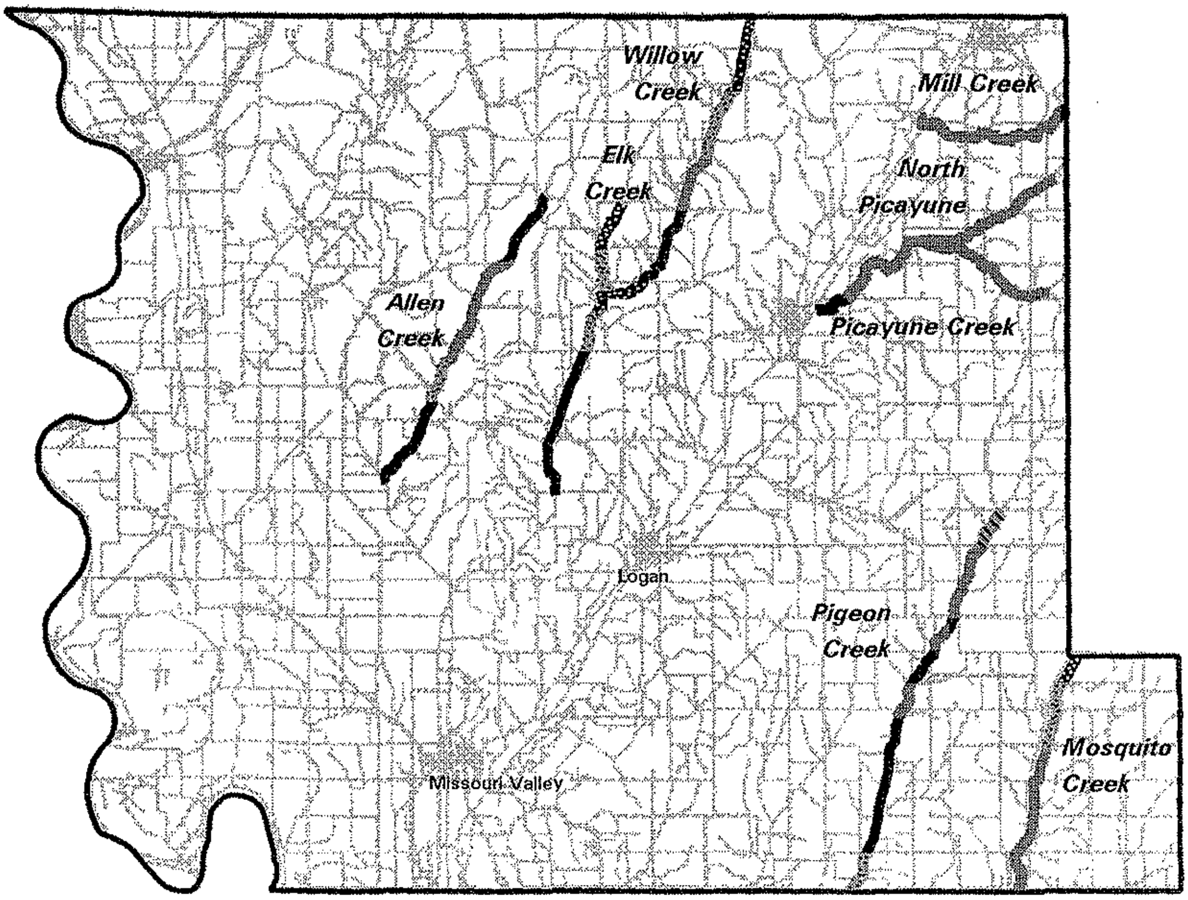
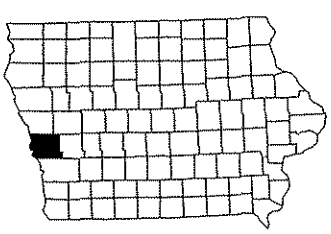


Approximate scale 1"=5 miles



Harrison County 1994	*Miles*	*Kilometers*	*% of Total*
stage 1	1.57	2.53	2.29%
stage 4	41.19	66.27	60.07%
stage 5	7.32	11.78	10.68%
stage 5i	9.70	15.61	14.15%
stage 6i	8.79	14.14	12.82%
Totals	68.57	110.33	100%

Stages of Stream Channel Evolution
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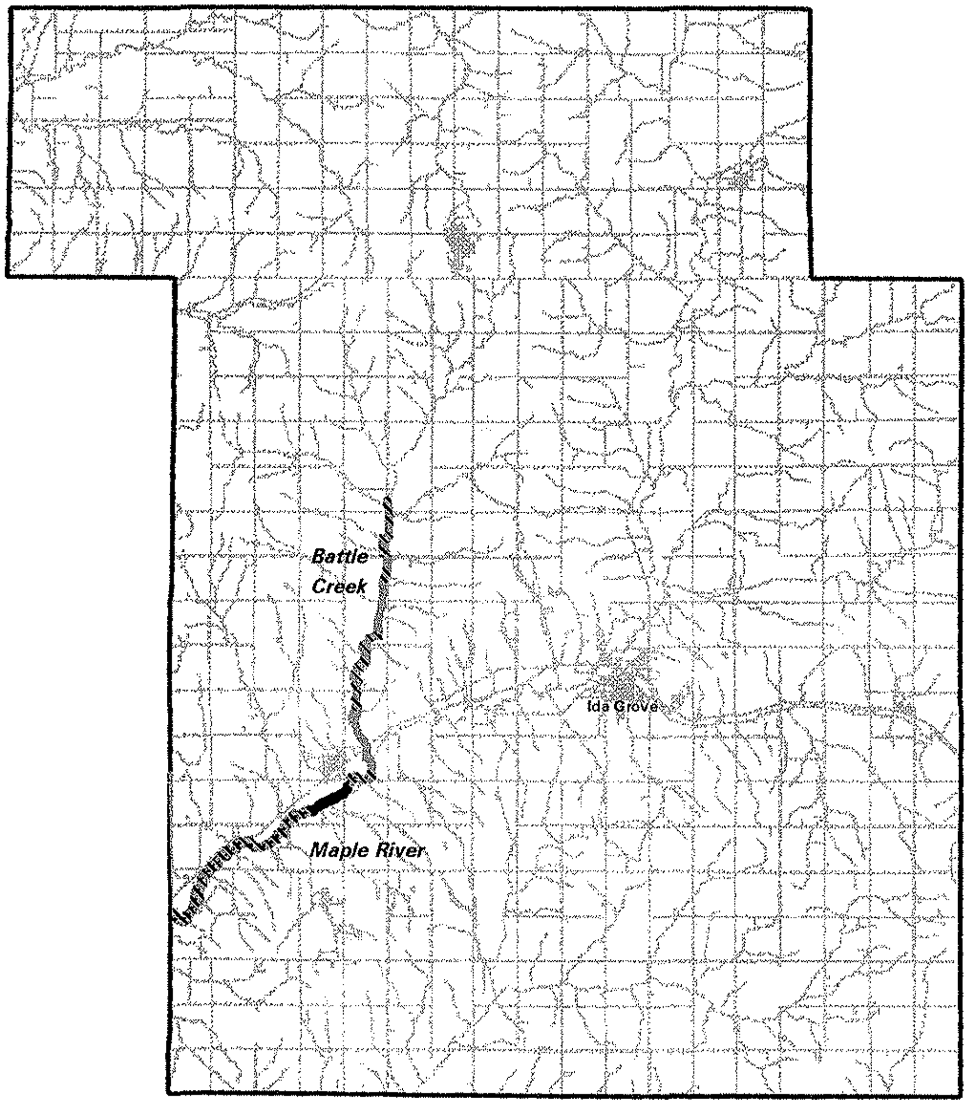
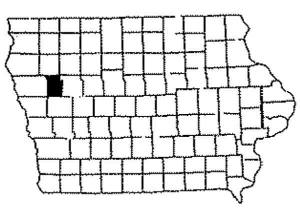


Approximate scale 1"=4 miles



Ida County 1994	*Miles*	*Kilometers*	*% of Total*
stage 1	4.68	7.53	30.53%
stage 3	2.76	4.44	18.00%
stage 5	0.89	1.43	5.81%
stage 6	7.00	11.26	45.66%
Totals	15.33	24.67	100%

Stages of Stream Channel Evolution
classified from March 1994 aerial reconnaissance video
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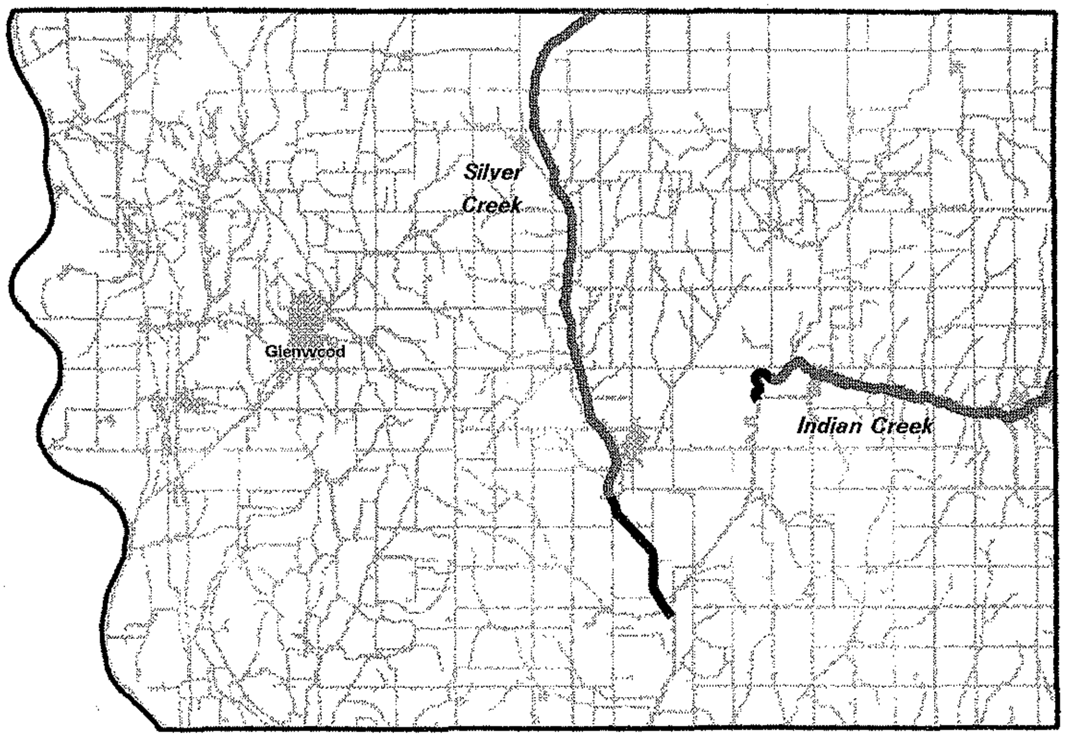
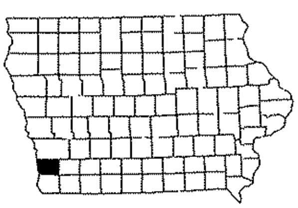


Approximate scale 1"=5 miles



Mills County 1993	*Miles*	*Kilometers*	*% of Total*
stage 4	24.03	38.66	88.02%
stage 5	3.27	5.26	11.98%
Totals	27.30	43.93	100%

Stages of Stream Channel Evolution
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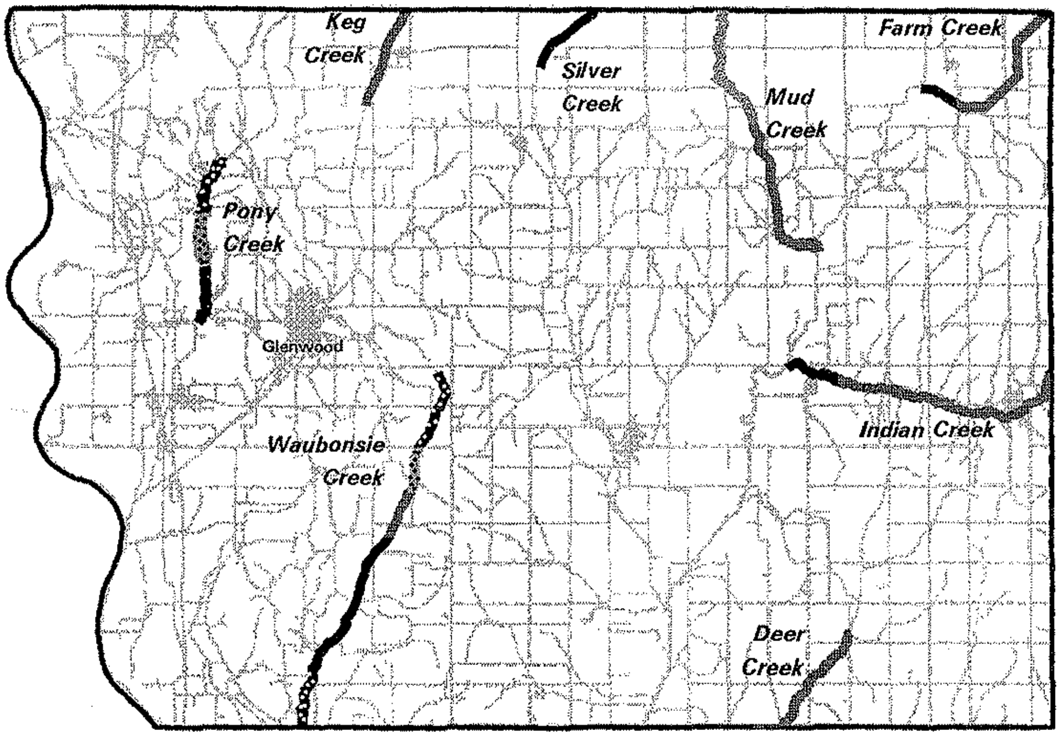
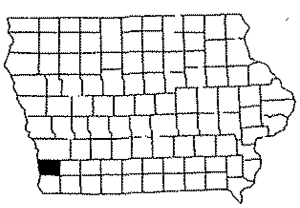


Approximate scale 1"=5 miles



Mills County 1994	*Miles*	*Kilometers*	*% of Total*
stage 3	3.08	4.96	6.86%
stage 4	22.93	36.89	51.07%
stage 5	10.37	16.69	23.10%
stage 5i	4.25	6.84	9.47%
stage 6i	4.27	6.87	9.51%
Totals	44.90	72.24	100%

Stages of Stream Channel Evolution
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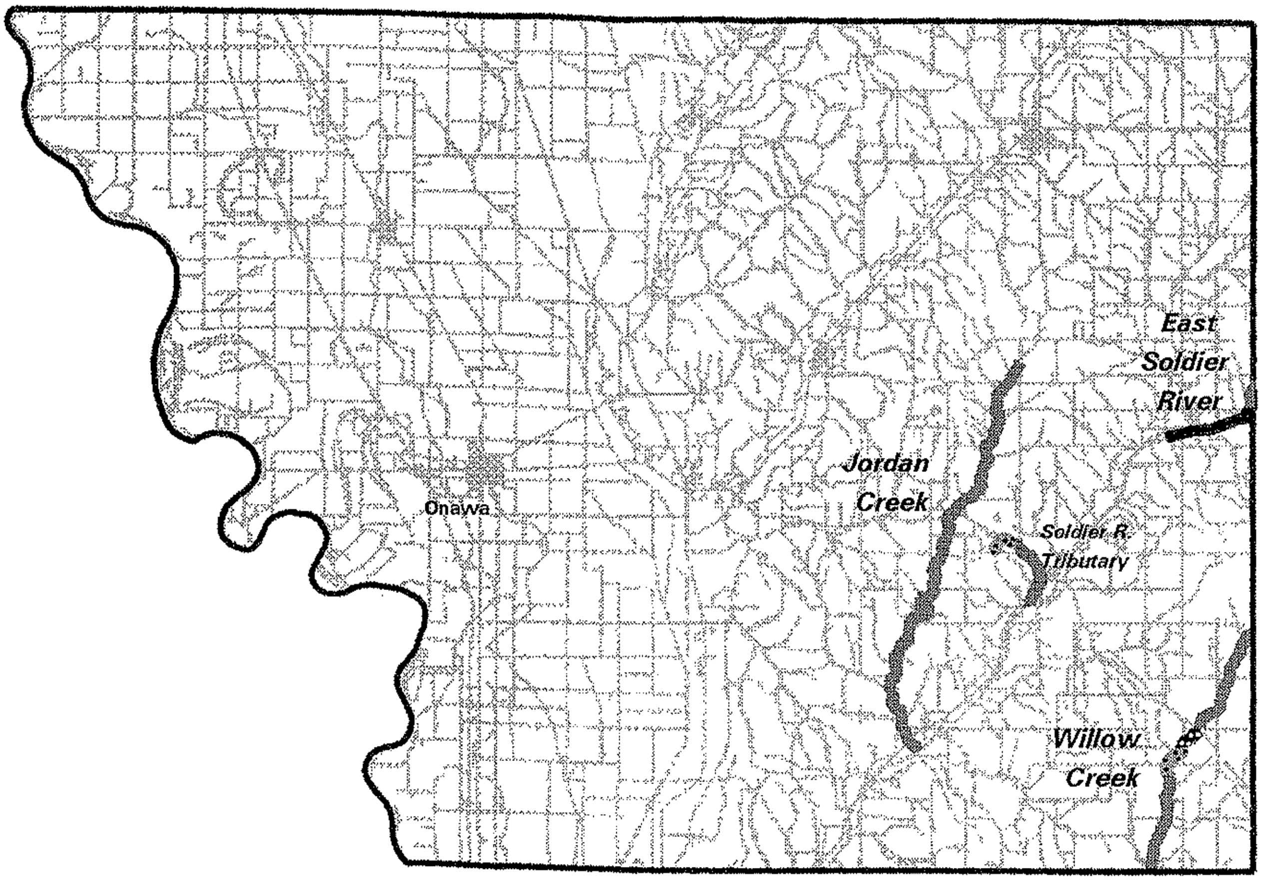

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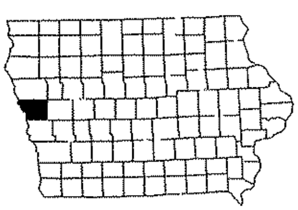

Monona County 1993	*Miles*	*Kilometers*	*% of Total*
stage 4	21.53	34.64	73.21%
stage 5	2.60	4.18	8.84%
stage 5i	3.15	5.07	10.71%
stage 6i	2.13	3.43	7.24%
Totals	29.41	47.32	100%

Stages of Stream Channel Evolution
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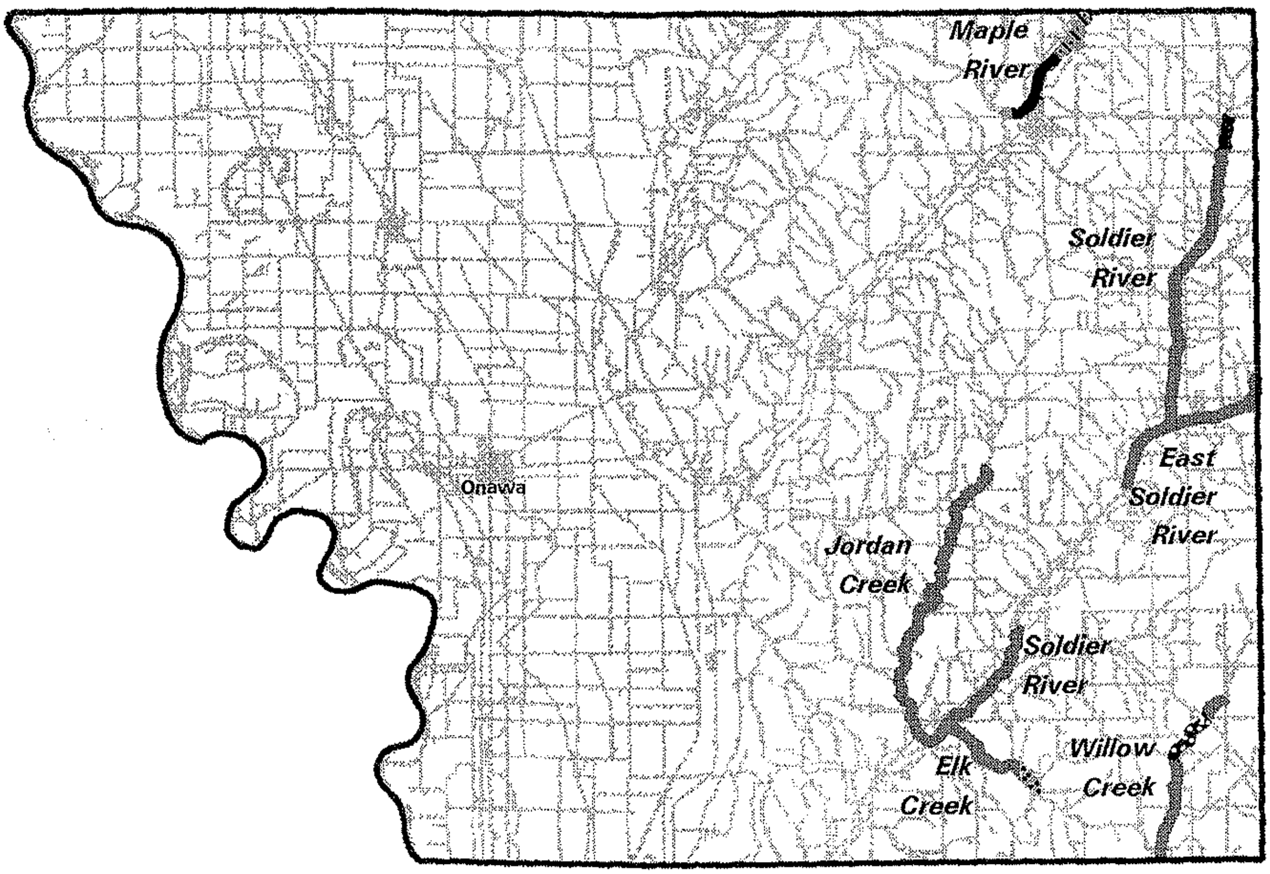

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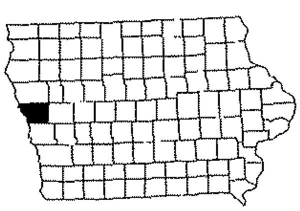

Monona County 1994	Miles	Kilometers	% of Total
stage 1	1.03	1.66	2.37%
stage 4	34.86	56.09	80.27%
stage 5	1.14	1.83	2.62%
stage 6	3.27	5.26	7.53%
stage 5i	2.58	4.15	5.94%
stage 6i	0.55	0.88	1.27%
Totals	43.43	69.88	100%

Stages of Stream Channel Evolution
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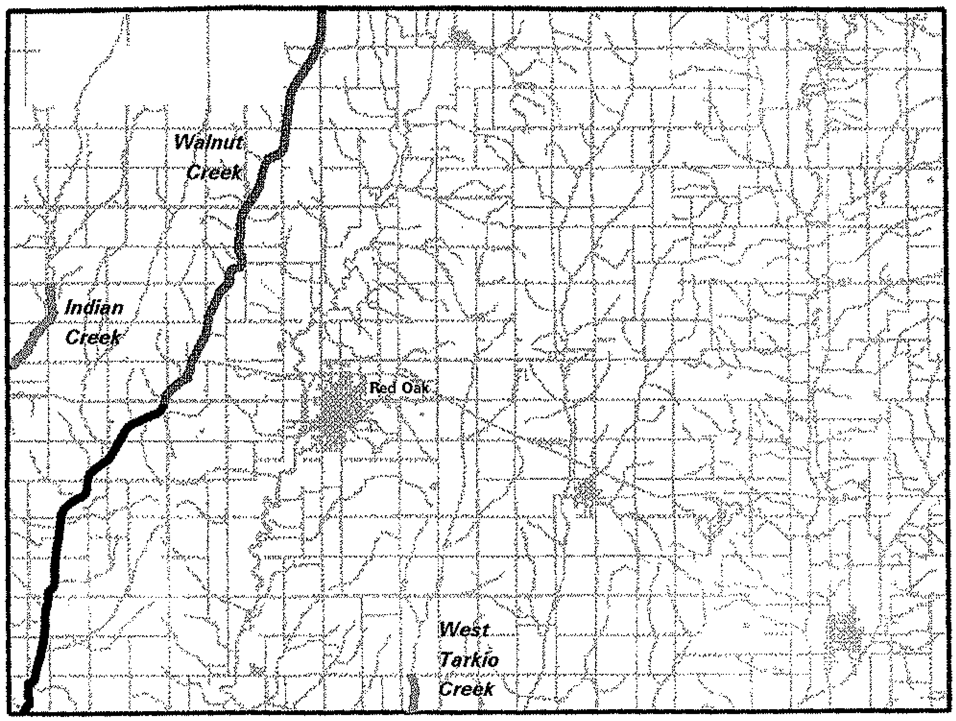

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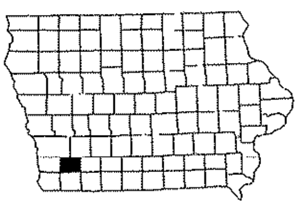

Montgomery County 1993	*Miles*	*Kilometers*	*% of Total*
stage 3	3.83	6.16	15.52%
stage 4	11.35	18.26	46.01%
stage 5	9.49	15.27	38.47%
Totals	24.67	39.69	100%

Stages of Stream Channel Evolution
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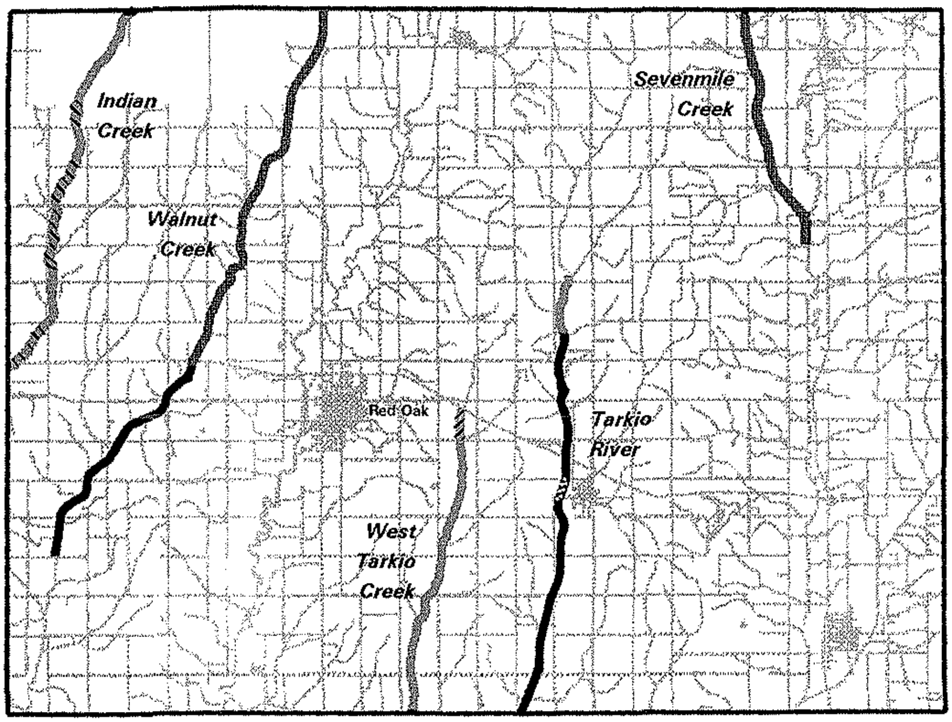
by Golden Hills RC&D, Oakland, Iowa



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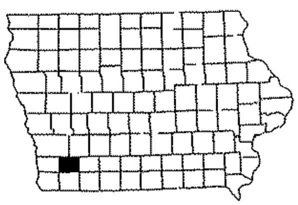

Montgomery County 1994	*Miles*	*Kilometers*	*% of Total*
stage 1	6.25	10.06	11.62%
stage 2	0.78	1.26	1.45%
stage 3	13.90	22.37	25.85%
stage 4	25.65	41.27	47.70%
stage 5	6.48	10.43	12.05%
stage 5i	0.71	1.14	1.32%
Totals	53.77	86.52	100%

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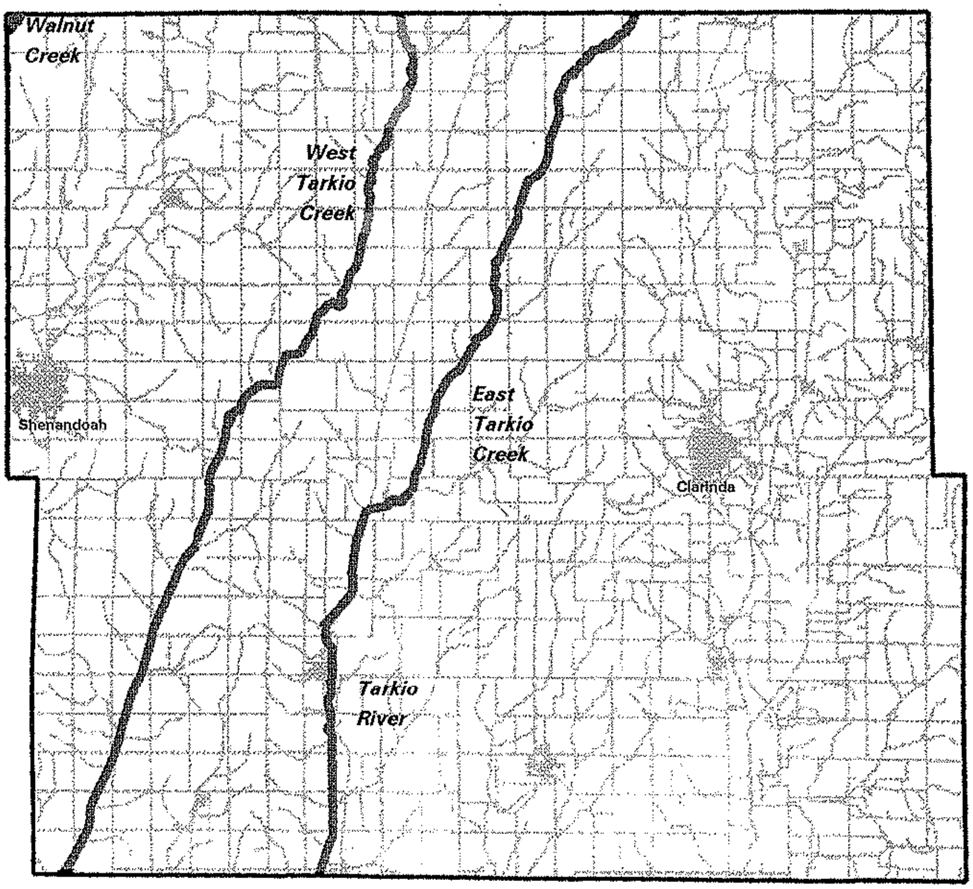
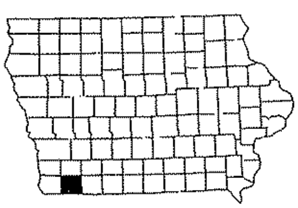


Approximate scale 1"=5 miles



Page County 1993	*Miles*	*Kilometers*	*% of Total*
stage 3	1.87	3.01	3.47%
stage 4	51.95	83.59	96.53%
Totals	53.82	86.60	100%

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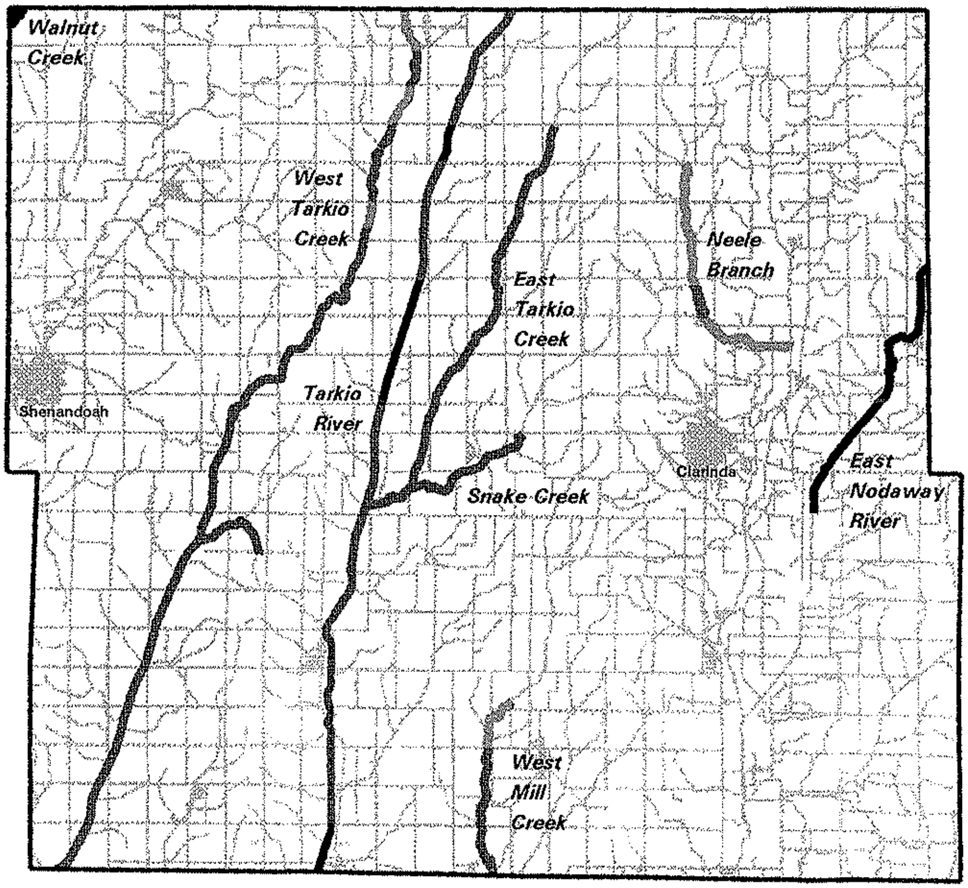
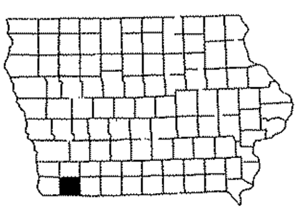


Approximate scale 1"=5 miles



Page County 1994	*Miles*	*Kilometers*	*% of Total*
stage 1	3.46	5.57	3.94%
stage 3	7.23	11.63	8.23%
stage 4	63.44	102.07	72.18%
stage 5	13.76	22.14	15.66%
Totals	87.89	141.42	100%

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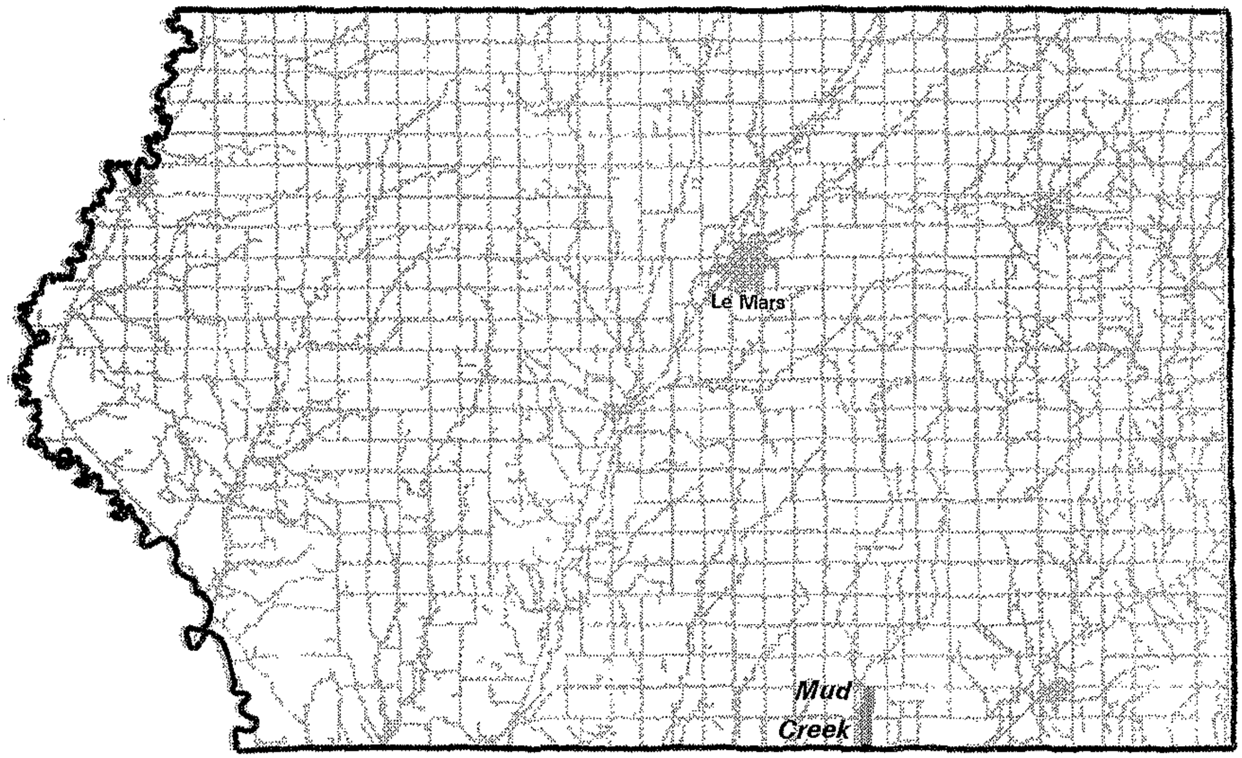
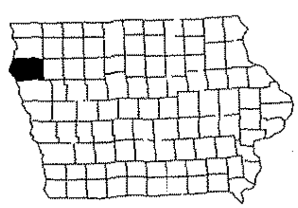


Approximate scale 1"=6 miles



Plymouth County 1994	*Miles*	*Kilometers*	*% of Total*
stage 3	2.04	3.28	100%
Totals	2.04	3.28	100%

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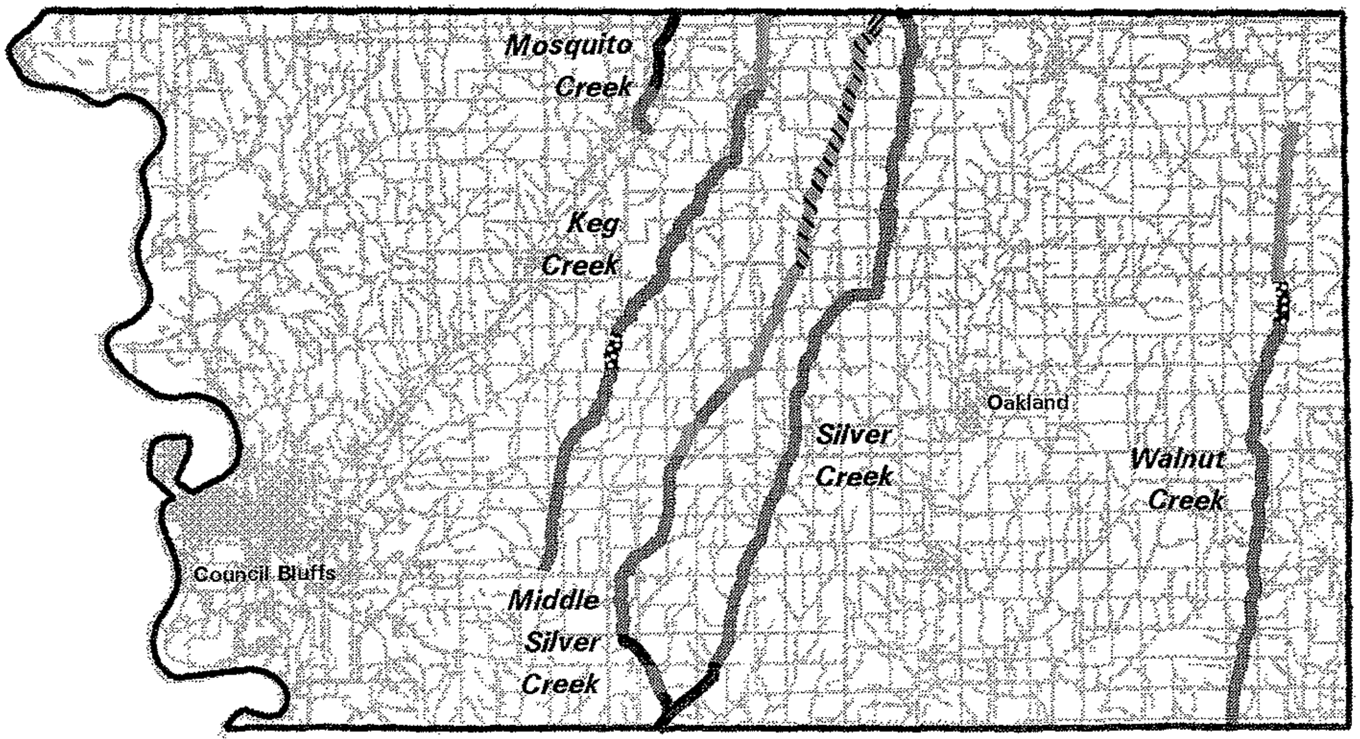
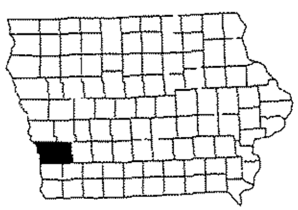


Approximate scale 1"=6 miles



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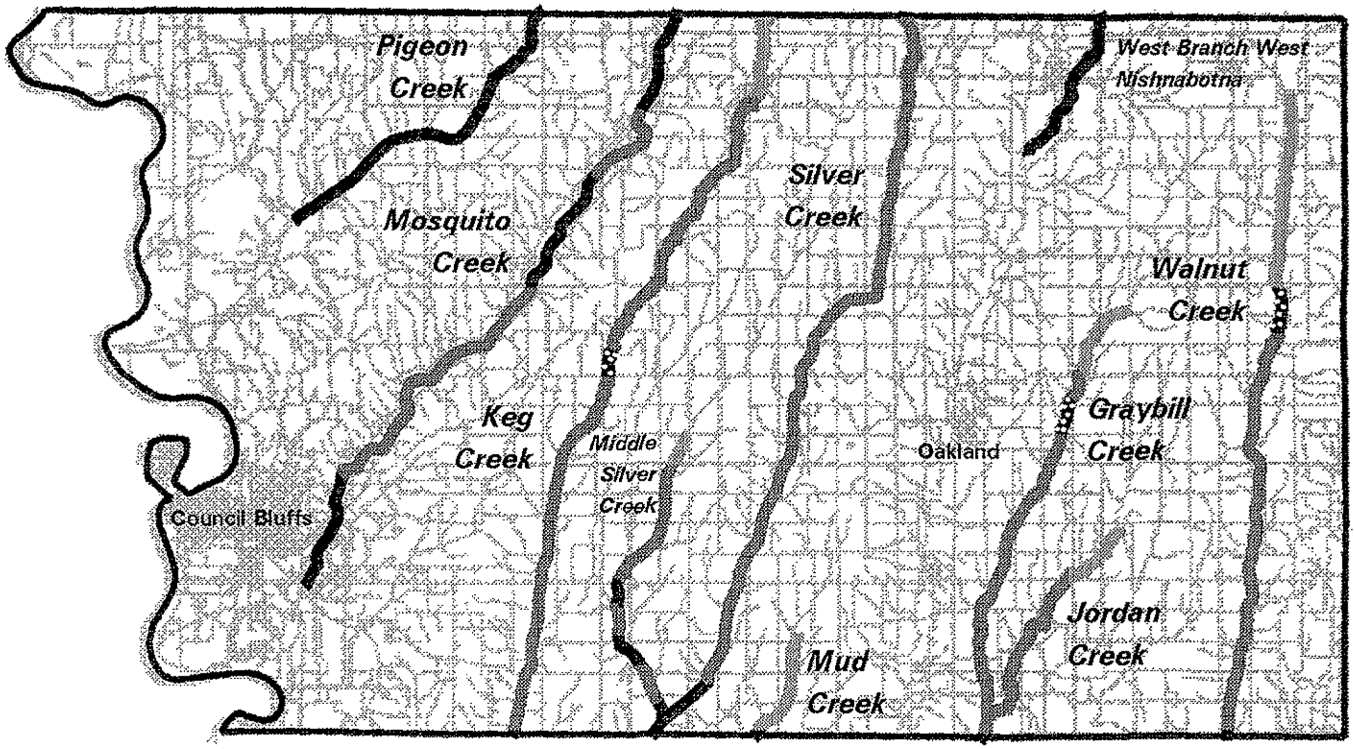
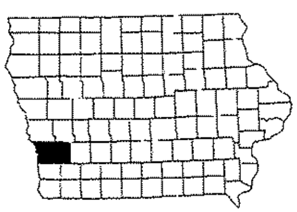
Pottawattamie County 1993	*Miles*	*Kilometers*	*% of Total*
stage 1	0.22	0.35	0.21%
stage 2	9.08	14.61	8.75%
stage 3	14.60	23.49	14.07%
stage 4	69.53	111.87	67.01%
stage 5	7.58	12.20	7.31%
stage 5i	2.75	4.42	2.65%
Totals	103.76	166.95	100%



Approximate scale 1"=6 miles



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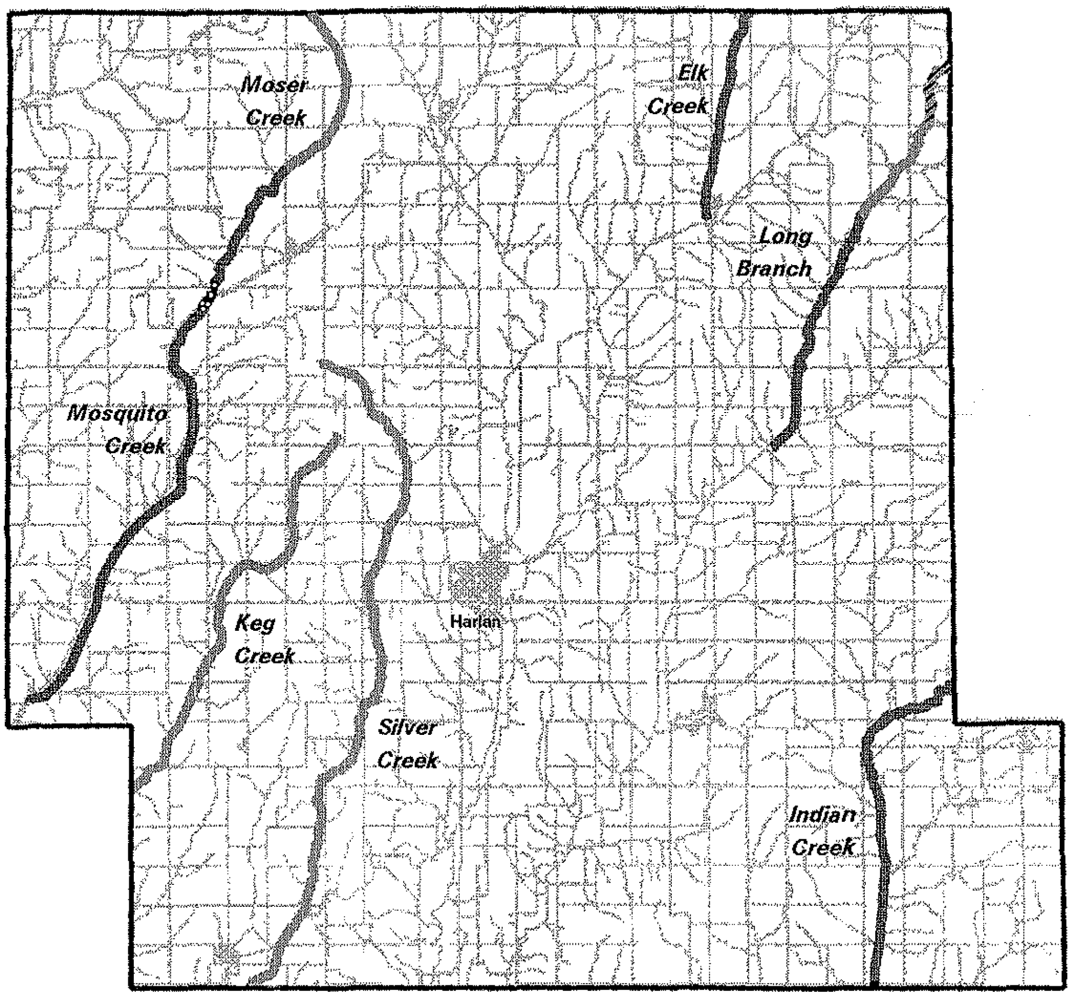
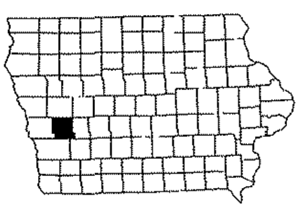
Pottawattamie County 1994	*Miles*	*Kilometers*	*% of Total*
stage 1	2.82	4.54	1.69%
stage 3	18.54	29.83	11.12%
stage 4	106.26	170.97	63.71%
stage 5	35.46	57.06	21.26%
stage 5i	3.72	5.99	2.23%
Totals	166.80	268.38	100%



Approximate scale 1"=5 miles



Shelby County 1993	*Miles*	*Kilometers*	*% of Total*
stage 2	2.33	3.75	2.88%
stage 3	40.92	65.84	50.66%
stage 4	36.72	59.08	45.46%
stage 5i	0.8	1.29	0.99%
Totals	80.77	129.96	100%

Stages of Stream Channel Evolution
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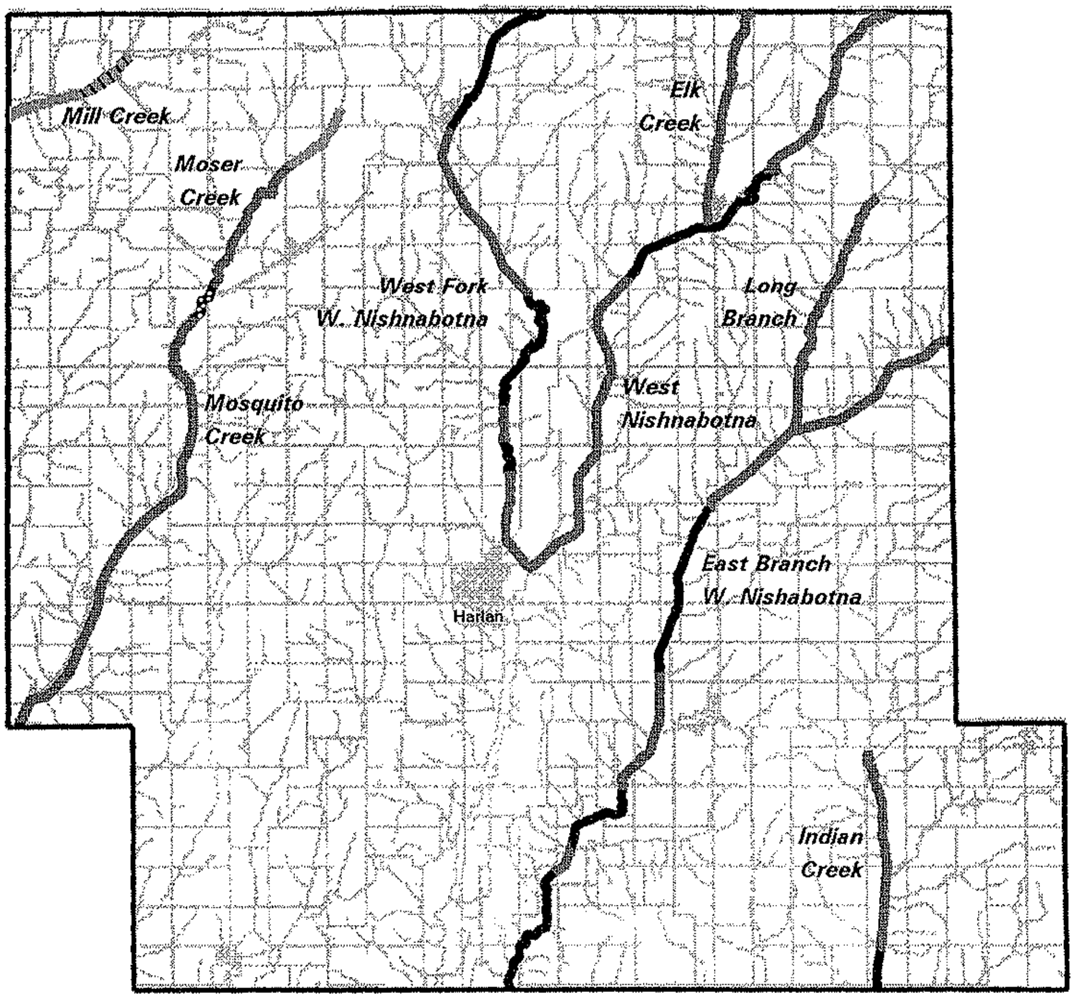
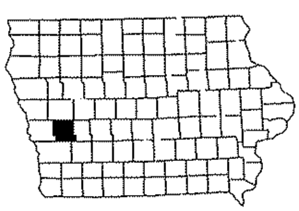


Approximate scale 1"=5 miles



Shelby County 1994	*Miles*	*Kilometers*	*% of Total*
stage 1	2.17	3.49	2.07%
stage 3	3.87	6.23	3.70%
stage 4	68.85	110.78	65.83%
stage 5	28.9	46.50	27.63%
stage 5i	0.8	1.29	0.76%
Totals	104.59	168.29	100%

Stages of Stream Channel Evolution
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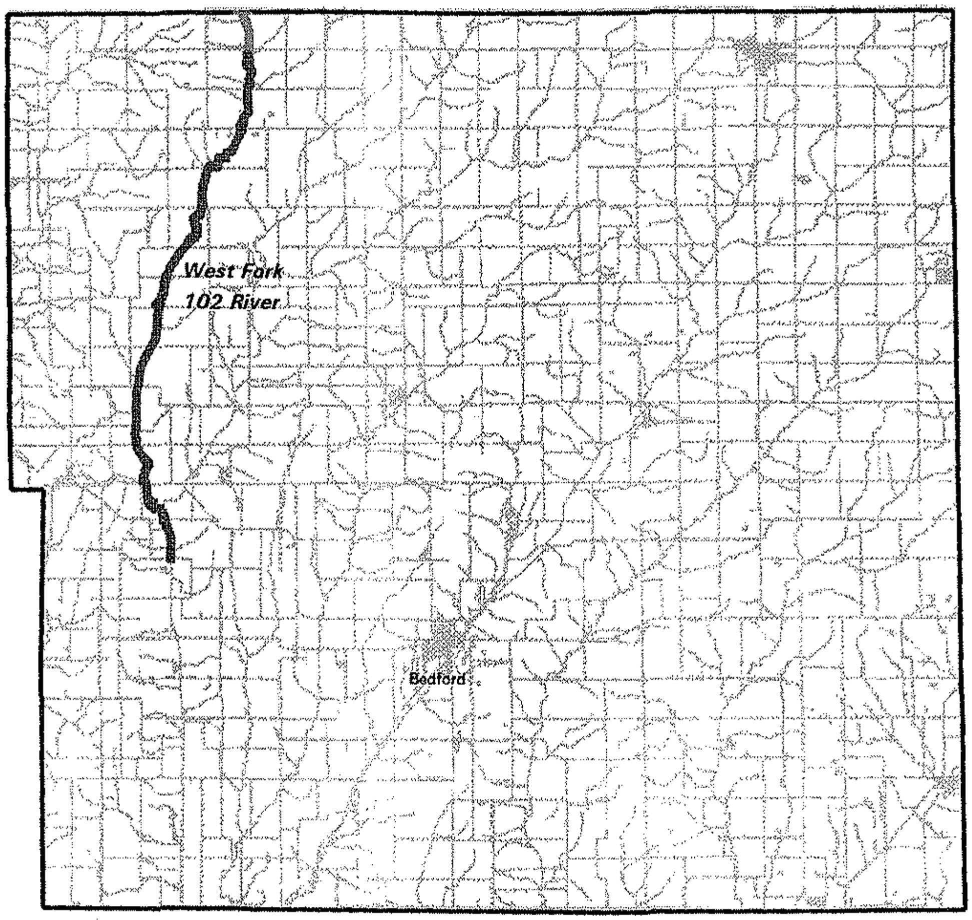
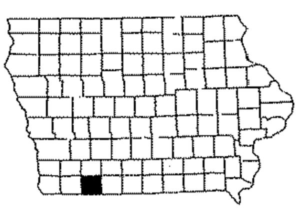


Approximate scale 1"=5 miles



Taylor County 1993	Miles	Kilometers	% of Total
stage 3	1.07	1.72	6.43%
stage 4	15.56	25.04	93.57%
Totals	16.63	26.76	100%

Stages of Stream Channel Evolution
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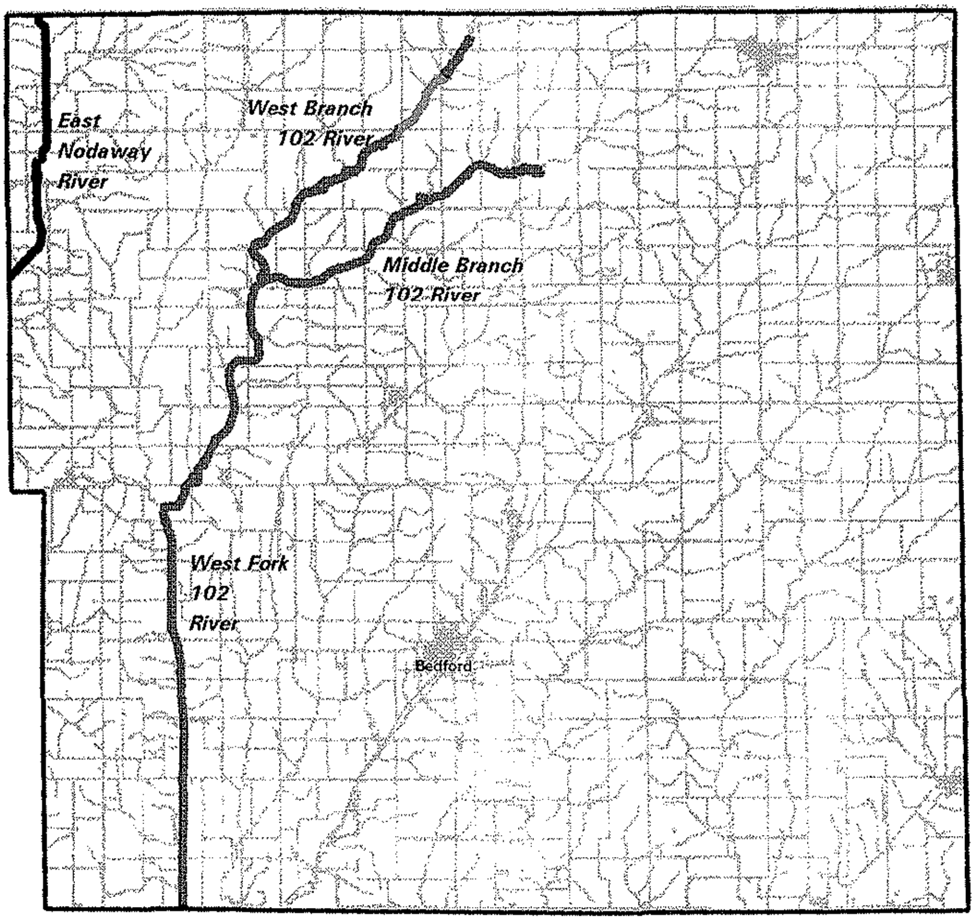
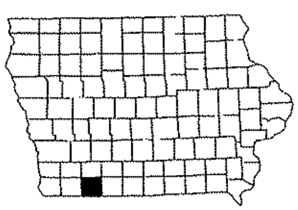
by Golden Hills RC&D, Oakland, Iowa



Approximate scale 1"=5 miles



Taylor County 1994	*Miles*	*Kilometers*	*% of Total*
stage 3	1.49	2.40	3.57%
stage 4	34.73	55.88	83.11%
stage 5	5.57	8.96	13.33%
Totals	41.79	67.24	100%

Stages of Stream Channel Evolution
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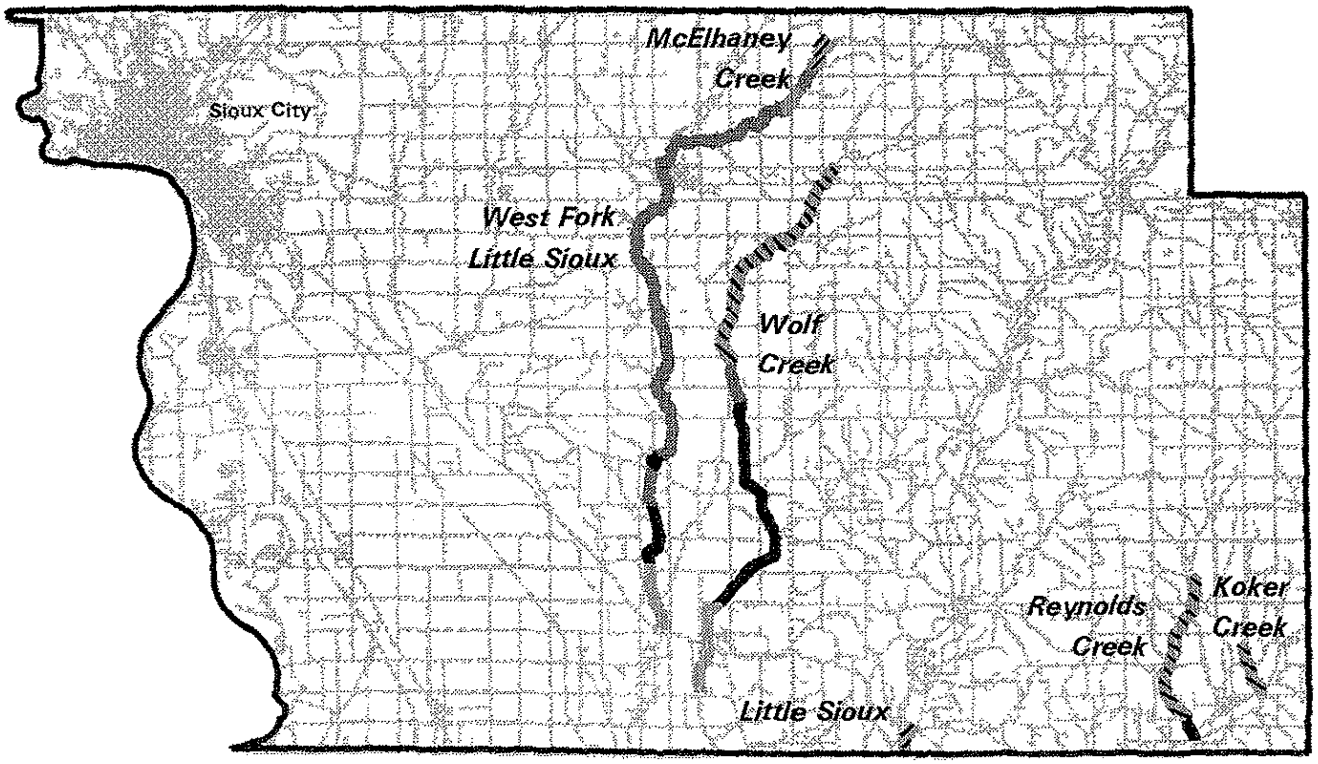
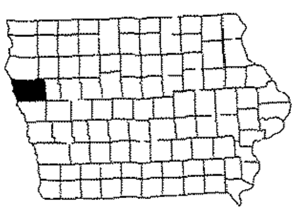
by Golden Hills RC&D, Oakland, Iowa



Approximate scale 1"=6 miles



Stages of Stream Channel Evolution

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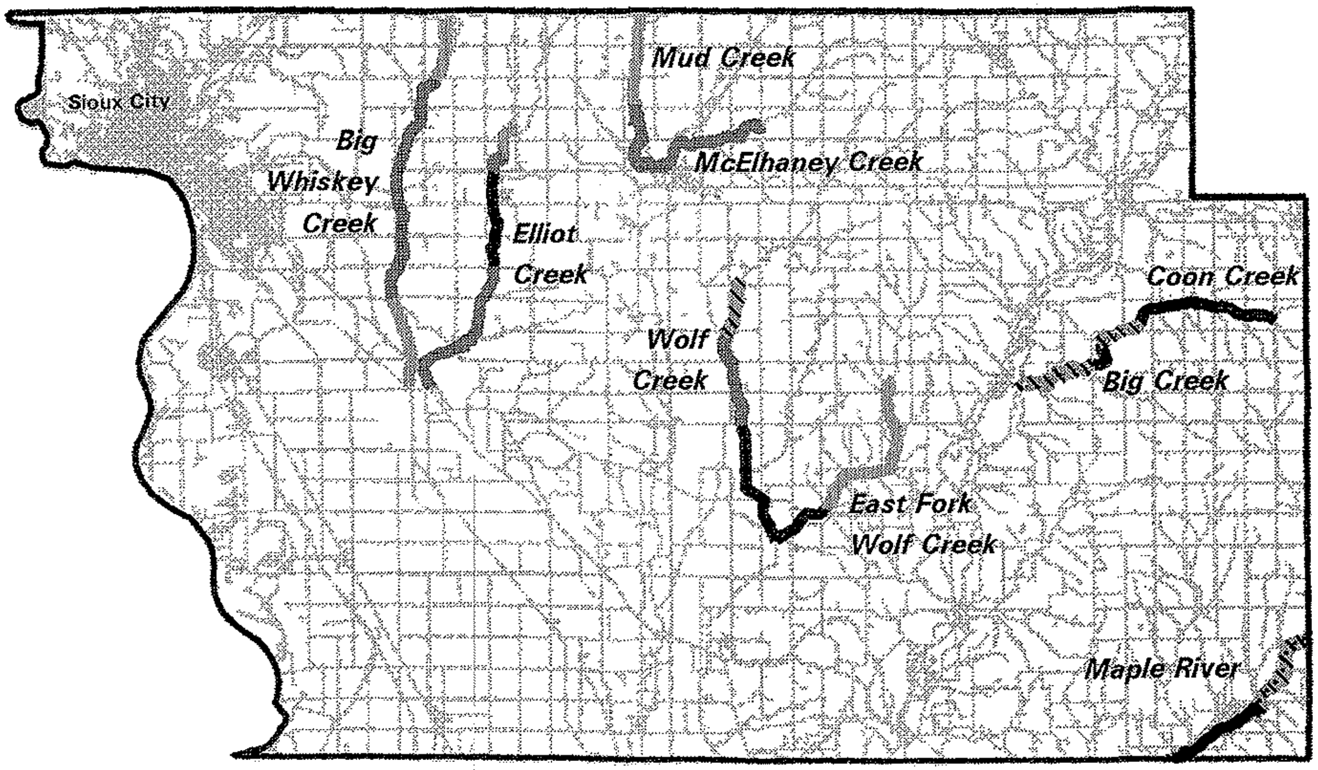
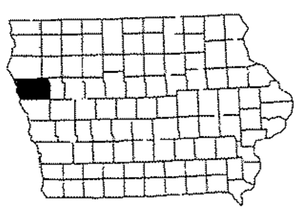
Woodbury County 1993	*Miles*	*Kilometers*	*% of Total*
stage 1	18.40	29.61	30.61%
stage 2	1.55	2.49	2.58%
stage 3	6.14	9.88	10.21%
stage 4	20.77	33.42	34.55%
stage 5	13.25	21.32	22.04%
Totals	60.11	75.40	100%



Approximate scale 1"=6 miles



Stages of Stream Channel Evolution
classified from March 1994 aerial reconnaissance video
by Golden Hills RC&D, Oakland, Iowa

Woodbury County 1994	*Miles*	*Kilometers*	*% of Total*
stage 1	4.4	7.08	6.19%
stage 3	15.51	24.96	21.82%
stage 4	25.14	40.45	35.37%
stage 5	22.07	35.51	31.05%
stage 6	3.96	6.37	5.57%
Totals	71.08	114.37	100%

Appendix B

Golden Hills RC&D Geographic Information System				
Pottawattamie County Data Layers				
Projection: UTM				
Spheroid: Clark66				
Resolution: 25 meters				
Layer Name		**Description**		**Source**
bou.pott		County boundary raster		USDC TIGER data
boundary		County boundary vector		USDC TIGER data
bridge_pott		Bridge replacements FY94-98		Golden Hills RC&D
byway_pott		Loess Hills Scenic Byway		Golden Hills RC&D
culvert_pott		Culvert replacements FY94-98		Golden Hills RC&D
dem.pott		Digital elevation model		Defense Mapping Agency
ewp_pott		EWP status map		Golden Hills RC&D
gradecs_pott		Grade control structures		Golden Hills RC&D
hu.pott		Hydrologic Units		SCS
hu_pott		Hydrologic Units		SCS
knick_pott		Stream knickpoint locations		Golden Hills RC&D
kp_pott		Knickpoints		Golden Hills RC&D
lf		Landform		IA DNR
lf.pott		Landform		IA DNR
nps_pott		Mo. River Corridor polygons		NPS, Golden Hills RC&D
nps_sites		Mo. River Corridor sites		NPS, Golden Hills RC&D
pipe_idot		Natural gas and other pipelines		IDOT DXF files
prairies_pott		Loess Hills prairie areas		IDNR
rail_idot		Railroads		IDOT DXF files
roads		All roads		USDC TIGER data
roads_co		County secondary system		IDOT DXF files
roads_fed		Interstate and federal roads		IDOT DXF files
roads_st		State roads		IDOT DXF files
roads_twn		Town roads		USDC TIGER data
slope.pott		Slope classification		Defense Mapping Agency
st_pott94		Stream stages report		Golden Hills RC&D
stab_sites		Stabilization structure locations		Golden Hills RC&D
stage.pott94		Stream stages in 1994		Golden Hills RC&D
stage_pott93		Stream stages 1993		Golden Hills RC&D
stage_pott94		Stream stages in 1994		Golden Hills RC&D
streams_idot		Streams		IDOT DXF files
streams_tgr		Streams		USDC TIGER data
towns.pott		corporate boundaries		USDC TIGER data
towns_pott		corporate boundaries		USDC TIGER data
video_pott93		Streams video taped in 1993		Golden Hills RC&D
video_pott94		Streams video taped in 1994		Golden Hills RC&D
walnut_old		Pre-channelized Walnut Creek		SCS

A. Digital Elevation Model for Pottawattamie County

Raw DEM data for the state of Iowa was provided by NRCS through the National Cartography and GIS Center on DC 6150 data cartridge tape. The Iowa coverage consists of eleven 1-degree DEM's.

1- degree DEM data are produced by the Defense Mapping Agency in 1-degree by 1-degree units. The data consist of a regular array of elevations referenced horizontally using the geographic (latitude/longitude) coordinate system of the World Geodetic System 1972 Datum. Spacing of the elevations along and between each profile is 3-arc seconds with 1,201 elevations per profile. The 1-degree DEM data has an absolute accuracy of 130 meters horizontally and 30 meters vertically. (U.S. Geological Survey, Earth Science Information Center)

1. The DEM's for Pottawattamie County consist of the files named "41095" and "41096", which correspond to the latitude and longitude of the southwest corner of the DEM's. Using the UNIX command **cpio "41095" "41096" -iudmvcB </dev/rmt/c0s0** the raw DEM's were loaded into $LOCATION.

2. The raw DEM data 41095 was converted into binary format using: **cat 41095|m.dmaUSGSread top=1 bottom=1201 left=1 right=1201 output=41095.dem logfile=log_41095**. This step was repeated for 41096.

3. The data was then rotated 90 degrees as required by GRASS using: **m.rot90 input=41095.dem output=41095.rot rows=1201 cols=1201 bpc=2**. This step was repeated for 41096.

4. The DEM data referenced using latitude and longitude coordinates were converted to a UTM-referenced map layer using: **r.in.ll input=41095.rot output=41095.model bpc=2 corner=sw,41:00N,95:00W dimension=1201,1201 res=3,3 spheroid=wgs72**. This step was repeated for 41096.

5. The new layer was checked using **d.rast 41095.model**. This step was repeated for 41096.

6. A window was set using: **g.region** to correspond to the boundaries of the 7.5' quadrangles for Pottawattamie County.

7. 41095.model and 41096.model were joined using: **r.patch**

B. IDOT DXF files to GRASS vector format

The Iowa Department of Transportation (IDOT) provided their county Highway and Transportation CADD files translated to Drawing eXchange File (DXF) ASCII format using Micro station 32 software. These files were compressed and then copied to diskettes using CPIO. The county IDOT files contain levels corresponding to a specific map feature, e.g., level # 23 features primary highway routes; level # 38 features railroads. The IDOT files were developed from USGS digital line graphs (DLG).

1. The DXF files were loaded from diskette using: **cpio -iudmvcB </dev/rdsk/f03ht** to $LOCATION/dxf and uncompressed using: **gunzip**.

2. The ASCII DXF files were converted to GRASS vector format using: **v.import** option #7. The resultant vector file is referenced using design coordinates. Steps 3 through 6 describe the procedure for transforming the file to UTM-referenced map layer.

3. The GRASS files were opened in **v.digit**. This allows for a detailed display of the file including nodes. The design coordinates of ten points were recorded using the **where am I** option under the **WINDOW** command. The UTM coordinates of the ten points were identified in a corresponding UTM-referenced map layer generated from TIGER data.

4. A *pointsfile* was created using the UNIX vi text editor in the user's $LOCATION/points directory. The format and an example of the *pointsfile* are shown:

FORMAT				EXAMPLE			
(Input Map)		(Output Map)		(design coordinates)		(UTM coordinates)	
E	N	E	N	-118.16	9.04	278477.02	4673338.67
E	N	E	N	-148.89	11.48	228928.10	4677750.87

The "E" and "N" represent the eastings and northings of the selected points; a total of ten points were included in the *pointsfile*. Note: ten points are required for the *pointsfile* option in "v.transform" to work correctly.

5. The GRASS vector file was transformed to a UTM-referenced map layer using: **v.transform** utilizing the *pointsfile* option.

6. The residuals were checked to show the amount of error associated with the transformation of the ten points; **v.import** option # 3 was run on the transformed file to build topology. The resulting map layer was displayed over an existing UTM-referenced map layer generated from TIGER data to check for accuracy.

C. U.S. Bureau of Census TIGER files to GRASS vector format

Topologically Integrated Geographic Encoding and Referencing System (TIGER) geographic database was developed by the U.S. Bureau of the Census in cooperation with the U.S. Geological Survey. The primary sources of the data base were the USGS 1:100,000-scale maps and the Census Bureau's 1980 GBF/DIME-Files. The USGS compiled the 1:100,000-scale maps from photographically reduced (to 1:100,000-scale) mosaic of 1:24,000-scale maps. (U.S. Bureau of Census, technical documentation).

TIGER files for western Iowa counties were provided by NRCS on DC 6150 data cartridge tape. There were two files provided for each county; Record Type 1, and Record Type 2. Record Type 1 are the basic data record including line segments and end points of the lines expressed in latitude/longitude coordinate values. Record Type 2 are shape coordinate points that provide an additional series of latitude and longitude coordinate values that describe the shape of each line segment that is not straight for the associated Record Type 1. (U.S. Bureau of Census, technical documentation). Files for Pottawattamie County include tgr19155.1 and tgr19155.2; "19155" is the State and County FIPS code.

1. The files for Pottawattamie County were first sorted for use in GRASS using: **sort -o t19155.1 tgr19155.1.** The sorted file "t19155.1" was moved to the user's $LOCATION/tiger directory. This step was repeated for tgr19155.2.

2. GRASS vector and needed support files were created using: **v.import** option # **8.** Specific Census Feature Class Codes (CFCC) were extracted in *v.import*, including classification "H" for hydrographic features, classification "A" for road features, and "BOU" to extract the county boundary. These codes are described in the TIGER/line Census Files 1990 Technical Documentation.

3. A program called *list.tiger* was provided by NRCS-Ft. Worth that was used to generate a TIGER listing of all lines in "t19155.1" After referring to the ouput list, specific entries can be extracted in *v.import*, for example the "A31" entries are for undivided county roads; a map layer showing these roads can then be generated in *v.import*.

D. NRCS Hydrologic Unit DLG files to GRASS vector and raster format

Roger Greenough of the NRCS Digital Cartographic Production Facility in Ames provided Hydrologic Unit data in ASCII Digital Line Graph (DLG) file format. 30 DLG's representing the 30 7.5' quadrangles that cover Pottawattamie County were provided on DC 6150 data cartridge tape. The files show the 11 digit Hydrologic Unit boundaries , i.e., the watershed boundaries and the 7.5' quadrangle boundary. The files were digitized and assigned an identification number (attribute) using LT-Plus software.

1. The DLG's were loaded into $LOCATION/dlg using: **cpio -iudmvcB </dev/rmt/c0s0.**

2. The process of converting an individual DLG file to GRASS vector format was to use: **v.import** option #1. This creates the needed support files and retains the Hydrologic Unit identification attribute data.

3. The GRASS vector file was then converted to a raster file using: **v.to.rast** the file retained the attribute data during this step.

It was necessary to create map layers that consisted of 2 or more of the DLG's that would allow for the display and analysis of an entire watershed. The individual DLG's could be patched together using *v.patch* following conversion to GRASS vector format, however the 7.5' quadrangle boundary lines dissected the individual watersheds. Therefore the individual watersheds were not read as unique polygons. Another difficulty was encountered in patching the Hydrologic Unit map layers together for Pottwattamie County; two of the files (Modale and Ft. Calhoun) occur in UTM zone 14, and the remaining 28 files in UTM zone 15. GRASS 4.0 cannot function properly with UTM referenced data layers from two different UTM zones. The following steps were taken to first transform the Modale and Ft. Calhoun files to read as zone 15, and then patch all 30 files together to display unique watersheds.

1. The 30 DLG files were converted to GRASS vector format using **v.import** option #1.

2. The Modale and Ft. Calhoun files were converted to ASCII format using **v.out.ascii** so that they were in a format that can be used in *v.transform*.

3. Using **m.geo**, contrived zone 15 UTM coordinates were calculated from the latitude longitude coordinates for the four corners of the Modale and Ft. Calhoun 7.5' quadrangles.

4. The zone 14 UTM-coordinates for the Modale and Ft. Calhoun files were transformed into the contrived zone 15 coordinates using: **v.transform.**

5. The files were converted to GRASS vector format using: **v.import** option **#3.**

6. The 30 files were patched together using: **v.patch**. Topology was built for the resultant file using: **v.support.**

7. The file was then opened in **v.digit** where the quadrangle boundary lines were removed using the editing tools. All green nodes (indicating degenerate nodes) were removed and all lines were toggled to "area edge". Using the label commands in *v.digit* each polygon (representing a watershed boundary) was labeled.

8. The edited vector file was converted to a raster map layer using: **v.to.rast.**

E. **Processing Aerial Reconnaissance video tape**

During April 1993 and again in March of 1994, low altitude aerial video tape was collected from a helicopter for the Hungry Canyons research project. The video tape covers over fifty streams in the project area and is being used to evaluate the conditions of the stream channels. Many of the streams were videotaped both years, providing information on the conditions of the streams both before and after the floods of the summer of 1993. A four stage channel evolution model was devised by geologists from IDNR and NRCS to be applied to the aerial reconnaissance video tape. The following steps were followed to process the video tape for the development of a GRASS raster map layer.

1. Each video tape of the streams in Pottawattamie County was reviewed, along side of a USGS 1:100,000 scale county topographic map. Each one mile segment of the streams was assigned a stage of a six-stage model of channel evolution. These stages were recorded on the USGS map.

2. A GRASS vector file indicating the streams that were videotaped in 1993 was derived from an existing county-wide stream map layer using the various editing tools in **v.digit.**

3. The resultant file called video_pott93 was copied using **g.copy** and opened in **v.digit**. Using the various editing tools, a file was created indicating all stage "1" stream segments in Pottawattamie County. This step was repeated and resulted in six separate files indicating the six stages of the model. The backdrop map option in *v.digit* "Customize" tool was helpful in creating the files.

4. Using **v.patch** all stream stage files were patched together.

SECTION THREE

Stream Stabilization Research

Submitted to:
Golden Hills Resource Conservation and Development, Inc.
Oakland, Iowa

Principal Investigator: Robert A. Lohnes
Research Assistants: Brad Levich, Jeff Magner

Department of Civil & Construction Engineering
Iowa State University
Ames, Iowa 50011

ABSTRACT

Since early in this century streams in western Iowa have degraded 1.5 to 5 times their original depth. This vertical erosion is often accompanied by widening of two to four times the original width. This deepening and widening of the channels has jeopardized the structural safety of 25% of the 5,223 bridges in the area by undercutting footings or pile caps and removing soil beneath and adjacent to abutments. This report suggests methods for predicting the extent of degradation and locating grade control structures.

One counter measure to degradation is to design stream crossings with sufficient width and foundation depth to accommodate impending degradation. Two methods to predict the amount of vertical degradation are evaluated. One method is a geomorphic approach that identifies the stable reach of a degrading stream and graphically projects the longitudinal profile upstream to the degrading reach to estimate the future amount of downcutting. The second method is an analytical iterative process of balancing applied tractive force with erosion resistance. Both methods show promise of being useful but are applicable only to streams of uniform bed material.

Grade control structures are another counter measure to the threat to infrastructure from channel erosion. Historical evidence indicates that some structures were placed where they were not needed and others placed at a location where they were less effective than they could have been. With increasing costs, the selection and placing of grade control structures requires effective planning. An economic analysis of currently used grade control structures is presented. A flow chart is presented to help engineers assess the need for a grade control structure. Geologic conditions that influence the structures' foundation and channel side slope stability are described. Methods are suggested to estimate the reach of river that will be influenced by the grade control structure. Finally, the various components of the planning process are related in a second flow chart.

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List of Photo Plates

Photos by Gregg Hadish, Golden Hills RC&D, Oakland, Iowa.

1.0 INTRODUCTION

1.1 Objectives

Stream degradation in western Iowa has caused problems since the early part of this century. As streams erode deeper, the channel banks become unstable and landslides occur. The deepening and widening of channels have placed pipelines, bridges and other utility crossings at risk and have resulted in the loss of valuable farm land. A method of predicting the final depth and width of these streams is needed to plan and design channel stabilization facilities. Also a rational method for determining the location and height required for the most effective grade stabilization is needed.

The objectives of this study are: 1) to evaluate procedures for predicting stable longitudinal profiles and identifying reaches of the streams that are in need of erosion protection and 2) to develop a procedure for identifying the most effective location for and height of grade control structures.

1.2 Geology of the Study Area

Western Iowa is especially vulnerable to degradation because of the highly erodible loess that comprises the surficial geology in the area. The loess is wind-blown silt that originated from the Missouri River floodplain. The thickness of the loess, as reported in Dahl et al. (1958), ranges from over 30 meters (100 ft) thick adjacent to the Missouri River floodplain to about 3 meters (10 ft) thick to the east.

The alluvium in the tributaries to the Missouri River is derived from loess and has been classified geologically as the DeForest Formation. The DeForest Formation consists of four members: Camp Creek, Roberts Creek, Corrington, and Gunder listed from youngest to oldest (Bettis, 1990). These stratigraphic units represent cut and fill deposits that date from the end of the Wisconsinan glaciation up through the present. The alluvial material in the deep loess watersheds is primarily silt and clay and is transported primarily as suspended load.

The DeForest Formation is comprised of a series of cuts and fills. Bettis (1990) divides the formation into four members which are reorganized from Daniels' et al. (1966) original description. The basal member of the formation is the Gunder containing both Watkins and Hatcher beds. Cut into the Gunder member is the Roberts Creek member containing both Mullenix and Turton beds. Cut into the Roberts Creek member is the Camp Creek member representing the youngest fill consisting of "post settlement alluvium". The Corrington member is limited to alluvial fans where small and moderate sized valleys enter major valleys (Figure 1.1 from Bettis). Figure 1.2 from Bettis shows the ideal sequence of cuts and fills of the DeForest Formation as they would exist in a channel cross section that has experienced degradation. These members outcrop discontinuously along the stream as both the process of degradation and stratigraphy of the members are not uniform.

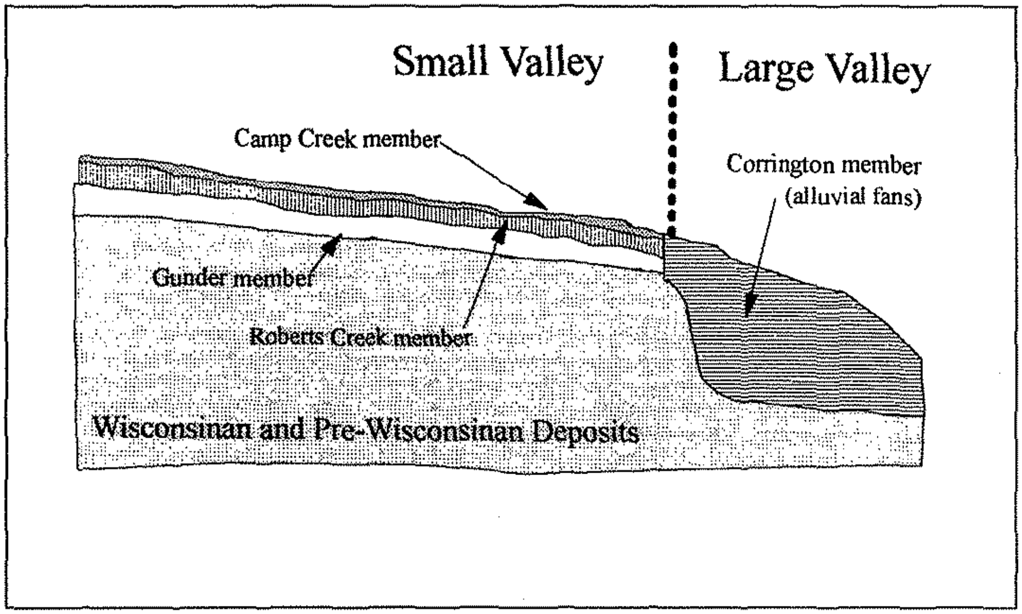

Figure 1.1. Small valley/large valley stratigraphic comparison of the Deforest Formation.

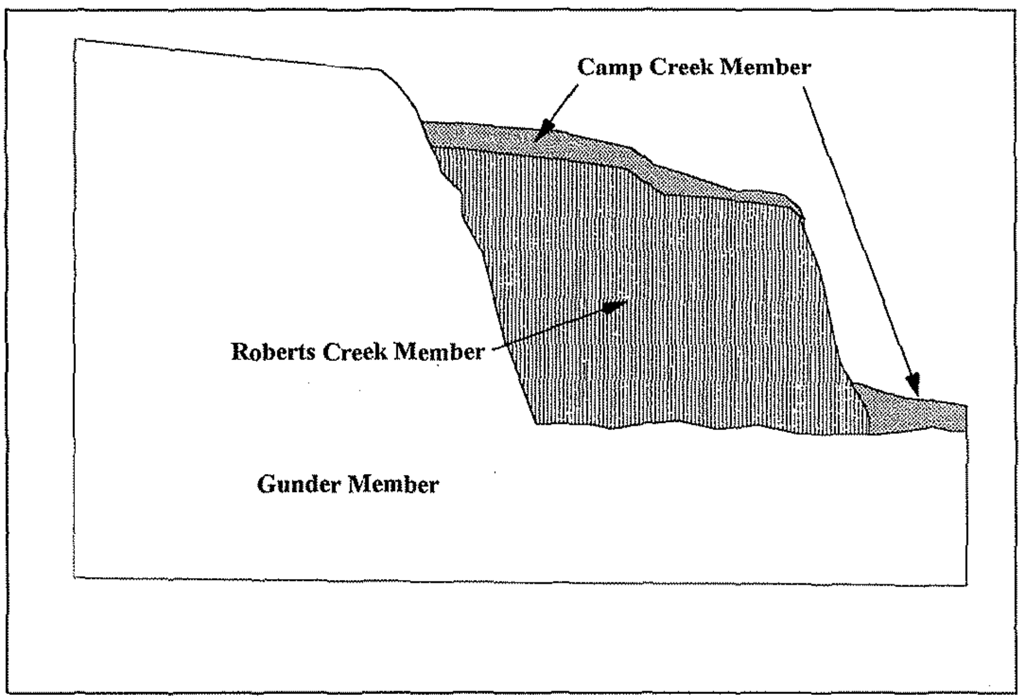

Figure 1.2. Sequence of cuts and fills comprising the Deforest Formation.

Table 1.1 from Bettis gives a lithologic description of the Camp Creek, Roberts Creek, Gunder, and Corrington members of the DeForest Formation. Because the Corrington member seldom appears in stream channels, its description is limited to that given in Table 1.1.

Table 1.1. Lithologic characteristics of DeForest Formation units from Bettis, 1990.

MEMBER	BED	LITHOLOGIC PROPERTIES
Camp Creek		stratified silt loam to clay loam (texture varies according to local source material); calcareous to noncalcareous; very dark gray to brown (10YR 3/1-5/3); no surface soil to very poorly expressed surface soil developed in upper part of unit.
Roberts Creek	Turton	stratified silty clay loam to loam; calcareous to noncalcareous in upper part; very dark gray to dark grayish brown (10YR 3/1-4/2); thin dark colored surface soils developed in upper part.
	Mullenix	stratified silt loam and clay loam with thin lenticular sand and gravel bodies in lower part; noncalcareous grading downward to calcareous, very dark gray to dark grayish brown (10YR 3/4-4/2); coarse columnar structural units evident on weathered sections; thick dark-colored surface soils in upper part.
Corrington		stratified to massive; calcareous to noncalcareous; loam to clay loam with lenses of sand and gravel; very dark brown to yellowish brown (10YR 2/5-5/4); several buried soils; thick well horizonated surface soil with brown B horizons developed in upper part; found in alluvial fans in large valleys.
Gunder	Hatcher	massive (to planar bedded in its lower part), calcareous to noncalcareous silt loam; brown to yellowish brown (10YR 4/3-5/4); prominent coarse columnar structural units evident on weathered sections; thick, moderately well horizonated surface soils with brown B horizons developed in upper part.
	Watkins	stratified, calcareous silt loam with sandy and loamy interbeds; dark greenish gray (5GY 4/1) to olive brown (2.5Y 4/4); often exhibits 7.5 YR hue secondary accumulation of iron oxides; deeply buried.

The Camp Creek member lines the top of banks and exhibits some stratification. It can vary in thickness from a few centimeters to over 5 meters (17 ft). It appears medium to dark brown and may exhibit a reddish hue from iron oxides. The Roberts Creek member varies in thickness from 1 to 10 meters (.3 to 33 ft) and appears dark gray to nearly black when moist. The Gunder member ranges from 1 to 20 meters (.3 to 67 ft) in thickness and typically outcrops low in the channel to form a firm stream bottom with a pock marked appearance. The Hatcher bed of the Gunder member appears brown to yellowish-brown and contains the great majority of alluvial sediments in streams of third order and smaller. The underlying Watkins bed is dark greenish-gray to olive brown with an accumulation of many, fine iron oxides.

In-situ test data from Soil Conservation Service borings done in the DeForest Formation throughout Iowa provide some evidence on the consistency and undrained shear strength of the different members. The majority of material tested was classified as a lean clay. The dutch cone penetration test measures the point resistance, qc, of a sixty degree angle cone as it is hydraulically pushed into the soil. Point resistance can be associated with the consistency of a cohesive soil. Though experience has shown this association to be unreliable at times, the point resistance values for tests run in the DeForest Formation were compared to look for trends in consistency among the different members. The data set contained high variability and no correlation was found. Data on a second test suited for estimating undrained shear strength, cu, of clays was also evaluated. The vane shear test relates strength to the torque required to induce failure of a cylindrical volume of soil surrounding a four vane apparatus that has been inserted into the base of a borehole. The results of this test completed in the members of the DeForest Formation were compared for trends in strength. The data set contained high variability with no correlation found. A study by Lohnes (1980) evaluated cohesion and friction angle of the DeForest Formation members with similar variability in the results.

In summary, these analyses show no significant differences in the shear strengths of the various members of the alluvial prism; however other factors may influence their erosion resistance.

1.3 Causes of Degradation

Several hypotheses have been suggested to explain the cause of stream degradation. One is that stream straightening from 1870 to 1960 caused an increase in the stream gradient thereby increasing the stream flow velocity (Massoudi, 1981). Another possible cause for degradation is that agriculture changed the vegetation from prairie to row crops and that resulted in greater runoff into stream channels (Piest et al.,1976 and 1977). A third hypothesis is that the streams are degrading from the degradation of the Missouri which has lowered the base level of its tributaries. Lohnes et al. (1977) indicate that the Missouri River south of Omaha, Nebraska has had vertical stability and the majority of tributaries in western Iowa enter the Missouri in this reach; therefore this cause is not likely. Finally, another explanation is that the streams may be experiencing a natural cycle of degradation and aggradation in response to hydrologic or climatic changes. The various stratigraphic units that comprise the alluvial fill supports this as a possibility (Hallberg et al. 1979).

Stream channel degradation is not unique to Iowa. The erosion process and stabilization has been studied in Missouri, Tennessee, and Mississippi, (Piest et al. 1976, Simon,1989, Little et al, 1983) while other states in which problems are reported include Kansas, Illinois, and Nebraska. A common factor in all these areas of entrenchment is the presence of loess and loess derived alluvium.

1.4 Process of Degradation

Degradation moves upstream in the form of an overfall or knickpoint that indicates where the most active entrenchment of the stream bed is occurring. Knickpoints are defined as a "short, oversteepened segment of the longitudinal profile" (Ritter, 1986). A typical knickpoint is shown in Figure 1.3. As a knickpoint moves upstream, the stream cuts vertically into the channel leaving a new, lower bed downstream. At a given reach of the stream some channel erosion precedes and follows the passage of a knickpoint; however the majority of degradation occurs as the knickpoint passes through the reach.

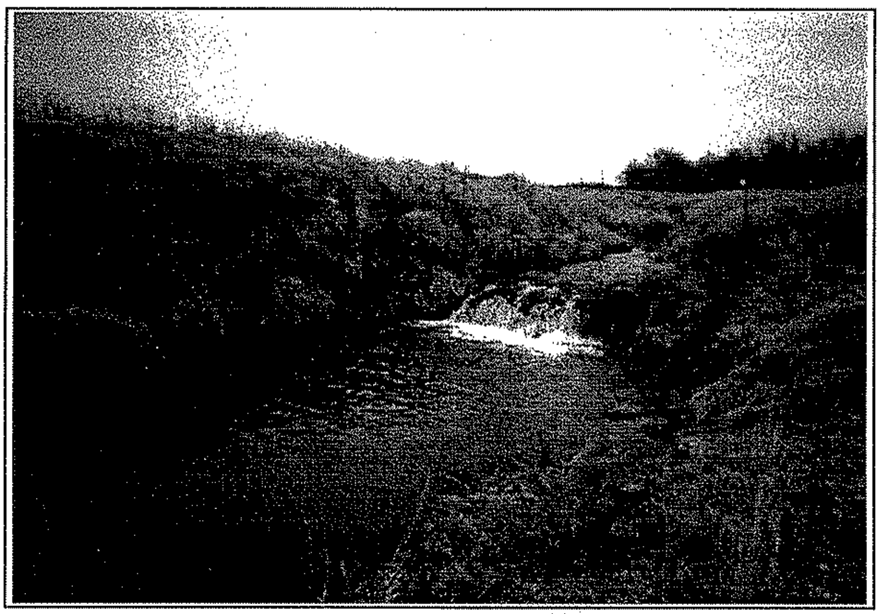

Figure 1.3. Example of a knickpoint on Jim's Branch at Highway 59, Pottawattamie County.

1.5 Grade Stabilization

One counter measure for stream channel degradation is grade stabilization which usually takes the form of one or more full flow check dams that inhibit erosion. These structures are termed full flow for they are capable of passing a design discharge without restricting the flow rate. The grade stabilization structure raises the flow line creating flat water upstream. Lower stream velocities cause the deposition of suspended sediments or aggradation. Aggradation upstream from the structure depends on channel characteristics and stream profile. A sediment prism forms with depth equal to the height of the stabilization structure at the crest. This sediment prism extends upstream until a new stable slope forms such that the channel is neither aggrading nor degrading.

The majority of grade stabilization structures have been placed to provide aggradation around bridge piles and utility crossings that have become exposed. A series of three flumes placed on Willow Creek in the late 1960's and early 1970's averaged $150,000 each to construct (Hanson, et al. 1985). In terms of today's costs, a similar structure will approach 1 million dollars for construction.

New designs using less expensive materials have helped to make grade stabilization more affordable. Current sheet pile and H-pile designs, or low drop structures, remove grade in the form of a sharp crested weir. Though they typically remove less grade than a flume, if their placement along the stream profile is done with some forethought, they can be an effective measure of grade control.

2.0 STAGES OF STREAM CHANNEL EVOLUTION

2.1 Simon's Classification

Streams in deep loess regions have been observed to go through adjustment of channel geometry, and phases of channel evolution. Simon (1989) proposed a model of six process-orientated stages of morphologic development: premodified, constructed, degradation, threshold, agrradation, and restabilization (Figure 2.1). General characteristics of each stage are presented below (from Simon, 1989, Simon and Hupp, 1992).

Stage I - "Premodified" The stream is an unaltered meandering channel with erosion on the outside bends; the banks are densely vegetated to the flow line.

Stage II - "Constructed" The stream channel has been re-shaped (channelized) with a trapezoidal cross-section; vegetation has been removed.

Stage III - "Degradation" The stream is degrading in response to steepened channel gradient; knickpoints form. The channel bank heights increase and bank slopes steepen due to stream downcutting and popout failures at the bank toe.

Stage IV - "Threshold" Continued channel degradation and major widening. The banks are shaped by the mass wasting process. Both rotational and planar failures exist. Tilted and fallen vegetation.

Stage V - "Aggradation" Beginning of bed aggradation and development of meandering thalweg, continued bank widening. Woody vegetation begins to re-establish at slough line.

Stage VI - "Restabilization" Significant reduction of bank heights by channel bed aggradation and by fluvial deposition on the upper bank and slough line; bank erosion subsides. Woody vegetation extends upslope to the former flood plain.

2.2 Use of Classification for Western Iowa

The Simon model of stream channel evolution has been applied to western Iowa streams through field and aerial reconnaissance conducted by Golden Hills Resource Conservation and Development in 1993 and 1994.

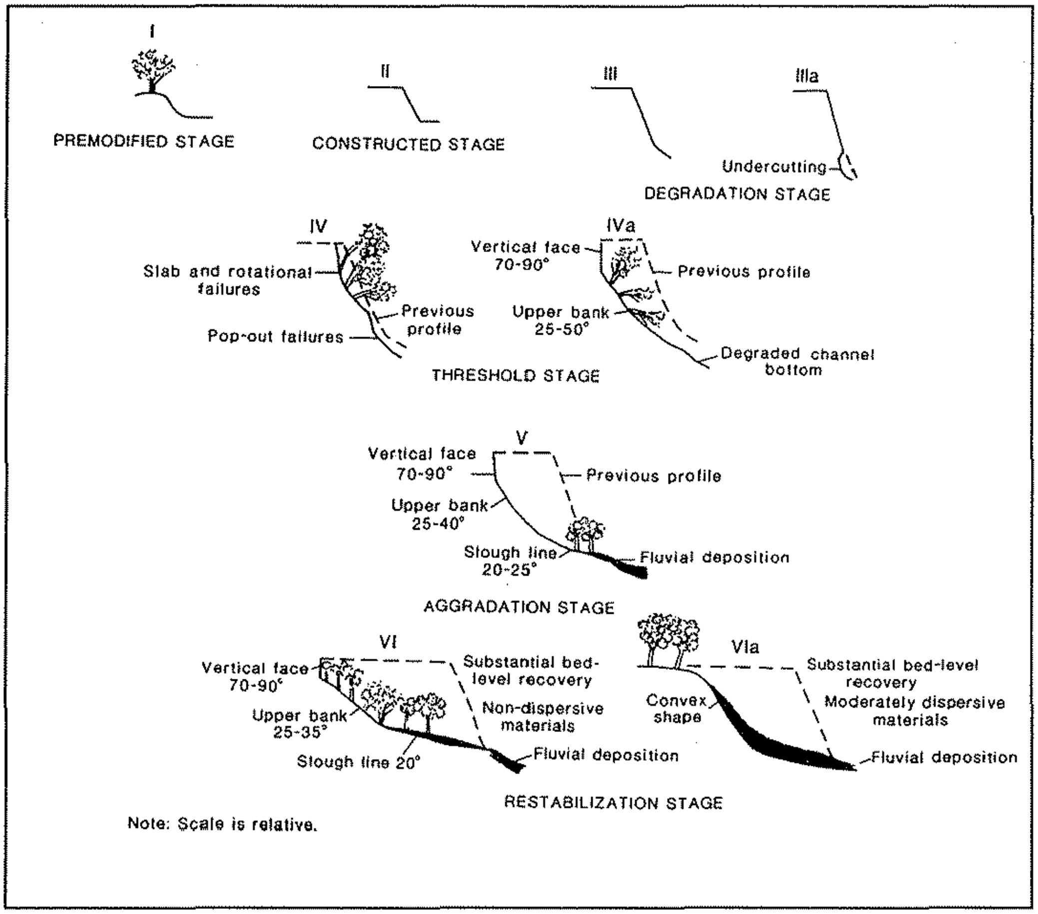

Figure 2.1. Six-stage model of bank-slope development. (From Simon, 1989)

3.0 DEGRADATION PREDICTION (ESTIMATION) METHODS

Two methods for estimating future degradation that appeared applicable to the western Iowa were found. One method defined as the Tractive Force model (Massoudi, 1981) is an approach based on hydraulic considerations; the second method based upon longitudinal profile projections (Hack, 1957) is referred to as a geomorphic method.

3.1 Geomorphic Method

Hack (1957) observed that the longitudinal profile of a stream can be expressed by a simple equation:

$$E = C - k \ln(L) \qquad 1$$

where E = channel bottom elevation, L = stream length from the drainage divide, and k, C = constants. This equation is a straight line on a semilogarithmic plot.

If a degrading stream is plotted on a semilogarithmic plot, the profile will consist of two linear segments, one upstream of the knickpoint and the other a stable downstream section as shown in Figure 3.1. If the lower stable profile is projected upstream beneath the yet-to-be-degraded profile, the amount of degradation that will occur in the upstream reach can be estimated.

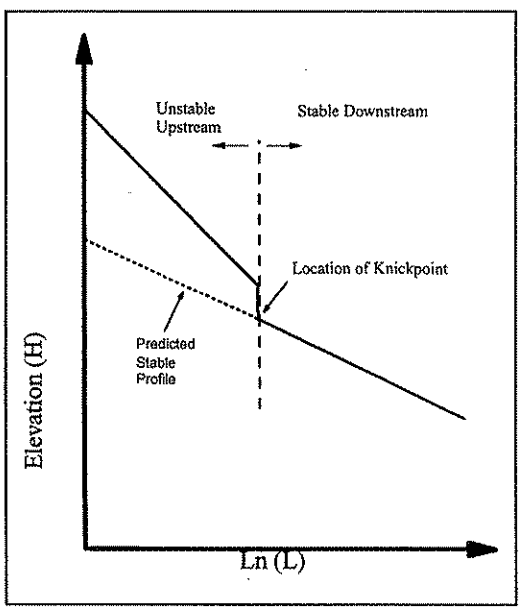

Figure 3.1. Ideal application of the Hack model from Lohnes (1991).

Daniels (1960) suggested that the semilog graphical projection could be used to predict degradation upstream of a knickpoint on Willow creek. Daniels' prediction was verified by Lohnes et. al. (1980) as shown in Figure 3.2. The Daniels prediction and its subsequent verification was applied to a reach of

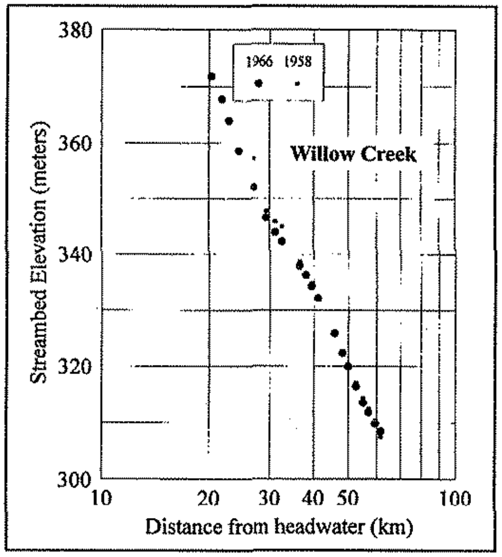

Figure 3.2. A reach of Willow Creek plotted on logarithmic paper, modified from Lohnes (1980)

Willow Creek that was between 20 and 40 km (12 and 25 mi)from the drainage divide. Although this method of predicting degradation appears promising on relatively short reaches of streams, it has limitations when extended to longer reaches.

Keg Creek, Walnut Creek, Indian Creek, and Maple River (see location map Appendix A3) in western Iowa have longitudinal profiles that plot concave down on the semilog plot, figures 3.3 and 3.4. This variation from linearity may be due to changes in bed material of the channels in the upstream reaches. In all of these streams, the upstream portions of the rivers extend into watersheds that are underlain by thin loess over glacial till or into areas where glacial till is the surficial material.

3.2 Tractive Force Model

The second method studied is an analytical method developed by Massoudi (1981) who used Willow Creek as the model stream. Five assumptions underlie this model. The first assumption is a constant width to depth ratio at a given location regardless of the depth of degradation. This ratio is calculated by the following empirical equation for Willow Creek:

$$\frac{W}{D} = 0.048X + 5.23 \qquad 2$$

where X = distance from the headwater in kilometers and W/D = the width to depth ratio.

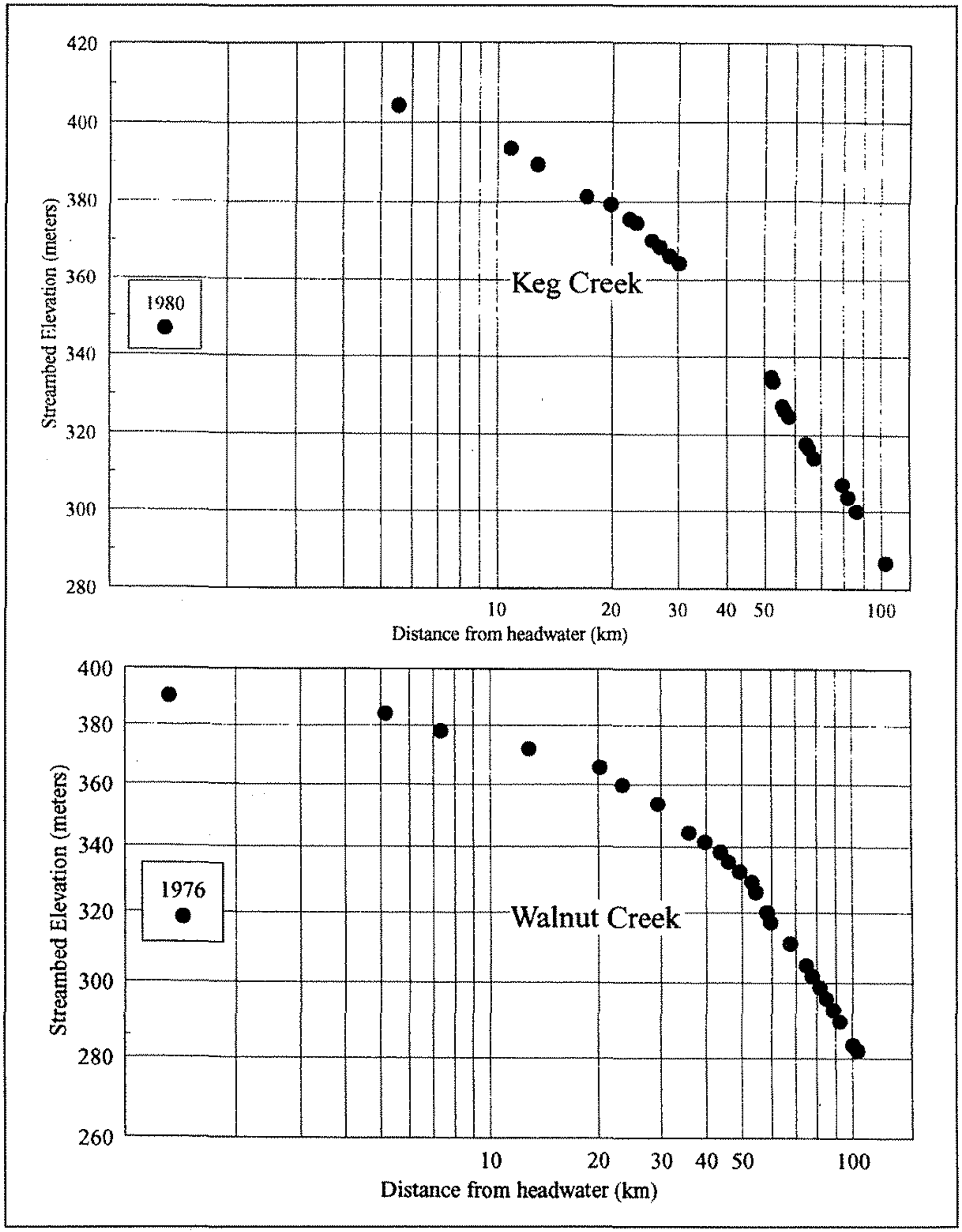

Figure 3.3. Keg Creek and Walnut Creek longitudinal profiles plotted on logarithmic scale.

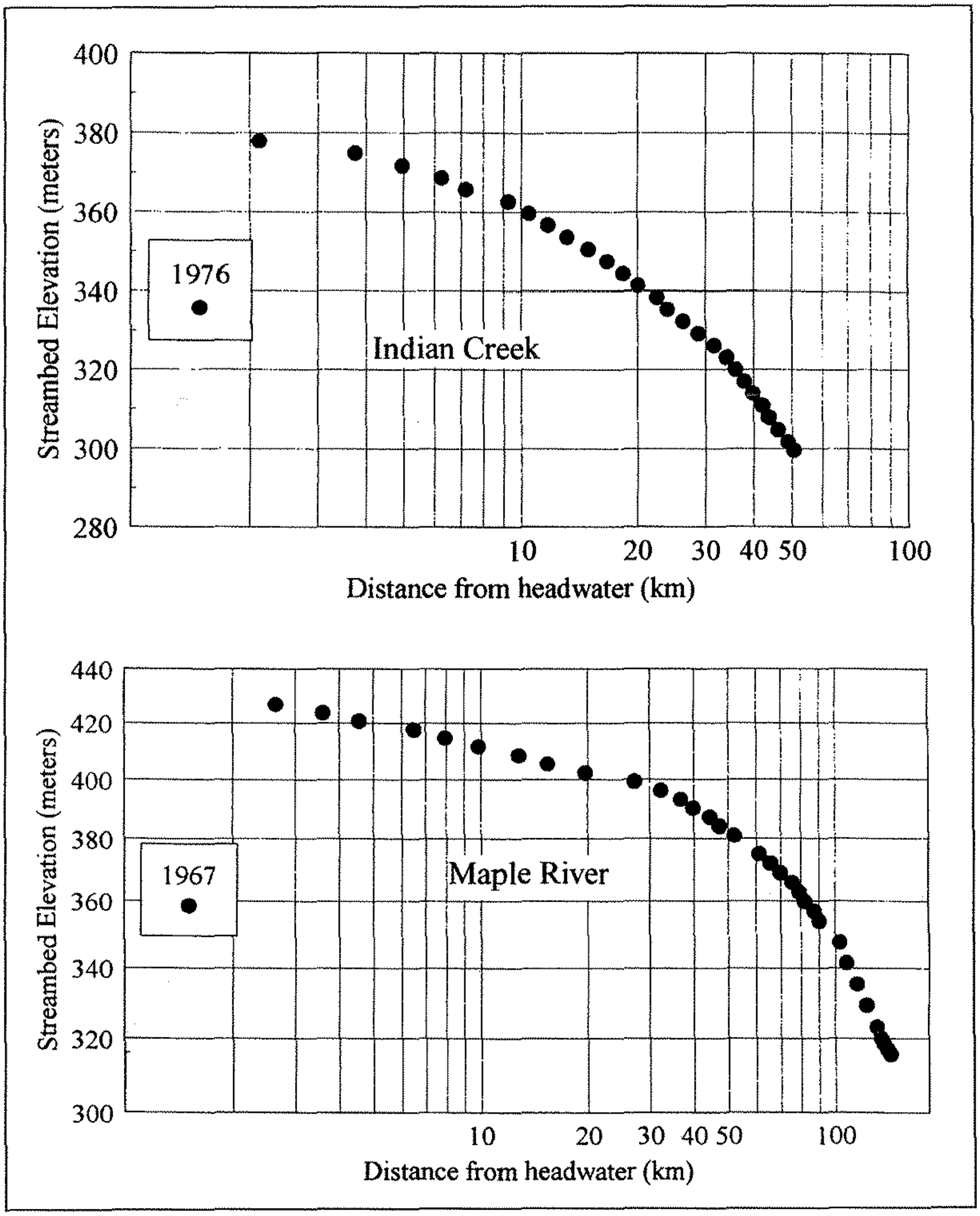

Figure 3.4. Indian Creek and Maple River longitudinal profiles plotted on logarithmic scale.

A second assumption is that the channel is trapezoidal with one to one side slopes and the bottom width is:

$$B = 1.04X + 3.90 \qquad 3$$

where B = the bottom width of a trapezoidal channel in meters and X = the distance from the headwater in kilometers. The third assumption is that the Manning roughness coefficient = 0.035. Fourth, shear stress on the channel bed, τ, is:

$$\tau = \gamma DS \qquad 4$$

where g = the unit weight of water, D = the depth of the water in the channel, and S = slope of the channel. The final assumption is that the erosion resistance can be calculated from the channel geometry of the stable reach of the stream. At the stable section, the tractive shear stress equals the erosion shear resistance. This erosion resistance was back calculated from the original, stable channel cross section at a reach of the Willow. The channel appeared to be in vertical equilibrium because it was aggrading downstream of the section. From the Willow survey data, a uniform slope of 0.12 percent and a uniform cross section was calculated. Massoudi (1981) assumed that the channel forming discharge equaled the bankfull flow in the original prestraightened channel. From bankfull capacity for the original Willow River, the erosion resistance and flow rate was determined to be 0.041 kN/m^2 and 76.46 m^3/s respectively.

Manning's equation is used to calculate the flow rate of the cross section:

$$Q = \frac{1}{n} A R^{\frac{2}{3}} S^{\frac{1}{2}} \qquad 5$$

where Q = discharge (m^3/s), n = Manning roughness coefficient, A = area of the cross section (m^2), R = hydraulic radius = wetted area / wetted perimeter (m), and S = slope of the channel.
This discharge was used to back calculate a recurrence interval, RI, from the following discharge equation Lara (1973):

$$Q = 7.408(LF)(RI)^{0.301}(D_a)^{0.504} \qquad 6$$

where LF = land use factor = 0.80, D_a = drainage area (km^2), and Q in m^3/s. The RI was found to equal the two year recurrence interval for Willow Creek. Pickup and Warner (1976) determined the 1.58 year flood to be the most effective discharge; therefore, the two year flow is a reasonable estimate of the channel forming discharge and is used in this study.

The steps used to calculate a stable stream bed elevation are as follows: First, a longitudinal profile of the present stream is plotted. Then the stable portion of the stream is identified so that the upstream end of the stable section can be used as the starting point. The upstream unstable channel is divided into equal segments and at each segment the cross section area, the stream bed elevation, drainage area, and distance from the headwater is measured or calculated. The next step is to use equation 6 assuming a land factor and a recurrence interval to calculate the discharge at each cross section. The land factor and recurrence interval that are used here are 0.80 and 2 respectively. Next, starting at the stable section, calculate the shear stress of the upstream unstable section and compare the shear stress to the erosion resistance. If the erosion resistance is less than the calculated shear stress the section is lowered by an increment of 7.62 cm and the shear stress recalculated. The section is lowered until the calculated shear stress is less than or equal to the erosion resistance. The channel will degrade until the shear stress equals the erosion resistance.

Given the information of elevation of the stream bed, drainage area, and distance from the headwater; the discharge is calculated from equation 6 and cross sectional geometry is calculated from equations 2 and 3. From the flow and cross sectional geometry at each location, a depth of flow can be calculated by trial and error using the continuity equation:

$$Q = VA = V(BD + D^2) \tag{7}$$

and equation 5 as modified by the assumption of a trapezoidal cross section to give equation 8:

$$V = \frac{1}{n}\frac{(BD + D^2)^{\frac{2}{3}}}{(B + 2D\sqrt{2})^{\frac{2}{3}}} S^{\frac{1}{2}} \tag{8}$$

where V = Mannings velocity (m^3/s), n = Mannings roughness coefficient = 0.035, B = channel bottom width (m), D = depth of flow (m), and S = slope of the channel section (m/m). Once the flow depth is determined, the shear stress is calculated with equation 4 and compared to the erosion resistance of 0.041 kN/m^2. If the calculated shear stress is greater than the erosion resistance, then the depth of the cross section is lowered by an increment of 7.62 cm and the change in cross section is recalculated by:

$$B_{i+1} = B_i + \Delta D(\frac{W}{D} - 2) \tag{9}$$

$$S_{i+1} = S_i - \frac{\Delta D}{\Delta L} \tag{10}$$

where B_{i+1} = new bottom width (m), B_i = bottom width prior to lowering (m), DD = change in depth (m), W/D = constant width to depth ratio, S_{i+1} = new slope, S_i= slope before lowering, and DL = length between sections (m). The section is lowered until the erosion resistance is greater than the calculated shear stress.

Although Massoudi (1981) did his calculation on a mainframe computer, a Quick Basic computer program was written for this repetitive process (Levich, 1994). This program can be run on any personal computer but preferably an IBM compatible 386 or 486.

3.2.1 Applications of tractive force model

This program was run on Willow Creek, Keg Creek, McElhaney Creek, Indian Creek, and Walnut Creek. The Willow Creek profile was obtained from a 1917, 1958 and 1966 survey prior to placement of grade stabilization structures in the early 1970's. Keg Creek's profile is from a 1954 survey. Walnut Creek and Indian Creek profiles are from 1976 U.S.G.S 1:24,000 quadrangle maps and McElhaney Creek is from a 1965 U.S.G.S. quad.

The Willow Creek 1966 profile was shown to be stable in the lower reaches but did degrade a maximum of 3.35 meters (11 ft)below the original stream bed elevation above the second grade control structure at kilometer 24.3 (15 mi) from the headwater (Figure 3.5 and 3.5a). The 1966 profile predicted by the Tractive Force Model is close to that measured in the 1966 survey. In general, on Willow Creek the tractive force model predicted well the degradation between 1966 and 1993 and the data indicate that the grade control structure constructed furthest down stream in 1972 was unnecessary to achieve bed stability because the channel was in equilibrium by that time.

Keg Creek at kilometer 56 (35 mi) from the headwater was predicted to degrade a maximum of 1.68 meters (5.6 ft) since 1954 by the Tractive Force model (Figure 3.6 and 3.6a). Walnut Creek's profile was predicted to degrade a maximum of 0.61 meters (2 ft) after 1976 (Figure 3.7). Indian Creek was predicted to downcut only 0.076 meters (.25 ft) in scattered areas (Figure 3.8). McElhaney Creek's stable profile was a maximum of 3.58 meters (12 ft) below the 1965 profile (Figure 3.9). The predicted degradation for each stream is shown in Table 3.1.

Table 3.1. Summary of predicted degradation using the Tractive Force Model.

Stream	Year from which the degradation is calculated	Maximum Future Degradation (meters)	Distance from headwater (km)
Willow Creek	1966	3.35	20.92
Keg Creek	1954	1.68	55.70
Walnut Creek	1976	0.61	53.27
Indian Creek	1976	0.076	32.19
McElhaney Creek	1965	3.58	5.52

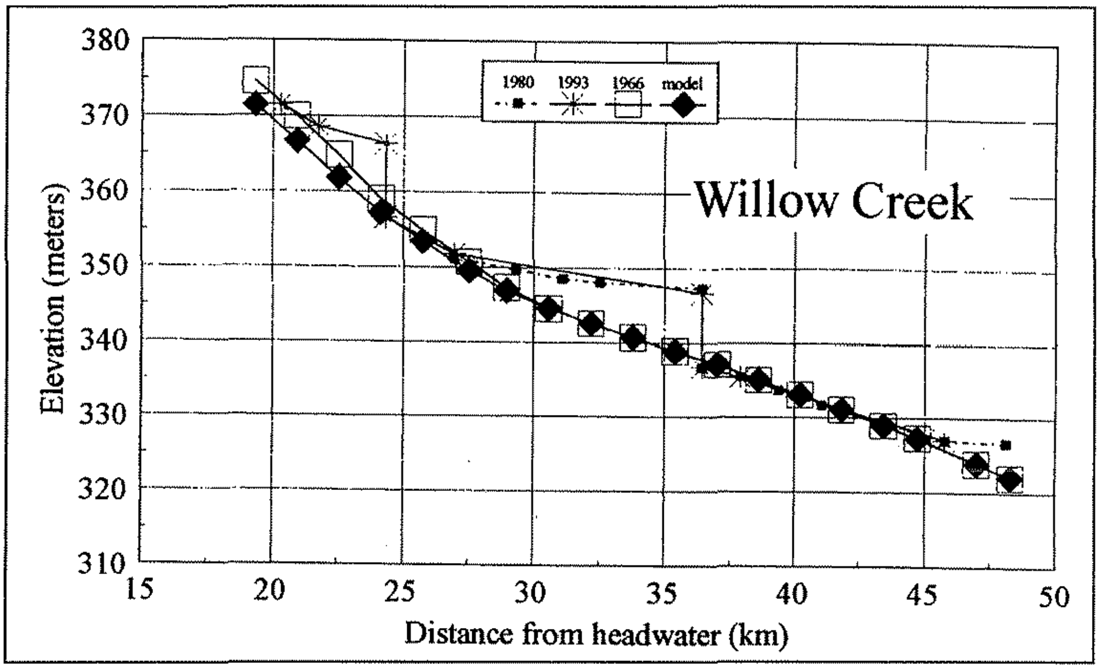

Figure 3.5. Willow Creek predicted stable longitudinal profile.

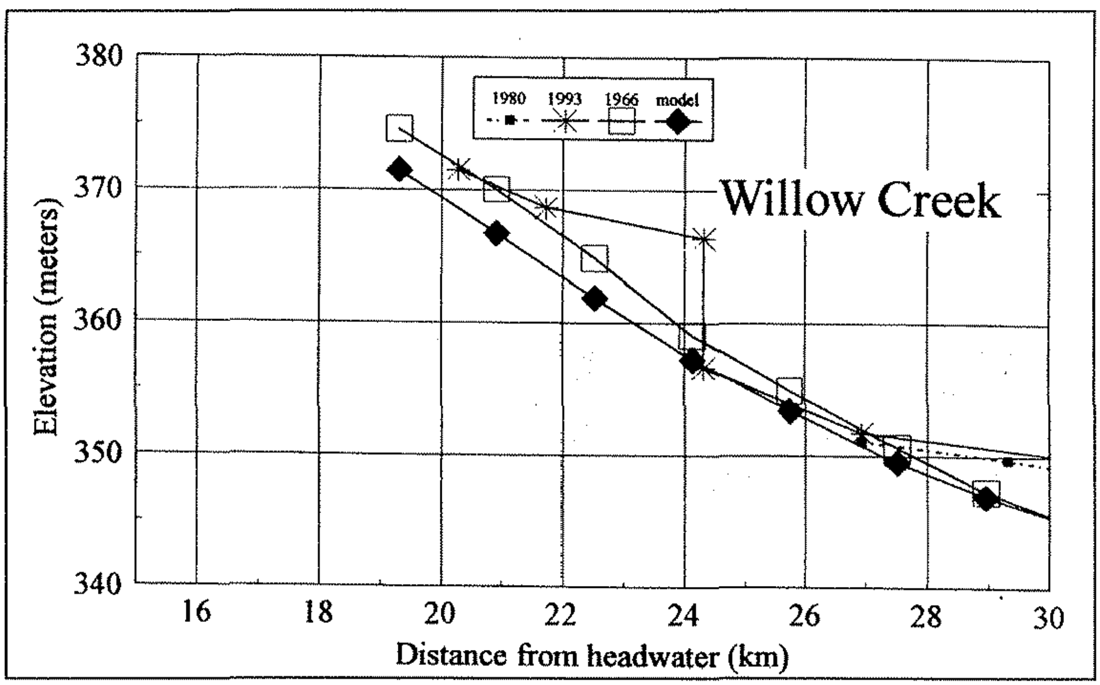

Figure 3.5a. Willow Creek predicted stable longitudinal profile (detail).

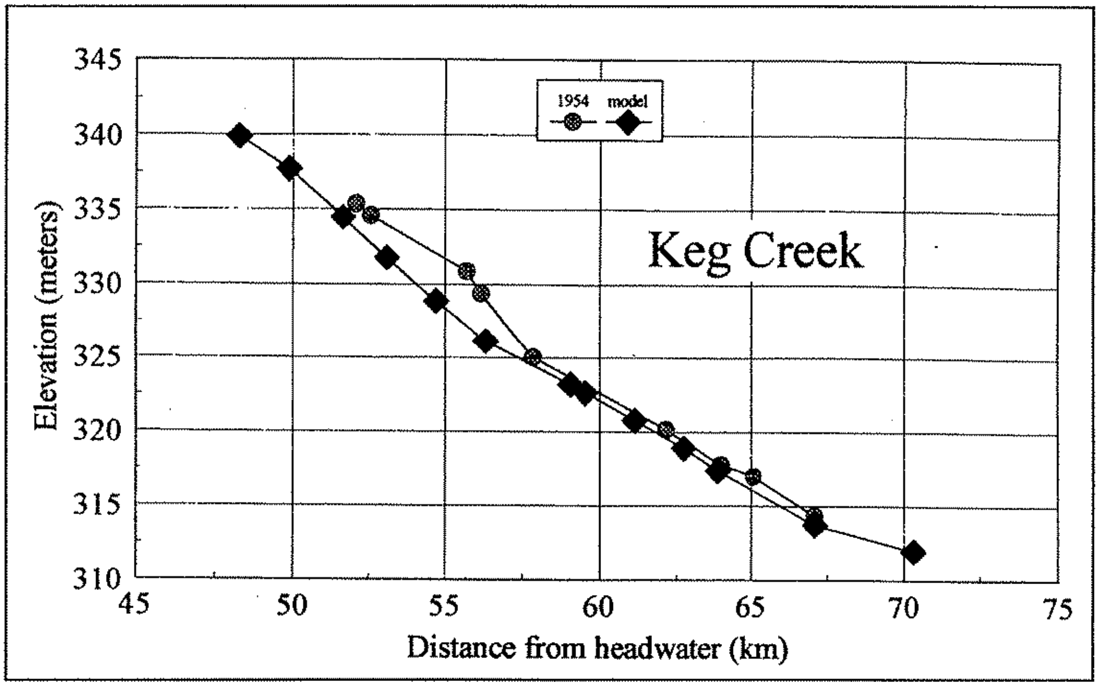

Figure 3.6. Keg Creek predicted longitudinal profile.

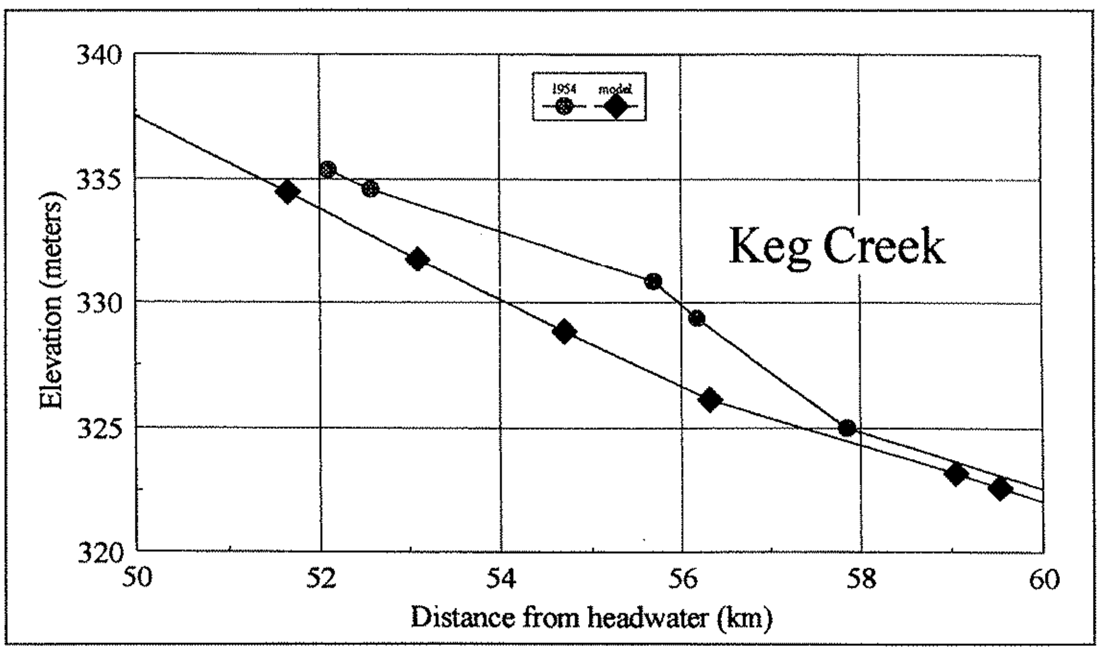

Figure 3.6a. Keg Creek predicted longitudinal profile (detail).

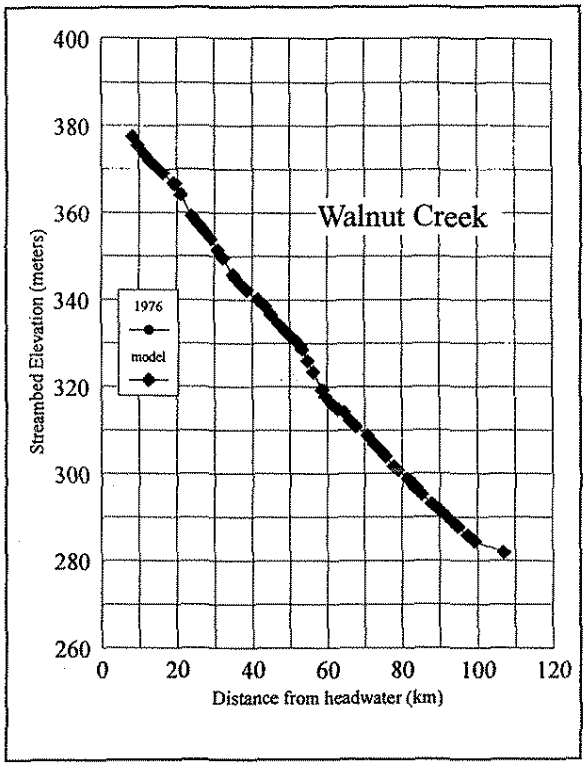

Figure 3.7. Walnut Creek predicted longitudinal profile.

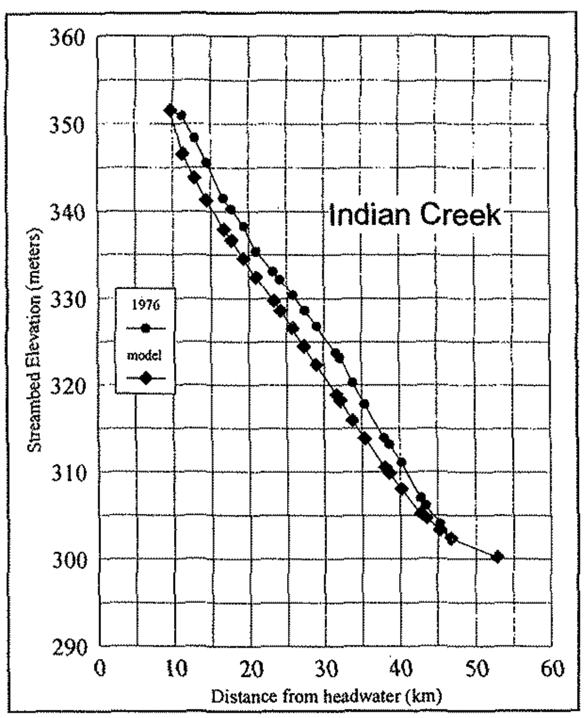

Figure 3.8. Indian Creek predicted longitudinal profile.

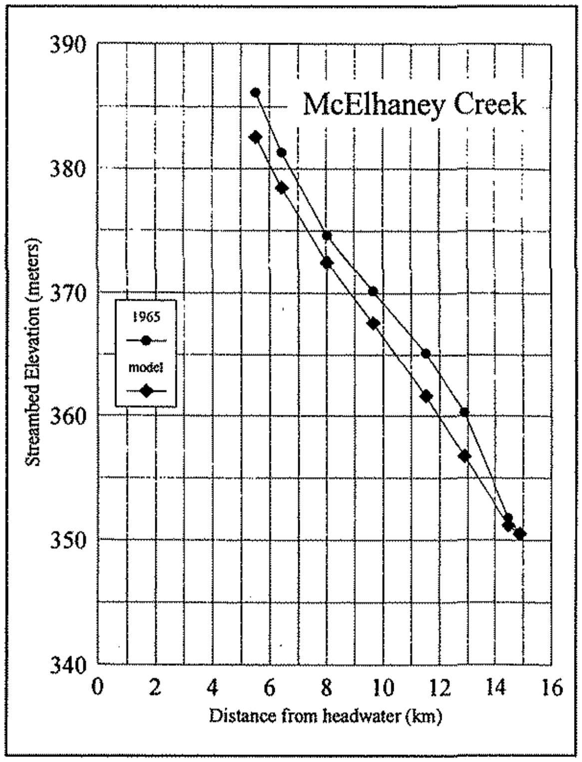

Figure 3.9. McElhaney Creek predicted longitudinal profile.

3.2.2 Analysis of erosion resistance

Massoudi (1981) calculated an erosion resistance of 0.041 kN/m^2 for Willow Creek using a stable cross section from the prestraightened Willow channel. Section 3.1 of this report showed that when stream longitudinal profiles are plotted on semilog paper a profile consisting of two linear segments; a flatter slope develops on the upstream segment suggesting that bed material and therefore erosion resistance is variable within a single stream.

Erosion resistances were calculated for Keg Creek, Walnut Creek, Indian Creek, and McElhaney Creek assuming that the furthest available cross section downstream was stable. This approach does not accommodate the variation of erosion resistance within a stream but does allow a comparison of theoretical erosion resistances between streams. Massoudi (1981) assumed that the width to depth ratio and the bottom width varied linearly downstream, and that the channel side slopes would remain at 45 degrees. These assumptions are not valid for all western Iowa streams; however because cross section data are unavailable for every stream the assumptions were used to simplify calculations in the Tractive Force model.

The erosion resistances for Keg Creek, Walnut Creek, Indian Creek, McElhaney Creek and Willow Creek are shown in Table 3.2.

Table 3.2. Calculated erosion resistance.

Stream	Calc. Erosion Res.	Distance from headwater (km)	Channel slope (%)	Clay	Loess Thick. (m)
Willow Creek	0.041	26.94	0.12	28	22.86
Keg Creek	0.043	70.33	0.08	22	22.86
Walnut Creek	0.043	30.90	0.08	35	7.01
Indian Creek	0.019	51.95	0.04	26	10.67
McElhaney Creek	0.059	13.86	0.32	27	<3.00

It was hypothesized that the calculated erosion resistances would correlate with watershed characteristics and/or bed material so Table 3.2 shows data on loess thickness and clay content of the loess as reported by Dahl et al (1958). These variables for the various stream watersheds do not correlate.

Table 3.2 shows the slope of the channel that was presumed to be stable and it can be seen that stable channel slope has an important influence on the calculated erosion resistance.

Another analysis of the Tractive Force model was to calculate the future degradation based on the calculated erosion resistance for each stream. Maximum calculated degradations for Keg Creek, Walnut Creek, Indian Creek and McElhaney Creek are shown in Table 3.3. The predicted maximum degradation varied from 4.95 meters (16.5 ft) on Indian Creek to 0.53 meters (1.76 ft) on Walnut Creek.

Table 3.3. Maximum predicted degradation using Tractive Force Model.

Stream	Calculated Erosion Resistance (kN/m^2)	Maximum Predicted Degradation (meters)	Distance from headwater (km	Percent of Stream Length
Keg Creek	0.043	1.45	55.70	54.4
Walnut Creek	0.043	0.53	53.27	51.5
Indian Creek	0.019	4.95	32.19	65.9
McElhaney Creek	0.059	1.75	12.87	37.1

The maximum degradation predicted with the different erosion resistances were located at the same reach in each stream except McElhaney Creek. In general, Table 3.3 shows that maximum degradation increases as the erosion resistance decreases; however both Keg and Walnut have the same calculated erosion resistance while the maximum erosion on Keg is nearly three times that of Walnut. Inspection of Figure 3.3 shows that Keg Creek's slope tends to be somewhat steeper than that of Walnut Creek. This again points to channel slope as the most important variable controlling the predictions from the Tractive Force Model.

3.3 Conclusions Regarding Degradation Predictions

Two models to predict degradation were analyzed. The geomorphic model can be applied to short reaches of a stream where the geology does not change. The geomorphic model is easy to use; however, for longer reach predictions where streams have flatter slopes in the upstream reaches it is impossible to apply. Therefore, the Tractive Force model may be more useful in predicting stable profiles for longer reaches of the streams.

The Tractive Force model is based on geohydraulic principles of stream channel erosion. This model depends on determining an erosion resistance of the stream by back calculating erosion resistance from the geometry of a stable reach of the degrading stream. The calculated erosion resistance depends heavily upon the slope of the presumed stable channel. However, to apply this model, a stable reach of the stream must be identified, detailed cross sectional data must be obtained, and the erosion resistance must be calculated. If the bed material changes the erosion resistance will change, requiring a new stable cross section to be surveyed in this reach.

Both the geomorphic and the Tractive Force models require detailed information on the stream's geology and show promise of being useful predictive methods if these data are available. Although the Tractive Force Model is intuitively pleasing from the process standpoint, the geomorphic model is much easier to apply.

4.0 GRADE CONTROL STRUCTURE LOCATION

4.1 Assessing the Need for a structure

A method of determining if a stream is degrading and how far it will degrade is outlined in the flowchart in Figure 4.1. First, the stage of channel evolution is determined at the location of interest from the stream cross sectional geometry, vegetative cover on side slopes, longitudinal profile, knickpoint location, and slope failure type. This information is used to determine whether the stream is in the premodified, constructed, degradation, threshold, aggradation, or restabilization stage of stream channel evolution as described in section 2.1.

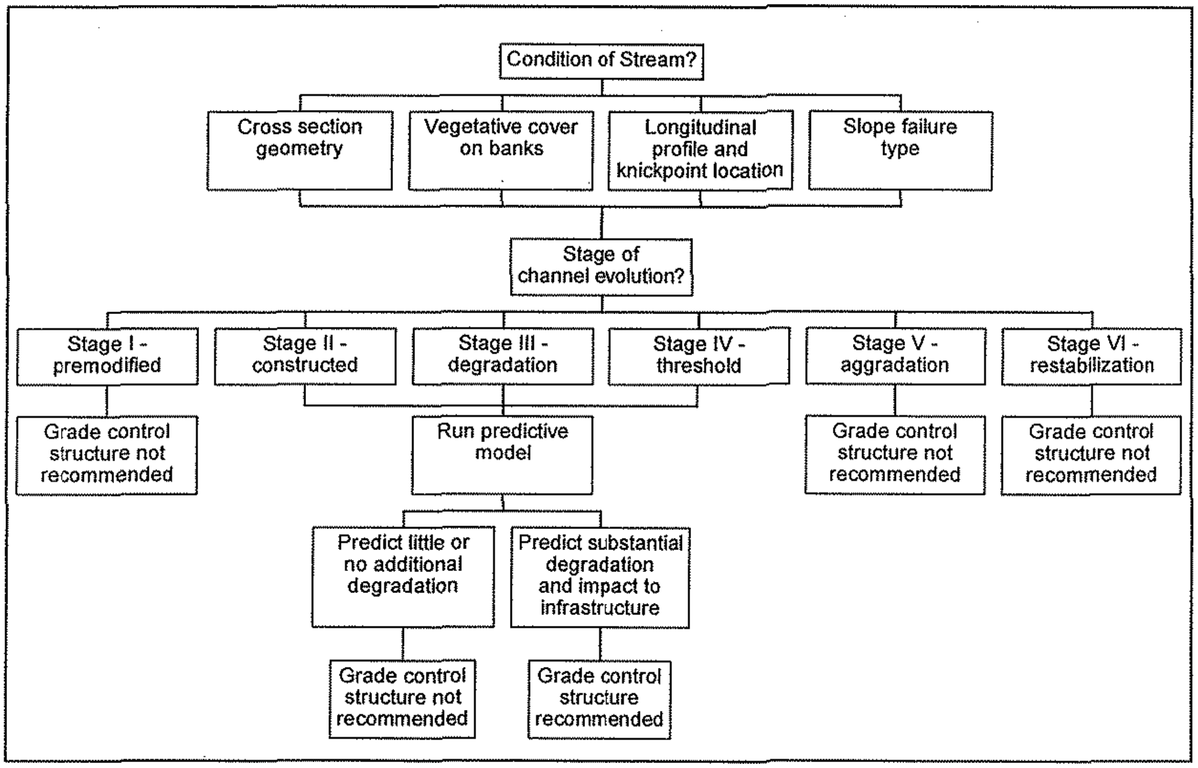

Figure 4.1. Flow chart for assessing the need for a grade control structure.

If it is determined that the stream is stage I - premodified, stage V - aggradation, or stage VI - restabilization, then a grade control structure is not recommended. However, if the stream system is disturbed and degradation is activated or reactivated, then a grade control structure may be needed to protect bridges and other infrastructure.

If it is determined that the stream is stage II - constructed, stage III - degradation, or stage IV - threshold then the geomorphic model or the tractive force model (described in Part 3 of this report) should be used to determine the expected amount of degradation. If the model(s) predict < 1 meter (3.3 ft) of additional degradation, then a grade control structure is not recommended. An exception to this guideline is a situation where existing bridges and pipelines cannot withstand additional degradation and grade control may be required. If the model(s) predict > 1 meter (3.3 ft) of additional degradation, then a grade control structure is recommended. In addition to amount of potential degradation, a decision to install a grade control measure should also be based on potential damages at the site, including damage to infrastructure and land loss.

4.2 Objectives of Grade Control Structures

Figure 4.2 shows a flowchart that summarizes the considerations relevant to planning the most effective grade control plan if the evaluation process indicates that a control structure is needed. The objective of the structure should be defined. Two objectives of grade stabilization structures are: 1) providing grade control for an extended reach and, 2) providing aggradation at a specific target. The design method will be based on the objective.

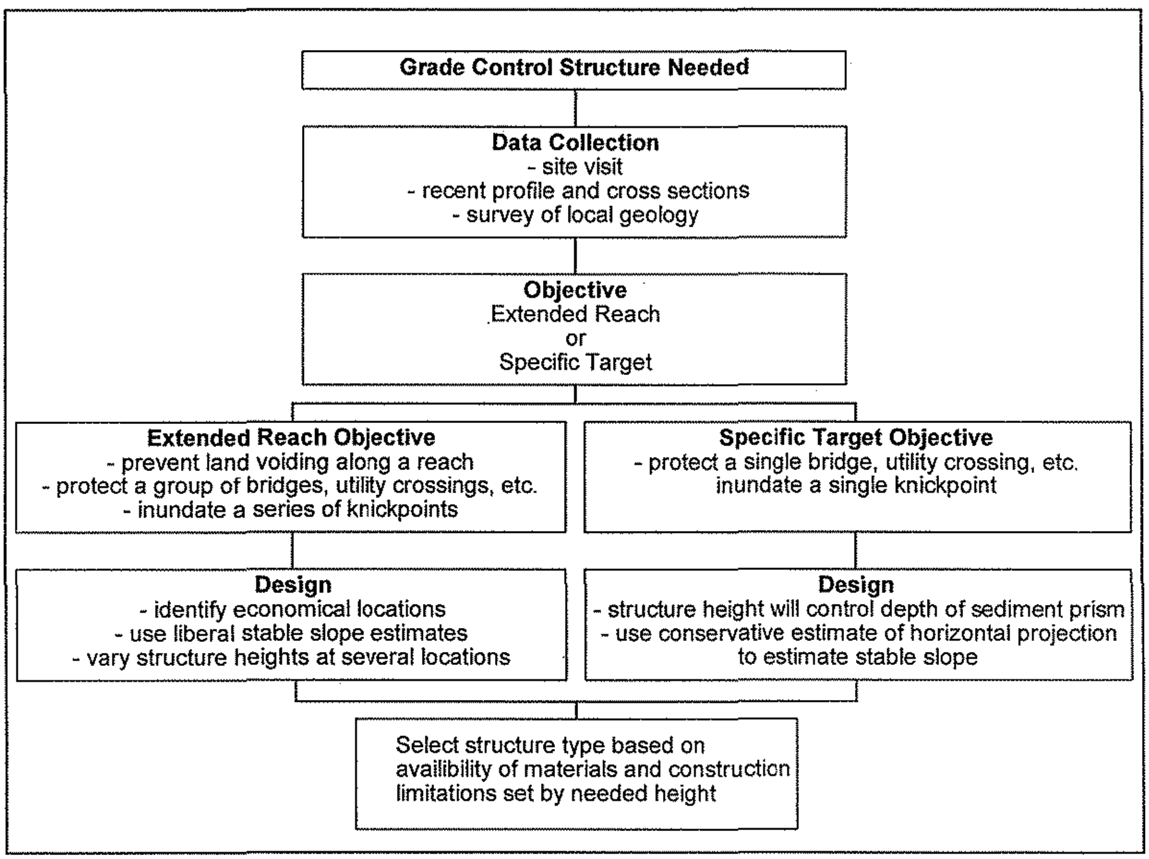

Figure 4.2. Flow chart for grade control planning.

4.3 Data Collection

Two important components used in determining the most effective location for a grade stabilization structure are: 1) a longitudinal profile of the stream, and 2) an understanding of the local geology. A visit to sites experiencing degradation is needed to identify local geology.

Although data on the strength of the stratigraphic members of the DeForest Formation show no significant variability, the geologic materials at the site need consideration. Bank instability associated with ground water seepage can affect a grade control structures' integrity. Seeps in the bank typically occur along a geologic contact between two materials of differing permeability; sand lenses in the basal portions of both the Roberts Creek and Gunder members is an example. Figure 4.3 illustrates pathways for water that often exist in and between the Gunder and Roberts Creek members. When these pathways become saturated it is common for failure planes to form (Bettis, 1993). It is suggested that flow within the saturated zone creates a drag force on the surrounding soil and that piping conditions may develop and lead to the removal of soil material. Voids left behind can initiate the failure of overlying bank material (Bettis,1993). This indicates that the designer should be aware of the presence of geologic contacts and/or sand lenses within the various stratigraphic units of the alluvium. It has also been suggested that the Gunder member is generally the most erosion resistant stratigraphic units and therefore may be the most desirable foundation soil of the DeForest Formation.

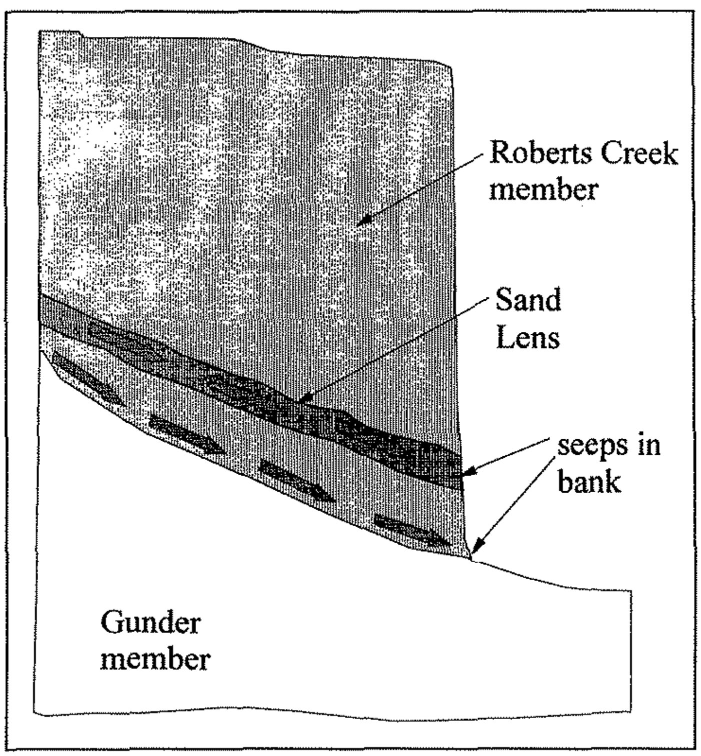

Figure 4.3. Seepage paths at geologic contacts.

A detailed longitudinal profile of the degrading reach should be completed following identification of the stage of channel evolution (see figure 2.1). The longitudinal profile should extend at least 1000 meters (3333 ft) above and below any knickpoint activity and contain enough detail to pinpoint the location of knickpoints within 100 meters (333 ft). The main purpose of the detailed profile is to determine the required height of the structure and to estimate the reach upstream of a grade control structure that will be affected by the aggradation.

4.4 Methods for Estimating Stable Slope Upstream of Structures

Three methods of estimating the slope of the sediment prism upstream from a grade stabilization structure are identified. These are: 1) horizontal projection method, 2) hydrodynamic method, and 3) empirical method.

These stable slope estimation methods presume that the existing stream slope remains constant throughout the controlled reach. Nearly all longitudinal stream profiles have steeper slopes near the headwaters. Often a stream's slope will change abruptly as the result of a knickpoint or change in bed material. These considerations must be taken into account when estimating stable slopes. A current longitudinal profile should be used and the estimated stable slope graphed onto the profile to estimate the controlled reach.

4.4.1 Horizontal projection method

The horizontal projection provides a lower bound for estimating channel control. It is the length of a line projected horizontally from the top of the structure to its intersection with the stream profile. To estimate the length of channel control provided by a horizontal projection use the equation:

$$R = \frac{d}{S_o} \qquad 11$$

where R = length of reach controlled (m), d = structure drop (m), and S_o = stream slope (m/m). Figures 4.4 and 4.5 provide a graphical estimate for the length of controlled reach by horizontal projection given the stream slope and grade control drop.

4.4.2 Hydrodynamic method

The Hydrodynamic method predicts a stable slope based on a derivation of Manning's equation for open channel flow (Hanson, 1985) and channel characteristics. The equation is:

$$i_e = \frac{(v_r u)^{10/3} B^{4/3} n^2}{Q^{4/3}} \qquad 12$$

where i_e = Hydrodynamic stable slope (m/m), v_r = ratio of mean velocity to channel bottom velocity; typically a value of 1.3 to 1.5 is used, 1.3 has been used in this report, u = velocity at which river bed

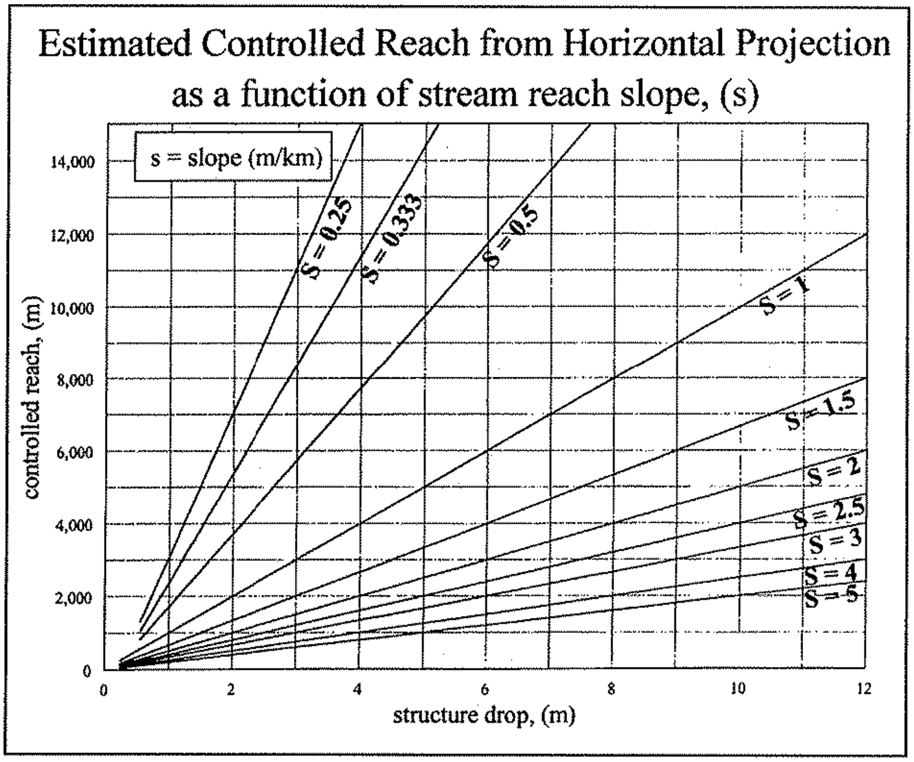

Figure 4.4. Reference chart for stable slope estimate with horizontal projection.

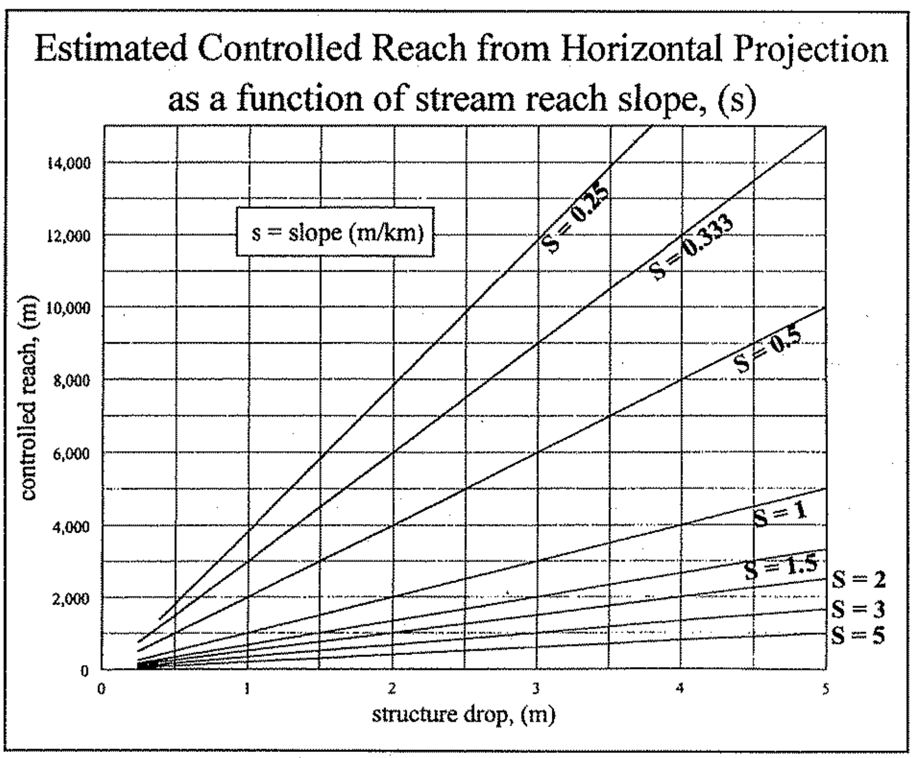

Figure 4.5. Reference chart for stable slope estimate with horizontal projection.

erosion starts; 1.06 for noncolloidal, alluvial silts has been chosen (m/s), B = width of stream (m), n = roughness coefficient ($s/m^{1/3}$); 0.04 has been used in this report, and Q = flood discharge for a 50yr return period (cms). The Hydrodynamic equation is less conservative than a horizontal projection.

The reach controlled can then be determined by the equation:

$$R = \frac{d}{S_o - S_{hydro}} \tag{13}$$

where R = length of reach controlled (m), d = structure drop (m), S_o = stream slope (m/m), and S_{hydro}= Hydrodynamic stable slope, i_e, (m/m). Figure 4.6 shows the controlled reach as a function of stream slope for a variety of drops using the Hydrodynamic Projection.

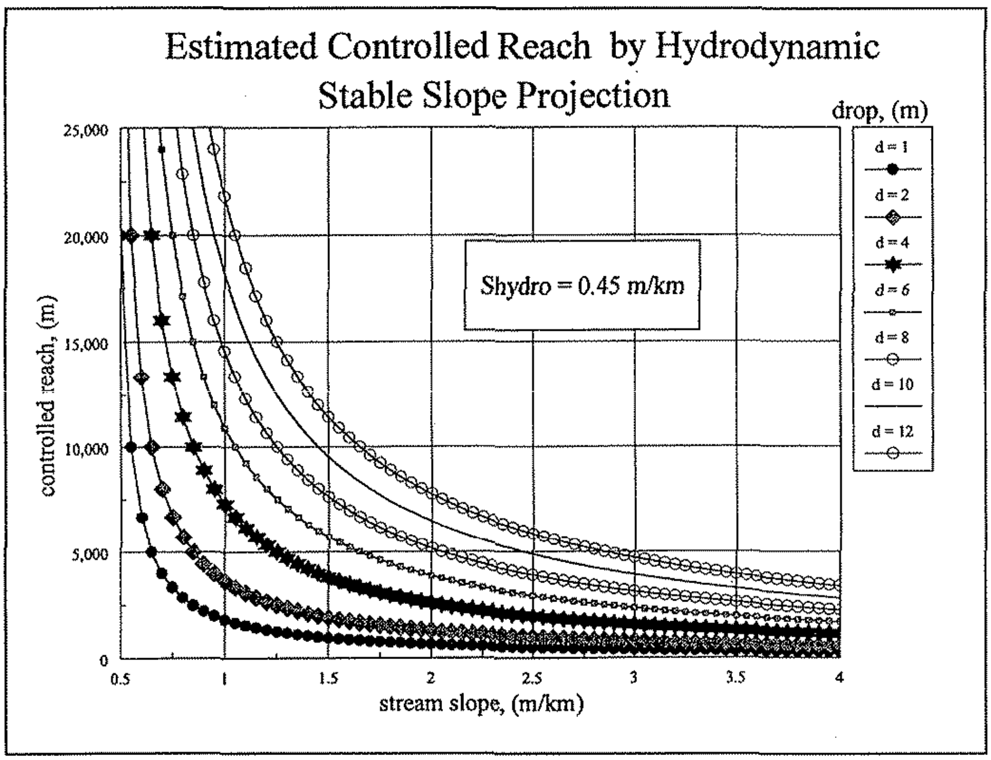

Figure 4.6. Reference chart for stable slope estimate with the hydrodynamic method.

4.4.3 Empirical method

Topset bed-slope formation in a reservoir is similar to sediment prism formation above a grade control structure. Borland (1971) suggests a relation of topset bed-slope to original stream slope for aggradation above impoundments. This relation has a linear trend when original stream slope is plotted against topset bed-slope on logarithmic scales.

A linear fit on logarithmic scales is a power function:

$$y = ax^{b} \tag{14}$$

where y is topset bed slope, x is original slope, and a and b are empirically determined parameters. This function represents an empirical method for estimating sediment prism slope at alluvial grade control sites of similar physiographic settings. Sediment prism slopes surveyed at four grade control sites on Willow and Keg creeks have been plotted against the stream slope at the time of grade control placement. This empirical fit (Figure 4.7) gives the following equation:

$$y = 0.112\, x^{0.93} \tag{15}$$

with a correlation coefficient of 0.89. This empirical relationship provides an additional stable slope estimating method applicable to western Iowa.

The reach controlled can then be estimated by the equation:

$$R = \frac{d}{S_o - y} \tag{16}$$

where R = length of reach controlled (m), d = structure drop (m), S_o = stream slope (m/m), and y = estimated stable slope (m/m).

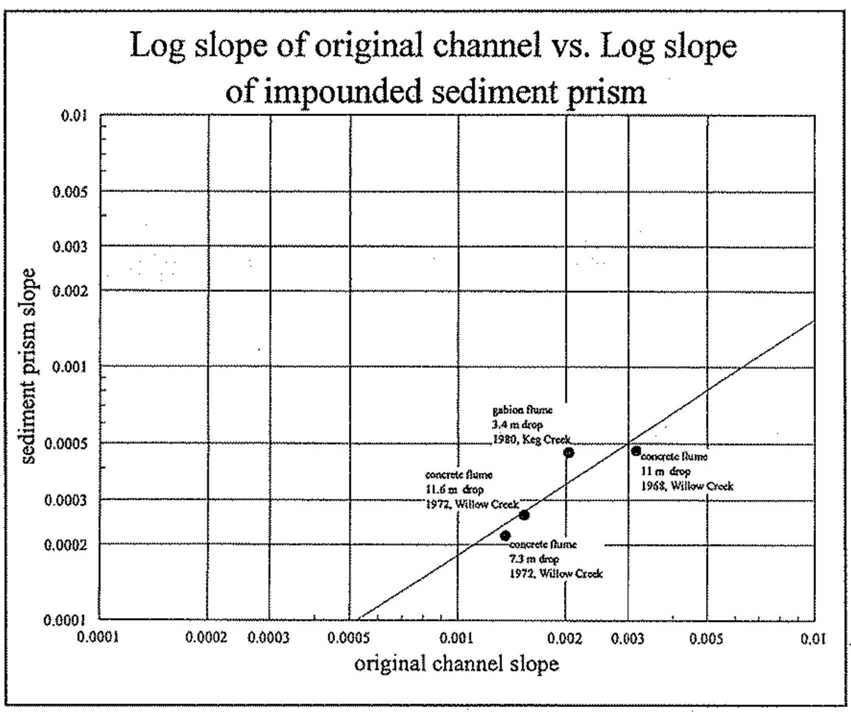

Figure 4.7. Observed sedimentation slopes upstream of structures placed in loess derived alluvium.

4.4.4 Comparison of observed and estimated stable slopes

At the four grade control structure sites where longitudinal profiles and cross section data were available, the horizontal projection, hydrodynamic, and empirical methods were evaluated. The calculated stable slope for each method was plotted against the observed stable slope obtained from longitudinal profiles. Figure 4.8 shows the calculated stable slope for each method plotted against the observed stable slope. The observed stable slopes were measured from longitudinal profiles where some interpolation of the surveyed data was required.

The solid line represents perfect agreement between observed and predicted slopes. The horizontal projection method, being zero, is obviously independent of any channel characteristics. The empirical method coincides well with the line of perfect agreement.

The hydrodynamic method which is dependent on channel width shows a great deal of scatter. The Keg Creek structure data fits closest to the line of perfect agreement. Good cross section data upstream of the structure prior to its placement were available for channel width estimation. The Willow Creek structures show a trend paralleling the line of perfect agreement. Channel widths for this data set were estimated from cross section data by Daniels (1960) from a 1958 survey. The cross sections were located in the general vicinity of the structure, not directly upstream as in the case of the Keg Creek site. The trend is pleasing, however the steeper predicted slopes for the Willow Creek data cannot be explained. Possible reasons for the steeper slopes may be linked to differences in Manning's coefficient or sediment gradation, both of which are factors in the hydrodynamic method.

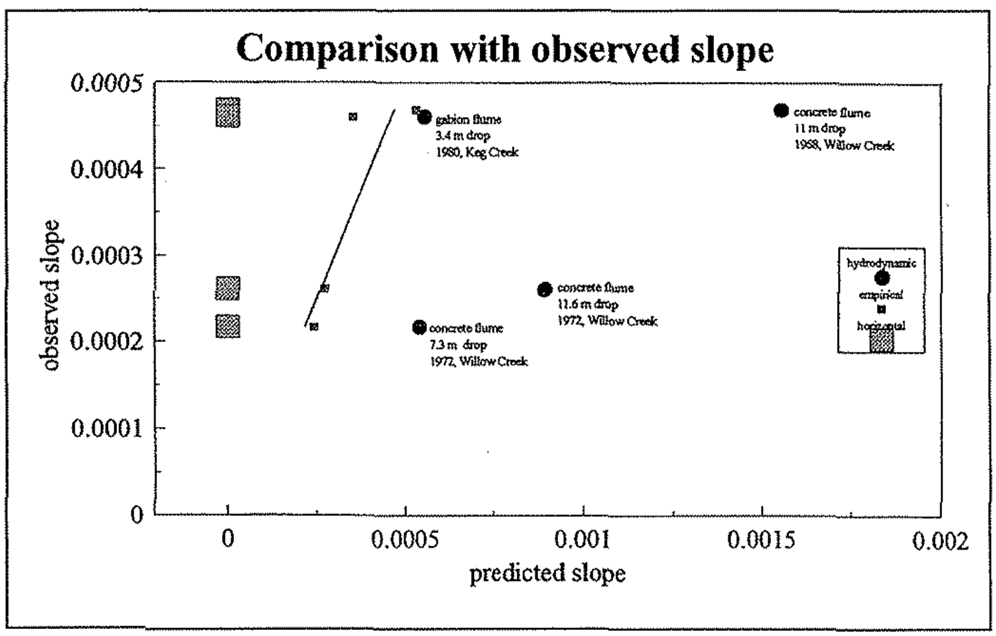

Figure 4.8. Comparison of stable slopes by predictive models.

Figure 4.9 shows the upstream extent of the sediment prism as estimated by the three methods plotted against the observed value. The extent of the sediment prism, or the controlled reach, is a valuable component of the grade control plan.

Again, the solid line represents perfect agreement between observed and predicted slopes. The horizontal projection method shows a trend similar to the line of perfect agreement; however differences by which this method underestimates actual controlled reach increases with increasing controlled reaches.

The empirical method shows a trend that nearly coincides with the line of perfect agreement. Figure 4.8 which plots predicted stable slope against observed stable slope shows a fair amount of scatter. Figure 4.9 incorporates original stream slope into this relation to plot predicted controlled reach against observed controlled reach. By incorporating the original stream slope into the calculation, the scatter exhibited in Figure 4.8 has decreased. This suggests the importance of original stream slope in predicting reach control.

Similarly, scatter exhibited by the hydrodynamic method has lessened. Structure sites from both Keg and Willow Creeks have the same trend. The Keg Creek site coincides with the line of perfect agreement while the Willow Creek sites show greater predicted reach control. This can be explained by figure 4.8 which shows the steeper predicted slopes for the Willow Creek sites. These steeper slopes will yield greater controlled reaches.

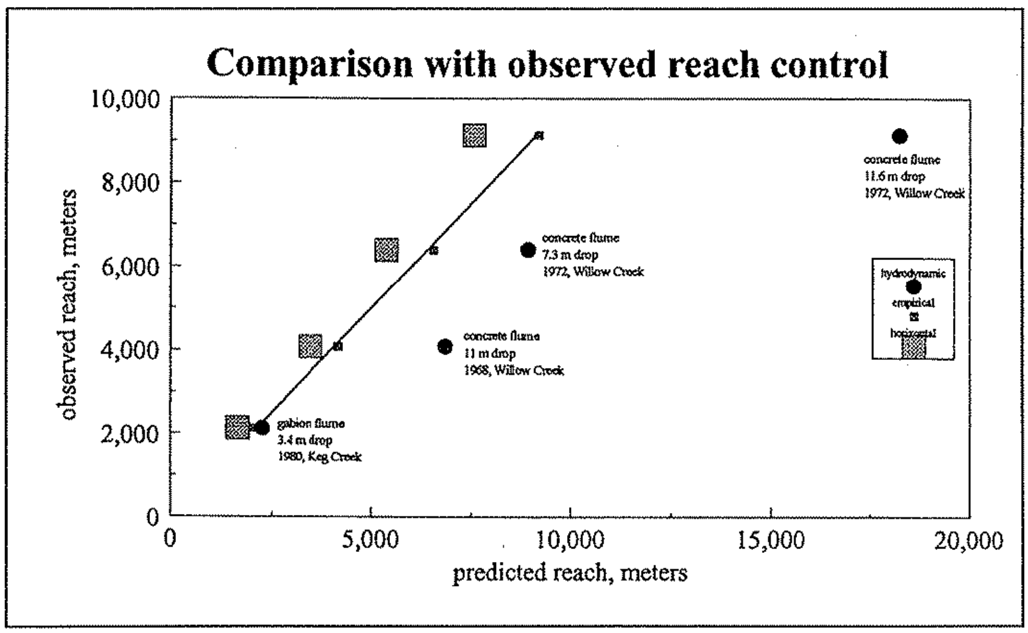

Figure 4.9. Comparison of reach control by predictive models.

4.5 Extended Reach Stabilization

The objective of grade stabilization may be to control an extended reach of a degrading stream in situations where the stream may have a number of knickpoints or bridge and utility crossings requiring aggradation. This approach may also be useful to prevent bank failures along actively degrading reaches.

In this situation a longitudinal profile is needed with the identification of all locations requiring aggradation. The locations and heights of grade stabilization structures can be varied along the longitudinal profile using an estimate of the stable slope created by the aggradation upstream of the structure. This is done until the depth of the associated sediment prisms inundates all knickpoints and provides the needed aggradation at all infrastructure locations. Figure 4.10 shows two plans to provide grade control along a reach containing active knickpoints.

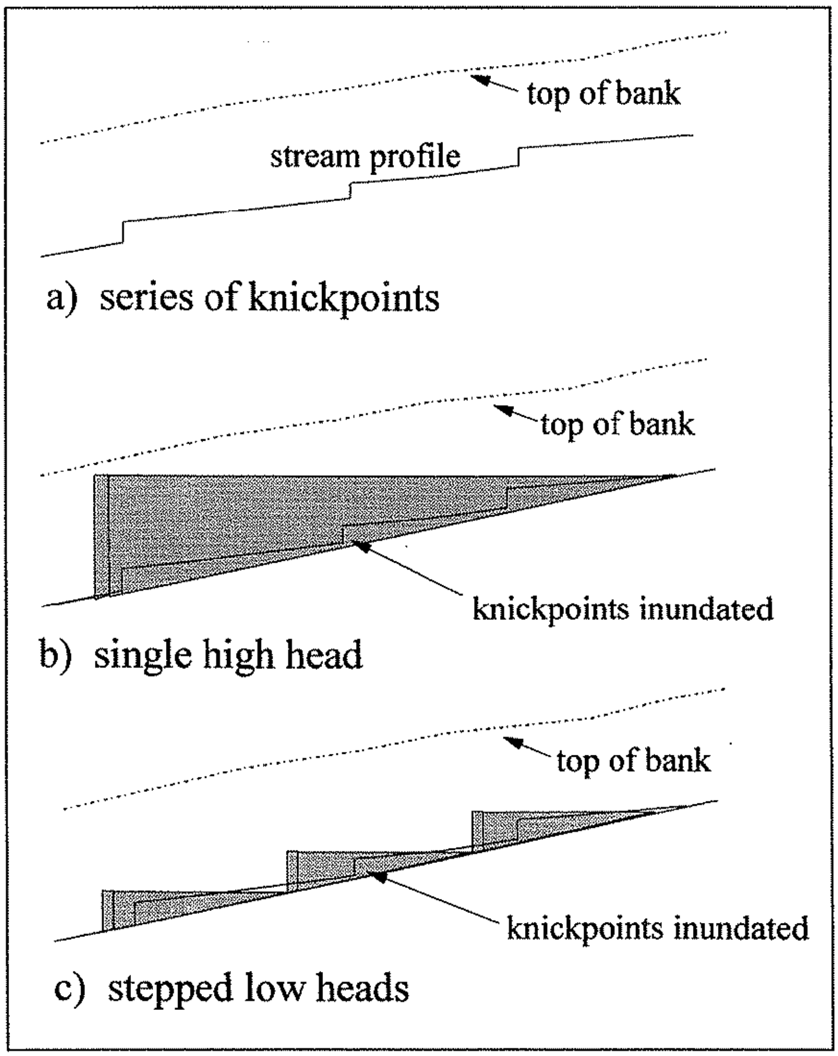

Figure 4.10. Examples of structure placement to provide grade control for an extended reach.

In designing a grade control plan for a lengthy reach of channel, Figures 4.4, 4.5, or 4.6 provide graphs that can be used to estimate the controlled reach for various grade control drops given the stream slope. Note that Figure 4.6 is applicable to a channel whose characteristics yielded a stable slope of 0.451 m/km according to the hydrodynamic method. Figure 4.11 compares the estimated controlled reach from stable slope projections by both the horizontal and hydrodynamic methods.

Alternatively, equations 11, 13, or 16 could be used to calculate the length of controlled stream reach. Graphs such as 4.4, 4.5, and 4.6 can be generated for a range of grade control drops, stream slopes, and other specific conditions with a spread sheet and graphing program.

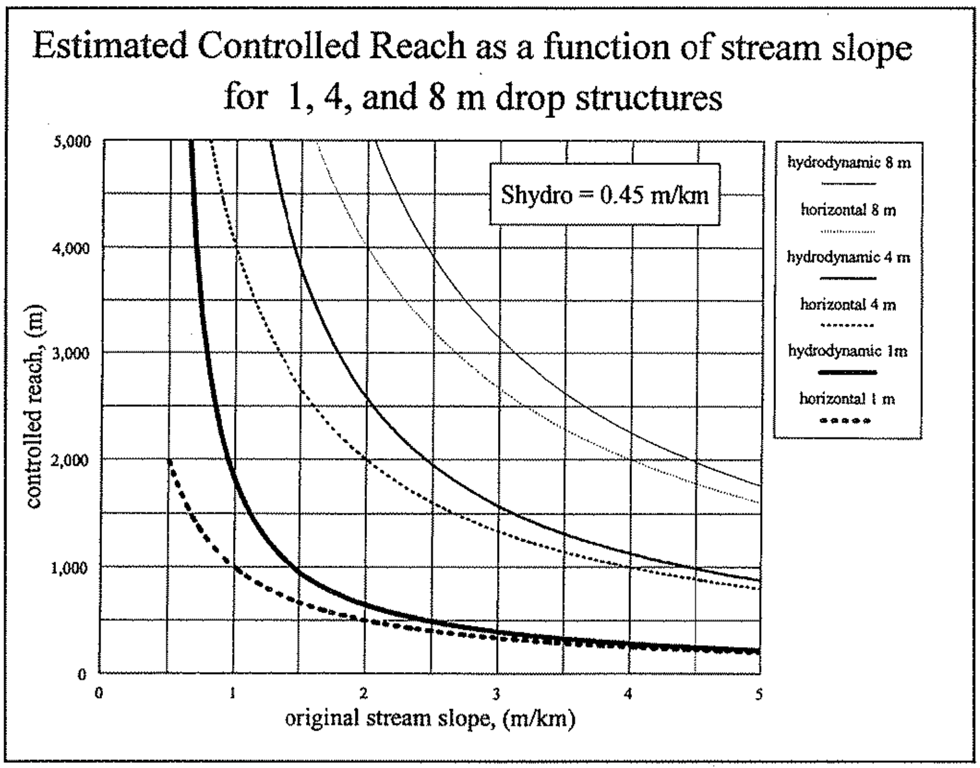

Figure 4.11. Reference chart for estimating differences in controlled reach by projection method used.

4.6 Protection of Specific Structure or Knickpoint Inundation

Figure 4.12 shows an example of grade control at a bridge where piers and footings have become exposed. The depth of aggradation, controlled by the height of the grade stabilization structure, will decrease upstream. The depth of the sediment prism at the location of the specific target should be sufficient to provide the needed aggradation.

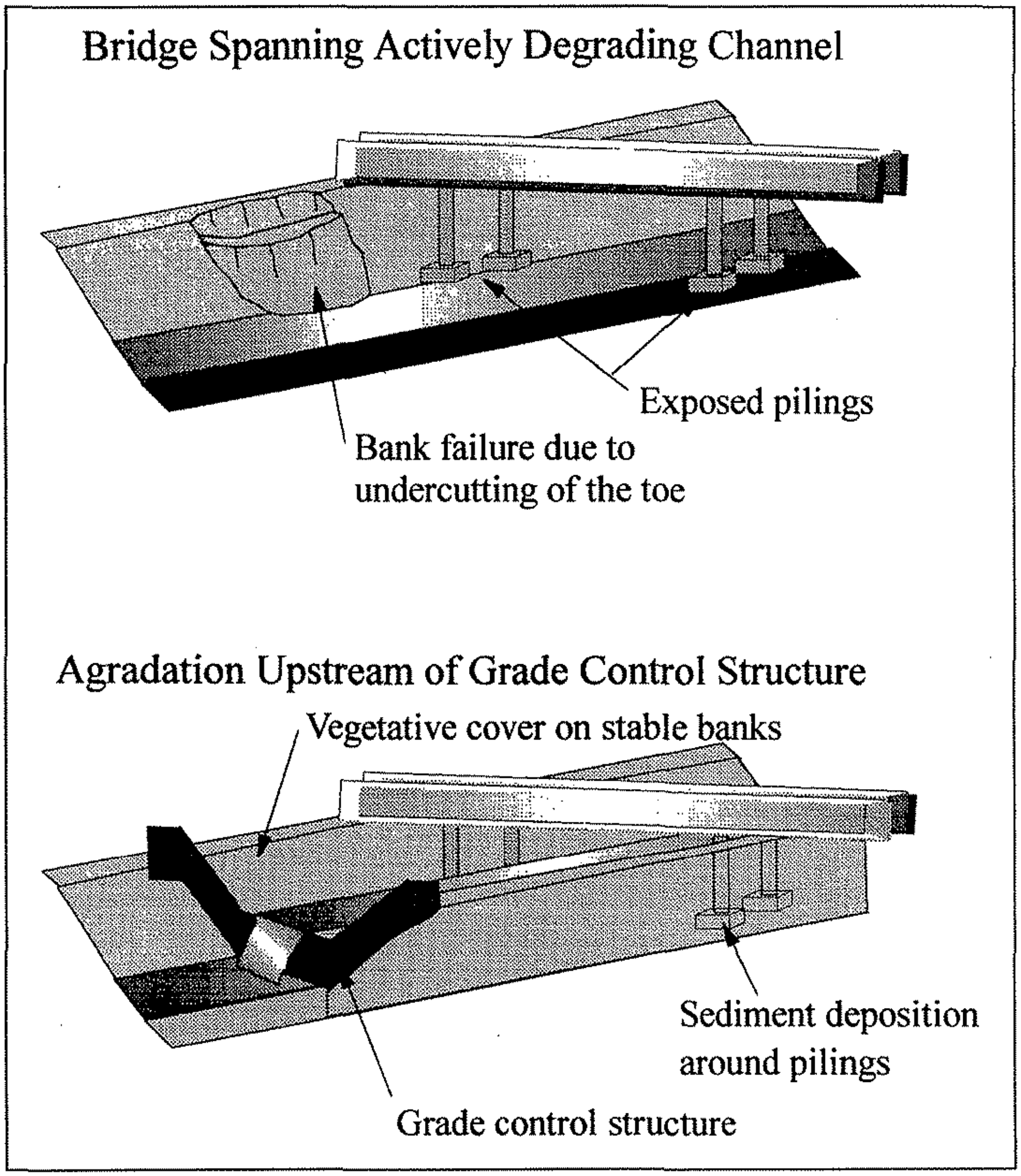

Figure 4.12. Example of structure placement to protect a specific target.

The stable slope representing the sediment prism can be estimated from equation 11 or Figures 4.4 and 4.5. When designing a structure to provide aggradation at a specific target a conservative stable slope estimation is suggested to ensure that the proper depth of sediment is achieved. Figure 4.13 shows a grade control structure placed on a stream slope and stable slope projections from the horizontal and hydrodynamic estimating methods to illustrate the conservative results obtained from equation 11.

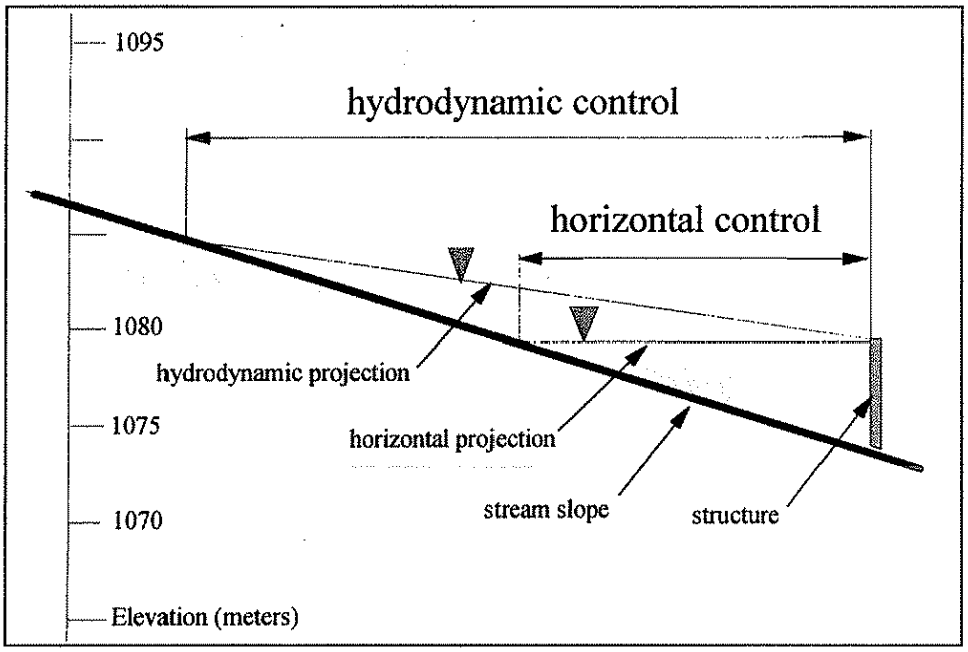

Figure 4.13. Stable slope projection with corresponding control.

5.0 TYPES OF STABILIZATION STRUCTURES

There is a great diversity in grade stabilization structure designs. Many were contrived to protect a specific structure such as the flumes which were designed to maintain a constant channel bed elevation beneath a bridge. Others were developed out of a need to reduce the costs of construction as with the sheet pile and H-pile designs. As federal, state, and local government tighten budgets, cost effective grade stabilization structures will dominate design selection. Plate numbers 1 through 6 show different designs in use throughout western Iowa. The designs were grouped into six categories: 1) reinforced concrete flumes (see example plate 1), 2) sheet piles (see example plate 2), 3) double drop sheet piles (see example plate 3), 4) H-piles (see example plate 4), 5) gabion flumes (see example plate 5), and 6) rock sills (see example plate 6).

A database was formed to reference grade control structure type and location to its associated cost and drop dimension. At each structure site physical characteristics related to the stream channel and basin were included. Two separate data sets exist. The first set in Table A1 (Appendix) contains structure locations where the majority of the data were readily attainable. All structures listed in this table are considered full flow structures. The second data set in Table A2 (Appendix) contains a larger number of structure locations, however their corresponding data were not available. Some of these structures create an impoundment and are not considered full flow. Tables A1 and A2 do not include all hydraulic structures found in western Iowa.

5.1 Economic Comparison of Grade Stabilization Structures

5.1.1 Method of analysis

Data on alternative stabilization structure designs were analyzed in an attempt to determine cost trends for the six designs of Part 5.0. This task is somewhat complicated by the large number of variables that affect the cost including drainage basin area, channel cross section, design discharge, stream slope, and structure drop. This problem was solved by using the structure characteristic number, SCN, or SCN = aS_cS_S, where a = drainage area (km^2) / cross sectional flow area (m^2) of design Q, S_c = stream slope (m/km), and S_s = structure length (m) / structure drop (m), suggested by Hanson et al (1985). Some modifications were made to the method by Hanson. Drainage areas were determined from construction plans or the book, "Drainage Areas of Iowa Streams" by Larimer (1957).

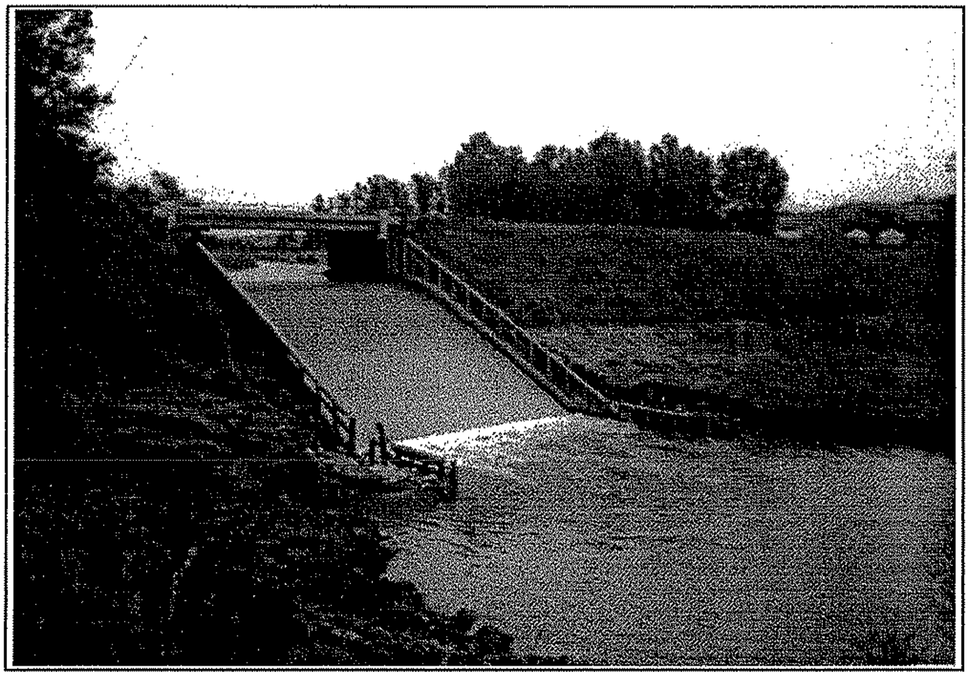

Plate 1. Reinforced concrete "Greenwood" flume, Willow Creek L16 bridge, Harrison County.

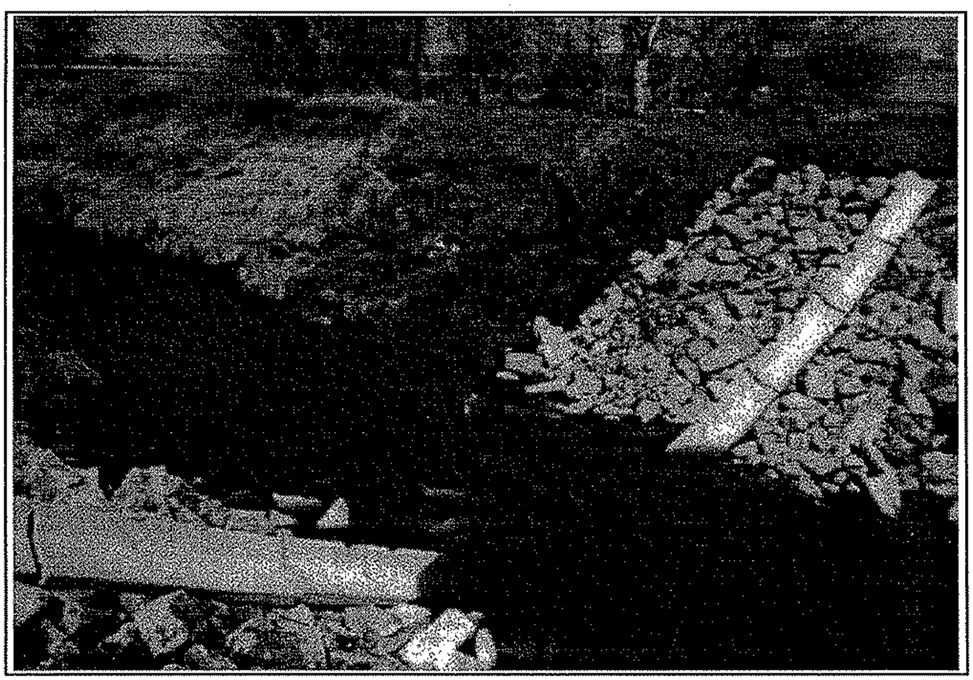

Plate 2. Sheet pile/riprap structure, Walnut Creek, section 34 Lincoln TWP, Pottawattamie County.

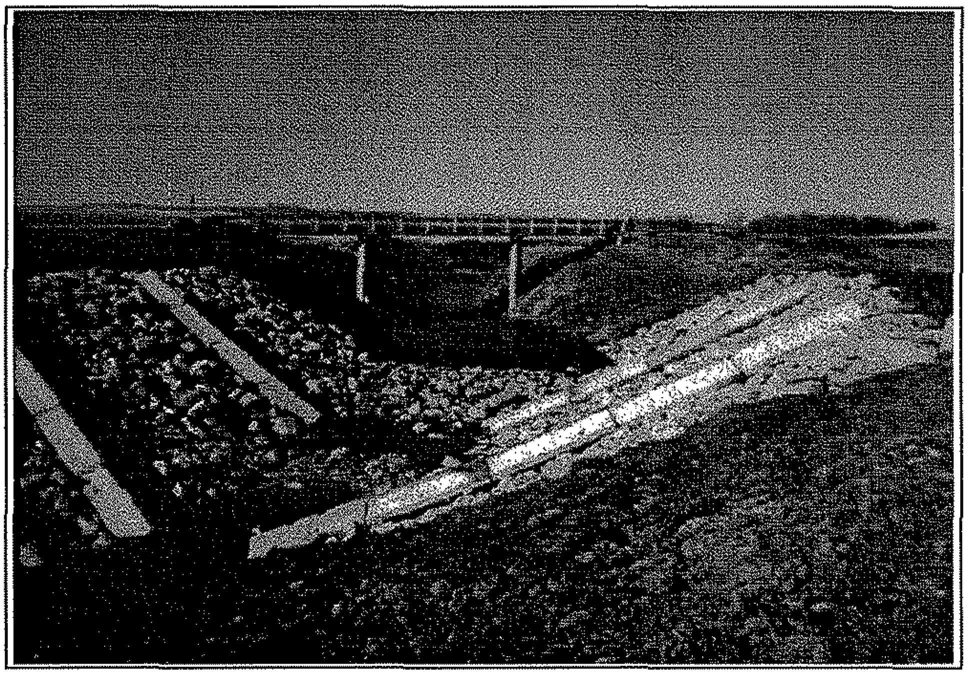

Plate 3. Double sheet pile/riprap structure, Little Walnut Creek, M47 bridge, Pottawattamie County.

Plate 4. H-pile/riprap structure, Elm Creek near Decatur Nebraska.

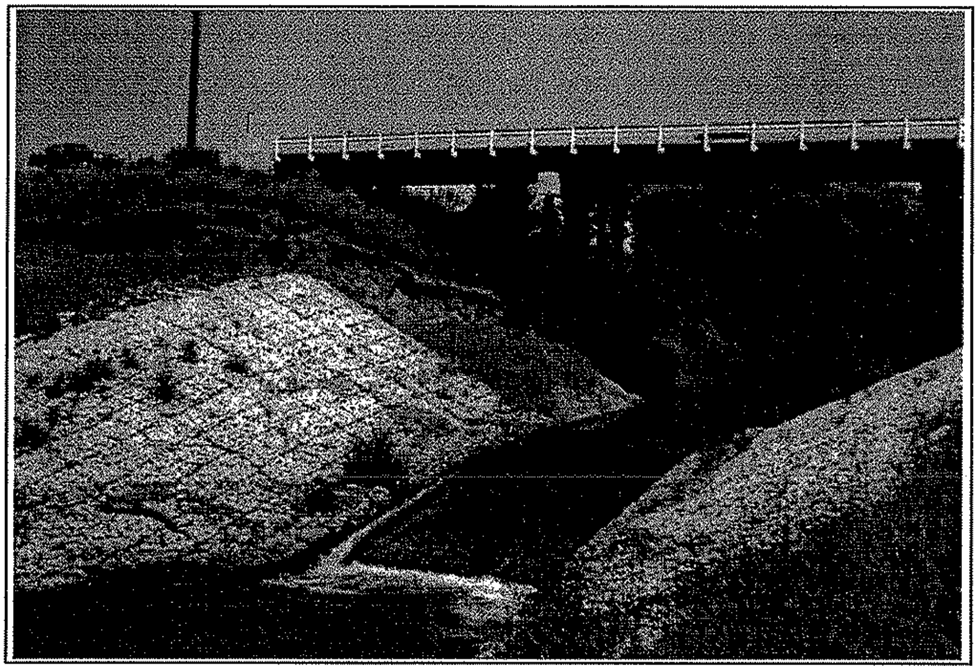

Plate 5. Gabion flume, Keg Creek, section 1 Hardin TWP, Pottawattamie County.

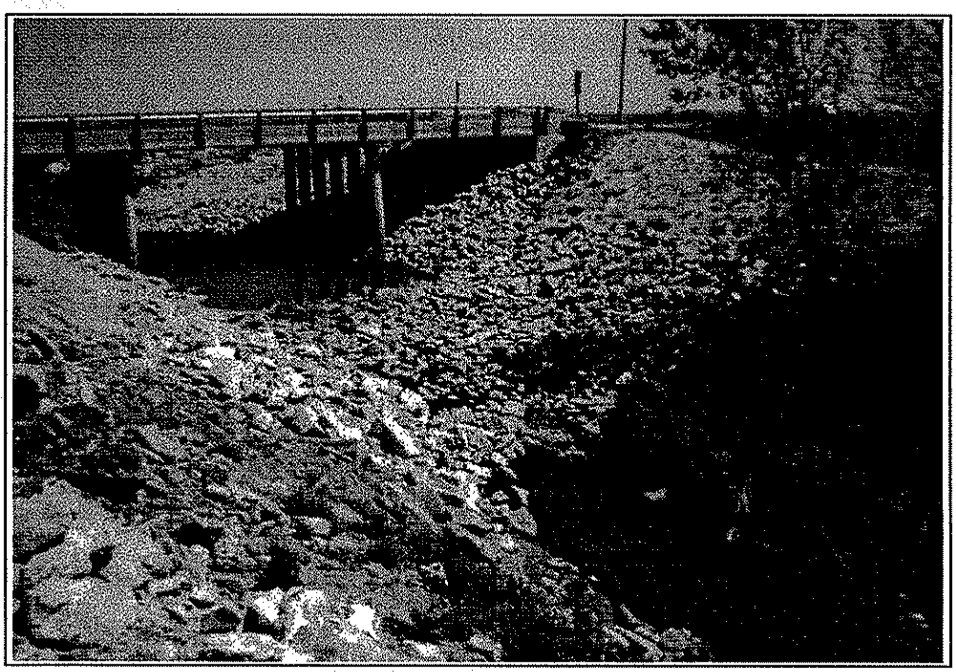

Plate 6. Rock sill, Baughman Creek, section 7 Pleasant TWP, Cass County.

Design flow was determined from the equation by Lara (1973):

$$Q = 7.408(LF)(RI)^{0.301}(DA)^{0.504} \qquad 17$$

where Q = flow (cms), LF = land factor equal to 0.8, RI = recurrence interval in years equal to 50, and DA = drainage area (km^2). To obtain the cross sectional area of flow during the design Q, a trapezoidal channel of 1 to 1 sideslopes with base length equal to structure width was assumed.Using a trial and error process, the depth of flow over the stabilization structure was varied until velocity from Manning's equation,

$$v = \frac{1}{n} r_h^{2/3} s^{1/2} \qquad 18$$

used in the continuity equation,

$$Q = V * A \qquad 19$$

yielded a Q equal to the design flow. The resulting area that satisfies both Manning's equation and the continuity equation is the cross sectional flow area. Stream slope was taken from construction plans, longitudinal profiles, and 1:24,000 quadrangle maps. Structure drop and length was taken from construction plans. The cost data on stabilization structures has been brought to the year 1994 from the year of construction using the formula:

$$Cost_{1994} = Cost_{yearofconstruction} * (1 + i)^n \qquad 20$$

where i = interest rate equal to 0.05 and n = number of years between construction date and 1994.

5.1.2 Results of economic analysis

Figure 5.1 shows the SCN versus cost. The data were fitted with a linear function to show cost trends based on structure design. Each data set for separate structure designs contains the point (0,0) representing zero cost for a stabilization structure with either a zero drop or zero length dimension. The data show increasing costs with increasing SCN with variations in structure type causing a difference in the rate of cost increase. The concrete flumes are the most expensive relative to other structure types of equivalent SCN. Sheet pile and H-Pile structures have a low rate of cost increase with increasing SCN.

The gabion and double drop sheet pile have a moderate rate of cost increase with increasing SCN. This simplistic analysis suggests that more consideration should be given to rock sills, sheet piles, and H piles instead of concrete flumes for future grade stabilization designs. Two important aspects of maintenance and structure longevity have not been considered in this analysis. While some concrete flumes were constructed thirty to fourty years ago and are still functioning, most sheet pile and H-pile structures have been in place ten years or less. Records on a structure's life performance and the maintenance required to keep it functional were not found. Future research should look at a method to maintain these records (Magner 1994).

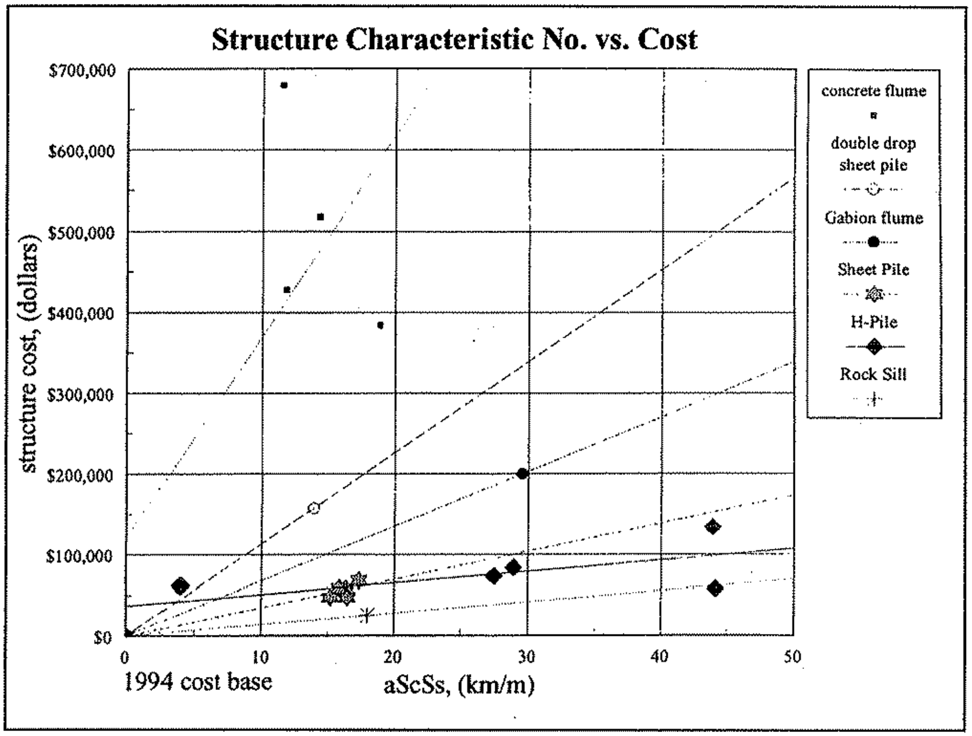

Figure 5.1. Economic comparison of stabilization structure design.

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Table A1. List of full flow grade control structures studied in western Iowa.

Structure Type	Legal Location	Location (county,tnshp,sec)	Placed on Main Branch or Tributary of	Cost	Year Built	Drop (meters)	Basin Area Above Structure (sq km)	Stream Gradient (m/km)	Channel bottom width (m)	Q50, flow (cms)	V, velocity (m/s)	A, cross-sec (sq m)
box flume	T79N R42W	har,jef,11	six mile				41.7					
box flume	T78N R39W	she,fai,13	dutch branch				25.2					
box flume	T81N R42W	har,lin,36	mud		1947		31.1					
box flume	T78N R43W	har,lag,11	harris grove		1900		21.3					
box flume	T80N R41W	har,dou,20	s. picayune		1979		13.0					
box flume	T81N R42W	har,lin,31	willow		1948		194.3	1.0				
twnbox flume	T80N R40W	she,was,7	picayune	$176,542.81	1988	5.2	25.3	3.4		81	1.8	
twnbox flume	T71N R43W	mil,lyo,25/24	waubonsie		1965	7.6	41.4			91	2.3	40.1
twin box flume	T84N R41W	cra,cha,23	emigrant creek			3.0	35.2					
greenwood flume	T79N R43W	har,cal,36	harris grove			4.6	36.3					
greenwood flume	T78N R41W	har,was,9/16	mosquito		1978	6.1	252.3	0.9				
greenwood flume	T80N R43W	har,mag,23	willow	$177,108.98	1972	7.3	255.1	1.6		205		
greenwood flume	T80N R44W	har,rag,11	steer		1963	6.1	20.7					
greenwood flume	T81N R42W	har,lin,29/20	willow	$146,146.09	1972	11.6	179.5	1.9		164		
greenwood flume	T80N R44W	har,rag,15	steer		early1970's	6.1	25.9					
greenwood flume	T80N R44W	har,rag,22	steer		1971		33.7					
greenwood flume	T78N R43W	har,lag,3	harris grove		1963		25.9					
greenwood flume	T80N R44W	har,rag,36	allen		1968		44.0					
greenwood flume	T80N R40W	she,was,23	tri,mosquito				31.1					
greenwood flume	T81N R43W	har,mag,30	allen				38.9					
greenwood flume	T78N R42W	har,uni,33	pidgeon	$326,981.00	1979	5.7	146.3	1.5		229		
greenwood flume	T80N R40W	she,was,14	tri,mosquito				25.9					
greenwood flume	T71N R42W	mil,raw,7	waubonsie		1965	7.0	25.9			68	1.9	36.2
greenwood flume	T82N R42W	mon,wil,15/22	willow	$108,064.78	1968	11.0	88.1	3.7		156	2.5	
conc. flume	T80N R41W	har,dou,4	picayune				49.2					
conc. flume		tay,	east fork 102 river	$1,120,000.00	1981							
gabion flume	T75N R42W	pot,har,1	keg	$101,000.00	1980	3.8	233.1	1.5		281		

Table A1. (continued)

Structure Type	Legal Location	Location (county,tnshp,sec)	Placed on Main Branch or Tributary of	Cost	Year Built	Drop (meters)	Basin Area Above Structure (sq km)	Stream Gradient (m/km)	Channel bottom width (m)	Q50, flow (cms)	V, velocity (m/s)	A, cross-sec (sq m)
sheet pile	T76N R38W	pot,lin,34	walnut	$65,019.50	1993	0.9	113.4	1.4	5.5	214	1.9	115.2
sheet pile	T76N R38W	pot,lin,34	walnut	$55,259.50	1993	0.9	109.0	1.4	3.0	210	1.9	110.6
sheet pile	T75N R38W	pot,wri,3	walnut	$55,460.00	1993	0.9	114.0	1.3	4.0	215	2.1	115.2
sheet pile	T75N R38W	pot,wri,9	walnut	$45,000.00	1993	0.9	139.3	1.2		239		
sheet pile	T75N R38W	pot,wri,22	walnut	$45,000.00	1993	0.9	158.5	1.2		256		
double drop sheet pile	T75N R38W	pot,wri,4	little walnut	$150,000.00	1993	2.7	21.0	3.2	3.7	236	1.3	65.0
sheet pile	T75N R39W	pot,cen,16	graybill		1975	1.2	95.8					
sheet pile	T82N R38W	cra,nis,	w. fork nishnabotna			1.2						
sheet pile		aud,ler,23/24	east nishnabotna			1.5						
sheet pile	T70N R37W	pag,dou,20	east tarkio	$316,591.25	1993	1.5						
sheet pile	T84N R40W	cra,cha,22	east soildier river		1993	2.7	150.2		18.3			
sheet pile	T81N R39W	she,uni,30	moser		1993	0.9	25.6	3.6	4.3	101	2.9	35.1
sheet pile	T81N R39W	she uni,30	moser		1993	0.8	25.6	3.6	4.3	101	2.0	51.7
sheet pile	T81N R39W	she,uni,21	moser		1993	0.9	19.9	1.9	2.7	91	1.6	58.0
sheet pile	T81N R37W	she,jef,7	elk creek	$39,436.00	1988	0.9	50.5	2.4	9.1	134	2.1	48.7
derrick stone/sht pile	T80N R40W	she,was,11	mosquito	$113,000.00	1963	3.8	85.5			184	0.0	0.0
weir	T80N R40W	she,was,11	moser				63.2	1.2				
weir	T69N R30W	rin,was,5/6	w. fork, grand river	$257,470.00	1992	1.5	220.2	0.9	30.5	218		
weir	T76N R38W	pot,lin,27	walnut creek		1974	0.9	102.8					
weir	T88N R46W	woo,con/flo,35/6	big whiskey creek		1983	1.5	133.1					
weir	T76N R38W	pot,lin,27	walnut creek		1974	0.9	103.6					
rock sill	T74N R37W	cas, ,7	baughmans creek	$25,000.00	1994	0.9	28.5	1.7	3.7	72	1.3	40.1
H - pile weir	T67N R38W	pag, ,25	mill creek		1994	1.2	51.8		8.2			
H - pile weir	T24N R E	bur,dec,1	elm creek	$53,210.18	1991	3	77.7	0.6				
H - pile weir	T24N R E	bur,dec,1	elm creek	$55,965.66	1992	3	80.3	0.6				
H - pile weir	T24N R E	bur,dec,10	elm creek	$74,430.14	1982	3	60.6	3.9				
H - pile weir	T24N R E	bur,dec,15	elm creek	$68,843.13	1990	3	46.6	3.3				
H - pile weir	T24N R E	bur,dec,21	elm creek	$57,130.25	1989	3	33.7	3.7				
H - pile weir	T23N R10E	bur,dec,2	elm creek	$57,619.84	1994	3	64.8	3.8				

Table A2. List of hydraulic structures in western Iowa.

Structure Type	Legal Location	Location (county,tnshp,sec)	Placed on Main Branch or Tributary of	Cost	Year	Drop (meters)	Basin Area Above Structure (sq km)	Stream Gradient (m/km)
box flume	T81N R40W	she,gro,6	not named					
box flume	T81N R40W	she,gro,6	not named					
box flume	T79N R42W	har,jef,35	harris grove				5.2*	
box flume	T78N R41W	har,was,10	mosquito		1940's			0.9
box flume	T79N R42W	har,jef,11	six mile				41.7	
box flume	T81N R43W	har,all,3	stowe		1900		7.8*	
box flume	T78N R39W	she,fai,13	dutch branch				25.2	
box flume	T78N R39W	she,fai,11	tri,e. branch w. nish					
box flume	T81N R42W	har,lin,36	mud		1947		31.1*	
box flume	T78N R43W	har,lag,11	harris grove		1900		21.3	
box flume	T81N R40W	she,gro,6	not named					
box flume	T80N R41W	har,dou,20	s. picayune		1979		13*	
box flume	T81N R42W	har,lin,31	willow		1948		194.3*	1.0
box flume	T78N R39W	she,fai,11	not named					
twnbox flume	T71N R43W	mil,lyo,25/24	waubonsie		1965	7.6	41.4	
twnbox flume	T80N R40W	she,was,7	picayune	$176,542.81	1988	5.2	25.3	3.4
twin box flume	T73N R40W	mil,and,29	not named	$115,000.00	1992	4.6*		
twin box flume		cra,was,9/16	not named		1962	1.9	4.9	
twin box flume		cra,cha,23	not named			3.0*	35.2	
twinbox flume	T79N R43W	har,cal,14	hog				5.2*	
twinbox flume	T81N R42W	har,lin,34	tri,boyer		1947			
twinbox flume	T79N R43W	har,cal,22	hog				7.8*	
twinbox flume	T78N R42W	har,uni,8	tri potato					

(*) denotes estimate

Table A2. (continued)

Structure Type	Legal Location	Location (county,tnshp,sec)	Placed on Main Branch or Tributary of	Cost	Year	Drop (meters)	Basin Area Above Structure (sq km)	Stream Gradient (m/km)
broken back	T79N R40W	she,cas,28	not named					
broken back	T78N R40W	she,she,21	not named					
broken back	T80N R39W	she,wes,14	not named					
broken back	T81N R40W	she,gro,10	tri,mill					
broken back	T80N R37W	she,pol,9	longbranch				51.8*	
broken back	T80N R40W	she,was,27	tri,mosquito	$41,183.30	1992	4.0	1.1	
broken back	T79N R38W	she,cen,3	not named	$23,087.70	1988	3.2		
broken back	T81N R40W	she,gro,29	tri,picayune			8.0		
drop inlet	T76N R43W	pot,haz,35	tri,mosquito	$83,700.00	1977	3.0*		
drop inlet	T76N R43W	pot,haz,13	hencho	$234,500.00	1975	3.7*	10.4*	
drop inlet	T74N R43W	pot,lew,15	tri,pony	$148,000.00	1986	4.3*		
drop inlet	T80N R38W	she,dou,16	not named					
drop inlet	T81N R39W	she,uni,11	tri,willow					
drop inlet	T79N R37W	she,jac,31	not named					
drop inlet	T79N R39W	she,lin,1	tri,w. fork nishna					
drop inlet	T80N R40W	she,was,34	tri,mosquito					
drop inlet	T78N R38W	she,mon,3	not named					
drop inlet	T79N R38W	she,cen,25	not named					
drop inlet	T79N R40W	she,cas,31	not named					
drop inlet	T80N R40W	she,was,23	tri,mosquito					
drop inlet	T79N R37W	she,jac,31	not named					
drop inlet	T81N R40W	she,gro,25	tri,moser	$22,385.08	1992	1.5	4.1	
drop inlet	T80N R37W	she,pol,9	tri,longbranch					
drop inlet	T81N R38W	she,gre,4	not named					
drop inlet	T81N R37W	she,jef,31	tri,w. nishnabotna					
drop inlet	T81N R40W	she,gro,4	tri,mill					
drop inlet	T81N R38W	she,gre,12	tri,greeley					
drop inlet	T81N R37W	she,jef,18	tri,elk					
drop inlet	T79N R40W	she,cas,18	not named					
drop inlet	T81N R37W	she,jef,7	tri,elk					
drop inlet	T80N R37W	she,pol,8	tri,longbranch					
drop inlet	T80N R37W	she,pol,4	tri,longbranch					
drop inlet	T79N R37W	she,jac,30	not named					
drop inlet	T81N R38W	she,gre,13	tri,greeley					

(*) denotes estimate

Table A2. (continued)

Structure Type	Legal Location	Location (county,tnshp,sec)	Placed on Main Branch or Tributary of	Cost	Year	Drop (meters)	Basin Area Above Structure (sq km)	Stream Gradient (m/km)
greenwood flume	T79N R43W	har,cal,36	harris grove			4.6	36.3	
greenwood flume	T78N R41W	har,was,11	mosquito			5-7*		0.9
greenwood flume	T80N R43W	har,mag,23	willow	$177,109.00	1972	7.3	255.1	1.6
greenwood flume	T80N R44W	har,rag,11	steer		1963	6.1	20.7	
greenwood flume	T81N R42W	har,lin,29/20	willow	$146,146.00	1972		179.5	1.9
greenwood flume	T80N R44W	har,rag,15	steer		early1970's	6.1	25.9	
greenwood flume	T80N R43W	har,mag,9	tri,allen				13.0*	
greenwood flume	T79N R41W	har,cas,25	tri,spring				5.2*	
greenwood flume	T80N R40W	she,was,16	pigeon				18.1*	
greenwood flume	T79N R41W	har,cas,24	tri,spring		1960,1982		5.2*	
greenwood flume	T80N R44W	har,rag,22	steer		1971		33.7	
greenwood flume	T80N R42W	har,boy,2	tri,boyer					
greenwood flume	T78N R41W	har,was,9/16	mosquito		1978		252.3	0.9
greenwood flume	T81N R44W	har,jac,3	tri,soldier					
greenwood flume	T78N R43W	har,lag,3	harris grove		1963		25.9	
greenwood flume	T80N R37W	she,pol,30	tri,w. nishnabotna					
greenwood flume	T79N R43W	har,cal,16	tri,willow					
greenwood flume	T80N R44W	har/rag/25	allen creek					
greenwood flume	T80N R43W	har/mag/4	allen creek					
greenwood flume		mon/spr/25/26	elk creek					
greenwood flume		mon/spr/15	elk creek					
greenwood flume	T81N R44W	har,jac,21	tri,soldier					
greenwood flume	T78N R44W	har,stj,25	tri,euclid		1960			
greenwood flume	T81N R43W	har,all,21	cobb				5.2*	
greenwood flume	T80N R44W	har,rag,36	allen		1968		44.0	
greenwood flume	T81N R41W	har,har,8	tri,boyer					
greenwood flume	T79N R43W	har,cal,26	hog				10.4	
greenwood flume	T80N R40W	she,was,23	tri,mosquito				31.1	
greenwood flume	T81N R43W	har,mag,30	allen				38.9	
greenwood flume	T78NR44W	har,stj,2	tri,boyer					
greenwood flume	T78N R42W	har,uni,33	pidgeon	$326,981.00	1979		146.3	1.5
greenwood flume	T80N R40W	she,was,14	tri,mosquito				25.9	
greenwoods (2)	T81N R43W	har,mag,14	tri,willow					
greenwood flume	T71N R42W	mil,raw,7	waubonsie		1965		25.9	
greenwood flume	T82N R42W	mon,wil,15/22	willow	$108,065.00	1968		88.1	3.7

(*) denotes estimate

Table A2. (continued)

Structure Type	Legal Location	Location (county,tnshp,sec)	Placed on Main Branch or Tributary of	Cost	Year	Drop (meters)	Basin Area Above Structure (sq km)	Stream Gradient (m/km)
gnwd or RCB	T71N R43W	mil,lyo,25	waubonsie				46.6*	
gnwd or RCB	T72N R42W	mil,cen,3	tri,silver					
gnwd or RCB	T71N R42W	mil,raw,26	spring valley				7.8*	
gnwd or RCB	T71N R42W	mil,raw,36	spring valley				13.0*	
gnwd or RCB	T71N R41W	mil,whi,31	spring valley				19.8	
gnwd or RCB	T71N R41W	mil,whi,35	kilpatric				7.8*	
gnwd or RCB	T72N R43W	mill,gle,36	not named					
gnwd or RCB	T71N R41W	mil,whi,34	kilpatric				11.2	
gnwd or RCB	T72N R41W	mil,sil,6	osborne				13.0*	
gnwd or RCB	T72N R40W	mil,ind,36	tri,indian					
gnwd or RCB	T73NR43W	mil,oak,15	tri,pony					
gnwd or RCB	T72N R42W	mill,cen,32	waubonsie				10.4*	
gnwd or RCB	T72N R40W	mil,dee,1	tri,indian					
gnwd or RCB	T73N R41W	mil,ing,30	prairie				18.0*	
gnwd or RCB	T73N R41W	mil,ing,33	osborne					
gnwd or RCB	T72N R43W	mill,gle,36	not named					
gnwd or RCB	T73N R41W	mil,ing,19	prairie				16.8	
gabion flume	T75N R42W	pot,har,1	keg	$101,000.00	1980		233.1	1.5
concrete flume	T80N R41W	har,dou,4	picayune				49.2	
concrete flume		tay,	east fork 102 river	$1,120,000.00	1981			
concrete flume		cra,sto,14	not named			2.7	0.6	
scs dam	T81N R40W	she,gro,33	picayune				10.4*	
scs dam	T80N R39W	she,wes,7	not named					
scs dam	T81N R40W	she,gro,32	picayune				13.0*	
scs dam	T78N R40W	she,she,30	tri,e. branch keg					
scs dam	T81N R40W	she,gro,3	bee tree				16.1	
scs dam	T81N R40W	she,gro,33	tri,picayune					
scs dam	T81N R40W	she,gro,5	tri,mill					
scs dam	T78N R40W	she,she,20	tri,e. branch keg					
scs structure	T81N R40W	she,gro,9	mill				19.1	

(*) denotes estimate

Table A2. (continued)

Structure Type	Legal Location	Location (county,tnshp,sec)	Placed on Main Branch or Tributary of	Cost	Year	Drop (meters)	Basin Area Above Structure (sq km)	Stream Gradient (m/km)
sheet pile	T76N R38W	pot,lin,34	walnut	$65,019.50	1993	0.9	113.4	1.4
sheet pile	T76N R38W	pot,lin,34	walnut	$55,259.50	1993	0.9	109.0	1.4
sheet pile	T75N R38W	pot,wri,3	walnut	$55,460.00	1993	0.9	114.0	1.3
sheet pile	T75N R38W	pot,wri,9	walnut	$45,000.00	1993	0.9	139.3	1.2
double drop sheet pile	T75N R38W	pot,wri,4	little walnut	$150,000.00	1993	2.7	21.0	3.2
sheet pile	T75N R38W	pot,wri,22	walnut	$45,000.00	1993	0.9	158.5	1.2
sheet pile	T75N R39W	pot,cen,16	graybill		1975	1.2	95.8	
sheet pile	T82N R38W	cra,nis	w. fork nishnabotna			1.2		
sheet pile		aud,ler,23/24	east nishnabotna			1.5		
sheet pile	T70N R37W	pag,dou,20	east tarkio	$316,591.25	1993	1.5	40.7	1.9
sheet pile	T84N R40W	cra,cha,22	east soildier river		1993	2.7	150.2	
sheet pile	T81N R39W	she,uni,30	moser		1993	0.9	25.6	3.6
sheet pile	T81N R39W	she uni,30	moser		1993	0.8	25.6	3.6
sheet pile	T81N R39W	she,uni,21	moser		1993	0.9	19.9	1.9
sheet pile	T81N R37W	she,jef,7	elk creek	$39,436.00	1988	0.9	50.5	2.4
sheet pile		car,ros,35	brushy creek					
derrick stone/sht pile	T80N R40W	she,was,11	mosquito	$113,000.00	1963	3.8	85.5	2.7
weir	T80N R40W	she,was,11	moser				63.2	1.2
wier	T81N R37W	she,jef,7	elk				46.6*	
weir	T69N R30W	rin,was,5/6	w. fork, grand river	$257,470.00	1992	1.5	220.2	0.9
?	T81N R41W	har,har,10	tri.boyer					
weir	T76N R38W	pot,lin,27	walnut creek		1974	0.9	102.8	
weir	T88N R46W	woo,con/flo,35/6	big whiskey creek		1983	1.5	133.1	
weir	T76N R38W	pot,lin,27	walnut creek		1974	0.9	103.6	
rock sill	T74N R37W	cas, ,7	baughmans creek	$25,000.00	1994	0.9	28.5	1.7
H - pile weir	T67N R38W	pag, ,25	mill creek		1994	1.2	51.8	
H - pile weir	T23N R10E	in decatur	elm creek	$53,210.18	1991	3.0	77.7	0.6
H - pile weir	T23N R10E	in decatur	elm creek	$55,965.66	1992	3.0	80.3	0.6
H - pile weir	T23N R10E	bur,dec,10	elm creek	$74,430.14	1982	3.0	60.6	3.9
H - pile weir	T23N R10E	bur,dec,15	elm creek	$68,843.13	1990	3.0	46.6	3.3
H - pile weir	T23N R10E	bur,dec,21	elm creek	$57,130.25	1989	3.0	33.7	3.7
H - pile weir	T23N R10E	bur,dec,2	elm creek	$57,619.84	1994	3.0	64.8	3.8

(*) denotes estimate

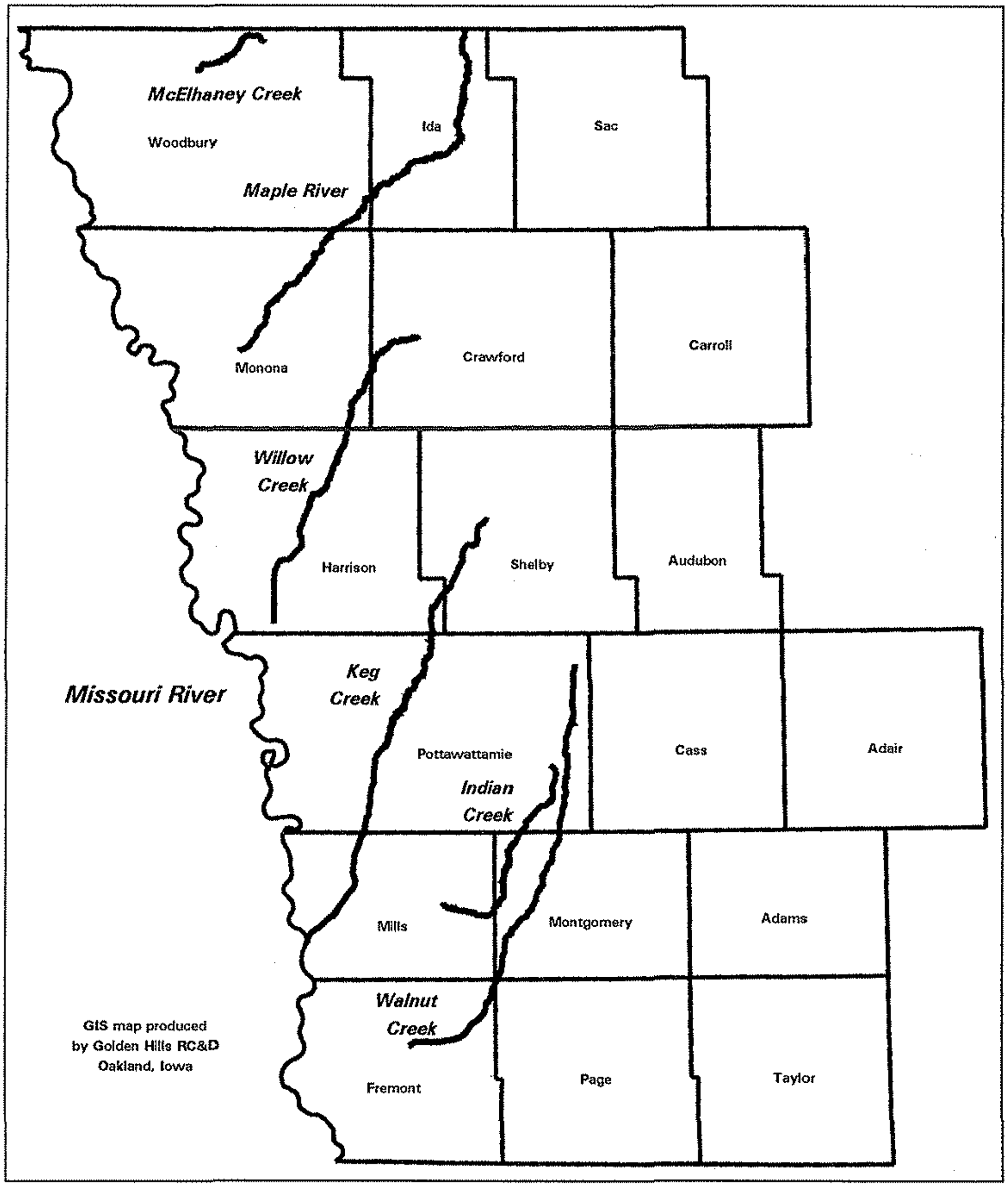

Figure A3. Location map of streams discussed in report.

SECTION FOUR

Impact of Degrading Western Iowa Streams on Private and Public Infrastructure Costs

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ABSTRACT

The purpose of this study was to estimate the degradation costs from stream straightening on land voiding and on public and private infrastructure crossing streams in the deep loess soil region of western Iowa. The widening and deepening stream channels has resulted in the loss of farmland and damage to highway and railroad bridges and rights-of-way, pipelines, telephone, electric, and rural water lines. Five streams in western Iowa were examined in detail. The estimated degradation costs from these five streams, along with data from the Natural Resources Conservation Service, were used to estimate the total degradation costs of streams in the deep loess soil region of western Iowa.

Two types of costs were estimated. One was simple time neutral costs estimated by multiplying lost land and damaged infrastructure by the 1992 per unit cost of the land and infrastructure. The second type was a time value cost estimated by recognizing that the costs were magnified by the time value of money from the dates of incremental widening of streams.

The estimated time neutral cost for 155 degrading streams in western Iowa was $174.9 million. The estimated total time value cost from the degrading streams was $1.1 billion. The time value estimate is the more accurate of the two estimates because it includes a 4 percent compound interest charge on the degradation losses during years prior to 1992. Damage to highway bridges represent the highest costs associated with channel erosion, followed by railroad bridges and right-of-way; loss of agricultural land represents the third highest cost.

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First, we wish to thank Marty Adkins, former Coordinator of Golden Hills Resource Conservation and Development, who initiated and developed this project. Gregg Hadish, Project Director of Golden Hills Resource Conservation and Development, provided patient guidance, assistance and encouragement throughout the research. Gregg was helpful in collecting data, in coordinating with the USDA Natural Resources Conservation Service (NRCS) and in serving on an advisory committee to help guide our work. Gregg also made numerous field measurements of stream widths to enable us to check the accuracy of our decay function width estimates and delineated the degrading sections of western Iowa streams. Martin Braster, current Coordinator, Golden Hills Resource Conservation and Development, provided valuable insights and suggestions for this research.

Dennis Miller, of the NRCS, gave invaluable assistance throughout this project. He guided us to focus on drainage areas and provided data on previous NRCS degradation studies on tributaries in the loess soil region. He listened to our problems and gave suggestions throughout this entire research project.

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Professor Robert Lohnes, of the Civil Engineering Department at Iowa State University, a national authority on stream degradation, was absolutely critical to the completion of this report. Bob helped us understand the basic problem of stream degradation and provided us with several of his engineering models to use as needed on the study. He encouraged two of his engineering graduate students, Brad Levich and Jeff Magner to make suggestions and help us with specific measurement problems. A special thanks to Bob, Brad and Jeff.

Brad Barrett, of the Iowa Department of Transportation, spent hours with the authors explaining the impact of stream degradation on bridges and how to measure these impacts. He provided all the bridge cost data used in the analysis. He generously served as a consultant throughout the study as specific problems arose in measuring bridge costs. Not once did he say he was too busy to help us!

Tom Valline, of the Iowa Department of Transportation, provided valuable information on the status of county and state bridges crossing the study streams.

Ms. Natalie Ruch provided competent data analysis in measuring drainage areas and in estimating stream widths. She cheerfully reworked her analyses as we changed our minds about how each part of the analysis should be made.

Ms. Shelly Coon and John Skerritt, of the NRCS, measured stream widths from aerial photographs. Their agreement to measure these widths from 2 x 2 inch aerial slides added greatly to the accuracy of our stream width estimates.

We wish to thank the many county engineers who provided guidance and data for this analysis. In particular, we wish to thank Eldo Shornhorst and Charles Trailer of the Shelby County Engineers Office. Eldo and Charlie helped us understand the degradation problem. Charlie dug into old files to provide data on the original stream straightening widths, dates and costs. He also asked his father, Merrill Trailer, to share his early year experiences of living near Indian Creek in western Iowa.

Other county engineers providing data were:

Orville Ives	Monona County Engineer
J. Munson	Assistant Pottawattamie County Engineer
Al Loebig	Cherokee County Engineer
Keith White	Ida County Engineer
Lloyd Kallsen	Woodbury County Engineer
H. D. Wright	Crawford County Engineer
Tom Stoner	Harrison County Engineer
James Ebmeier	Mills County Engineer

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Kenneth Bruestle	Burlington Northern Railroad
Fredrick Yokum	Iowa Interstate Railroad
Stanley DeRoo	Cherokee Rural Water District No. 1
Mike Blum	Shelby Rural Water District No. 1
Mike Waters	AT&T
Lonnie Laws	U.S. West
Sherry Harrison	Vista Telephone
Arvin Peterson	GTE Telephone
Howard Train	Farmers Mutual Telephone Company
Joe Hansen	Jordan-Soldier Cooperative Telephone Company
Douglas Furlick	Western Iowa Telephone Association
Gary Pool	Nishnabotna Valley Rural Electric Cooperative

Donald Christensen	Midwest Power Systems
Ronald Kunkel	Woodbury County Rural Electric Cooperative
Bruce Bosworth	Iowa Lakes Rural Electric Cooperative
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Gary Chapman	South Crawford Rural Electric Cooperative

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Mrs. Shirley Baum, our outstanding and talented secretary, tirelessly and willingly typed several drafts of this report.

We credit the Iowa Highway Research Board for their participation in the study. The opinions, findings, and conclusions expressed in this publication are those of the authors and not necessarily those of the Highway Division of the Iowa Department of Transportation.

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Thank you all!

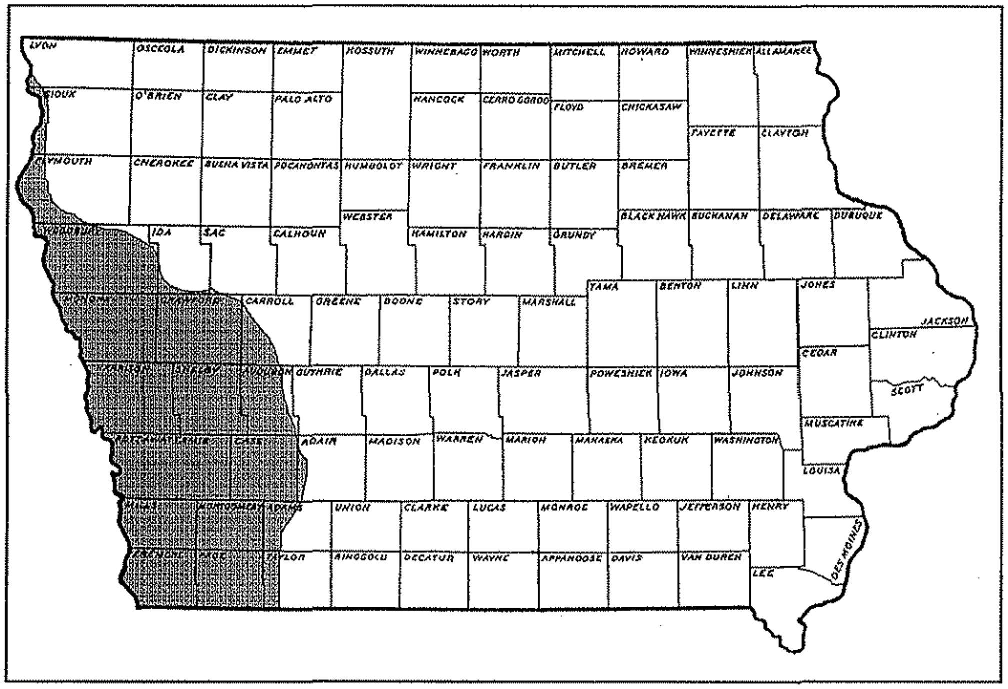
1.0 INTRODUCTION

Much of western Iowa is covered by wind blown loess soils that were deposited 125- to 1,500-centuries ago (Prior). Loess material consists primarily of silt and clay sized particles and is highly susceptible to erosion. These deposits range from 100-feet deep along the Missouri River to less than 15-feet deep to the east and north.

Prior to and during the early 1900s, the meandering streams in western Iowa frequently flooded their valleys. The meandering nature of the streams reduced water velocity and increased the amount of flooded and unusable land. The slow water velocity increased the frequency and severity of flooding, which in turn, created untillable swamps and frequently covered tillable land. Crops were often damaged or destroyed. Farmers also sustained substantial losses from animals being washed down flooded streams. Long-time western Iowa residents retell stories told by their parents about animals and property floating down the flooded rivers. One version of a telephone party-line conversation described a "play-by-play" of what was floating down the floodwater of Indian Creek -- "Oh, there goes another cow - a couple of hogs - another cow - Oh my goodness! There goes a whole string of steel fence posts! Of course, she meant wooden posts, but she was excited!" (Trailer).

Stream-straightening programs were undertaken in many western Iowa counties to stop the frequent flooding and to make the bottomlands suitable for cultivation and other agricultural uses. Most of the major straightening projects were undertaken during the period from 1890 to 1920 (Dirks). Stream-straightening was achieved by constructing drainage ditches using mechanical dredges with drag lines equipped with 2-cubic yard capacity buckets. The size of the drainage ditches varied with the drainage area. For example, the Mosquito Creek drainage ditch constructed in Shelby County, Iowa, in 1916-1917, had a bottom width of 10-feet, one-to-one side slopes, and depths varying from 8- to 16-feet. This corresponds to top-of-bank widths ranging from 26- to 42-feet. The drainage areas ranged from 35- to 80-square miles.

The stream straightening projects usually accomplished their goal of reduced flooding, which reduced flood damage to land already in cultivation and made possible the drainage of most swamp land. Over time, it became apparent that stream straightening had side effects. The reduced stream lengths and increased channel grades made the water flow faster. The straightened streams eroded the deep loess soils to greater depths, resulting in mass sliding of bank land into the streams (Lohnes). The bank land that fell into the water subsequently washed downstream. These mass landslides resulted in substantial top-of-bank widening. Many channels have deepened from 10-feet to over 30-feet. Bank-to-bank widths on many streams increased from 15-feet to 120-feet or more. Map 1 shows the approximate boundary of where stream degradation is occurring in the deep loess region of western Iowa.



Map 1. Approximate boundary where stream degradation is occurring in western Iowa. (Map by Golden Hills RC&D)

Channel degradation and subsequent increased stream widths imposed substantial costs on public and private infrastructure crossing these streams. State and county governments have been forced to add spans to highway bridges. Buried natural gas, petroleum and water pipelines became exposed and damaged by trees and other debris floating down stream. For example, Mapco Inc., a large pipeline company, reported a large tree that had washed down McElhaney Creek in Woodbury County and lodged against a pipeline. The lodged tree diverted the water channel to the south bank of the stream. The diverted water washed out a large part of the south bank and exposed 60- to 70-feet of the pipeline (Lenz). Buried electric, telephone and pipelines have also been exposed and damaged. These lines must be reburied or inserted on bridge crossings or strung on poles to cross the wider streams.

A major cost of stream widening is the loss of irreplaceable land sliding into the stream. Deep loess soils are among the most productive in the world. Soil that falls into the stream and its embodied productivity are lost forever.

Anecdotal information on the economic cost of stream degradation has been reported by individual landowners and county engineers. The United States Department of Agriculture Natural Resources Conservation Service (NRCS) estimated the cost of stream degradation on several small watersheds. However, there have been no systematic analyses of the total cost of stream degradation over the entire deep loess soil area in western Iowa.

2.0 PURPOSE OF STUDY

The purpose of this study is to estimate the total cost of stream degradation on land voiding and public and private infrastructure crossing streams in the western Iowa deep loess soil region from the date of stream straightening. Public infrastructure includes bridges crossing county and state roads. Private infrastructure includes railroad bridges and roadbeds and electric, telephone, cable, pipeline, and waterline crossings.

3.0 METHOD OF ANALYSIS

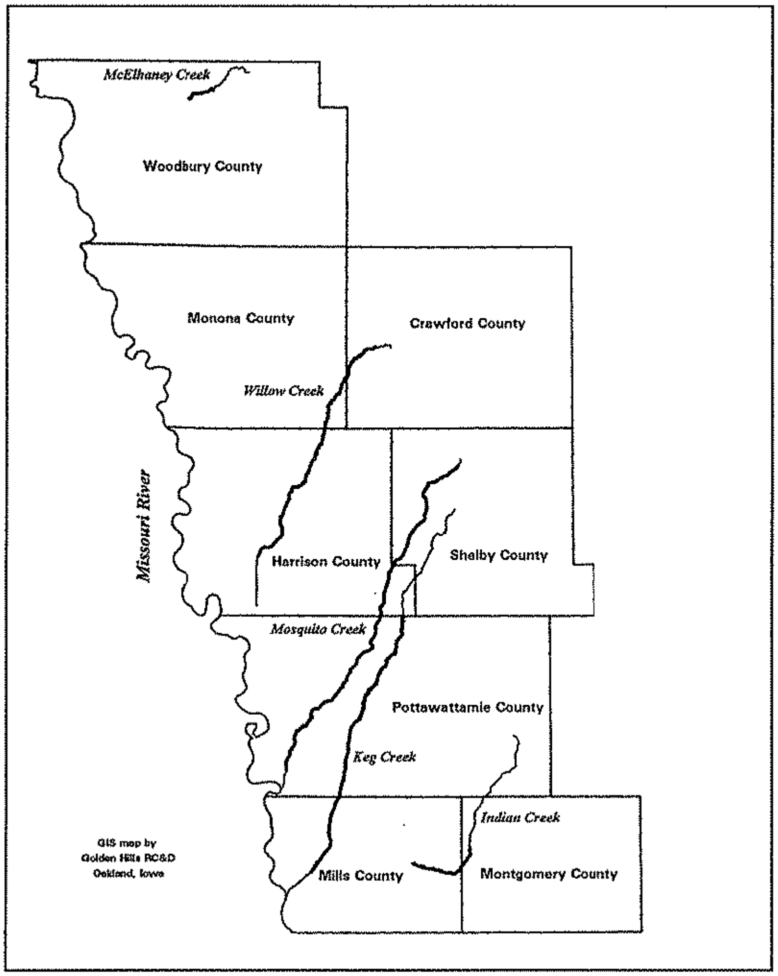
3.1 Study Stream Selection

Five western Iowa streams were selected for detailed analysis. These streams are: McElhaney Creek in Woodbury County; Willow Creek in Crawford, Monona and Harrison counties; Mosquito Creek in Shelby, Harrison and Pottawattamie counties; Keg Creek in Shelby, Pottawattamie and Mills counties and Indian Creek in Pottawattamie, Montgomery and Mills counties.

Only the portions of the five streams that have degraded were included in the analysis. The degraded portions of the five streams were identified from aerial and field reconnaissance over the five streams. The location of the entire reaches and the degraded portions of the five study streams are shown in Map 2. Table 1 shows the drainage area intervals of the degraded portions included in this analysis. Drainage area intervals measure the cumulative drainage area served by specific points along a stream. *The locations of drainage area intervals listed in table 1 are identified in Larimer.*

Table 1. Five study streams' degrading drainage area intervals included in the analysis.

Stream	Degrading drainage area intervals included in the analysis (square miles)
Keg Creek	59.6 - 190.0
Mosquito Creek	4.5 - 23.0
Willow Creek	7.1 - 129.0
Indian Creek	33.0 - 68.0
McElhaney Creek	13.5 -19.0



Map 2. Location of the five study streams (Darkened areas indicate the degrading portions of the streams).

These five-streams were chosen for the following reasons:

1. They represent a range of stream lengths and drainage areas in the deep loess soil region.
2. The stream locations are widely dispersed throughout the deep loess soil region.
3. Several of the five streams had been the subject of previous engineering analyses, so more data were available on these streams than on the other streams in the area.
4. These streams were judged to be representative of the many degrading streams in the deep loess soil area in western Iowa.

These five streams represent a purposive sample of degrading streams in western Iowa. The estimated costs imposed by degradation on these streams will be used to estimate the degradation costs on other degrading streams in the deep loess soil areas of western Iowa.

3.2 Study Stream Conditions and Measurements

The estimated costs of stream degradation are based on the change in the top-of-bank width from the time the streams were straightened until 1992. Data collection had been nearly completed before the severe flooding in the summer of 1993, so the estimates do not include any degradation that may have occurred during the 1993 floods.

There are few published data of the original straightened stream widths. Moreover, most of the original stream straightening records have been discarded by the drainage districts and county recorders. Therefore, this study relied on the few original stream straightening records that were found in recorder and engineer offices of the counties where the study streams are located. In some cases, data were taken from dredging contracts for nearby streams. In addition, personal telephone calls seeking information on original straightened stream widths were made to veteran county engineers located in counties with study streams. Some original width data were taken from previous studies (Massoudi, Larimer). The original channel widths were grouped by size of drainage area, and a generalized channel width was assumed for all drainage areas of similar size on the five study streams.

The 1992 stream widths were estimated using 1992 aerial photographs and remote sensing work stations. Aerial photographs do not accurately show the top-of-bank widths because of bank vegetation and stream cover. Therefore, stream width measurements from the aerial photographs were made at the top-of-barren earth bordering grass or trees. Only streams $\geq$ 15 feet wide at the barren earth level could be measured. Personnel from the NRCS made these measurements using Model 1280-24 Lasico digitizers. The digitizers have a measurement accuracy of $\pm$ six feet.

The NRCS measurements were adjusted to reflect the differences between the width of the top-of-barren soil levels and the top-of-bank stream widths. These adjustments were based on recent stream drawings by county engineer personnel showing the top-of-bank width of the streams at bridge locations. These estimated top-of-bank widths at bridge locations were regressed on NRCS measurements at the closest measured locations. The regression coefficients were then used to adjust the NRCS measurements to estimated top-of-bank stream widths.

3.3 Degradation Cost Estimates

3.3.1 Infrastructure and land voiding

The costs of stream degradation were estimated by multiplying the change in stream width by the estimated 1992 per unit cost of land, and the 1992 per unit cost of constructing highway bridges, railroad bridges, pipelines, and electric, water, fiber optic, and telephone lines. The per unit costs of constructing highway and railroad bridges, pipelines, and electric, fiber optic, and telephone lines were obtained from the Iowa Department of Transportation, the Burlington Northern Railroad, Murphy Brothers, Inc. Pipeline Company, AT&T Company, and Vista Telephone Company. The stream degradation costs for electric lines were obtained directly from electric companies with lines crossing the study streams. The locations of the infrastructure were obtained from the Iowa Department of Transportation, county engineer's offices, and from railroad, electric, telephone, pipeline, water, and cable companies operating in the five stream areas.

Two sets of costs were estimated. The first set is a simple, time neutral, 1992 unit cost of the land or infrastructure multiplied by the change in stream width. The second set was based on the time value of the losses.

A decay function (equation 1) was used to estimate the rate of stream degradation over time for each drainage area interval on each study stream.

$$\mathbf{SW(t)} = \mathbf{IW} + (\mathbf{FW} - \mathbf{IW})\left[\frac{\mathbf{t} - \mathbf{t_0}}{\mathbf{1992} - \mathbf{t_0}}\right]^{\alpha}, \tag{1}$$

where:

SW(t) = top-of-bank stream width in feet at time t,

IW = initial channelized top-of-bank stream width in feet (obtained from historical records),

FW = final top-of-bank stream width (1992 weighted average top-of-bank width),

t = year corresponding to top-of-bank stream width being estimated,

t_o = year corresponding to initial channelization of stream,

α = estimated parameter equal to the percentage change in top-of-bank stream width given a one percent change in time since channelization.

Acres of land lost from each drainage area on the five streams during year y was defined by equation (2) as:

$$AC_{iy} = [(SW_t - SW_{t-1})\ L_i\ ][43{,}560\ ]^{-1}, \tag{2}$$

where:

AC_{iy} = acres of land lost by each stream drainage area i in year y,

L_i = length of drainage area i in feet,

SW_t = top-of-bank stream width in feet at time t.

The estimated time value total cost of land voiding was obtained from equation (3):

$$LC = \sum_{y}^{1991} P_y (V_y * AC_y)(F|P\ r,1992-y), \tag{3}$$

where:

LC= estimated annual total cost of land voiding,

AC_y= total number of acres voided in year y,

(F | P r, 1992-y) = future value of a given amount of money in year y,

V_y = land value in year y,

P_y = index to account for inflation,

y = year the land was voided,

r = long-run interest rate.

Equation (3) adds the compound interest and inflation up to 1992 to the value of the voided land from the year it was voided.

The procedure to estimate the total time value cost of stream degradation on public and private infrastructure is given by equation (4):

$$COST = \sum_{y}^{1992} Py\ (C * \Delta\ SW_{(y)}) * C)(F|P\ r,1992-y), \tag{4}$$

where:

COST = estimated total cost of stream degradation,

$DSW_{(y)}$ = change in stream width in year y,

C = per unit cost of the infrastructure in year y,

P_y = index to account for inflation,

y = year corresponding to width change in the stream,

r = long run interest rate,

(F | P r, 1992-y) = future value of a given amount of money in year y.

Equation (4) adds a compound interest to the cost of degradation in the year the losses occurred. Estimates of C in year y were not available. Therefore, estimates of C were 1992 per unit infrastructure costs, adjusted for inflation.

3.3.2 Rerouted Bridge Traffic

Only one bridge over the study streams had been closed and vacated. However, most of the bridges on the study streams have had repairs or spans added because of the widening of the streams. Based on discussions with Iowa Department of Transportation bridge planners, each bridge was assumed to have been closed for 60 days for these repairs and expansions. Thus, travelers incurred additional costs to the close circumvent bridges while they were being repaired.

Transcad, a Transportation Geographic Information System (GIS) software package, was used to reroute traffic over these bridges. First, a cost minimizing base solution was run to estimate travel cost with each bridge open. Assumed destinations were the county seat town for household traffic and the nearest town for farm, school bus, and post office traffic. Then, a minimum cost solution was obtained after each bridge was closed for a 60-day period. The difference between the costs of the two solutions was the estimated cost of rerouting the traffic from the closed bridge.

Equation (5) was used to estimate travel cost:

$$\mathbf{TC} = \sum_{d}^{2} \sum_{v}^{5} \sum_{r}^{3} (VC_{rvd})(M_{rd})(TP_{vd}), \tag{5}$$

where:

TC = total travel cost,

VC = variable vehicle cost for vehicle type v, road type r, to destination d,

M = miles traveled on road type r to destination d,

TP = total trips for vehicle v to destination d.

3.3.3 Tributary degradation costs

In this study, a tributary was defined as a stream with a total drainage area ≤ five square miles. Most tributaries are less than 15 feet wide at the top-of-barren soil level. Therefore, the aerial photographs could not be used to measure their widths. NRCS has conducted several studies of the simple time neutral costs of degradation on upstream tributaries. A set of the NRCS watershed study results was used to estimate the damages caused by tributary degradation. The estimated damages from the NRCS studies were regressed on the size of the corresponding drainage areas. The regression was then used to estimate the time neutral degradation costs on degrading tributaries.

4.0 THE DATA

4.1. Initial Channelized Stream Widths

The estimated initial channelized top-of-bank stream widths by the size of the drainage area are shown in table 2. Table 2 also shows the range of documented top-of-bank channelized widths. No initial top-of-bank widths were available for drainage areas ≤ 20 square miles. Therefore, the 15-feet width was assumed for drainage areas of 10 square miles or less and a 20-foot width was assumed for drainage areas of 11- to 20-square miles.

Table 2. Estimates of initial top-of-bank widths by size of drainage area.

Drainage area in square miles	Range of documented channelized widths (feet)	Generalized channel widths (feet)
0-5	NA	<15
6-10	NA	15
11-20	NA	20
21-40	26	26
41-70	26-42 & 34-40	34
71-100	42	42
101-130	42	42
131-170	36-42	42
171-220	36	42

4.2 Estimated 1992 Stream Widths

Recent bridge inspection report drawings were used to adjust the top-of-barren soil NRCS widths to estimated top-of-bank stream widths. The estimated top-of-bank stream widths obtained from the bridge inspection report drawings were regressed on the estimated NRCS top-of-barren soil widths to obtain corrected 1992 top-of-bank stream widths as follows:

$$TW = a + b\,NRCSW, \qquad (6)$$

where:

TW = estimated 1992 top-of-bank stream widths,

NRCSW = NRCS estimated top-of-barren soil widths,

b = adjustment coefficient.

The constant (a) was not statistically significant. Therefore, equation (6) was estimated without an intercept. Table 3 shows the results of the regression from equation (6) for each of the five streams. The regression coefficients in table 3 were used as the b value in equation (6).

Table 3. Regression results from equation (6).

Stream	Regression coefficient	R^2	"t" statistic
McElhaney	1.97	0.45	10.3
Indian	1.45	0.56	13.6
Willow	3.13	0.61	9.6
Keg	2.47	0.53	18.5
Mosquito	2.58	0.87	4.5

Estimates of the corrected weighted average 1992 top-of-bank stream widths for each drainage area interval were obtained by equation (7):

$$W_{da} = \sum_{i=1}^{N} \left(\frac{L_i}{L_t}\right) W_i, \tag{7}$$

where:

W_{da} = weighted average top-of-bank stream width for each drainage area interval,

N = number of NRCS measurements within each drainage area interval,

L_i = distance (feet) between each NRCS measurement within each drainage area interval,

L_t = total length (feet) of the drainage area interval,

W_i = estimated top-of-bank stream widths calculated from NRCS top-of-barren soil measurement.

Field measurements of three streams were made in mid-1993 to check for the accuracy of the estimated top-of-bank stream widths. These field measurements along with the estimated stream widths are presented in table 4.

On Keg Creek, the average estimated width was 106 percent of the average field measured width. Therefore, the study overestimated the measured Keg Creek widths by 6 percent. The average difference between the two measurements was 6.9 feet with a standard deviation of 19.3 feet. Thus, two-thirds of the differences were less than 19.3 feet.

The procedure underestimated field measured widths on both the Mosquito and Indian creeks by 12 and 8 percent, respectively. The average differences of the estimated measurements relative to the field measurements were -13.5 and -3.9 feet on Mosquito and Indian creeks, respectively. The standard deviations were 13.9 and 8.9 feet, respectively.

Table 4. Comparison of estimated top-of-bank stream widths and field measured top-of-bank stream widths.

Stream	Location	Estimated width	Field measured width (feet)	Estimated width as percent of field measured width
	Mills County			
Keg Creek	T73 R42 Sec 5, 8	124	85	146
	T73 R42 Sec NL5	108	90	120
	T72 R43 Sec NW24	124	80	154
	T72 R43 Sec 13	98	95	103
	T72 R42 Sec NL6	116	140	83
	T73 R42 Sec 30/31	116	130	89
	T73 R42 Sec NL30	116	124	94
	T73 R42 Sec NW17	121	95	127
	T73 R42 Sec 8	111	105	106
	T73 R42 Sec 5	108	96	113
	Pottawattamie County			
	T74 R42 Sec 21/28	96	100	96
	T74 R42 Sec 3	116	110	105
	T74 R42 Sec 4/9	101	105	96
	T75 R42 Sec 27/22	126	130	97
	Total	**1,581**	**1,485**	**106**
	Mean difference (feet)			**6.9**
Mosquito	T76 R42 Sec 29/30	90	120	75
	T76 R42 Sec 16/21	106	112	95
	T76 R42 Sec 15/16	98	103	95
	Total	294	335	88
	Mean difference (feet)			**-13.5**
	Mills County			
Indian	T72 R40 Sec 24	51	60	85
	T72 R40 Sec 27/26	52	70	75
	T72 R40 Sec 21/22	67	80	83
	T72 R40 Sec 20/21	73	75	97
	T72 R40 Sec WL19	80	103	77
	Pottawattamie County			
	T74 R38 Sec 8/11	26	25	104
	T74 R38 Sec 18/17	28	32	86
	T74 R38 Sec 18/19	29	32	91
	T74 R39 Sec 23/24	38	37	102
	T74 R39 Sec 23/26	44	36	121
	T74 R39 Sec 27/34	38	38	99
	T74 R39 Sec SL34	45	45	100
	Montgomery County			
	T73 R39 Sec 3/4	42	48	88

Table 4. Comparison of estimated top-ofbank stream widths and field measured top-of-bank stream widths (cont.).

Stream	Location	Estimated width	Field measured width (feet)	Estimated width as percent of field measured width
Indian	Montgomery County (cont.)			
	T73 R39 Sec 4/9	42	45	93
	T73 R39 Sec NW16	42	56	75
	T73 R39 Sec 17/10	36	36	101
	T73 R39 Sec 20/29	38	38	99
	T73 R39 Sec 29/32	38	25	151
	T72 R39 Sec NL5	39	32	122
	T72 R39 Sec 5/8	39	34	115
	T72 R39 Sec NE18	48	56	86
	T72 R39 Sec 18/19	48	63	76
	Total	**980**	**1,066**	**92**
	Mean difference (feet)			**-3.9**

4.3 Rate of stream degradation over time

The rate of stream degradation over time was estimated by equation (8) using Willow Creek widths at the four locations presented in table 5. This was the most complete time series of stream width data available on any stream. Equation (8) is simply the natural logarithm form of equation (1).

$$\ln\ (SW_t - IW) - \ln(FW - IW) = \alpha\ \ln\left[\frac{(t - t_o)}{1992 - t_0}\right], \tag{8}$$

The estimated parameters were:

α = 0.73,

R^2 = 0.84,

"t" statistic = 13.6.

An $\alpha < 1.0$ indicates that degradation is occurring, but at a decreasing rate.

Table 5. Top of bank stream widths of Willow Creek (in feet).

	Upper Willow Drainage District No. 1		Upper Willow Drainage District No. 2	
Year	T79N R43W	T80N R43W	T81N R43W	T81N R42W
1919	42	42		
1919	42	42		
1920	-	-	34	34
1929	-	-	50	-
1931	-	57	-	-
1933	72	-	-	-
1936	80	-	-	-
1942	-	-	80	-
1950	-	-	-	100
1952	-	-	-	110
1958	110	100	96	120
1992	139	123	128	128

Source: Daniels, 1960; 1992 widths are calculated using equations (6) and (7).

4.4 Tributary degradation costs

No data were collected on the cost of degradation on tributaries to the five study streams. However, the NRCS has conducted several degradation cost studies on small tributary watersheds. The results of the NRCS studies were used to develop a linear regression of the cost of degradation of these small watersheds on the size of the corresponding watershed drainage area. The estimated regression equation was:

$$Y = \$1{,}302.90 + \$9{,}754.70DA, \tag{9}$$

where:

Y = total dollar cost of degradation,

DA = drainage area in square miles,

R^2 = 0.68,

"t" statistic = 1.68,

n = 43.

This procedure requires the measurement of the size of the drainage area of each degrading tributary to the five streams. The degrading tributaries to each of the five streams were identified by NRCS and Golden Hills Resource Conservation and Development personnel. The size of the drainage areas were taken from the Larimer report. If the Larimer report failed to list the size of the drainage area, the size of the drainage area was estimated by the following procedure: 1) using 7.5 minute series and topographic maps, the drainage area was defined and outlined using watershed contour lines, 2) a planimeter was used to measure the outlined drainage area in inches, and 3) the measurement was then converted to square miles by equation (10):

$$DA = \left[(M)(24{,}000)^2\right]\left[2.49^{-10}\right] \tag{10}$$

where:

DA = drainage area in square miles,

M = the planimeter measurement,

24,000 = map scale of 1:24,000,

2.49^{-10} = conversion factor to square miles.

4.5 Traffic rerouting costs

Table 6 shows the estimated variable vehicle operating costs on gravel, paved county and state roads used to estimate rerouting costs.

Table 6. The estimated variable cost per vehicle mile and road type in cents per mile.

		Type of Road	
Vehicle Type	**State**	**Paved County**	**Gravel**
Auto/pickup	20.2	21.6	28.1
Single axle truck	42.8	44.9	62.5
Tandem axle truck	58.7	61.6	85.7
Semi-tractor-trailer	66.9	70.3	97.7
Tractor-wagon	113.0	118.7	165.0

Source: Baumel, et al., 1991.

Table 7 shows the distribution of types of trips assumed in the analysis of traffic rerouting costs. The data in table 7 were obtained from a survey of travel patterns in a 100-square mile area of Shelby County, Iowa. Traffic volumes for each bridge were taken from the most recent county engineer bridge inspection reports.

A total of 86 county bridges are located on the degrading portions of the five study streams. A total of 24 bridges were randomly selected for rerouting analysis and rerouting costs were estimated on each of these 24 bridges. The estimated cost of the 24 bridges was multiplied by 3.6 to estimate total rerouting costs on all the streams on the five study streams. An average rerouting cost per trip was generated by dividing total rerouting costs by total average daily traffic (ADT).

Table 7. Percentage of travel by purpose and vehicle type.

Type of travel	Percent of total
Household	
Auto	58.9
Pickup	7.5
Truck single axle	2.0
Subtotal	**68.4**
Farm	
Auto	0.6
Pickup	23.4
Truck	
Single axle	1.93
Tandem axle	0.75
Semi	0.22
Tractor-wagon	0.28
Subtotal	**29.7**
Other	
School bus	0.8
Post Office	1.1
Subtotal	**1.9**
Grand total	**100.0**

Source: Baumel, et al., 1989.

4.6 Per unit infrastructure costs

Table 8 shows per unit costs used to estimate damages from stream degradation. Pipeline and waterline costs vary by diameter of the pipe. Actual costs incurred by companies may vary from the estimated costs in table 8 depending on the conditions at the repair site.

4.7 Land Values

County land values for years up to 1982 were taken from Banard and Jones. These data include the value of buildings. These building values were adjusted out of the data. Land values for 1982-1992 were taken from Duffy, et al. The Duffy survey presents high, medium and low land values. The low land values from the Duffy survey were selected for this analysis to make the land value data series as consistent as possible. The consumer price index was used to calculate the inflation rate. A long run interest rate of 4 percent was used to calculate the present value of the annual land voiding in equation (3).

Table 8. Per unit costs used to estimate the damage of stream degradation by type of infrastructure.

Infrastructure	Per unit measurement	Cost per unit
Highway bridges	Square foot	$40
Railroad bridges	Linear foot	1,300
Land voiding	Acre	*
Pipelines	Linear foot	
2 inch		27
6 inch		83
8 inch		111
10 inch		138
16 inch		221
20 inch		276
24 inch		331
36 inch		497
42 inch		597
Waterlines	Linear foot	
2 inch		27
3 inch		40
4 inch		53
5 inch		68
6 inch		83
Telephone	Linear foot	9.25
Bridge attached		10.75
Buried		5.10
Fiber optic	Linear foot	625
Coaxial		625
Electric lines	Actual cost	**
Rerouting costs	Average daily traffic	40***

* Varied by years.

** Reported damages.

*** Obtained from table 6.

5.0 RESULTS

5.1 Time neutral costs of the five study streams

Table 9 shows the estimated time neutral cost from degradation of the five study streams. Highway bridge repair costs were $5.8 million, or almost 62 percent of the total time neutral costs. Almost 95 percent of the bridge costs were on Willow, Keg, and Mosquito creeks. The incidence of bridge costs among streams was related to the length and degradation of the streams. Bridge costs were related to length of the stream because the one-mile rectangular road grid system in Iowa results in more bridges over longer streams.

Table 9. Estimated time neutral costs of stream degradation for the five study streams from date of straightening through 1992.

	Streams					
Type of cost	McElhaney	Indian	Willow	Keg	Mosquito	Total
Land voiding	$14,000	$105,300	$356,200	$412,000	$432,300	$1,319,800
Highway bridges	178,200	144,900	1,615,300	1,943,400	1,919,700	5,801,500
Railroad bridges and right-of-way	0	23,400	0	91,000	1,604,900	1,719,300
Pipelines	7,500	13,100	0	61,900	2,100	84,600
Telephones	0	300	400	12,700	5,500	18,900
Electric	2,800	0	4,100	0	800	7,700
Rural water	0	0	0	0	400	400
County bridge traffic re-routing	23,600	65,000	75,200	163,600	135,200	462,600
Total	$226,100	$352,000	$2,051,200	$2,684,600	$4,100,900	$9,414,800

Railroad bridge and right-of-way repair costs were the second largest time neutral degradation cost. Over 93 percent of the railroad bridge and right-of-way costs were on Mosquito Creek. Of the total $1.7 million in railroad costs, 76 percent was for bridges and 24 percent for stabilizing banks with rip-rap.

Land voiding was the third largest time neutral cost on the five study streams. Land voiding costs were related to length and change in width of the five study streams. Keg and Mosquito creeks had 64 percent of the land voiding costs.

The fourth largest cost was the traffic rerouting cost over county bridges. These costs were distributed among the five study streams according to the number of bridges on each stream. There were 86 county bridges on the five study streams, resulting in an average rerouting cost of $5,198 per bridge. The range of the per bridge costs, however, was from a high of $45,539 to a low of $57. For this reason, the impact of rerouting varied widely among bridges.

The fifth largest cost was for pipelines. Almost three-fourths of those pipeline costs were on Keg Creek, mostly for large natural gas lines in Mills County.

The sixth largest cost was for telephone lines. Almost 68 percent of all telephone costs were on Keg Creek.

The seventh largest cost was for electrical lines. These were actual expenditures by electric companies, mostly during the 1980s. The electric companies had no records of earlier costs. Since most electric lines are overhead, it was not logical to estimate electric line cost on a per linear foot of stream degradation. Almost 54 percent of all electric costs were on Willow Creek.

The smallest cost was for water lines. There were no water line crossings on McElhaney, Indian or Willow creeks. There were large water line costs reported on non-study streams during the 1993 floods, especially on West Tarkio Creek. However, no large water line costs were reported on the five study streams prior to 1993. It is possible that waterline costs for the entire western Iowa area may be underestimated, because of the small number of waterline crossings on the five study streams.

Total time neutral cost for the five study streams was estimated to be $9.4 million. Mosquito Creek had 44 percent of the total time neutral costs. Mosquito Creek had a relatively large share of the total cost because of its high railroad and highway bridge costs.

Table 10 shows the time neutral costs by county. Pottawattamie and Harrison counties had the largest costs, $3.8 and $2.3 million, respectively. Pottawattamie had the largest highway and railroad bridge and land voiding costs. The other counties with large degradation costs from the five study streams were Harrison, Mills, Shelby, Monona and Woodbury. Crawford and Montgomery counties had the smallest costs; only small portions of Willow and Mosquito creeks are located in Crawford County and only a small portion of Indian Creek is located in Montgomery County.

Table 10. Estimated time neutral costs of degradation by county for the five study streams.

	Counties							
Type of cost	Pottawattamie	Harrison	Mills	Shelby	Monona	Woodbury	Crawford	Montgomery
Land voiding	$585,600	$290,900	$226,100	$72,300	$76,700	$14,000	$44,200	$10,000
Highway bridges	2,121,500	1,729,000	$967,200	218,500	388,900	178,200	164,600	33,600
Railroad bridges and right-of-way	942,500	187,200	114,400	475,200	0	0	0	0
Pipelines	0	2,100	63,600	0	0	7,500	0	11,400
Telephones	16,100	400	1,900	200	0	0	0	300
Electric	0	3,400	0	0	500	2,800	1,000	0
Rural water	0	100	0	300	0	0	0	0
County bridge traffic re-routing	143,200	65,200	164,600	24,200	28,200	23,600	8,000	5,600
Total	**$3,808,900**	**$2,278,300**	**$1,537,800**	**$790,700**	**$494,300**	**$226,100**	**$217,800**	**$60,900**

5.2 Time value costs on the five study streams

Table 11 presents the estimated time value costs by stream and source of cost. The estimated time value cost for the five streams from the date of stream straightening was $61.8 million. This is almost $52 million, or 6.6 times more than the time neutral costs. The reason for the large time value relative to the time neutral costs is that the early costs, beginning at the stream straightening dates, were charged a compound interest rate and were multiplied by an inflation rate to place all annual costs at 1992 dollar values. While the time neutral costs are easier to understand, the time value costs are a more accurate estimate of the total degradation costs.

Table 11. Estimated time value costs of degradation for the five study streams from date of stream straightening through 1992.

	Streams					
Type of cost	**McElhaney**	**Indian**	**Willow**	**Keg**	**Mosquito**	**Total**
Land voiding	$45,300	$824,900	$1,626,000	$1,490,300	$3,021,900	**$7,008,400**
Highway bridges	471,600	1,281,600	11,490,000	11,486,200	16,602,800	**$41,332,200**
Railroad bridges and right-of-way	0	207,000	0	614,100	10,945,900	**$11,767,000**
Pipelines	19,200	37,600	0	144,600	4,800	**$206,200**
Telephones	0	2,700	2,600	58,700	45,300	**$109,300**
Electric	8,400	0	12,300	0	2,400	**$23,100**
Rural water	0	0	0	0	700	**$700**
County bridge traffic re-routing	70,800	195,100	225,600	490,800	405,600	**1,387,900**
Total	**$615,300**	**$2,548,900**	**$13,356,500**	**$14,284,700**	**$31,029,400**	**$61,834,800**

On a time value basis, highway bridge costs were $41.3 million or 67 percent of the total time value cost. Thus, bridge costs were a higher percent of the total time value cost than the 62 percent of the time neutral costs.

Land voiding costs, on a time value basis, were $7.0 million or 11.3 percent of total time value cost compared to 14 percent on a time neutral basis. The reason for the lower percent of the time value cost is that land values were very low during the early years following stream straightening. Therefore, the time value cost of land voiding was low in the early years and the 4 percent compound interest cost did not accumulate rapidly.

Railroad bridge and right-of-way costs were 19 percent of total time value cost and 18.2 percent of time neutral costs. Thus, there was essentially no difference in the railroad share of total time neutral and time value costs.

Pipelines, telephone, and rural water were relatively small proportions of both time value and time neutral costs. The reasons were that the telephone and pipeline costs were relatively small in both the time neutral and time value measurements and the pipelines had relatively little time to accumulate compound interest costs.

Electric companies had no records of the dates of electrical repairs; therefore, electric time value costs were calculated based on a ratio of time value to time neutral costs of similar infrastructures including telephone lines, pipelines and rural water lines. The ratio of the electric time value costs to time neutral costs was calculated as follows:

$$
\begin{aligned}
\textit{cost ratio} &= \frac{\sum_{i=1}^{3} (\textit{time value costs})}{\sum_{i=1}^{3} (\textit{time neutral costs})} , \\
&= \frac{\$316{,}200}{\$103{,}900} , \\
&= 3.0 ,
\end{aligned}
\tag{11}
$$

where:

i = 1 = telephone lines,

2 = pipelines,

3 = rural water lines.

The time neutral electric costs were multiplied by a factor of 3.0 to obtain an estimate of time value costs. The result was a total of $23,100 of time value electric costs, less than 0.04 percent of total time value cost.

County bridge re-routing time value costs were estimated to be $1.4 million or 2.2 percent of total time value cost.

Table 12 shows the time value costs of the five study streams by county. Pottawattamie County had the largest costs – $27.1 million. Most of these high costs were for highway and railroad bridges, and land voiding. Harrison County had the second largest costs of $16.9 million, also mostly from highway and railroad bridges and land voiding. Mills County had estimated costs of $8.3. Shelby and Monona counties had costs of $3.9 and $3.2 million, respectively. Crawford, Woodbury, and Montgomery counties had the smallest costs of $1.4, $0.6 and $0.4 million, respectively.

Table 12. **Estimated time value of stream degradation for the five study streams from date of stream straightening through 1992 by county.**

	Counties							
Type of cost	Pottawattamie	Harrison	Mills	Shelby	Monona	Crawford	Woodbury	Montgomery
Land voiding	$3,165,400	$1,421,800	$1,216,700	$541,800	$338,400	$192,300	$45,300	$86,700
Highway bridges	15,564,000	13,744,100	5,565,800	1,767,900	2,748,200	1,173,400	471,600	297,200
Railroad bridges and right-of-way	7,835,400	1,556,300	821,100	1,554,200	0	0	0	0
Pipelines	0	4,800	156,100	0	0	0	19,200	26,100
Telephones	91,800	2,600	11,100	1,100	0	0	0	2,700
Electric	0	10,200	0	0	1,500	3,000	8,400	0
Rural water	0	200	0	500	0	0	0	0
County bridge traffic re-routing	429,600	195,600	493,800	72,600	84,600	24,000	70,800	16,900
Total	$27,086,200	$16,935,600	$8,264,600	$3,938,100	$3,172,700	$1,392,700	$615,300	$429,600

5.3 Generalization of the Study Stream Cost to Total Degradation Cost

A total of 150 non-study streams in western Iowa have been identified as degrading. Of this total, 112 streams had drainage areas > 5-square miles. The 38 streams ≤ 5-square miles were assumed to be tributaries. The estimated degradation cost of the five study streams and the NRCS estimated degradation cost of the tributary streams were used to estimate the total degradation cost in the following manner:

Degradation costs on the 112 non-study streams > 5 square miles:

- Only the degrading portions of the 112 non-tributary streams were used to estimate degradation costs. The degrading sections of the 112 streams were identified from:
  - video tapes shot from helicopter flights over some streams
  - information provided by the Iowa Geological Survey of the Iowa Department of Natural Resources
  - information provided by county engineers.
- Total time neutral and time value degradation costs for the five study streams were converted to an average cost per square mile of drainage area. These average per square mile were $14,803 for time neutral and $97,225 for time value costs. To estimate the degradation costs on the 112 non-study streams, these average costs per square mile were multiplied by the square miles of drainage area for the degrading portions of each of the 112 non-study streams with > 5 square miles of drainage area.

Degradation costs on the 38 non-study streams with ≤ five square miles of drainage area:

- Time neutral costs for the 38 tributaries were estimated by equation (9).
- Time value costs for the 38 tributaries were estimated by multiplying the time neutral costs from equation (9) by the ratio of time value to time neutral costs from the five study streams. This ratio was 6.6.

Table 13 shows the estimated time neutral and time value costs of degradation on the 150 degrading streams in western Iowa. The estimated time neutral costs totaled $165.5 million and time value costs totaled $1.1 billion. Since these estimates were based on the number of square miles of drainage area, the larger the drainage area of a stream, the larger the estimated cost of degradation. The largest degradation costs were estimated for the West and East Nishnabotna, Boyer and West Nodaway rivers. These four rivers had an estimated $67 million or 40.5 percent of the total time neutral degradation costs. These same four rivers had an estimated $439.8 million of the $1.1 billion in time value degradation costs.

Table 13. Time neutral and time value costs of degradation for 150 non-study streams.

Degrading stream	Time neutral cost	Time value cost
W. Nishnabotna River	$24,405,200	$160,282,800
E. Nishnabotna River	16,990,400	111,585,600
Boyer River	13,778,800	90,493,200
W. Nodaway River	11,795,600	77,468,400
Soldier River	7,118,800	46,753,200
W. Fork Little Sioux	5,905,200	38,782,800
Middle Nodaway River	5,046,800	33,145,200
E. Nodaway River	4,943,200	32,464,800
Silver Creek	4,173,600	27,410,400
E. Branch W. Nishnabotna	3,359,600	22,064,400
Walnut Creek	3,300,400	21,675,600
W. Fork 102 River	3,137,600	20,606,400
Tarkio River	3,048,800	20,023,200
Indian Creek (Cass)	2,723,200	17,884,800
W. Fork W. Nishnabotna	2,234,800	14,677,200
Pidgeon Creek	1,983,200	13,024,800
Turkey Creek	1,983,200	13,024,800
E. Boyer River	1,938,800	12,733,200
Troublesome Creek	1,938,800	12,733,200
W. Fork Middle Nodaway	1,909,200	12,538,800
West Branch 102 River	1,850,000	12,150,000
Sevenmile Creek	1,835,200	12,052,800
Farm Creek	1,805,600	11,858,400
Wolf Creek	1,746,400	11,469,600
Sixmile Creek	1,465,200	9,622,800
E. Soldier River	1,456,300	9,564,500
W. Tarkio Creek	1,369,000	8,991,000
Broken Kettle Creek	1,332,000	8,748,000
Middle Silver Creek	1,108,500	7,280,300
Big Whiskey Creek	923,500	6,065,300
Middle Fork 102 River	919,100	6,036,100
David's Creek	902,800	5,929,200
Elliot Creek	867,300	5,695,900
E. Tarkio Creek	861,400	5,657,000
Perry Creek	806,600	5,297,400
Graybill Creek	782,900	5,141,900
Middle Branch 102 River	763,700	5,015,500
Dry Creek	744,400	4,889,200
Picayune Creek	691,200	4,539,200
Otter Creek	673,400	4,422,600
Buck Creek (Cass)	627,500	4,121,300
Paradise Creek	560,900	3,683,900
Mill Creek (Harrison)	553,500	3,635,300

Table 13. Time neutral and time value costs of degradation for 150 non-study streams (cont.).

Degrading stream	Time neutral cost	Time value cost
Mill Creek	552,000	3,625,600
Mud Creek	547,600	3,596,400
Elkhorn Creek	529,800	3,479,800
Elk Creek	522,400	3,431,200
Deer Creek	510,600	3,353,400
Bacon Creek	497,300	3,265,900
Jordan Creek	494,300	3,246,500
Crooked Creek	485,400	3,188,200
Buffalo Creek	467,700	3,071,500
Potato Creek	467,700	3,071,500
Waubonsie Creek	449,900	2,954,900
Jordan Creek (Monona)	448,400	2,945,200
Westfield Creek	447,000	2,935,400
Beaver Creek	447,000	2,935,400
Long Branch	421,800	2,770,200
Bluegrass Creek	370,000	2,430,000
Fiddle Creek	367,000	2,410,600
Mill Creek (Page)	365,600	2,400,800
Middle Soldier River	364,100	2,391,100
Reynolds Creek	362,600	2,381,400
Honey Creek (Pottawattamie)	361,100	2,371,700
Moser Creek	361,100	2,371,700
Fisher Creek	347,800	2,284,200
Allen Creek	319,700	2,099,500
Neele Branch	309,300	2,031,500
Buck Creek	307,800	2,021,800
Willow Creek (Shelby)	284,200	1,866,200
Snake Creek	272,300	1,788,500
Honey Creek (Fremont)	267,900	1,759,300
Ramp Creek	254,600	1,671,800
Porter Creek	253,100	1,662,100
E. Otter Creek	253,100	1,662,100
Little Silver Creek	242,700	1,594,100
Little Tarkio Creek	239,800	1,574,600
Pony Creek	235,300	1,545,500
Coon Creek	235,300	1,545,500
Ninemile Creek	233,800	1,535,800
Steer Creek	222,000	1,458,000
South Willow Creek	220,500	1,448,300
Crabapple Creek	213,100	1,399,700
Brushy Creek	210,200	1,380,200
Emigrant Creek	201,300	1,321,900
Iker Branch	190,900	1,253,900

Table 13. Time neutral and time value costs of degradation for 150 non-study streams (cont.).

Degrading stream	Time neutral cost	Time value cost
Jim Branch	182,000	1,195,600
Long's Branch	162,800	1,069,200
Trinkle Creek	162,800	1,069,200
Rocky Run	161,300	1,059,500
Middle Tarkio Creek	156,900	1,030,300
South Picayune Creek	151,000	991,400
Miller Creek	149,500	981,700
Cooper Creek	144,400	948,700
Little Keg Creek	140,600	923,400
North Picayune Creek	137,800	904,900
Rush Creek	134,100	880,600
Little Mosquito Creek	133,500	876,700
Wheeler Creek	128,800	845,600
Middle Willow Creek	126,700	832,000
Buck Creek (Page)	125,500	824,300
Little Walnut Creek	120,000	788,300
Creek 7 69N 37W (Page)	111,600	732,900
Creek 7 69N 37W (Page)	111,000	729,000
Possum Creek	107,300	704,700
Timber Creek	102,900	675,500
Hog Creek	100,500	660,000
Creek 21 72N 40W (Mills)	94,700	622,100
Creek 14 68N 39W (Page)	93,200	612,400
Fulton's Creek	82,100	539,500
Creek 24 86N 42W (Woodbury)	77,000	505,400
Koker Creek	76,200	500,600
Creek 26 80N 40W** (Shelby)	49,100	324,100
Creek 26 75N 41W** (Pottawattamie)	44,200	291,700
Creek 18 77N 41W** (Pottawattamie)	37,400	246,800
Creek 3 79N 40W** (Shelby)	36,400	240,200
Creek 16 78N 41W** (Harrison)	36,400	240,200
Creek 32 79N 40W** (Shelby)	35,400	233,600
Creek 16 76N 40W** (Pottawattamie)	35,400	233,600
Creek 28 89N 44W** (Woodbury)	31,500	207,900
Hay Creek**	30,600	202,000
Creek 33 68N 39W** (Page)	27,600	182,200
Creek 30 74N 41W** (Pottawattamie)	25,700	169,600
Creek 34 82N 42W** (Monona)	23,700	156,400
Creek 4 74N 42W** (Pottawattamie)	22,800	150,500
Creek 18 73N 42W** (Mills)	22,800	150,500
Creek 4 74N 42W** (Pottawattamie)	19,800	130,700
Creek 20 78N 41W** (Harrison)	19,800	130,700
Creek 22 74N 41W** (Pottawattamie)	17,900	118,100
Creek 9 67N 39W** (Page)	17,900	118,100

Table 13. Time neutral and time value costs of degradation for 150 non-study streams (cont.).

Degrading stream	Time neutral cost	Time value cost
Creek 5 67N 38W** (Page)	15,900	104,900
Creek 21 79N 40W** (Shelby)	14,000	92,400
Creek 22 68N 39W** (Page)	14,000	92,400
Creek 9 74N 42W** (Pottawattamie)	13,000	85,800
Creek 3 81N 42W** (Harrison)	12,000	79,200
Creek 17 67N 39W** (Page)	11,100	73,300
Creek 10 79N 40W** (Shelby)	11.1	73,300
Creek 35 80N 40W** (Shelby)	10,100	66,700
Creek 16 79N 40W** (Shelby)	10,100	66,700
Creek 23 75N 41W** (Pottawattamie)	10,100	66,700
Creek 35 80N 40W** (Shelby)	9,100	60,100
Creek 29 81N 42W** (Harrison)	8,100	53,500
Creek 31 73N 42W** (Mills)	7,200	47,500
Creek 22 82N 42W** (Monona)	7,200	47,500
Creek 9 81N 42W** (Harrison)	6,200	40,900
Creek 12 75N 41W** (Pottawattamie)	6,200	40,900
Creek 34 82N 42W** (Monona)	6,200	40,900
Creek 20 72N 40W** (Mills)	5,200	34,300
Creek 23 80N 40W** (Shelby)	3,300	21,800
Creek 32 81N 42W** (Harrison)	2,300	15,200
TOTAL	**$165,507,700**	**$1,087,007,300**

* Stream names taken from Larimer.

** Denotes a tributary in the study with drainage area less than 5 square miles.

Table 14 shows the estimated combined study and non-study stream degradation costs. The total time neutral costs are estimated to be $174.9 million and the total time value costs are estimated to be $1.1 billion.

Table 14. Estimated total time value and total time neutral costs of degradation of study and non-study streams in western Iowa.

	Total time neutral costs	Total time value costs
Five study streams	$ 9,414,800	$61,834,800
150 non-study streams	165,507,700	$1,087,007,300
TOTAL	$174,922,500	$1,148,842,100

The estimated $1.1 billion of time value costs are undoubtedly more accurate than the $174.9 million of time neutral costs. This is because the time value costs recognize that a dollar received (or lost) in 1925 is of greater value in 1992 because of compound interest. Losses or repair costs in earlier years could have been earning interest or invested in productive activities. The time value estimates include a 4 percent interest on those costs. Thus, stream degradation has generated a very large cost to western Iowa. Undoubtedly, this cost has been a barrier to economic growth in western Iowa because it has absorbed a great number of dollars for infrastructure repair and has generated large opportunity costs from the loss of highly productive agricultural land and from the opportunity to invest infrastructure repair costs into higher return investments.

Table 15 shows the incidence of stream degradation costs by county. Twenty-one western Iowa counties have suffered large stream degradation costs. The largest time neutral costs were $20.0 million for Crawford County and the smallest was $163 thousand in Sac County. The average per county time neutral cost was $8.3 million.

Table 15. Estimated time neutral and time value degradation costs of 155 streams by county.

County	Time neutral cost	Time value cost
Crawford	$20,026,000	$131,484,900
Pottawattamie	19,846,800	132,423,600
Cass	16,552,500	108,710,500
Montgomery	14,382,100	94,485,200
Mills	13,087,300	84,118,000
Shelby	12,720,400	82,293,200
Harrison	10,909,400	73,624,000
Woodbury	10,713,100	69,490,400
Fremont	10,317,200	67,759,100
Page	9,026,100	59,281,700
Taylor	7,472,500	49,076,300
Audubon	6,640,700	43,613,700
Adair	5,620,700	36,914,700
Monona	5,378,500	35,250,400
Adams	5,091,200	33,436,800
Plymouth	2,585,600	16,980,800
Sioux	2,209,600	14,512,000
Carroll	938,300	6,162,500
Ida	874,700	5,744,500
Cherokee	367,000	2,410,600
Sac	162,800	1,069,200
TOTAL	**$174,922,500**	**$1,148,842,100**

The largest time value cost was $132.4 million in Pottawattamie County and the smallest cost was $1.1 million in Sac County. The average time value cost per county for the 21 counties was $54.7 million. Ten counties suffered the largest losses. These ten counties in descending order were: Pottawattamie, Crawford, Cass, Montgomery, Mills, Shelby, Harrison, Woodbury, Fremont, and Page. The combined losses of these ten counties were $903 million -- an average of $90.4 million per county.

6.0 SUMMARY AND CONCLUSIONS

The purpose of this study was to estimate the total cost of stream degradation on land voiding and public and private infrastructure crossing degrading streams in the western Iowa deep loess soil region. Detailed analyses were made of the degrading portions of five streams including McElhaney Creek in Woodbury County; Willow Creek in Crawford, Monona, and Harrison counties; Mosquito Creek in Shelby, Harrison, and Pottawattamie counties; Keg Creek in Pottawattamie and Mills counties and Indian Creek in Montgomery and Mills counties.

Degradation costs were calculated by first estimating the change in widths of the five study streams from the time they were first straightened until 1992. The initial widths were obtained from original straightening contracts, from veteran county engineers, and from previous engineering studies. The 1992 widths were estimated using Natural Resources Conservation Service (NRCS) aerial photographs and county engineer bridge inspection reports. A decay function was fitted to data from Willow Creek to estimate the rate at which the streams widened since the original stream straightening dates. The decay function provided estimates of the year-to-year change in stream width. Data were collected from county engineers and from railroad, telephone, electric, pipeline, and waterline companies on the per unit costs resulting from stream widening. In addition, a time series of data were collected on annual land values from the original straightening dates until 1992. Finally, data on the degradation costs of a set of small tributaries were obtained from the NRCS. These values, combined with the rate of stream widening, permitted the estimation of time neutral and time value costs of degradation on the five study streams. The average degradation cost per square mile of drainage area from the five study streams and from the NRCS tributary cost data were used to estimate the degradation costs of 150 non-study degrading rivers and streams in western Iowa.

The estimated time neutral cost for the 155 degrading streams in western Iowa was $174.9 million. The estimated total time value cost from the degrading streams was $1.1 billion. The time value estimate is the more accurate of the two estimates because it includes a 4 percent compound interest charge on the degradation losses during years prior to 1992.

The degradation costs for the 21 counties were estimated up to 1992. The lost income from the voided land and from the repairs that have been or will be made on the public and private infrastructure will continue through time. Thus, the costs up to 1992 do not tell the full story because these costs will continue indefinitely.

Undoubtedly, stream degradation has been and will continue to be a substantial drag on the economic growth of these 21 western Iowa counties. The dollars invested in repairing the damaged infrastructure and the opportunity cost of the lost land and repair dollars could have been invested in productive activities which would have generated a substantial amount of additional income to these Iowa counties. Cost will continue to rise if these streams are allowed to continue to degrade.

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Estimates of Future Impacts of Degrading Streams in the Deep Loess Soil Region of Western Iowa on Private and Public Infrastructure Costs

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ABSTRACT

A previous study (Baumel, et al., 1994), provided estimates of the costs associated with the impact of past stream degradation on public and private infrastructure and land voiding in the deep loess soils region of western Iowa. These costs were estimated from the dates of stream channel straightening until 1992. The purpose of this study was to estimate the costs associated with damages to infrastructure and land voiding resulting from future degradation on actively degrading streams and their tributaries in the deep loess soils region of western Iowa.

This study examined in detail four streams and their tributaries in western Iowa. A predictive model together with field data were used to estimate future stream widening associated with channel bed degradation on the four streams. The costs associated with future damages to public and private infrastructure and land voiding resulting from predicted stream widening were then estimated. The results from these four streams and their tributaries in terms of future degradation and associated costs were generalized to the remaining 102 actively degrading streams in the deep loess soils region of western Iowa.

This study estimated two types of costs associated with future degradation. One was a simple time neutral cost which provides an indication of the magnitude of future costs which will be incurred should no action be taken to address the problem of stream channel degradation. The second type was a time value cost which provides an accurate estimate of the future costs of stream channel degradation in 1992 dollars. The estimated time neutral future degradation costs for the 106 actively degrading streams and their tributaries in western Iowa was $177.3 million. The estimated time value future degradation costs for these streams and their tributaries was $70.1 million. The study found that damages to infrastructure and land voiding in 9 of the 21 western Iowa counties located in the deep loess soils region accounted for 73.0% of the total time neutral and time value future degradation costs. These counties are Cass, Crawford, Fremont, Harrison, Mills, Montgomery, Pottawattamie, Shelby, and Woodbury.

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1.0 INTRODUCTION

Many streams in the deep loess soil region in western Iowa were straightened in the early to mid-1900s. Since straightening, many of these streams have deepened and widened substantially. This degradation has caused damage to bridges, pipelines, waterlines and communication lines. In a previous study (Baumel, et al. 1994), cost estimates were provided of the impact of degradation of 155 western Iowa streams on land voiding and public and private infrastructure from the dates of straightening until 1992. Public infrastructure included bridges crossing county and state roads. Private infrastructure included railroad bridges and roadbeds and electric, telephone, cable, pipeline and waterline crossings. The research methodology from the previous study is modified and extended in the present study to estimate future degradation of actively degrading streams in the deep loess soil region of western Iowa and the associated land voiding and private and public infrastructure costs.

2.0 Method of Analysis

The basic procedure in the previous study (Baumel, et al., 1994) was to estimate the change in stream width from the dates of stream straightening to 1992. The estimated changes in stream widths were then used to estimate the acres of land voided as well as the additional lengths required on highway and railroad bridges. They were also used to estimate the costs of damage to pipeline and communications infrastructure. In the current study, expected changes in stream widths are used to estimate future land voiding and private and public infrastructure costs. Thus, predicting future stream widening is critical in predicting future degradation costs.

In this study, 155 degrading streams from the previous study were segmented into three groups:

I. Segments of these streams are no longer actively degrading and are becoming stable. These stream segments were eliminated from this analysis because these segments are unlikely to degrade in the future.

II. Segments of these streams that continue to degrade.

III. Segments of these streams that are newly degrading. Generally, these are the upper segments of these streams. In this analysis, these streams are assumed to have begun degrading in 1992.

This analysis focuses on stream segments II and III. Detailed analyses were made on four study streams. These streams include: McElhaney Creek in Woodbury County; Willow Creek in Crawford, Monona and Harrison counties; Indian Creek in Pottawattamie, Montgomery and Mills Counties and Keg Creek in Shelby, Pottawattamie and Mills Counties. The results from these four study streams were generalized to the remaining streams that have segments that continue to degrade or newly degrading segments.

2.1 Estimating Stream Widening for Streams that Continue to Degrade (Group II)

A model for predicting stream widening due to degradation was used to estimate future land loss and stream widening from channel degradation (Lohnes, 1991). The Lohnes model assumes that widening results from mass bank movement and is based upon well established principles of soil mechanics and slope stability analyses. A soil mass becomes unstable if the shearing stresses within the mass exceed the shear strength. The shear strength of soil is manifest in cohesion and friction angle while the stresses result from the unit weight of the soil. In general, higher and steeper slopes will be the most likely to be unstable. As the streams degrade, their channel side slopes become higher and steeper until landslides occur to produce less steep slopes. The process continues until the slope angles are gentle enough to be stable.

The Lohnes model requires the following data inputs to estimate future stream widening:

1. Initial stream channel side slopes (AB). By assumption, the initial side slopes were set at 80 degrees.
2. Expected vertical degradation (HMP). Figure 1 illustrates the concept of expected vertical degradation (Lohnes, 1991).

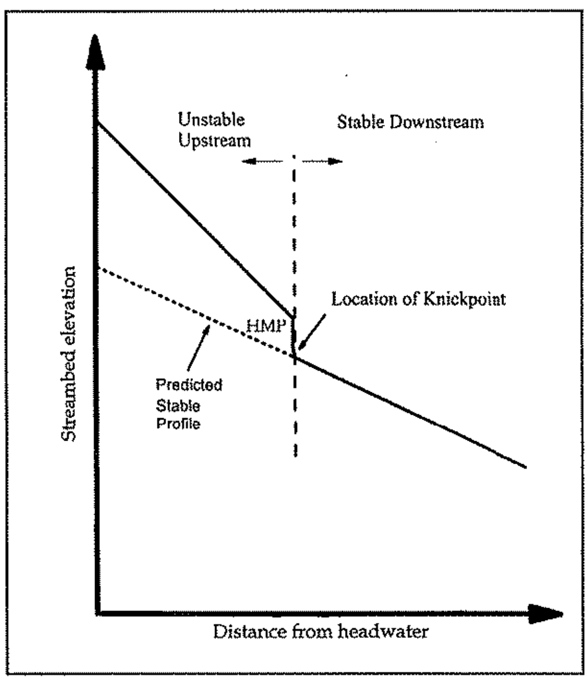

Figure 1. Longitudinal profile of a degrading stream (Lohnes 1991).

HMP is estimated by extrapolating the stable downstream profile beyond the knickpoint and underneath the unstable, upstream profile. Estimates of HMP were obtained from a tractive force model, (Levich, 1994).

The tractive force model, an analytical method developed by Massoudi (1981) to estimate depth of degradation, is based on hydraulic principles of stream channel erosion. This model depends on back calculating erosion resistance of the stream from the geometry of a stable reach of the degrading stream. At the stable reach, the calculated tractive force is equal to the erosion resistance. The upstream unstable channel is divided into equal segments. The cross sectional area, the discharge at each cross section, stream bed elevation, drainage area, channel slope, and distance from the headwater are measured or calculated at each segment. Starting at the stable section, the tractive force of the unstable upstream segment is calculated using the discharge, channel cross sectional area and channel slopes. The tractive force is compared to the erosion resistance. If the tractive force is greater than the erosion resistance, the channel bottom is lowered and the tractive force recalculated. The new tractive force will be less than the previous tractive force because of the increased channel capacity and decreased slope resulting from the lowering the channel bottom of the upstream section. The calculations are repeated at each section and the channel bottom is lowered until the calculated tractive force is less than or equal to the erosion resistance. The channel will degrade until the tractive force equals the erosion resistance. This section is now considered stable and the iterative process is repeated for each successive upstream segment.

Longitudinal profiles were obtained for the four study streams for the following dates:

Stream	Date of profile
McElhaney Creek	1965
Indian Creek	1976
Willow Creek	1966
Keg Creek	1980

Given these longitudinal profiles on the specified dates, the tractive force model was used to predict the final equilibrium longitudinal profile of each stream. The differences between the predicted elevations from the tractive force model and the measured elevations from the longitudinal profile at the above specified dates provided an estimate of the predicted vertical degradation along each stream. These differences were then used as the estimated vertical degradation (HMP) in the Lohnes model.

3. Existing channel depth, (H) is defined as the difference between the streambed elevation and the floodplain elevation in feet.

The value of H was estimated by the following equation where channel side slopes were assumed to be 1:1.

$$H = \left(\frac{BW}{W / D - 2}\right), \tag{1}$$

where:

H	=	existing stream channel depth, in feet,
BW	=	the channel bottom width as a function of the distance from the drainage divide X, in feet,
	=	12.79 + 1.67X (Massoudi),
W/D	=	width to depth ratio of the stream channel as a function of distance from the drainage divide X,
	=	5.23 + .077X (Massoudi).

In addition to the variables AB, HMP, and H, the Lohnes model requires data on soil characteristics. These soil characteristics include soil cohesion, angle of internal friction, and unit weight of the soil. The unit weight of the soil was a saturated unit weight to create a maximum degradation scenario. Three stratigraphic units of loess derived alluvium were included in this analysis and the characteristics of each are listed in table 1.

Table 1. Soil characteristics of the study streams used in the computer simulation of stream widening

Stratigraphic units	Soil cohesion (c) (psf)	Mean angle of internal friction (phi)	Saturated unit weight of soil (pcf)
Post settlement	139	29	115
Mullenix	221	27	119
Hatcher	190	28	121

Source: Levich, 1994.

The soil characteristics in table 1 represent conditions most likely to cause bank instability. Consequently, the estimated degradation and stream widening will represent the worst case scenario. The following soil type assignments were given to the streams included in the analysis (Levich, 1994):

<u>Stream</u>	<u>Soil type</u>
McElhaney Creek	Post settlement
Indian Creek	Hatcher
Willow Creek	Mullenix
Keg Creek	Mullenix

The Lohnes model was computerized in FORTRAN language and used to simulate additional widening from vertical degradation of each stream segment. The additional widening was added to the stream width at the profile dates to obtain a final stream width.

2.2 Allocating Stream Degradation Over Time

Equation 2 was used to estimate the rate of degradation for each drainage area interval over time:

$$SW_{(t)} = CW + (FW - CW)\left[\frac{t - t_o}{t_f - t_o}\right]^{0.73}, \tag{2}$$

where:

$SW_{(t)}$	= width at time t, date of profile,
CW	= the initial width,
	= 1992 widths for newly degrading streams,
	= channelized widths for previously degrading streams,
FW	= final stream width at t_f,
t_o	= the time degradation began on previously degrading segments, and
t_f	= t_o + 64 years, where 64 is the average number of years over which costs were estimated in the previous study (Baumel, et al., 1994).

No records exist indicating the date that degradation began on the streams that continue to degrade. Therefore, the expression t_o is unknown and was estimated by equations (3) and (4).

$$PW_{(t)} = CW + (FW - CW)\left[\frac{t - t_o}{t_f - t_o}\right]^{0.73}, \tag{3}$$

where:

PW(t)	= the width of the stream at the date of the profile,
CW	= the estimated channelized width,
FW	= the final width,
t	= date the stream profile was taken,
t_f	= 1992, and
t_o	= date degradation began.

Given an estimate of CW, PW(t), and FW, the date that degradation began, (t_o) was estimated as follows:

$$t_0 = \frac{t_f \left[\frac{(PW - IW)}{(FW - CW)} \right]^{\frac{1}{0.73}} - t}{\left[\frac{(PW - CW)}{(FW - CW)} \right]^{\frac{1}{0.73}} - 1}, \qquad (4)$$

where all terms were defined previously.

2.3 Estimated Degradation Costs on Previously Degrading Streams

Degradation costs are estimated by equation (5):

$$DC_{si} = \sum_{1992}^{t_f} \left[\frac{SW_i(t+1) - SW_i(t)}{\Delta SW_i} \right] \left[(C)(DA) \frac{1}{(1+i)^n} \right], \qquad (5)$$

where:

DC_{si} = total discounted degradation costs on previously degrading stream i,

C = degradation cost per square mile of drainage area taken from the previous study (Baumel, et al., 1994),

= $14,803 per square mile,

DA = total square miles of drainage area,

i = interest rate, and

n = years after 1992.

Equation (5) uses the percentage change in stream width to allocate total degradation costs over time. Costs occurring after 1992 are discounted back to current dollars from each year they occur and summed to obtain an estimate of present value costs of degradation in 1992 dollars on streams which continue to degrade.

2.4 Newly Degrading Streams

Newly degrading stream segments were identified from low altitude aerial videos of the degrading western Iowa streams. These newly degrading segments were assumed to have begun degrading in 1992 and degradation costs are estimated for 64 years into the future, i.e., 2056. The 64 years is the average number of years over which stream degradation was estimated in the previous study on historical degradation costs (Baumel, et al., 1994).

Changes in stream width on newly degrading streams were estimated in equation (6) as a function of the drainage area served by the stream segment.

$$\Delta SW = a + b\,(DA), \tag{6}$$

where:

ΔSW = change in stream width,

a = constant,

b = coefficient,

DA = drainage area in square miles.

Change in stream width in equation (6) was estimated using data from Willow Creek, Mosquito Creek, Keg Creek, McElhaney Creek, Indian Creek and Maple River. The estimated coefficients are shown in equation (9):

$$\begin{array}{c} \Delta SW = 20.32 + 0.486(DA)' \\ (4.135) \quad (25.69) \end{array} \tag{7}$$

where:

ΔSW = change in stream width,

DA = drainage area in square miles.

The r^2 value was 0.8955 and the numbers in parentheses are "t" values.

The final width was defined as:

$$FW = W_{1992} + \Delta SW, \tag{8}$$

where:

FW = final width,

W_{1992} = estimated 1992 width.

Equation (9) was used to allocate the change in stream width over the 64 years.

For a given reach of stream,

$$SW(t) = IW + (FW - IW)\left[\frac{t - t_o}{t_f - t_o}\right]^{0.73}, \tag{9}$$

where:

$SW(t)$	= width at time t,
IW	= the initial width at the start of degradation in 1992,
FW	= final stream width at t_f,
	= 1992 width + ΔSW,
t_0	= the time degradation began on drainage intervals expected to degrade,
	= 1992 on newly degrading stream, and
t_f	= t_o + n years where n is the number of years in the future to estimate costs on newly degrading streams,
	= 2056.

The cost of degradation on newly degrading streams was estimated by equation (5).

2.5 Generalizing to the Degrading Segments of 102 Streams in Western Iowa

There were 155 degrading streams in the previous study on historical degradation costs. It was determined that some of these streams were no longer undergoing significant channel degradation and were therefore not included in this analysis. In addition, all tributaries were combined with their main stem streams. The net effect resulted in 102 degrading non-study streams in this analysis.

The estimated costs for both previously degrading and newly degrading drainage intervals on the four study streams were totaled and divided by the total drainage area of those drainage intervals. This provided an estimate of the cost per square mile for those drainage intervals which continue to degrade and for the newly degrading drainage intervals. These cost estimates were then multiplied by the total square miles of drainage area on the previously degrading and newly degrading drainage intervals of the non-study degrading streams in western Iowa.

3.0 RESULTS

3.1 Previously Degrading Streams

The estimated vertical degradation (HMP) of previously degrading segments are presented in table 2. The expected vertical degradation (HMP) in table 2 was obtained by subtracting the elevation in the profile year from the predicted final elevation. For all four streams, the upper segments are predicted to degrade more than the lower stream segments. The reason is that the lower segments are generally previously degrading intervals and are closer to reaching equilibrium.

Table 2. Stream profile elevations and predicted final elevations of previously degrading segments of four study streams.

Stream	Drainage Area in square miles	Streambed profile elevation in feet	Profile date	Predicted final streambed elevation in feet	Expected vertical degradation (HMP)
Keg Creek	91.4	1,100.10	1980	1,076.85	23.25
	95.23	1,090.95	1980	1,070.45	20.50
	99.5	1,080.18	1980	1,063.93	16.25
	103.76	1,070.10	1980	1,058.26	11.84
	111	1,060.30	1980	1,049.80	10.50
Willow Creek	28.22	1,214.00	1966	1,170.50	43.50
	30.03	1,197.00	1966	1,157.50	39.50
	31.84	1,178.00	1966	1,145.75	32.25
	33.65	1,164.00	1966	1,135.50	29.00
	48.25	1,150.50	1966	1,125.00	25.50
	52.06	1,139.50	1966	1,118.00	21.50
	55.75	1,130.50	1966	1,111.25	19.25
	59.06	1,124.00	1966	1,105.00	19.00
	62.08	1,118.00	1966	1,098.75	19.25
	64.87	1,112.00	1966	1,092.50	19.50
	67.48	1,106.50	1966	1,086.25	20.25
	69.95	1,099.50	1966	1,079.75	19.75
Indian Creek	33	1,062.30	1976	1,046.30	16.00
	33.38	1,060.18	1976	1,043.93	16.25
	34.48	1,050.76	1976	1,036.51	14.25
	35.59	1,042.69	1976	1,029.69	13.00
	37.4	1,029.80	1976	1,018.80	11.00
	38.94	1,027.38	1976	1,016.63	10.75
	43.21	1,020.67	1976	1,010.67	10.00
	50	1,007.25	1976	1,001.50	5.75
	53.08	1,004.50	1976	999.75	4.75
	61.4	997.4	1976	995.15	2.25

Table 2. Stream profile elevations and predicted final elevations of previously degrading segments of four study streams (cont.).

Stream	Drainage Area in square miles	Streambed profile elevation in feet	Profile date	Predicted final streambed elevation in feet	Expected vertical degradation (HMP)
McElhaney Creek	13.5	1,198.00	1965	1,169.50	28.50
	15.71	1,182.00	1965	1,160.00	22.00
	18.34	1,154.17	1965	1,150.92	3.25
	19	1,150.00	1965	1,150.00	0.00

Table 3 presents the estimated change in width of the previously degrading drainage intervals of the four study steams along with the estimated beginning degradation dates. The change in widths were estimated by the Lohnes model and the beginning degradation dates were estimated by equation (4). The dates to which costs were estimated are 64 years beyond t_o, the estimated beginning degradation date. For example, the estimated beginning date of degradation on McElhaney Creek is 1955. Thus, degradation costs were estimated for 64 years beyond 1955 or until 2019. The reason for selecting 64 years beyond 1955 is that, in the previous study (Baumel, et al., 1994), the degradation costs were estimated for an average of 64 years up to 1992. The 64 year period does not mean that the streams will have reached equilibrium by that time. Rather, the 64 year period was chosen so that the estimated costs from the previous study and the current analysis would cover approximately the same lengths of time.

The estimated discounted future costs of degradation after 1992 on the four study streams are presented in table 4. The estimated discounted degradation cost of $16,700 on McElhaney Creek was for the period from 1992 through 2019. The time periods for the other streams are shown in table 3. The average discounted cost per square mile of drainage area on the four study streams from 1992 to these dates is shown in table 4. The average discounted cost per square mile over the four study streams was $2,854.

Table 3. Estimated additional widening and dates of previously degrading streams.

Stream	Drainage area interval	Initial channelized	Profile	Final	Profile date	Beginning date of degradation	Date to which costs were estimated	Predicted land voiding in acres
			Widths in feet					
McElhaney	13.5 - 19.0	20	45	58.0	1965	1955	2019	7.3
Indian	33.0 - 37.4	26	44	63.5	1976	1967	2031	10.4
Indian	37.4 - 50.0	34	42	56.2	1976	1971	2035	19.9
Indian	50.0 - 61.4	34	48	57.7	1976	1961	2025	13.0
Willow	29.1 - 53.9	34	83	113.1	1966	1938	2002	27.3
Keg	91.4 - 111.0	42	117	140.8	1980	1954	2018	53.0

Table 4. Estimated discounted future degradation costs on previously degrading segments of the four study streams

Stream	Drainage area		Estimated discounted degradation cost
	Interval	Square miles	
McElhaney Creek	13.5-19.0	5.5	$ 16,700
Indian Creek	33-37.4	4.4	$ 17,400
	37.4-50.0	12.6	$ 53,500
	50.0-61.4	11.4	$ 40,500
Willow Creek	29.1-53.9	24.8	$ 36,200
Keg Creek	91.4-111.0	19.6	$ 59,400
Total		78.3	$ 223,500
Average cost per square mile			$ 2,854

3.2 Newly degrading streams

Table 5 shows the newly degrading segments of the four study streams. The table also shows the 1992 stream widths, the predicted additional widening, and final stream widths.

Table 6 shows the estimated degradation costs on the newly degrading segments of the four study streams. The average cost per square mile on the newly degrading streams--$6,724--is 2.4 times higher than the cost per square mile on the previously degrading streams. This is because the full degradation costs from 1992 to 2056, discounted back to 1992, are charged to the newly degrading streams. On the previously degrading streams, a large share of the total degradation costs occurred prior to 1992. Therefore, future degradation costs on previously degrading streams will naturally be less than on the newly degrading streams. The degradation costs prior to 1992 on previously degrading streams were included in the estimates in the previous study (Baumel, et al., 1994).

Table 5. Estimated additional widening of newly degrading segments of four study streams.

Stream	Drainage area intervals	1992	Predicted widening	Final
		Width in feet		
McElhaney	0-6.5	35	23.5	58.5
	6.5-13.5	50	26.9	76.9
Indian	0-6.7	25	23.5	48.5
	6.7-15.0	39	27.6	66.6
	15.0-19.8	38	29.9	67.9
	19.8-33.0	45	36	81
Willow	0-26.1	68	33	101
	26.1-29.1	84	34.5	118.6
Keg	0-10.4	37	25.4	59.7
	10.4-20.2	52	30.1	75.4
	20.2-29.4	66	34	89.4
	29.4-50.4	72	44.8	97.6
	50.4-59.6	57	49.3	83.3
	59.6-70.5	69	54.6	95.2
	70.5-81.0	76	59.7	102.3
	81.0-91.4	102	64.7	127.7

Table 6. Estimated discounted degradation costs on newly degrading segments of the four study streams.

Stream	Drainage area		Estimated discounted degradation cost
	Interval	Square miles	
McElhaney Creek	0-6.5	6.5	$ 44,000
	6.5-13.5	6.9	$ 46,700
Indian Creek	0-6.7	6.7	$ 45,300
	6.7-15.0	15	$ 55,500
	15.0-19.8	4.8	$ 32,300
	19.8-33.0	13.2	$ 88,800
Willow Creek	0-26.1	26	$ 174,800
	26.1-29.1	3.1	$ 20,900

Table 6. Estimated discounted degradation costs on newly degrading segments of the four study streams (cont.).

Stream	Drainage area		Estimated discounted degradation cost
	Interval	Square miles	
Keg Creek	0-10.4	10.4	$ 69,900
	10.4-20.2	9.8	$ 65,900
	20.2-29.4	9.2	$ 61,900
	29.4-50.4	21	$ 141,200
	50.4-59.6	9.2	$ 61,900
	59.6-70.5	10.9	$ 73,300
	70.5-81.0	10.5	$ 70,600
	81.0-91.4	10.4	$ 69,900
Total		166.9	$ 1,122,900
Cost per square mile			$ 6,724

3.3 Estimated Future Tributary Degradation Costs

Tributary degradation costs were estimated from tributaries in the drainage basins of the four study streams. The tributaries were defined as streams with a cumulative drainage area less than 5 square miles. Tributaries that are controlled by grade control structures or are stable were omitted from the analysis.

Drainage areas for the study tributaries were calculated from U.S.G.S. 1:24,000 scale topographic maps. The time neutral costs for the expected future degradation costs for each tributary of the study streams were calculated by equation (10):

$$TC_{TN} = (\$14{,}803)DA, \tag{10}$$

where:

TC_{TN} = the total time neutral cost of future degradation on the study stream tributary,

DA = the total drainage area of the tributary.

The $14,803 was taken from equation (5).

The time value costs for the expected future degradation costs for each tributary of the study streams was calculated from equation (11):

$$TC_{TV} = (\$6{,}724)DA, \tag{11}$$

where:

TC_{TV} = the total time value cost of future degradation on the study stream tributary,

DA = the total drainage area of the tributary.

The $6,724 was taken from table 6.

3.3.1 Generalization of tributary degradation costs to non-study streams

Tributary degradation costs on non-study streams were estimated in the following manner:

1. Equations (10) and (11) were used to estimate the tributary costs on the study streams.
2. The estimated tributary costs on the study streams were then converted to cost per square mile of total drainage area of the four study streams by dividing the estimated tributary costs by the total drainage area of the four study streams. As shown in table 7, the estimated tributary cost per square mile of total drainage area for the four study streams were $7,077 for time neutral costs and $3,203 for time value costs.
3. The estimated average tributary cost for the entire drainage area of the four study streams were then multiplied by the total drainage area of each non-study stream.

Table 7. Estimated tributary degradation costs on the four study streams

Stream	Drainage area	Tributary drainage area	Time neutral costs	Time value costs
McElhaney	19	8.29	$122,800	$55,700
Indian	68	34.21	506,600	229,900
Willow	146	60.51	905,200	406,600
Keg	190	98.53	1,459,035	662,800
Total	423	201.54	$2,993,635	$1,355,000
Cost per square mile			$7,077	$3,203

3.4 Generalization of the Four Study Stream Costs to Total Degradation Costs

Two types of cost estimates are provided in table 8. One is a time neutral cost obtained by multiplying the square miles of drainage area by $14,803, the estimated time neutral cost per square mile of drainage area on newly and previously degrading stream segments from the previous study (Baumel, et al., 1994). The second cost estimate is a time value cost obtained by multiplying the square miles of drainage area on previously degrading streams and on newly degrading streams by the appropriate discounted average cost per square mile of drainage area in tables 4 and 6. The appropriate estimate of tributary cost was added to the estimated degradation cost of the main stem streams.

Table 8. Estimated future degradation costs on 102 degrading streams and their tributaries in western Iowa.

Stream	Estimated degradation costs	
	Time neutral	Time value
Allen Creek	$ 972,300	$ 357,900
Bacon Creek	$ 579,700	$ 174,600
Beaver Creek	$ 660,800	$ 299,000
Big Whiskey Creek	$ 1,365,300	$ 576,200
Bluegrass Creek	$ 547,000	$ 247,600
Boyer River	$ 9,132,800	$ 3,947,300
Broken Kettle Creek	$ 2,031,500	$ 577,500
Brushy Creek	$ 310,700	$ 86,700
Buck Creek	$ 185,500	$ 84,000
Buck Creek	$ 927,700	$ 419,900
Buffalo Creek	$ 691,400	$ 283,700
Coon Creek	$ 390,400	$ 116,200
Cooper Creek	$ 257,000	$ 79,200
Crabapple Creek	$ 315,100	$ 142,600
Crooked Creek	$ 717,600	$ 324,900
David's Creek	$ 1,334,700	$ 604,100
Deer Creek	$ 754,900	$ 341,700
Dry Creek	$ 1,100,600	$ 307,000
Elk Creek	$ 772,300	$ 349,600
Elkhorn Creek	$ 783,300	$ 354,600
Elliot Creek	$ 1,282,200	$ 580,300
Emigrant Creek	$ 297,500	$ 134,700
E. Boyer River	$ 2,679,800	$ 763,000
E. Branch W. Nishnabotna	$ 3,530,900	$ 1,560,100
E. Nishnabotna River	$ 11,011,000	$ 4,983,500
E. Nodaway River	$ 4,880,200	$ 1,562,800
E. Otter Creek	$ 374,100	$ 104,400
E. Soldier River	$ 2,153,000	$ 974,500
E. Tarkio Creek	$ 1,273,400	$ 576,300
Farm Creek	$ 2,669,400	$ 1,208,200
Fiddle Creek	$ 542,600	$ 151,300
Fisher Creek	$ 514,200	$ 232,800
Fulton's Creek	$ 121,500	$ 33,900
Graybill Creek	$ 1,157,500	$ 497,200
Hog Creek	$ 148,600	$ 41,400
Honey Creek	$ 552,900	$ 157,600
Iker Branch	$ 282,300	$ 78,700
Indian Creek	$ 3,773,800	$ 1,465,100
Jim Branch	$ 269,100	$ 121,800
Jordan Creek (Pottawattamie)	$ 730,600	$ 330,800
Jordan Creek (Monona)	$ 663,500	$ 300,000

Table 8. Estimated future degradation costs on 102 degrading streams and their tributaries in western Iowa (cont.).

Stream	Estimated degradation costs	
	Time neutral	Time value
Koker Creek	$ 134,700	$ 61,000
Little Keg Creek	$ 207,800	$ 94,100
Little Mosquito Creek	$ 197,300	$ 89,300
Little Silver Creek	$ 358,900	$ 162,400
Little Tarkio Creek	$ 354,400	$ 160,400
Little Walnut Creek	$ 177,500	$ 80,300
Long Branch	$ 619,200	$ 280,200
Long's Branch	$ 240,600	$ 67,100
Middle Branch 102 River	$ 1,129,000	$ 511,000
Middle Fork 102 River	$ 1,358,100	$ 614,700
Middle Nodaway River	$ 6,809,800	$ 2,188,000
Middle Silver Creek	$ 1,638,900	$ 693,100
Middle Soldier River	$ 538,300	$ 243,600
Middle Tarkio Creek	$ 231,900	$ 105,000
Middle Willow Creek	$ 178,900	$ 48,400
Mill Creek	$ 540,400	$ 244,600
Miller Creek	$ 221,000	$ 61,700
Moser Creek	$ 533,900	$ 241,700
Mosquito Creek	$ 5,294,300	$ 1,657,900
Mud Creek	$ 809,500	$ 366,400
Neele Branch	$ 457,300	$ 206,900
Ninemile Creek	$ 345,700	$ 156,500
North Picayune Creek	$ 203,700	$ 56,800
Otter Creek	$ 832,700	$ 245,800
Paradise Creek	$ 829,200	$ 375,300
Perry Creek	$ 1,603,800	$ 447,400
Picayune Creek	$ 1,021,800	$ 462,500
Pidgeon Creek	$ 2,796,000	$ 1,100,600
Porter Creek	$ 374,100	$ 104,400
Possum Creek	$ 158,600	$ 44,200
Potato Creek	$ 691,400	$ 312,900
Ramp Creek	$ 376,300	$ 105,000
Reynolds Creek	$ 536,300	$ 149,600
Rocky Run	$ 238,500	$ 66,500
Rush Creek	$ 198,200	$ 89,700
Sevenmile Creek	$ 2,713,100	$ 954,000
Silver Creek	$ 4,837,900	$ 1,748,400
Sixmile Creek	$ 2,166,100	$ 604,200
Snake Creek	$ 402,600	$ 182,200
Soldier Creek	$ 8,823,400	$ 3,871,900
South Picayune Creek	$ 223,200	$ 62,300
South Willow Creek	$ 326,000	$ 147,500

Table 8. Estimated future degradation costs on 102 degrading streams and their tributaries in western Iowa (cont.).

Stream	Estimated degradation costs	
	Time neutral	Time value
Steer Creek	$ 315,600	$ 85,800
Tarkio River	$ 4,507,300	$ 1,510,300
Timber Creek	$ 152,100	$ 42,500
Trinkle Creek	$ 240,600	$ 67,100
Troublesome Creek	$ 2,512,500	$ 1,053,600
Turkey Creek	$ 2,931,900	$ 1,243,400
Walnut Creek	$ 2,798,000	$ 1,153,100
Waubonsie Creek	$ 665,100	$ 158,600
Westfield Creek	$ 660,800	$ 184,300
Wheeler Creek	$ 106,500	$ 36,700
Willow Creek	$ 420,100	$ 190,100
Wolf Creek	$ 2,581,900	$ 1,107,800
W. Branch 102 River	$ 2,735,000	$ 1,237,900
W. Fork 102 River	$ 4,386,900	$ 1,401,800
W. Fork Little Sioux	$ 6,746,500	$ 2,901,500
W. Fork Middle Nodaway	$ 2,822,500	$ 1,277,500
W. Fork W. Nishnabotna	$ 3,303,900	$ 1,354,800
W. Nishnabotna River	$ 16,288,500	$ 6,492,800
W. Tarkio Creek	$ 2,023,900	$ 916,100
TOTAL	**$170,668,400**	**$67,440,900**

As presented in table 8 the estimated time neutral costs of the 102 streams and their tributaries is $170.7 million and the estimated time value costs are $67.4 million. Consideration of the time value of money results in the present value of future degradation costs being substantially less than the time neutral estimate of those costs. Time value costs, in other words, provide an accurate estimate of future degradation costs in current dollars. Time neutral costs, on the other hand, provide an estimate of future degradation costs without regard to the year in which the costs are incurred. For that reason, while time neutral estimates give an indication of the degradation costs which will be incurred without the implementation of control measures, time value estimates should be used for making decisions regarding the investment of resources to avoid future degradation costs.

Table 9 shows the combined total future degradation costs of the four study streams and the 102 non-study streams including their tributaries. The estimated total time neutral costs were $177.3 million and the time value costs were $70.1 million. Based on the soil characteristics used in the Lohnes model, these cost estimates represent the worst case scenario.

Table 9. **Estimated time neutral and time value future degradation costs on four study streams and 102 non-study streams**

Type of stream	Estimated degradation costs	
	Time neutral	Time value
Four study streams	$ 3,631,200	$ 1,346,400
Study stream tributaries	$ 2,993,600	$ 1,355,000
Non-study streams	$ 94,286,100	$32,870,800
Non-study stream tributaries	$ 76,382,300	$34,570,100
Total	$177,293,200	$70,142,300

Table 10 shows estimated time neutral and time value degradation costs by county. 9 of the 21 counties in table 10 are estimated to each have over $10 million in time neutral degradation costs. These counties are Cass, Crawford, Fremont, Harrison, Mills, Montgomery, Pottawattamie, Shelby, and Woodbury. These 9 counties have 73.0 percent of the total $177.3 million time neutral future degradation costs. The average estimated time neutral future costs for the 21 counties with degrading streams in the deep loess soil region of western Iowa is $8.4 million per county.

Nine of the 21 counties are estimated to have over $4.0 million each in discounted future degradation costs. These are the same counties that have over $10 million in time neutral costs. These 9 counties are expected to incur 73.0 percent of the total time value costs. The average discounted future degradation costs is $3.3 million per county.

Table 10. **Estimated future degradation costs for 106 degrading western Iowa streams and their tributaries by county in western Iowa.**

County	Estimated degradation costs	
	Time neutral	Time value
Adair	$ 5,691,200	$ 2,251,600
Adams	$ 5,159,200	$ 2,041,100
Audubon	$ 6,737,100	$ 2,665,400
Carroll	$ 957,400	$ 378,800
Cass	$ 16,754,200	$ 6,635,500
Cherokee	$ 407,800	$ 154,300
Crawford	$ 20,300,100	$ 8,024,300
Fremont	$ 10,460,300	$ 4,138,400
Harrison	$ 11,063,100	$ 4,496,100
Ida	$ 886,500	$ 350,700
Mills	$ 13,261,500	$ 5,134,400

Table 10. Estimated future degradation costs for 106 degrading western Iowa streams and their tributaries by county in western Iowa (cont.).

County	Estimated degradation costs	
	Time neutral	Time value
Monona	$ 5,442,900	$ 2,153,400
Montgomery	$ 14,573,500	$ 5,765,700
Page	$ 9,148,300	$ 3,619,300
Plymouth	$ 2,623,900	$ 1,038,100
Pottawattamie	$ 20,122,800	$ 8,087,400
Sac	$ 159,600	$ 63,100
Shelby	$ 12,889,200	$ 5,022,200
Sioux	$ 2,233,900	$ 883,800
Taylor	$ 7,570,400	$ 2,995,100
Woodbury	$ 10,850,300	$ 4,243,600
Total	$ 177,293,200	$ 70,142,300

4.0 SUMMARY AND CONCLUSIONS

The purpose of this study was to estimate the future cost of degradation on land voiding and public and private infrastructure crossing degrading streams in the deep loess soil region of western Iowa. This study is an extension of a previous study estimating the historical degradation costs on 155 streams in this area.

The 155 streams were segmented into three groups.

I. Segments of these streams are no longer actively degrading and are becoming stable. These stream segments were eliminated from this analysis because these segments are unlikely to degrade in the future.

II. Segments of these streams that continue to degrade.

III. Segments of these streams that are newly degrading. Generally, these are the upper segments of these streams. In this analysis, these streams are assumed to have begun degrading in 1992.

This analysis focused on stream segments II and III. By eliminating streams no longer experiencing active degradation and combining tributaries with their main stems, the total number of streams analyzed declined from 155 to 106.

Detailed analyses were made on four study streams and their tributaries. These streams include: McElhaney Creek in Woodbury County; Willow Creek in Crawford, Monona and Harrison Counties; Indian Creek in Pottawattamie, Montgomery and Mills Counties and Keg Creek in Shelby, Pottawattamie and Mills Counties. The results from these four study streams were generalized to the remaining streams and their tributaries.

The basic problem in this study was to predict future stream widening. Expected vertical stream degradation was provided by a tractive force model. Expected vertical degradation was then used in the Lohnes model to predict future stream widening. The soil characteristics used in the Lohnes model resulted in the worst case scenario cost estimates. A decay function, along with the estimated cost of degradation on land voiding and private and public infrastructure from a previous study (Baumel, et al., 1994) were used to estimate future stream widening and time neutral degradation costs over time. Estimated future degradation costs were then discounted back to 1992 to provide estimates of future degradation costs in 1992 dollars.

Estimated time neutral degradation costs on 106 western Iowa streams and their tributaries were $177.3 million. Time value degradation costs were estimated to be $70.1 million. Almost 75 percent of the $70.1 million of time value degradation costs are expected to occur in 9 of the 21 counties in the deep loess soil region in western Iowa. These 9 counties are Cass, Crawford, Fremont, Harrison, Mills, Montgomery, Pottawattamie, Shelby, and Woodbury.

This study develops a procedure to estimate future degradation costs. It also presents two types of degradation cost estimates. One is a time neutral cost that does not consider the dates on which the degradation costs are incurred. The second is a time value cost which considers the dates on which the costs are incurred and then discounts these costs back to 1992 dollars. Time neutral cost estimates provide an indication of the costs which will be incurred should no action be taken to address the problem of channel degradation. The time value costs provide accurate estimates of the cost of future degradation in 1992 dollars and should be used for investment decision purposes regarding implementation of measures to control degradation.

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Estimated Benefits and Costs of a Grade Stabilization Structure on Keg Creek in Western Iowa

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ABSTRACT

Two recent studies predicted that channel degradation and the accompanying stream widening will continue to cause significant damage to public and private infrastructure and valuable farmland in the deep loess soils region of western Iowa (Baumel, et al., 1994 and Lohnes, et al., 1994).

Measures to stabilize stream channels such as grade control structures have been found to be effective in reducing damages caused by channel degradation and widening. The purpose of this study was to develop procedures to estimate the benefits and costs of implementing stream stabilization measures such as grade control structures. The study applied these procedures to evaluate the benefits and costs of installing a grade control structure on Keg Creek in western Iowa.

The study used models from Lohnes et al. (1994) to predict future stream degradation and widening. Benefits of channel stabilization were estimated in terms of the avoidance of damages to infrastructure and lost farmland which would have occurred due to continued channel degradation and widening. The estimated costs were those associated with the installation of the selected stream stabilization measure. The benefit-cost analysis performed for a grade control structure on Keg Creek found that the present value of future degradation costs avoided by the structure, which included lost farmland, damages to two highway bridges and one railroad bridge, and traffic rerouting costs, exceeded the cost of installing the structure by $74,193, resulting in a benefit-cost ratio of 1.49.

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1.0 INTRODUCTION

Land owners, state and county governments, railroads and utility firms have incurred large losses from the widening and deepening of streams and rivers in western Iowa (Baumel, et al. 1994). Two recent studies predicted continued stream widening, accompanied by large land losses and damage to infrastructure crossing these streams (Lohnes, et al., 1994 and Baumel, et al., 1994). Grade control structures can reduce the damages caused by stream degradation on the reaches of the stream affected by the structures.

The purposes of this study are to:

1. develop procedures to estimate future benefits and costs of grade control structures, and
2. apply these procedures to evaluate the benefits and costs of a grade control structure on Keg Creek in western Iowa.

This study uses models from Lohnes, et al. (1994) to predict future stream deepening and widening of a 1.5 mile stretch of Keg Creek in Pottawattamie County, Iowa. The benefits of a proposed grade control structure on Keg Creek are based on estimated costs in Baumel, et al. (1994) and from data provided by Pottawattamie County Engineers Office, Golden Hills Resource Conservation and Development, and the Iowa Interstate Railroad Ltd. (IAIS).

2.0 PROCEDURES

A site on Keg Creek has been selected as a possible location for a grade control structure. Figure 1 shows the approximate location of the proposed site in Norwalk Township (T76N, R42W, Sections 22, 23, 25 and 26) in Pottawattamie County, Iowa. This location contains a new knickpoint at approximately 87.6 square miles of drainage area, a distance of 29 miles from the drainage divide. A detailed survey of the proposed site was conducted in the summer of 1994 by USDA Natural Resources Conservation Service (NRCS). Table 1 shows the stream characteristics from the survey.

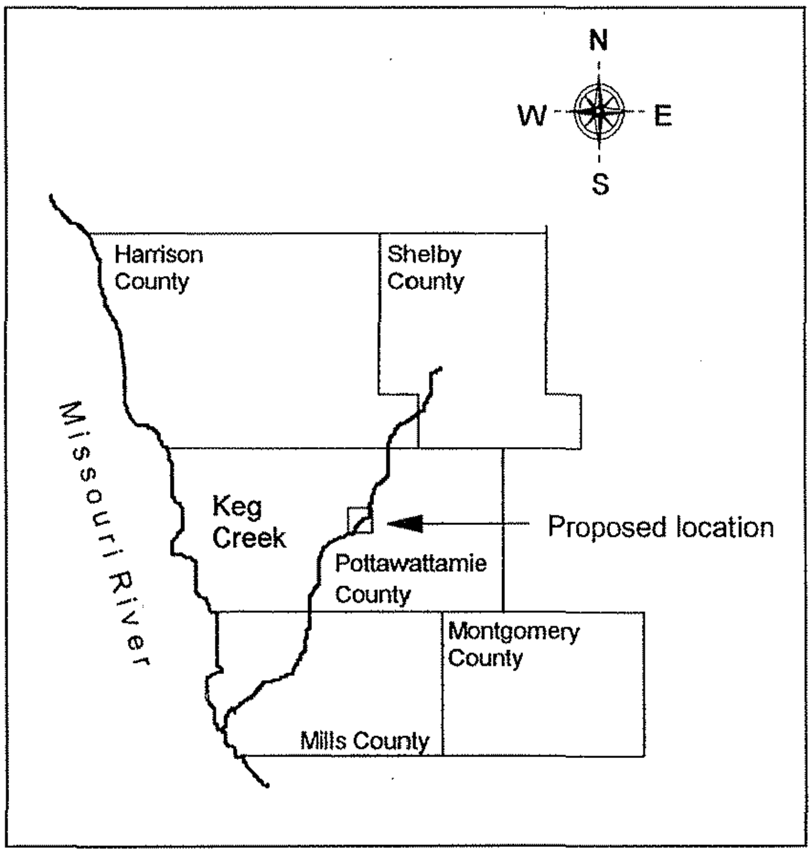

Figure 1. Proposed location for a grade stabilization structure on Keg Creek, Pottawattamie County.

Table 1. Profile characteristics of the Keg Creek site for the proposed grade control structure, summer, 1994

Stream profile characteristics	Feet
Top of bank width	70
Vertical depth	25
Streambed width	20

A final stable profile of the proposed erosion control segment between 28 and 30 miles from the drainage divide was predicted by a tractive force model (Lohnes, et al., 1994). This model predicts vertical degradation based on hydraulic principles of stream channel erosion. The model predicts that vertical stream erosion will occur until the tractive force is equal to the erosion resistance. Once erosion resistance ≥ shear force, the stream becomes stable. A shear force of 0.4 was used in the tractive force model to predict vertical degradation and will result in predicting a worst case degradation scenario.

Table 2 shows the predicted stable streambed elevations from the tractive force model for the affected segment between 28 and 30 miles from the drainage divide for the proposed grade stabilization structure. The average predicted vertical degradation was 8.9 feet over the 2.0 mile stream segment.

Table 2. Predicted vertical degradation of the proposed grade stabilization structure site and control segments.

Location		Elevation in feet		Predicted vertical degradation in feet
Miles from drainage divide	Drainage Area in square miles	1994	Predicted stable	
28	83.9	1126.4	1115.1	11.3
30	87.6	1112.1	1105.6	6.5

The predicted vertical degradation in table 2 was used in the Lohnes model (Lohnes, 1991) to predict stream widening. The Lohnes model also requires data on the initial stream channel slopes, assumed to be 80 degrees, existing stream depth and the stream soil characteristics shown in table 3. The values in table 3 represent conditions most likely to cause bank instability. Consequently, the estimated stream widening and degradation costs will represent the worst case scenario. The Lohnes model predicted additional widening of 19.5 feet and the loss of 3.5 acres of land on the 1.5 mile stretch of Keg Creek. These results, of course, are based on the assumption of no action to control degradation of the 1.5 mile stretch of Keg Creek.

Table 3. Soil characteristic values used in the Lohnes model of stream widening.

Characteristic	Unit	Values
Soil cohesion	psf	221
Mean angle of internal friction	phi	27
Saturated unit weight of soil	pcf	118.5

Equation (1) was used to estimate vertical degradation over time (Lohnes, et al., 1980):

$$\ln\left[\frac{h_1}{h_0}\right] = -k\,(t), \tag{1}$$

where:

h_1 = streambed elevation above base level at time t_1,

h_o = streambed elevation above base level at time t_0,

$-k$ = the rate of vertical degradation,

t = time in years.

The rate (-k) of vertical degradation was estimated from bridge inspection reports over time. The rate for Keg Creek was -.001208 (Yang 1994). The average elevation above base level for the stream segment was used to calculate vertical degradation for specific years where the base level is defined as the elevation above the mouth of stream.

Equation (2) was used to allocate stream widening over time.

$$SW(t) = IW + (FW - IW)\left[\frac{t - t_o}{t_f - t_o}\right]^{0.73}, \tag{2}$$

where:

SW(t) = width at time t,

IW = the initial width at the start of degradation in 1994,

FW = final stream width at t_f,

t_o = 1994

t_f = t_o + n years where n is the number of years to stabilization or 2058, whichever occurs first.

= 2058 where 64 years is the number of projected years.

The 64 year time period was selected to be consistent with the previous analyses (Baumel, et al. May 1994).

The cost of degradation after 1994 was estimated by equation (3).

$$DC_j = \sum_{1994}^{t_f} \left[\frac{SW(t+1) - SW(t)}{\Delta SW} \right] \left[(C)(Q) \frac{1}{(1+i)^n} \right], \tag{3}$$

where:

DC_j = total discounted degradation costs,

C = per unit cost of repairing degradation damage to infrastructure j,

j = type of infrastructure,

Q = physical units of infrastructure j,

i = interest rate,

n = years after 1994.

Equation (3) uses the percentage change in stream width to allocate total degradation costs over time. Costs occurring after 1994 are discounted back to current dollars from each year they occur and summed to obtain an estimate of present value costs of degradation in 1994 dollars.

3.0 PROPOSED GRADE STABILIZATION STRUCTURE

The stream profile data in table 2 indicate an existing slope of 14.3-feet over two miles. The steep channel slope on this reach of Keg Creek is creating active degradation. Two H-pile cribbed rip-rap structures are proposed for this stream segment. Conceptually, each structure would consist of a double row of H-pile. Rows will be 8-feet apart with the piling within each row to be approximately 8-feet apart. The rows of H-pile would be driven perpendicular to the centerline of the creek. The rows would extend across the stream bottom and up the channel side slopes to design high water elevation. The rows of piling across the stream bottom would be driven to the desired grade control elevation.

Heavy gauge welded wire panels would be attached to each row of H-pile to form a crib containing rip-rap. The stream bottom and side slopes immediately up and down from the structure would also be armor coated with rip-rap. The preliminary cost estimates are approximately $150,000 for the two H-pile structures and rip-rap to protect the 1.5 miles of stream grade.

4.0 ESTIMATED BENEFITS OF A STABILIZATION STRUCTURE

The benefits from the proposed grade stabilization structure include the avoidance of the loss of 3.5 acres of land as well as damage to transportation and communication infrastructure crossing the stream in the 1.5 mile reach impacted by the structure. The 1.5 miles of stream above the proposed grade stabilization project contains two highway bridges, four Gabion drop structures on either side of the two highway bridges, a railroad bridge and aerial telephone lines crossing the stream. The aerial telephone lines are unlikely to be affected by the stream widening. Therefore, the telephone lines were omitted from the analysis.

4.1 Bridge NO 20

The 19.48 feet of widening would require Bridge NO 20 to have new spans added to each end of the bridge. Pottawattamie County Engineer officials indicated that these spans would need to be added when the stream incurs 2-feet of vertical degradation. Using equation (1), vertical degradation of 2-feet was estimated to occur in 2003. The cost of the added bridge spans was estimated to be $2,000 per linear foot by the Pottawattamie County Engineers Office. The estimated present value cost for adding 19.48 feet of length to Bridge NO 20 in 2003 was estimated by equation (4):

Present value of NO 20 span addition =

$$\textit{(19.48 linear feet)(\$2,000 per foot)}\left(\frac{1}{(1+i)^{n}}\right) = \$27{,}373 \tag{4}$$

where:

$1/(1+i)^n$ = 0.7026, the 4 percent discount factor to convert 2003 costs into 1994 dollars.

4.2 Bridge NO 21

Bridge NO 21 sits at a bend on Keg Creek. About two-thirds or 13-feet of the widening at NO 21 will occur on the east side of the stream and the remaining one-third or 6 feet will erode on the west side. The east side currently has a 6-foot wide berm, a mound of earth at the top of the bank, and the west side has 8 feet of berm. Given a 3-foot minimum berm, a 10-foot span would need to be added to the east end of the bridge in the year 2003. On the west side, the 6 feet of land voiding would reduce the 8-foot berm to 2-feet. However, an armor coating of 300 tons of rip-rap would need to be applied after 5-feet of widening to protect and maintain a 3-foot berm on the west bank. Using equation (2), 5-feet of widening would occur by 2004. Equations (5) and (6) were used to calculate the cost of protecting NO 21 without a grade control structure.

Present value of span addition =

$$(10 feet)(\$2,000 \text{ per linear foot})(0.7026) = \$14,051 \tag{5}$$

Present value of rip-rap cost =

$$(300 tons)(\$35 / \text{per ton})(0.6756) = \$7,094 \tag{6}$$

The total cost of protecting bridge NO 21 is estimated to be $21,152.

4.3 Gabion Drop Structures NO 20 and NO 21

To prevent erosion of the four ditches parallel to bridges NO 20 and NO 21, there are currently 8 gabion drop baskets--wire baskets full of rocks--located at the point where drainage water enters into Keg Creek. Without the grade control structure, these 8 gabion drop baskets are estimated to begin sliding into Keg Creek after one additional foot of stream widening. Using equation (2), one additional foot of widening is estimated to occur in 1995. The cost of shoring up these gabions is estimated to be $30,000 per bridge. The present value of this cost is estimated in equation (7).

Present value of gabion protection =

$$(\$60,000)(0.9615) = \$57,690 \tag{7}$$

4.4 Railroad Bridge

A railroad bridge owned by the IAIS crosses Keg Creek in the 1.5 mile area above the proposed grade control structure site. Engineering personnel from the IAIS indicated that 3 additional feet of vertical degradation would require that sheet piling be driven around each of the two bridge piers to prevent exposure of the pier footings. The estimated cost of driving the sheet piling is $95,000 for each pier. Using equation (1), three additional feet of vertical degradation is estimated to occur in 2007. The present value of the cost of protecting the two piers is estimated in equation (8).

Present value of railroad pier protection cost =

$$(2)(\$95{,}000(0.6006) = \$114{,}114 \tag{8}$$

4.5 Traffic Rerouting

Traffic must be rerouted during the time that spans are being added to a bridge. Traffic rerouting was assumed to take place for 60 days while spans were added to each bridge. Average daily traffic (ADT) was 45 vehicles per day on NO 20 and 30 vehicles per day on NO 21. The average rerouting cost per ADT was estimated to be $40 over a 60 day period (Baumel, et al., 1994). The present value of the rerouting costs on the two bridges are estimated in equations (9) and (10).

Present value of rerouting costs =

$$NO20 = (45)(\$40)(0.7026) = \$1{,}265 \tag{9}$$

$$NO\ 21 = (30)(\$40)(0.7026) = \$843 \tag{9}$$

Total = $2,108

4.6 Land Voiding

Land voiding was estimated by the Lohnes model of stream widening. The total predicted land voiding was 3.54 acres. The value of the land voided was based on Duffy, et al. (1993). The high land values were chosen in the analysis. The discounted cost of land voiding (DCLV) was estimated by equation (11) where t_o is 1994 and t_f is 2058.

$$DCLV = \sum_{t_o}^{t_f}\left[\frac{SW(t+1) - SW(t)}{\Delta SW}\right] [(\$1{,}093)(3.54)](P|F,n,4\%) = \$1{,}756 \tag{10}$$

where:

P | F = Present value discount factor.

5.0 BENEFIT-COST ANALYSIS

A benefit-cost ratio is expressed as

$$B / C = \frac{Benefits}{Costs} \tag{11}$$

where:

B/C	=	benefit cost ratio,
Benefits	=	present value of land voiding and infrastructure cost savings from building a grade control structure,
Costs	=	present value of building the grade control structure.

A ratio > 1 means that the present value benefits of the investment exceed the cost of the structure and that, in the absence of budget constraints, the structure should be built.

Table 4 presents the present value estimates of the land voiding and infrastructure cost savings from building a grade control structure on Keg Creek in Norwalk Township in Pottawattamie County, Iowa.

Table 4. Estimated present value of land voiding and infrastructure cost savings from a grade control structure on Keg Creek in Pottawattamie County, Iowa.

Type of cost	Present value of savings
Land voiding	$ 1,756
Bridge NO 20	$ 27,373
Bridge NO 21	$ 21,145
Gabion drop baskets	$ 57,690
Railroad bridge	$114,114
Traffic rerouting	$ 2,108
Total	$224,186

The estimated cost of building the grade control structure is $150,000. The benefit/cost ratio is calculated in equation (13):

$$B / C = \frac{\$224,186}{\$150,000} = 1.49 \tag{12}$$

The 1.49 B/C ratio means that one dollar invested in the grade control structure would return $1.49 in 1994 in reduced land voiding and infrastructure costs.

A more detailed engineering analysis may lead to a higher benefit-cost ratio. For example, the proposed grade control structure may control degradation on tributaries flowing into Keg Creek as well as the 1.5-mile stretch of main stream above the structure, thereby increasing benefits from the structure. Secondly, a detailed engineering analysis could lead to the conclusion that vertical degradation will undermine the structural integrity of either or both bridges NO 20 and NO 21. Thus, in the absence of a grade control structure, one or both of the bridges might need to be replaced, rather than merely adding spans as was assumed in this analysis. In this case, the estimated present value of savings to bridges NO 20 and NO 21 and therefore benefits of the proposed structure would increase.

6.0 SUMMARY AND CONCLUSIONS

This study evaluates the benefits and costs of constructing a grade control structure on Keg Creek in T76N, R42W, Sections 22, 23, 25, 26 in Pottawattamie County, Iowa. This reach of Keg Creek is actively degrading. This degradation is estimated to result in Keg Creek widening 19.48 feet. This will result in the loss of an estimated 3.54 acres of land and substantial damage to two highway bridges and one railroad bridge. In addition, repairs to the two highway bridges will result in a 60 day closure which, in turn, will cause vehicles normally crossing these bridges to be rerouted.

The extent of vertical stream degradation is estimated by a tractive force model. The coefficients in the tractive force model projected a worst case scenario. The stream widening is estimated by the Lohnes model. Infrastructure damages and related costs were estimated by the Pottawattamie County Engineers Office, Golden Hills Resource Conservation & Development, officials of the IAIS railroad, and from data in Baumel, et al.(1994). All future degradation costs were discounted back to 1994 dollars. The benefit-cost analysis indicated that the benefits from the grade control structure would exceed the costs by $74,193 resulting in a benefit-cost ratio of 1.49. This ratio will be higher (lower) if the construction costs of the stabilization structure are lower (higher) than $150,000.

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SECTION FIVE

ABSTRACT

Efforts to control stream channel degradation and associated widening in western Iowa have been carried out since the 1970's. Much of this early work was undertaken by individual county governments, utility companies, and the state to address specific cases of stream channel erosion impacting public and private infrastructure. These isolated efforts did not have a significant impact on the overall problem of stream channel erosion that occurred throughout the region. The region-wide planning and implementation of stream channel erosion control measures in western Iowa has been severely impeded by the lack of an organized approach to addressing the problem and developing alternative solutions. Local governments and agencies concerned about the issue of stream channel erosion determined that such an approach was essential given the need to plan control measures based on an assessment of a stream's overall characteristics and the condition of affected land and infrastructure, facilitate the exchange of information concerning alternative erosion control measures, and secure the technical and financial resources required to address an issue of the magnitude of stream channel erosion in western Iowa.

To that end, the current research project had as one its principal objectives the development of an organizational structure and administrative procedures which would be used to plan, coordinate, implement, and administer stream stabilization projects and programs in western Iowa. Activities carried out during the research project resulted in the creation and evolution of three organizations with their corresponding administrative procedures. The three organizations, the Degrading Streams Task Force, Hungry Canyons Alliance, and Loess Hills Development and Conservation Authority, have successfully planned, directed resources toward, and carried out educational, research, and demonstration projects and activities related to stream channel erosion and its control in western Iowa. More specifically, these organizations have developed information systems and internal procedures to assess the extent of stream channel erosion, its impact on land and infrastructure, and the need for control measures; organized and conducted educational activities which have significantly increased the awareness and understanding of stream channel erosion among elected officials and agency personnel at the local, state, and federal levels; and secured considerable financial and technical support for demonstration erosion control projects and stream channel erosion research. The organizational structure and administrative procedures sought after and developed during the course of the research project have been incorporated into and put into operation through the Loess Hills Development and Conservation Authority.

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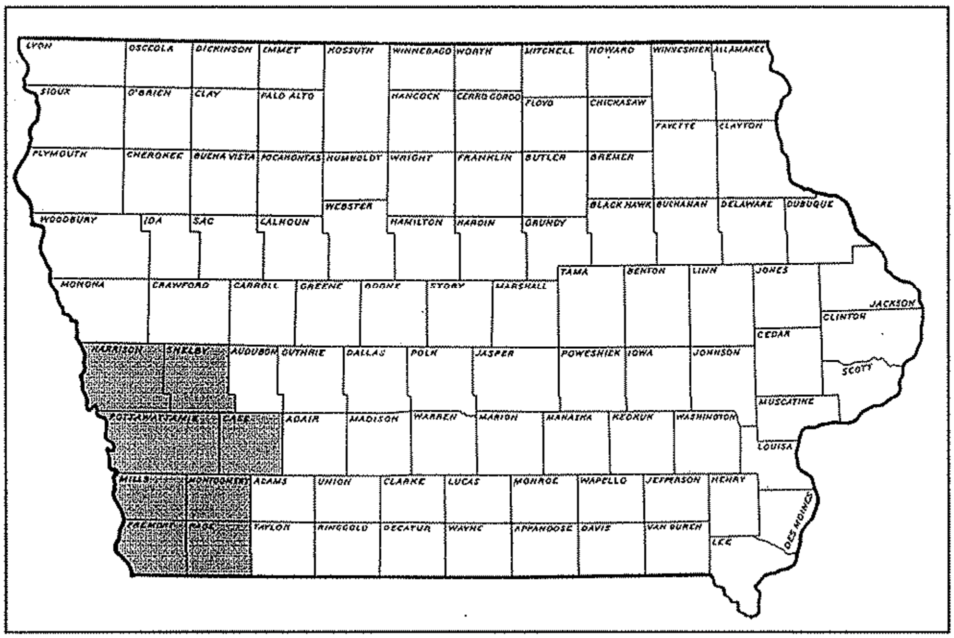
1.0 INTRODUCTION

Efforts to control stream channel degradation and associated widening in western Iowa have been carried out since the 1970's. This early work, for the most part, had been undertaken by individual counties, utility companies, and the state in an effort to address specific cases of stream erosion impacting public and private infrastructure. While these isolated efforts were effective in protecting targeted infrastructure, they did not have a significant impact on the overall problem of stream channel erosion that occurred throughout the region. One of the most frequently cited reasons that no region-wide approach to stream channel erosion in western Iowa had been undertaken was the lack of an organized effort among concerned parties to attract attention and direct resources to the problem. Local governments and other entities working on stream channel erosion found that such an approach was essential given the need to: 1.) plan and design erosion control measures based on an assessment of a stream system's overall characteristics and the condition of and potential impact on land and infrastructure; 2.) facilitate the exchange of information concerning alternative designs for stream stabilization measures in an effort to reduce the cost of conventional channel erosion control structures; and 3.) pursue and secure the considerable technical and financial resources required to successfully address an issue of the magnitude of stream channel erosion in western Iowa.

In an effort to address these needs, the research project *Stream Stabilization in Western Iowa* had as one of its principal objectives the development of an organizational structure and administrative procedures which would be used to plan, coordinate, implement, and administer stream stabilization projects and programs in western Iowa. Such a structure and associated procedures would facilitate: 1.) the region-wide assessment of stream channel erosion and related damages; 2.) the identification of priority stream segments in need of erosion control measures; 3.) the efficient and effective allocation of technical and financial resources on stream erosion control projects; and 4.) the exchange of information among public and private entities and professionals concerned with and working to carry out stream channel erosion control activities.

2.0 THE DEGRADING STREAMS TASK FORCE

The Degrading Streams Task Force (DSTF) was organized in May, 1990 with assistance from Golden Hills Resource Conservation and Development (RC&D), Inc. The DSTF was formed for the specific purposes of initiating, encouraging, and supporting region-wide efforts to address the problems caused by eroding stream channels in western Iowa. Participants in the DSTF included supervisors, engineers, and soil and water conservation district commissioners from the 8 counties in the RC&D area in southwest Iowa (map 1). These counties represented a large percentage of those in which damages to infrastructure and land loss caused by stream channel erosion has been most severe.



Map 1. Counties participating in the Degrading Streams Task Force

The DSTF identified and pursued the following priority activities in carrying out its work:

1. Assemble and develop information related to stream channel erosion in western Iowa: The DSTF focused its efforts in this area on the preliminary inventory of streams in western Iowa that were experiencing varying degrees of channel erosion. During this inventory, efforts were also made to identify damages to public infrastructure, particularly highway bridges and culverts, caused by stream channel erosion. Information was also assembled regarding alternative stream channel erosion control measures. Much of this information was gathered from county engineer offices, soil and water conservation districts, and the Iowa Department of Transportation. Information on alternative erosion control measures was also obtained from other cooperating state and federal agencies. This initial inventory provided the informational base needed to plan and carry out future activities such as the

recruitment of additional counties impacted by stream channel erosion, development and funding of research activities related to the problem of stream erosion, and the identification of priority streams and sites for the demonstration of channel erosion control measures.

2. Inform and educate elected officials and representatives of public agencies and private entities regarding the problems associated with stream channel erosion: Educational and informational activities of the DSTF targeted non-participating counties (supervisors, engineers, and commissioners) in western Iowa affected by stream channel erosion, state legislators in 18 house and 11 senate districts, congressional representatives in districts 3, 4, and 5 and the state's 2 senators. These activities were also directed at agency personnel in the USDA Natural Resources Conservation Service (NRCS), Iowa Division of Soil Conservation (DSC), Iowa Department of Transportation (DOT), and Iowa Department of Natural Resources (DNR). Representatives of private utility companies with infrastructure impacted or threatened by stream channel erosion were also targeted by these efforts. Major informational and educational activities carried out by the DSTF included planning and conducting field tours to demonstrate the effects of stream channel erosion and alternative approaches to its control and the development of slide and video presentations and their use at local, regional, and state meetings such as those held by the Iowa State Association of Counties and Iowa Association of Soil and Water Conservation Districts. In addition, informational sessions were frequently held between representatives of the DSTF and small groups of legislators, agency personnel, and utility representatives.

3. Secure the necessary technical and financial resources to: a.) perform much needed research on the impact of eroding streams and alternative methods to control the problem and b.) plan, design, and demonstrate promising stream channel stabilization measures: The initial technical and informational work accomplished by the DSTF led to the development and funding of research activities related to stream channel erosion in western Iowa. Most significant among these activities has been the research conducted to: 1.) collect and integrate information pertaining to stream channel erosion such as stream characteristics and conditions and impacted or threatened infrastructure; 2.) develop technical guidelines for preliminary planning and cost forecasting of stream channel erosion control measures; and 3.) evaluate the economic impact of past and continued stream channel erosion on infrastructure and farmland. This research has been supported financially by the Highway Division of the Iowa DOT and the Iowa Highway Research Board, the NRCS, and member counties in the DSTF. These entities and others including Iowa State University (ISU), Iowa DNR, the US Army Corps of Engineers (ACOE), and the US Geological Survey (USGS) have provided much of the technical support required to carry out the DSTFs research activities.

The DSTF was successful in identifying and securing the technical and financial resources needed to plan, design, and implement stream channel erosion control measures on 3 streams in western Iowa. These streams included Walnut Creek in Pottawattamie, Moser Creek in Shelby County, and Middle Soldier River in Crawford County. The purpose of these projects was to demonstrate cost effective alternative methods of controlling stream channel erosion. Funding for these projects in the amount of $400,000 per year was provided from federal appropriations to the DSTF through the NRCS in fiscal years 1992 and 1993. Participating counties contributed at least 20 percent of these projects' total cost. The planning, design, and construction of the demonstration projects brought together the technical expertise of private engineer firms and county engineering offices with that of assisting agencies including the NRCS, ISU, and Iowa DNR. This high degree of cooperation was achieved primarily through a series of DSTF facilitated project planning sessions and frequent updates throughout the projects' installation.

4. Develop an organizational structure and procedures necessary to continue to plan and carrying out the activities described above in order to implement a long range approach to the problem of stream channel erosion and its control: Two internal committees which dealt with technical and legislative issues were established by the DSTF in order to address the need for a permanent organizational structure and associated administrative procedures. In addition, in August of 1992 the DSTF employed a full time Director to plan, coordinate, and carry out day-to-day activities of the research and demonstration projects and to arrange for and provide assistance to DSTF members and committees.

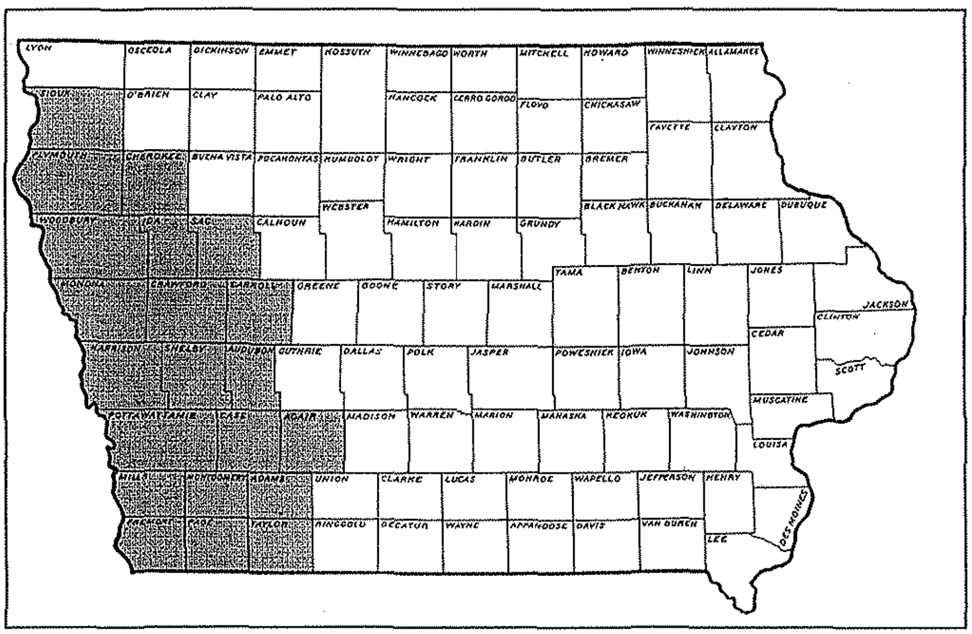
The committee concerned with technical issues consisted of county engineers and supervisors, conservation district commissioners, and personnel from the NRCS and RC&D. In addition to being responsible for technical aspects of the DSTFs activities, this committee was charged with establishing the initial procedures and criteria used by the DSTF to prioritize demonstration stream channel erosion control projects for funding and implementation. The procedures established involved: a.) the distribution of a request for proposals outline to member counties; b.) the development and submittal of proposals from member counties interested in participating in a demonstration project; c.) the evaluation and ranking of proposals by a scoring subcommittee; and d.) review and approval of the DSTF membership based on the results of the scoring subcommittee's evaluation and ranking. The criteria used to develop, evaluate and prioritize project proposals was incorporated into the request for proposals outline found on page 5-19. In addition to the raw score and ranking which resulted from the evaluation of proposals, the scoring subcommittee took into consideration other factors in arriving at a final list of priority projects. Among these factors were the: a.) overall cost of projects relative to available funding; b.) the ability of a given county to meet the local contribution requirement in the case of more than one project being located in a single county; and c.) the desire to locate stream channel erosion control projects throughout the affected area in western Iowa for the purposes of demonstrating and evaluating control measures under different resource conditions as well as for the educational and informational value of doing so. The initial request for and review of proposals resulted in 6 demonstration stream channel erosion control projects being selected for funding. These projects included Walnut Creek in Pottawattamie County, Moser Creek in Shelby County, Middle Soldier River in Crawford County, Keg Creek in Pottawattamie County, West Tarkio Creek in Page County, and Mosquito Creek in Harrison County.

This DSTF committee was also responsible for working with the NRCS to develop the procedure by which available funds could be accessed by counties in order to implement demonstration stream channel erosion control projects. Federal funds appropriated for the demonstration projects were administered by the NRCS. As such, member counties in the DSTF that participated in demonstration projects received administrative and technical assistance as needed from the NRCS. Once a member county's proposed project was approved by the DSTF, a project agreement between the county and NRCS was entered into. The purpose of the agreement was to outline the roles and responsibilities of each entity in planning and carrying out the proposed project. In general, the county's responsibilities under the agreement included providing a minimum of 20 percent of the total cost of the project, being responsible for project planning and design, project administration including contracting and land rights acquisition, complying with all applicable local, state, and federal laws and regulations, performing construction inspection, and providing for long term operation and maintenance of the completed project. The NRCS, in turn, was responsible for contributing a maximum of 80 percent of the total cost of the project as well as providing the technical and administrative assistance needed to ensure its successful completion.

The DSTFs legislative committee also consisted of county engineers and supervisors, conservation district commissioners, and personnel from the NRCS and RC&D. In addition to concentrating on meeting with, providing information to, and gaining the support of legislators and agency personnel at the local, state, and federal levels regarding the issue of stream channel erosion, committee members were responsible for developing a more formal organizational structure to carry on the work of the DSTF. DSTF member counties determined that such a structure would contribute toward the development of a long term approach and solution to the problem of stream channel erosion by providing a greater degree of permanence to DSTF activities and by facilitating the search for and acquisition of financial support for these activities. As a result, DSTF member counties formed a grass-roots, non-profit organization called the Hungry Canyons Alliance in October of 1992.

3.0 THE HUNGRY CANYONS ALLIANCE

The Hungry Canyons Alliance (HCA) incorporated, expanded, and formalized the organizational structure and administrative procedures initially established by the DSTF and described above. The HCA was organized as a not-for-profit corporation in accordance with Chapter 504(A) of the Code of Iowa and the Iowa Non-Profit Corporation Act. As described in the HCAs articles of incorporation, the purpose of the organization is to focus attention on the problems of, and develop solutions related to, *stream channel degradation in the deep loess soils region of western Iowa*. Specific goals of the HCA as outlined in the organization's constitution and bylaws are to: 1.) foster regional cooperation related to the degrading streams issue; 2.) communicate with state and federal legislators on issues relating to degrading stream; 3.) focus technical and financial resources on the problems associated with degrading streams; and 4.) serve as an advocacy group for acquiring resources necessary for stream degradation control projects. Membership in the HCA expanded from the original 8 counties that participated in the DSTF to include 21 counties in western Iowa impacted by stream channel erosion (map 2).



Map 2. Member counties in the Hungry Canyons Alliance

The HCA established a board of directors which consisted of one representative from each member county. Directors are appointed by the county supervisors in consultation with local soil and water conservation districts. An executive committee composed of 5 county representatives has also been established to supervise and carry out the daily operations of the organization. Members of the executive committee are selected from among the directors and are to consist of a county supervisor, a soil and water conservation district commissioner, a county engineer, an individual actively engaged in farming, and an at-large member. The HCA continues to employ a full time Director to assist the executive committee with the day-to-day management of the Alliance's activities and projects. The organization's constitution and bylaws established guidelines for the election of officers, terms of office, officer duties, and conditions for removal as well as for meetings of the executive committee (monthly), board of directors (quarterly), annual meeting, and special meetings. Operating funds for the organization consist primarily of annual membership fees from participating counties. Standing technical, legislative, and stream erosion control project scoring committees have also been established by the organization. Membership in the technical and legislative committees is voluntary and includes county supervisors, county engineers, conservation district commissioners, and representatives from cooperating organizations and agencies. The HCA executive committee appoints the members of the project scoring committee. The executive committee determined that membership in the scoring committee should represent the entire HCA region and would consist of 2 county supervisors, 2 county engineers, 2 conservation district commissioners, and 2 technical personnel from the NRCS.

Since its formation, the HCA has carried out the following major activities in pursuit of its goals and in continuing the work initiated by the DSTF:

1. The HCA has coordinated and supervised completion of the demonstration stream channel erosion control projects on Walnut Creek, Moser Creek, and Middle Soldier River that were initiated by the DSTF. As a result of the legislative committee's on-going work with state and federal legislators and agency personnel, the HCA has been successful in obtaining additional funds to continue to construct demonstration stream channel erosion control projects. As with the financial support secured previously by the DSTF, these funds were in the form of federal appropriations administered by the NRCS. These federal appropriations were in the amount of $400,000 annually for both fiscal years 1994 and 1995. These funds were assigned to the following demonstration projects; Keg Creek in Pottawattamie County, West Tarkio Creek in Page County, Mosquito Creek in Harrison County, McElhaney Creek in Woodbury County, Deer Creek in Mills County, Ninemile Creek in Adair County. These projects were selected following their review and evaluation by the

HCAs scoring committee. Final approval of the projects was made by the HCAs executive committee based upon the results of their review and evaluation. As with previous demonstration projects, financial, technical, and administrative assistance was provided to participating counties through the execution of a project agreement with the NRCS.

2. The HCA has also directed and supervised the completion of research activities initiated by the DSTF. These research activities included assembling and integrating information related to stream channel erosion, developing technical guidelines for planning erosion control measures, and evaluating the economic impact of channel erosion. Financial support for this research was provided by the Highway Division of the Iowa DOT and the Iowa Highway Research Board, the NRCS, and member counties. The HCA has also worked with cooperating agencies and entities to identify future areas of research important to understanding and addressing the issue of stream channel erosion in western Iowa. Several of these potential research topics include the need to: a.) verify the various approaches utilized to predict stream channel degradation such as the geomorphic and tractive force methods; b.) test and modify models used to predict stream channel widening in order to account for rotational and planar slope failures; c.) test hydrodynamic and empirical methods of predicting the upstream effect of stream channel erosion control measures; d.) verify the model that describes the various stages and processes in the evolution of stream channel erosion; e.) develop planning and design standards for stream channel erosion control measures; and f.) identify, evaluate, and demonstrate alternatives to strictly structural stream channel erosion control measures such as the use of bio-engineering techniques and channel slope and shape alterations.

3. The HCAs technical and scoring committees reviewed and modified the request for proposals outline and procedures used to evaluate and rank demonstration stream channel erosion control projects. Modifications were based upon suggestions from DSTF members and cooperating agency personnel who participated in the initial development, review, and scoring of project proposals. Revisions in the request for proposals outline were also made in order to incorporate results from ongoing research activities such as the improved ability to estimate future stream degradation and widening and the associated costs of damaged infrastructure and lost farmland. The revised request for proposals outline is included on page 5-20.

The technical and scoring committees determined that the sections of the request for proposals that described project scope, cost, and areas to benefit from the project provided necessary background information but were not essential items in evaluating the potential benefits and success of a project. As such, these sections remained in the request for proposals but were not assigned point values for the purpose of scoring and ranking projects. The committees decided that a measure of the potential benefits of a proposed project, as expressed in terms of damages avoided, was the most significant factor in its evaluation. Therefore, the section of the request for proposals that described potential damages was weighted most heavily (a maximum of 60 points). Regarding specific damages, extent of erosion was assigned the greatest weight (a maximum of 30 points) followed by threatened infrastructure (maximum of 21 points) and increased transportation costs (maximum of 9 points).

The committees decided that the potential success of a proposed project was the second most important factor in its evaluation. Support for a project as indicated by the willingness of local governments, other entities, and land owners to participate, not only in the project itself but in the overall efforts of the HCA, was determined to be the most acceptable measurement of a project's potential for success. As such, the section of the request for proposals that described local support was assigned the remaining evaluation points (maximum of 40 points). Willingness to participate was, in turn, divided into two components each with its own weight or portion of the total points assignable for the evaluation of local support. The first component which described the willingness of local governments to participate in the HCAs regional efforts was assigned a maximum of 20 points. Counties that had not appointed a representative nor provided financial support to the HCA were awarded between 0 and 7 points. Counties that had appointed a representative but had not provided financial support to the HCA were awarded between 8 and 14 points. Counties that had both appointed a representative and provided financial support were awarded between 15 and 20 points. The second component of the local support section described and awarded a maximum of 20 evaluation points for the: a.) financial contribution committed by local sponsors toward the cost of the proposed project; b.) willingness of local sponsors to assume the future operation and maintenance of the project; c.) existence of complementary work completed or planned in the area of the proposed project such as upland conservation treatment; and d.) willingness of land owners in the areas affected by the project to cooperate with its implementation.

In addition, the committees established the following procedures for the development, submittal, evaluation, and approval of future demonstration project proposals:

a. The list of priority projects selected for funding is in effect for one year. Projects not funded during a given year are not carried over to subsequent request for proposal cycles. Funding in a given fiscal year will be used to support as many of the projects as possible in the order in which they appear on the priority list. For projects not funded, a county will need to resubmit a proposal to be considered in subsequent years. This will allow new proposals to compete equally with previously submitted proposals.

b. A project on the priority list can be removed if the sponsoring county is not able to provide the required local contribution. The county can resubmit the proposal in subsequent request for proposal cycles.

c. The scoring and executive committees reserve the right to vary from the raw scores in ranking and approving projects for funding. The primary reasons for making such a decision will be to: 1.) balance the amount of funds available with the estimated costs of proposed projects; 2.) take into consideration the ability of a single sponsor to satisfy the local contribution requirement for multiple projects; and 3.) locate stream channel erosion control projects throughout the HCA area for the purposes of demonstrating control measures under different resource conditions and to a wider audience. Reasons for any variations will be made known to the membership of the HCA as well as to the counties whose proposals are affected by such decisions.

The second request for proposals cycle which made use of the revised format resulted in 5 projects being selected for funding. These projects included McElhaney Creek in Woodbury County, Deer Creek in Mills County, Ninemile Creek in Adair County, Long Branch in Shelby County, and Pigeon Creek in Harrison County.

4. The HCA has, through its research activities and demonstration projects and advocacy efforts, become a recognized leader and source of technical assistance and information with respect to stream channel erosion control. As a result, the HCA has played a central role in many important regional activities and events related to stream channel erosion and alternative control measures. More specifically, the most significant of these activities and events have included the following:

a. A HCA organized and sponsored multi-state stream channel erosion conference was held in Omaha in March, 1993. The conference was attended by elected officials and representatives of governmental agencies at the local, state, and federal levels from Iowa, Nebraska, Kansas, and Missouri. The purpose of the conference was to initiate multi-state cooperation in addressing the issue of stream channel erosion. In addition to the frequent exchange of technical information which has occurred as a result of the conference, the HCA has provided extensive assistance to the Natural Resource Districts in southeastern Nebraska in support oftheir efforts to implement stream channel erosion control activities similar to those underway in Iowa.

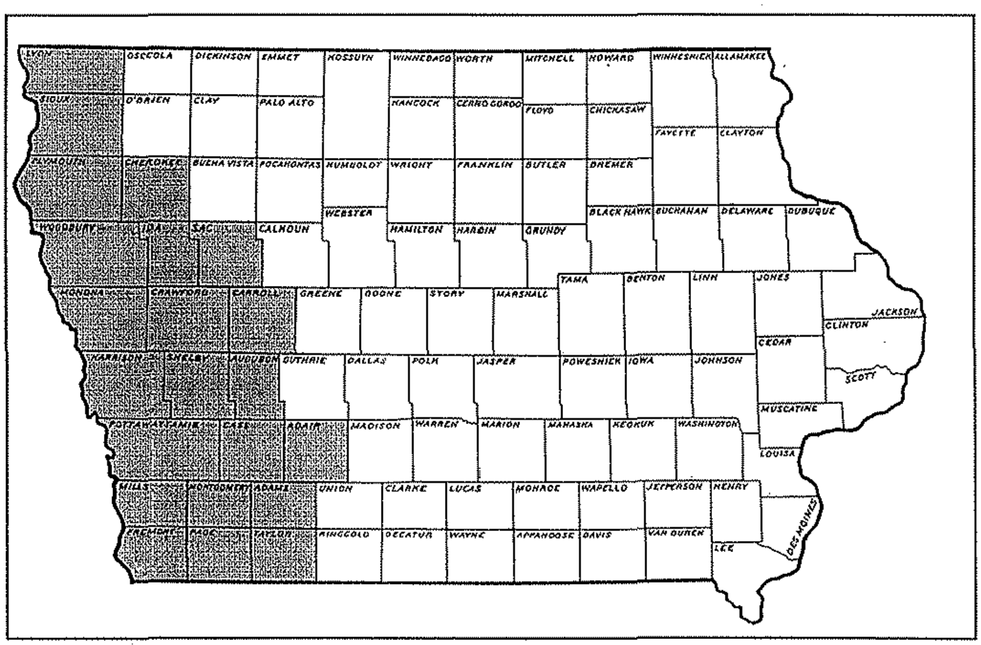
b. The NRCSs Emergency Watershed Protection (EWP) program, which is responsible for assisting local governments with repairing damages to infrastructure caused by the flooding in 1993, has relied extensively upon the HCAs information and expertise to guide the planning and implementation of EWP sponsored stream channel erosion control projects in western Iowa. HCA assistance has included the use of the its aerial reconnaissance and geographic information system (GIS) as well as its experience with demonstration projects and the results of HCA directed research activities. In addition, at the request of the NRCSs EWP program, the HCA organized and conducted a one day technical workshop on stream channel erosion and alternative control measures. This workshop was attended by county engineers and their staffs, private engineering consulting firms, and technical personnel from the NRCS and other cooperating agencies at the local, state, and federal levels.

c. The HCA has been able to provide information and assistance to other entities carrying on research related to stream channel erosion and its control. More specifically, the HCA has cooperated extensively with researchers with the Federal Highway Administration (FHwA) and the USGSs Water Resources Division who are undertaking a project to assess stream channel instability in the deep loess soils region of the Midwest. Frequent exchanges of information and assistance have also taken place between the HCA and the ACOEs Omaha District which will help the District to evaluate and classify stream channel erosion in Nebraska and develop standards for alternative channel erosion control measures. The results of these HCA assisted research activities will contribute enormously to the Alliance members' improved understanding of stream channel erosion and their ability to plan and implement control measures.

5. The HCA, in cooperation with the entities responsible for providing much of the Alliance's financial support, identified the need for establishing an entity and associated mechanisms within the state bureaucracy that could receive and administer funds to support activities and projects related to stream channel erosion control. It was determined that the creation of such an entity would facilitate the procurement of funds needed to carry out current and future activities and projects, increase awareness of the problem of stream channel erosion and the alternative solutions among state legislators and agency heads, and further emphasize the need to support a sustained, long term approach to the problem of stream channel erosion. As a result, the HCA worked successfully with state legislators and cooperating entities to establish the Loess Hills Development and Conservation Authority.

4.0 THE LOESS HILLS DEVELOPMENT AND CONSERVATION AUTHORITY

Legislation authorizing the establishment of the Loess Hills Development and Conservation Authority, House File 214, was passed unanimously by the Iowa Legislature and signed into law by the Governor in May, 1993. According to the authorizing legislation, the Loess Hills Development and Conservation Authority is responsible for the development and coordination of plans for projects related to the unique natural resource, rural development, and infrastructure problems of counties in the deep loess region of western Iowa. More specifically, the legislation identifies the erosion and degradation of stream channels, associated damages to natural resources and infrastructure, and alternative control measures as the primary concern of the Authority. Membership in the Authority is open to 22 counties in the deep loess soils region of western Iowa. These counties include all of the member counties of the HCA with the addition of Lyon County in the northwestern corner of the state. Member counties of the Loess Hills Development and Conservation Authority are indicated on map 3. In addition to the Authority itself, the legislation also created the Loess Hills Development and Conservation Fund in the state treasury. Furthermore, the legislation enabled the Authority to accept and deposit contributions into the fund and to administer the resources available in the fund for the planning and implementation of development and conservation activities or measures in the Authority's member counties.



Map 3. Member counties in the Loess Hills Development and Conservation Authority.

The authorizing legislation also enabled the Loess Hills Development and Conservation Authority to meet, organize and adopt rules and procedures as deemed necessary to carry out its duties. In order to facilitate implementation of the legislation, member counties decided that the goals, internal structure, and administrative procedures previously established for the HCA and described in the Alliance's articles of incorporation and constitution and bylaws could be appropriately adopted by the Authority. These governing documents were amended as necessary to include the relevant portions of the authorizing legislation including the mission of the Loess Hills Development and Conservation Authority, addition of Lyon County, and the creation and administration of the Loess Hills Development and Conservation Fund. The constitution and bylaws of the Loess Hills Development and Conservation Authority, therefore, incorporate the contents of the HCAs articles of incorporation and constitution and bylaws and the authorizing legislation into a single document which governs the organizational structure and administrative procedures of the Authority. The HCA, while still an active not-for-profit organization, continues to carry out its efforts to address issues and problems associated with stream channel erosion in western Iowa through the Loess Hills Development and Conservation Authority.

Member counties in the Loess Hills Development and Conservation Authority have developed and are aggressively pursuing the implementation of a 5-year plan of work to address the problems related to stream channel erosion in western Iowa. The Authority's plan of work builds upon the information and experience acquired through the past efforts of the DSTF and HCA. The plan of work details a series of specific objectives which will enable the Authority to accomplish the following goals: 1.) demonstrate cost effective alternative methods of protecting public and private infrastructure, agricultural land, and natural areas from damages caused by stream channel erosion; 2.) promote, sponsor, and carry out research activities which support the protection of public and private infrastructure, agricultural land, and natural areas from damages caused by stream channel erosion; 3.) plan and carry out region-wide implementation of measures to protect public and private infrastructure, agricultural land, and natural areas from damages caused by stream channel erosion; and 4.) plan and carry out projects and activities to conserve natural resources, promote rural development, and protect public and private infrastructure that are closely related to stream channel erosion and stabilization measures.

5.0 SUMMARY AND CONCLUSIONS

Efforts at the region-wide planning and implementation of stream channel erosion control measures in western Iowa were severely impeded by the lack of an organized approach to addressing the problem and developing alternative solutions. Local governments and agencies working on the issue of stream channel erosion found that such an approach was essential given the need to plan and design control measures based on an assessment of a stream's overall characteristics and the condition of affected land and infrastructure, facilitate the exchange of information concerning alternative designs for erosion control measures, and secure the technical and financial resources required to address an issue of the magnitude of stream channel erosion in western Iowa. This perceived need led to the creation and evolution of a series of organizational structures and corresponding administrative procedures.

The first of these organizations, the Degrading Streams Task Force (DSTF), was created in May, 1990 and consisted of the 8 counties in the Golden Hills Resource Conservation and Development (RC&D) area in southwest Iowa. The DSTFs success in drawing attention to the problem of stream channel erosion and obtaining support for demonstration erosion control projects and research activities led to the creation of the Hungry Canyons Alliance (HCA) in October, 1992. The HCA is a grass-roots, not-for-profit organization whose membership consists of 21 counties in western Iowa which are impacted by stream channel erosion. The HCA formalized the structure and procedures initially developed by the DSTF and continued the work of the DSTF to address issues related to stream channel erosion and its control. In May 1993, the HCA worked successfully to gain passage of legislation which authorized the Loess Hills Development and Conservation Authority. Creation of the Authority was considered an essential step in the overall approach to addressing stream channel erosion in western Iowa as its existence would emphasize the need for a sustained, long term approach to the problem of stream channel erosion, facilitate the acquisition of funds needed to support stream channel erosion control related activities and projects, and increase awareness of the problem and its alternative solutions among state legislators and agency heads.

These 3 organizations, the Degrading Streams Task Force, Hungry Canyons Alliance, and Loess Hills Development and Conservation Authority, have been successful in planning, directing technical and financial resources toward, and carrying out educational and research activities related to stream channel erosion and the demonstration of channel erosion control measures in western Iowa. The organizations have developed information systems and internal procedures to help assess the extent of stream channel erosion and its impact on associated land and infrastructure in order to prioritize the implementation of proposed control measures. The 3 organizations have, through their educational efforts, significantly increased the awareness and understanding of stream channel erosion in western Iowa among elected officials and agency personnel at the local, state, and federal levels. These educational efforts have generated widespread support for their activities. As a result, more than $1.6

million in federal funds have been appropriated for projects to demonstrate stream channel erosion control measures. In addition, at least $400,000 in funds from local governments have been used to implement these demonstration projects. The organizations have also acquired funds to support, actively participated in, and been responsible for planning and carrying out research activities related to stream channel erosion and its control. Technical assistance from numerous local, state, and federal agencies including county engineer offices, soil and water conservation districts, Iowa Departments of Transportation and Natural Resources, Iowa State University, USDA Natural Resources Conservation Service, US Geological Survey, and US Army Corps of Engineers has also been secured to support the educational, research, and demonstration activities and projects of the three organizations.

The organizational structure and administrative procedures sought after and developed during the course of the research project have been incorporated into and put into operation through the Loess Hills Development and Conservation Authority. The most significant challenge now facing member counties of the Authority and cooperating entities is the continued acquisition of financial support sufficient to carry out current and future activities and projects related to stream channel erosion control in western Iowa. To that end, the Authority, in consultation with cooperating entities, has developed and is actively pursuing the financial support required to implement its 5-year plan of work. The Authority's 5-year plan of work details specific goals and objectives which address the need for projects to demonstrate cost effective measures to control stream channel erosion, continued research activities to gain a better understanding of stream channel erosion processes and alternative control measures, and region-wide implementation of stream channel erosion control measures based upon the results of demonstration projects and research activities.

Request for Proposals Outline

Degrading Streams Task Force

I. Project Scope and Cost (Score 0-15)

   A. Stream Size

      1. Drainage area: total at mouth and at proposed stabilization site

      2. Channel length from beginning to end of degrading segment

   B. Proposed stabilization measures planned and their cost (preliminary concepts are acceptable)

II. Potential Damages (Score 0-40)

   A. Extent of erosion

      1. On main channel

      2. On tributaries

   B. Private and public infrastructure and other property threatened (bridges, culverts, roads, pipelines, cables, buildings, etc.)

      1. Number of each

      2. Anticipated repair and replacement costs (estimated)

   C. Imminent threat to any infrastructure, homes, or other buildings

   D. Potential loss of life

   E. Anticipated extra transportation costs caused by failures of infrastructure cited above.

III. Local Support (Score 0-35)

   A. Willingness of local governments or other entities to commit funds for part of project cost (include likely amount of local share)

   B. Willingness of local governments or other entities to assume responsibility for operation, maintenance, and repairs of erosion control structures after installation

   C. Complementary work done or planned in the area of the proposed stream by local entities such as upland conservation treatment

   D. Willingness of landowners in affected areas to cooperate

      1. Willingness to grant easements

      2. Other indications of cooperativeness

IV. Areas to Benefit (Score 0-10)

   A. List the communities and counties that will benefit from the project

Revised Request for Proposals Outline

Hungry Canyons Alliance/Loess Hills Development and Conservation Authority

I. Project Scope and Cost
   A. Stream Size
      1. Drainage area: total at mouth and at proposed stabilization site
      2. Channel length from beginning to end of degrading segment
   B. Proposed stabilization measures planned and their cost
      (cost effective measures are encouraged; preliminary concepts are acceptable)

II. Areas to Benefit
   A. List the communities and counties that will benefit from the project

III. Potential Damages (Score 0-60)
   A. Extent of erosion (Score 0 to 30)
      1. On main channel
      2. On tributaries
   B. Private and public infrastructure and other property threatened including bridges, culverts, roads, pipelines, cables, buildings, etc. (Score 0 to 21)
      1. Number of each
      2. Anticipated repair and replacement costs (estimated)
   C. Anticipated effects on essential community services caused by failure of infrastructure cited above such as mail delivery, emergency medical services, fire protection, school bus routes, delivery of agricultural supplies and commodities, extra transportation costs, etc. (Score 0 to 9)

IV. Local Support (Score 0-40)
   A. Willingness of local government to participate in regional stream stabilization efforts according to the following (Score 0 to 20)
      1. Counties that have not appointed a representative nor provided financial support to the Hungry Canyons Alliance (Score 0 to 7)
      2. Counties that have appointed a representative but have not provided financial support to the Hungry Canyons Alliance (Score 8 to 14)
      3. Counties that have appointed a representative and have provided financial support to the Hungry Canyons Alliance (Score 15 to 20)

Revised Request for Proposals Outline

Hungry Canyons Alliance/Loess Hills Development and Conservation Authority

IV. Local Support contd.

B. Additional indication of local support including the: a.) financial contribution committed by local sponsors toward the cost of the proposed project; b.) willingness of local sponsors to assume the future operation and maintenance of the project; c.) existence of complementary work completed or planned in the area of the proposed project such as upland conservation treatment; and d.) willingness of land owners in the areas affected by the project to cooperate with its implementation such as the granting of easements (Score 0 to 20)