Stevens Creek Watershed
Master Plan

Volume I

March 2005

Stevens Creek Watershed Master Plan

CITY OF LINCOLN
NEBRASKA
MAYOR COLEEN J. SENG
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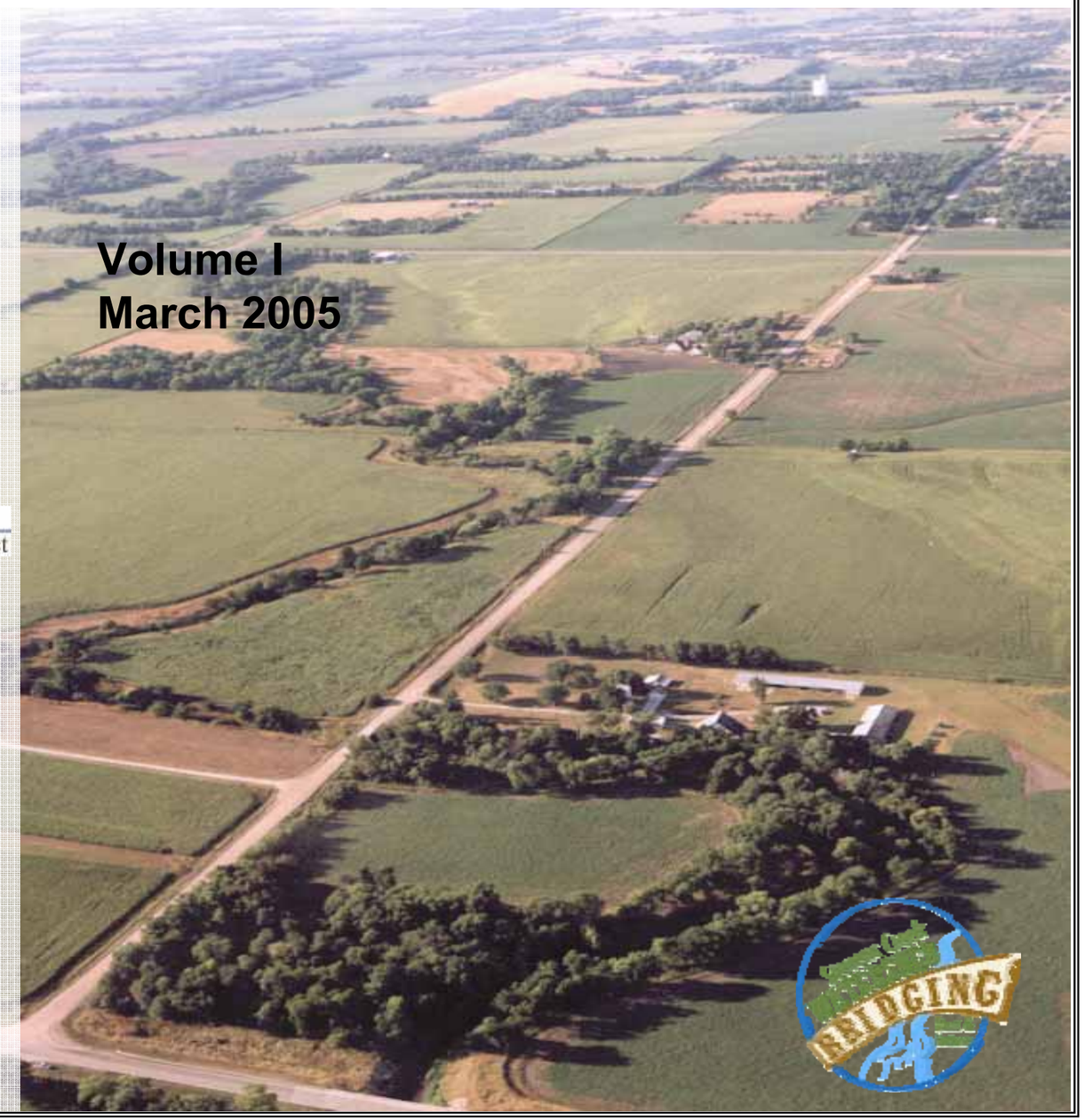
Lower Platte South
Natural Resources District



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CDM

In Association With
Intuition & Logic
Heartland Center
Kirkham Michael
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REGISTERED PROFESSIONAL ENGINEER
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STATE OF NEBRASKA

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Acronyms

BFE	base flood elevation
BMP	best management practice
CAFOs	confined animal feedlot operations
cfs	cubic feet per second
CIP	capital improvement project
CMP	corrugated metal pipe
DFIRM	Digital Flood Insurance Rate Map
EIS	environmental impact statement
EPA	Environmental Protection Agency
FEMA	Federal Emergency Management Agency
FIRM	Flood Insurance Rate Map
FIS	Flood Insurance Study
GIS	geographical information system
GPS	global positioning system
HEC-HMS	Hydrologic Engineering Center-Hydrologic Modeling System
LiDAR	light detection and ranging
NDOR	Nebraska Department of Roads
NPDES	National Pollutant Discharge Elimination System
NRCS	Natural Resources Conservation Service
NRD	Natural Resources District
RCB	reinforced concrete box
RCP	reinforced concrete pipe
STORM	Storage, Treatment, Overflow, and Runoff Model
TIN	triangular irregular network
U of N	University of Nebraska
USGS	United States Geological Survey
WQCV	water quality control volume
WSE	water surface elevation

Stevens Creek Watershed Master Plan

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Executive Summary

March 2005

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Natural Resources District

CDM

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Kirkham Michael
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Executive Summary

Introduction

The City of Lincoln (City) and the Lower Platte South Natural Resources District (NRD) are in the process of developing a Comprehensive Watershed Management Plan for the City of Lincoln and its future growth areas. This comprehensive watershed plan is being developed basin by basin, through the completion of watershed master plans for individual basins. Watershed master plans are used as planning tools to be referenced in conjunction with proposed development and as a guide in the preparation of future capital improvement projects.

The City and NRD have previously adopted watershed master plans for the Beal Slough and Southeast Upper Salt Creek basins (Figure ES-1). The Stevens Creek Watershed Master Plan (Master Plan) is the third master planning effort to date and is summarized in this report, together with the study components that served as its foundation. The Master Plan for the Stevens Creek Watershed has been prepared because significant near-term growth within the basin is expected as identified in the Lincoln-Lancaster County Comprehensive Plan.

The Stevens Creek Watershed is located immediately east of the City's existing municipal limits (Figure ES-1). The watershed drains approximately 55 square miles from the headwaters near Highway 2 to its confluence with Salt Creek located just north of Highway 6. The watershed is approximately 15 miles in length with a maximum width of about 6 miles. The purpose of the Master Plan is to outline long-term planning tools and improvement projects to address water quality, flood management, and stream stability to provide guidance for sustainable urban growth in the watershed.

The project team was led by the City and NRD, in cooperation with Lancaster County (County). The City/NRD retained the consultant team of Camp Dresser & McKee Inc. (CDM), in association with Intuition & Logic (I&L), Heartland Center for Leadership Development (HC), Kirkham Michael Consulting Engineers (KM), and E&A Consulting Group, Inc. (E&A) to provide assistance with the master planning effort.

Public Participation Process

As part of the master planning process, a comprehensive public participation process was used to solicit input from a broad range of stakeholder groups. The stakeholder groups included landowners, developers, realtors and other business interests, environmental groups, and neighborhood representatives. The public participation process included the following:

- A questionnaire sent to approximately 4,000 people early in the study process to gather input from a wide range of stakeholders.
- The involvement and input of a 25-member Citizen Advisory Committee representing a broad cross section of interests in the watershed, including elected officials, which met with the project team on a monthly basis. Committee members included Ann Bleed, Andrew Campbell, Robert Christiansen, Dick Dam, Mike Eckert, Peggy Fletcher, Beth Goble,

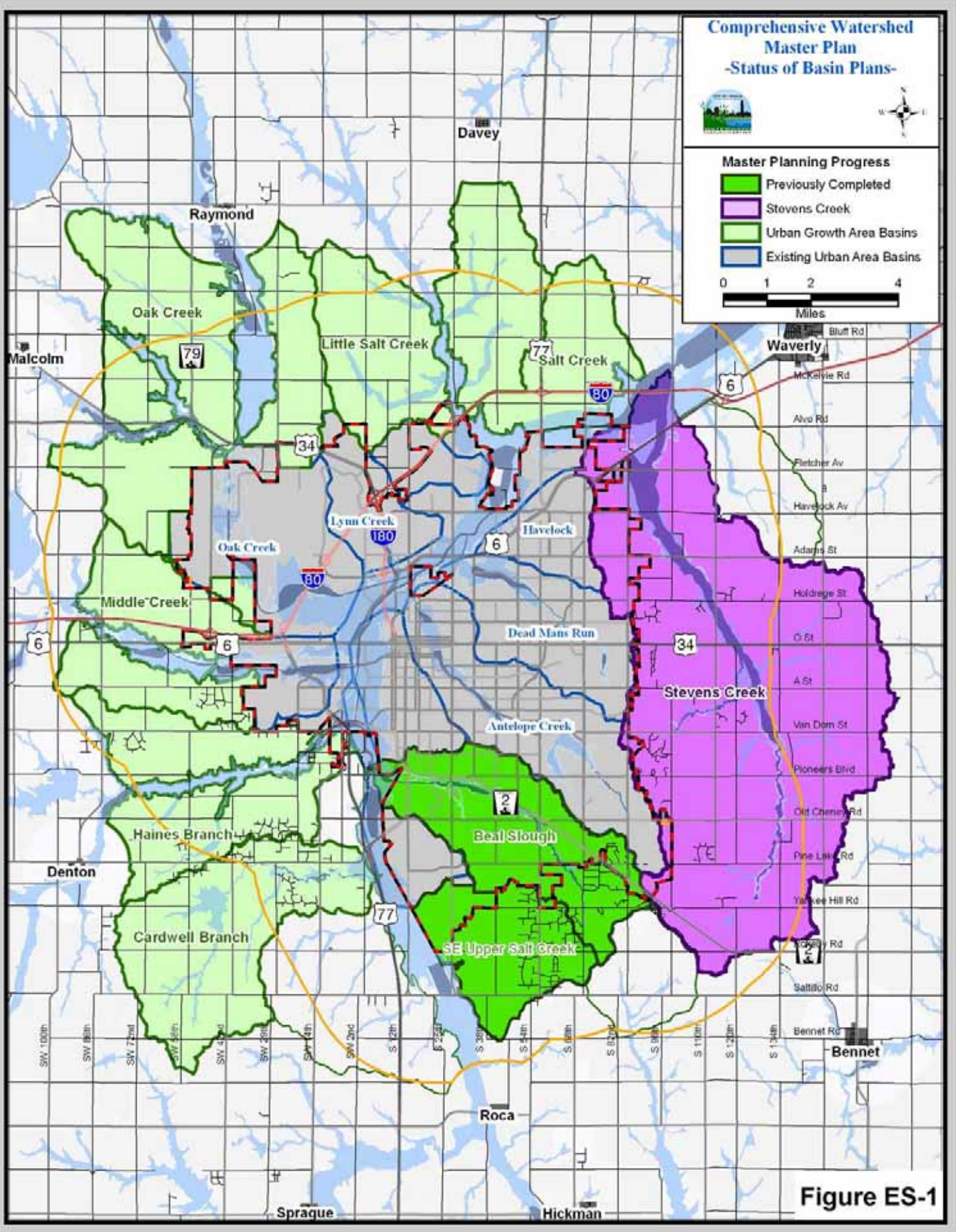

Comprehensive Watershed Master Plan
-Status of Basin Plans-
Master Planning Progress
Previously Completed
Stevens Creek
Urban Growth Area Basins
Existing Urban Area Basins
0 1 2 4
Miles
Davey
Raymond
Malcolm
Waverly
Denton
Roca
Sprague
Hickman
Bennet
Oak Creek
Little Salt Creek
Salt Creek
Lynn Creek
Oak Creek
Havelock
Middle Creek
Dead Mans Run
Stevens Creek
Antelope Creek
Haines Branch
Beal Slough
Cardwell Branch
SE Upper Salt Creek
Bluff Rd
McKelvie Rd
Alvo Rd
Fletcher Av
Havelock Av
Adams St
Holdrege St
O St
A St
Van Dorn St
Pioneers Blvd
Old Cheney Rd
Pine Lake Rd
Yankee Hill Rd
Saltillo Rd
Bennet Rd
SW 100th
SW 86th
SW 72nd
SW 56th
SW 42nd
SW 28th
SW 14th
SW 2nd
S 12th
S 28th
S 54th
S 68th
S 82nd
S 98th
S 110th
S 126th
S 134th

Figure ES-1

Rick Hodtwalker, Tony Koester, Marvin Lambie, Russell Miller, Kathy Newberg, Patte Newman, Brock Peters, Dean Petersen, Marleen Rickertsen, Jane Schroeder, Alan Slattery, Jason Smith, Steven Smith, Lyle Vannier, Jack Wagener, John Watson, Bob Wolf, and Bob Workman.

- A series of three open houses in September 2003, September 2004, and January 2005 that attracted over 500 people, and representation at four additional public information events.
- A series of six meetings with landowners regarding alternative management approaches.
- A series of three interest group meetings with a range of stakeholders to discuss alternative management approaches, attended by approximately 100 individuals.
- A series of eight newsletters mailed to over 700 individuals and organizations. In addition, a project website was used to post alternatives under consideration, upcoming events, and materials distributed to the Advisory Committee.
- Watershed bus tours for Advisory Committee members and elected officials.

The public input and feedback received during this process was used by the project team to formulate and refine its master plan recommendations. Section 1 of the Master Plan provides further details regarding the public participation process.

Master Plan Elements

The Master Plan consists of four major elements: 1) Floodplain Management Tools, 2) Capital Improvement Projects, 3) Site-Specific Structural Best Management Practices (BMPs), and 4) Opportunity Areas. A brief summary of each major element follows:

Floodplain Management Tools

One of the major elements of the Master Plan is updated 100-year floodplain and floodway boundary maps. This information will provide a planning tool to protect future homes and businesses from flood hazards and provide guidance for sustainable urban growth in the watershed. The Master Plan reflects the floodprone areas shown on Figure ES-2 as adopted by the City Council in December of 2004 for local regulatory purposes. The Master Plan recognizes that these floodprone areas will be reflected on the Federal Emergency Management Agency (FEMA) floodplain maps at some time in the future when FEMA finalizes the Flood Insurance Rate Map Physical Map Revision.

The Master Plan also includes a strategy for adopting design standards needed to address stormwater volume and timing issues of individual detention basins within the larger watershed to avoid adverse downstream flooding impacts. As described in Section 6, this will involve using the computer models developed as part of the master planning process to design stormwater facilities for private development. In addition, the Master Plan assumes the goals and objectives of the Comprehensive Plan regarding floodplain management and the Flood Standards for New Growth Areas will be implemented. These

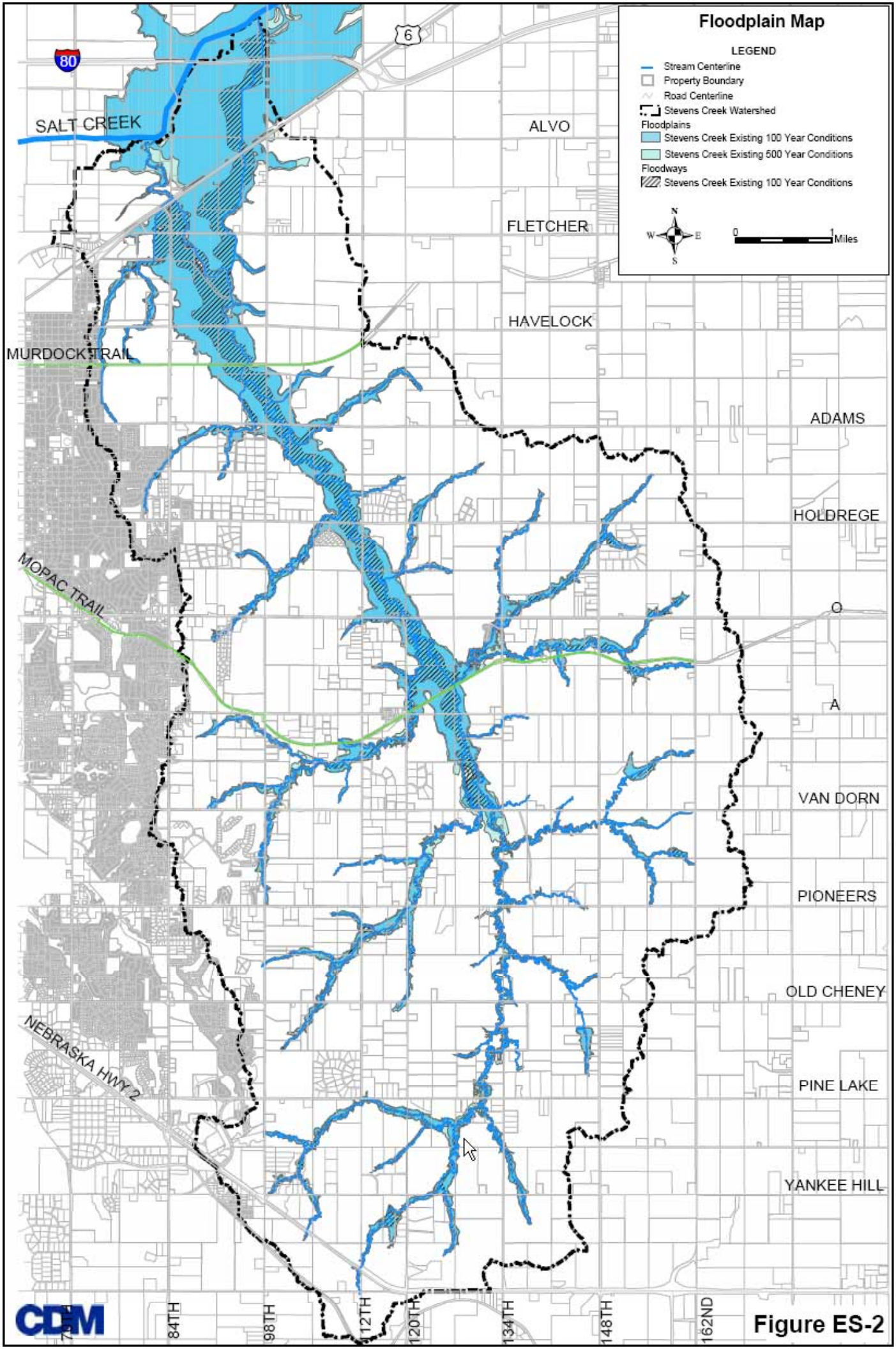

Floodplain Map
LEGEND
Stream Centerline
Property Boundary
Road Centerline
Stevens Creek Watershed
Floodplains
Stevens Creek Existing 100 Year Conditions
Stevens Creek Existing 500 Year Conditions
Floodways
Stevens Creek Existing 100 Year Conditions
N
W
E
S
0
1
Miles
80
6
SALT CREEK
ALVO
FLETCHER
HAVELOCK
MURDOCK TRAIL
ADAMS
HOLDREGE
MOPAC TRAIL
O
A
VAN DORN
PIONEERS
OLD CHENEY
NEBRASKA HWY 2
PINE LAKE
YANKEE HILL
84TH
98TH
112TH
120TH
134TH
148TH
162ND
CDM

Figure ES-2

include designating areas for future urban development generally outside of the floodplain and applying No Net Rise, Compensatory Storage, and preservation of Minimum Flood Corridors where development encroaches into the floodplain.

Capital Improvement Projects

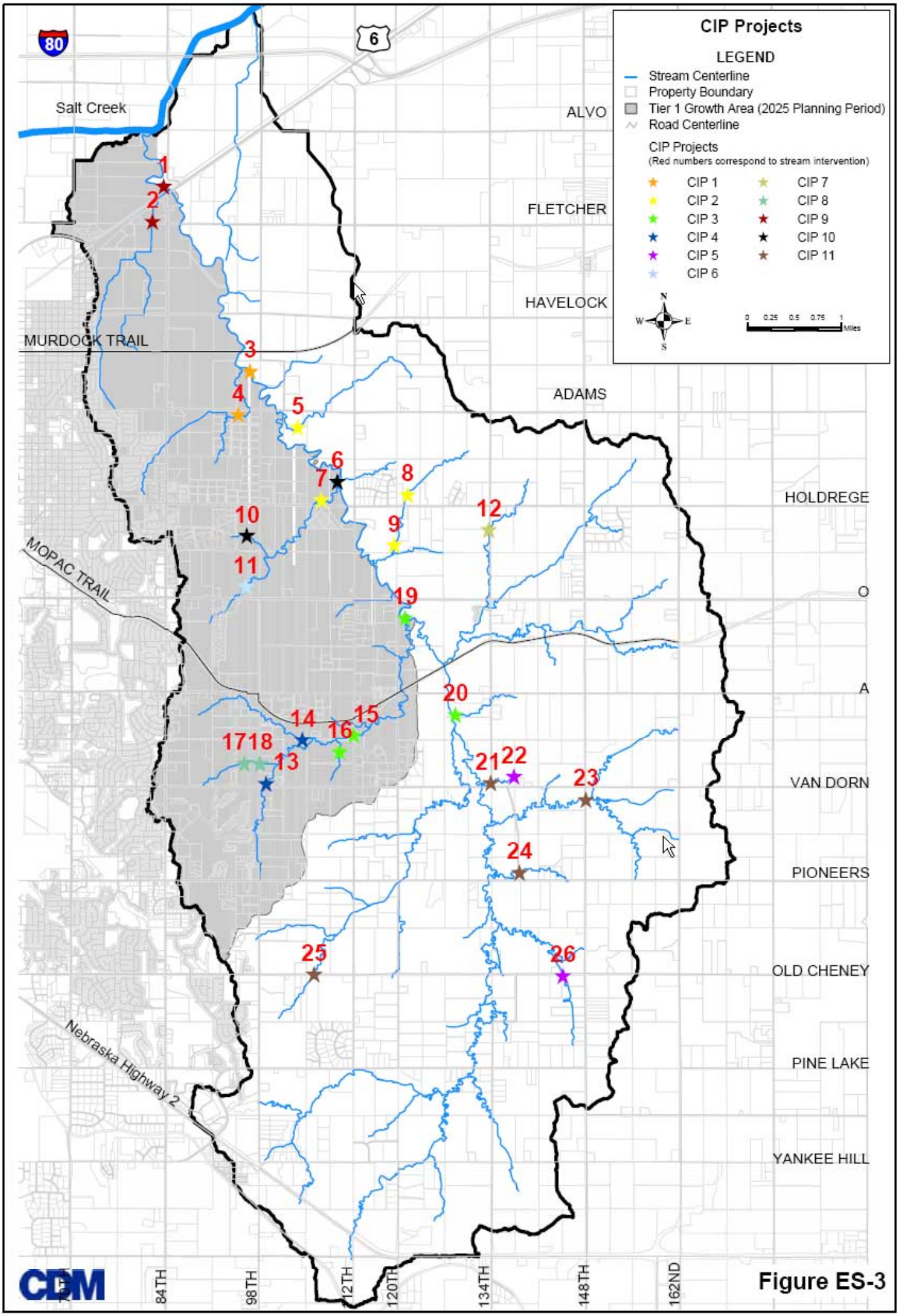
The process of formulating capital improvement projects required the identification of primary and secondary problem areas in relation to the public interest. Primary problems are those that pose a public safety concern with respect to building flooding, stream instability, or severe maintenance conditions. In addition, primary problems include systemic problems that create a clear influence elsewhere in the watershed and will be significantly more costly to address the longer they are delayed into the future.

Secondary problems include sites where stream degradation or instability exist but are not likely to propagate to other areas of the watershed. Secondary problems also include infrequent flooding of habitable buildings. Secondary problems are not considered as serious primary problems and should be addressed in conjunction with other infrastructure projects occurring in the watershed. For example, many secondary problems can be addressed at the same time roadways are improved and water and wastewater pipelines are installed if they are located in the same general vicinity. In addition, secondary problems can be combined with routine maintenance activities.

The Master Plan includes 11 capital improvement projects to address the 26 primary problem areas identified in the watershed. In this watershed, only stream instability problems met the criteria for primary classification. The primary problem areas were grouped and prioritized to form the basis for 11 capital improvement projects that are shown on Figure ES-3. The photographs shown below illustrate the typical type of improvements recommended for the Stevens Creek Watershed. The total capital cost for all 11 capital improvement projects is estimated to be approximately $10.3 million as summarized in Table ES-1. Section 9 of the Master Plan provides further detail regarding the classification process and conceptual improvements for the 26 primary problem areas.

Typical stream improvement project recommended for Stevens Creek.

6 months after construction


CIP Projects
LEGEND
Stream Centerline
Property Boundary
Tier 1 Growth Area (2025 Planning Period)
Road Centerline
CIP Projects
(Red numbers correspond to stream intervention)
CIP 1
CIP 2
CIP 3
CIP 4
CIP 5
CIP 6
CIP 7
CIP 8
CIP 9
CIP 10
CIP 11
N
W
E
S
0 0.25 0.5 0.75 1 Miles
80
6
Salt Creek
ALVO
FLETCHER
HAVELOCK
MURDOCK TRAIL
ADAMS
HOLDREGE
MOPAC TRAIL
O
A
VAN DORN
PIONEERS
OLD CHENEY
PINE LAKE
YANKEE HILL
Nebraska Highway 2
84TH
98TH
112TH
120TH
134TH
148TH
162ND
1
2
3
4
5
6
7
8
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CDM

Figure ES-3

Table ES-1
Capital Improvement Project List

Capital Improvement Project	Stream Intervention Number	Construction Sequence	Project Cost
1	3	1	$1,256,000
	4	1	
2	5	1	$1,336,000
	7	1	
	9	1	
	8	1	
3	19	1	$1,201,000
	15	1	
	16	1	
	20	1	
4	14	2	$776,000
	13	2	
5	22	2	$725,000
	26	2	
6	11	3	$863,000
7	12	3	$1,118,000
8	17	3	$1,006,000
	18	4	
9	1	3	$657,000
	2	4	
10	6	4	$748,000
	10	4	
11	21	4	$594,000
	23	4	
	24	4	
	25	4	
		Total	$10,280,000

The City, County, and NRD should use this Master Plan as a reference and guide for the implementation of improvement projects in the Stevens Creek Watershed through the City and County Capital Improvement Programs and NRD's Long Range Implementation Plan. The agencies should use cooperative efforts to address project timing, prioritization between basins, and the sharing of responsibility.

Site-Specific Structural Best Management Practices

The Master Plan includes using structural BMPs to offset the impacts from urban development on stream stability and water quality. The urbanization process significantly alters the hydrologic characteristics of a watershed, increasing flow rate, volume, and velocity of stormwater runoff, which causes long-term erosion problems. In addition, the impervious surface area collects pollutants such as oil and grease that leak from automobiles, which are eventually washed away by the stormwater runoff into natural streams and lakes. Structural BMPs are constructed facilities designed to remove pollutants and slow down the runoff before the stormwater enters the receiving stream. Structural BMPs are designed to address the smaller, more frequent rainstorms that carry the majority of pollutants and are believed to cause the greatest amount of erosion and sediment deposition.

Two alternative methods were generated to install BMPs in the watershed based on a range of approaches discussed with the Citizen Advisory Committee. The methods included 1) Regional Structural BMPs, and 2) Site-Specific Structural BMPs. Advantages and disadvantages for each method were evaluated, which included an analysis of cost and effectiveness. The evaluation is described in Section 6 of the Master Plan and resulted in selecting site-specific structural BMPs as the recommended alternative. This method provides a cost-effective approach to maintain the integrity of the natural streams, preserve water quality, and can be efficiently integrated in the City's current development standards. The Master Plan includes guidance for revisions to the City's design standards for site-specific BMPs, which would be applied consistently to all new developments. Section 7 of the Master Plan provides further details on how to integrate structural BMPs into new development sites. When revised design standards are drafted, all low cost options providing the same or greater water quality benefits should be considered and included as options for the developer.

Currently, City standards for new developments require detention basins designed to control the 2-, 10-, and 100-year storm events. Structural BMPs can be efficiently integrated with detention basins as shown on Figure ES-4. This includes adding a sediment forebay and designing the outlet structure to control the smaller, more frequent rainstorms. This integrated facility will provide both water quantity (flooding) and quality (pollutant removal and stream stability) benefits**.** Structural BMPs can also be integrated into the site using alternative approaches independent from the stormwater detention basin.

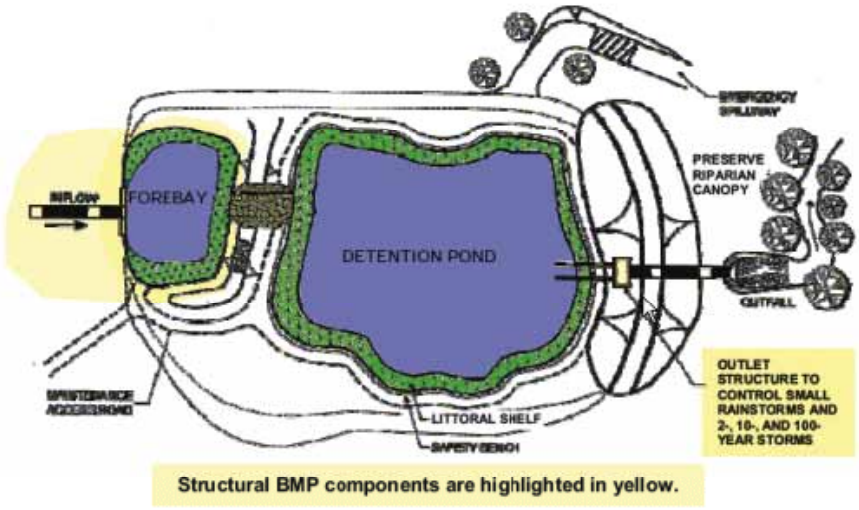


Figure ES-4
Integrated Detention Pond and Structural BMP

The estimated cost to integrate a structural BMP into the City's current detention basin design requirements is $210 per acre of drainage area. The additional cost for maintenance is estimated to be $500 per year per facility.

One of the key concerns expressed during the public participation process was the question of who should bear the cost for offsetting the impacts to water quality and stream stability caused by future urbanization. In response to this input, the cost-share concept embodied in this Master Plan assumes that there is both private and public responsibility relative to how structural BMPs function together as a system to address water quality and stream stability throughout the watershed. The following concepts are embodied as part of this Master Plan element that outline public/private roles and responsibilities:

- A public-private cost share concept where the City and NRD share in the cost of constructing the BMP portion of the facility, jointly providing funding for $100 of the $210 cost estimated per acre of drainage area. City/NRD funding is anticipated to be provided on a first-come, first-serve basis and be contingent upon City/NRD approval of the proposed cost share program. In addition, the cost share program would be subject to yearly budget approvals, voter approval of general obligation bonds, and NRD board approval.

- Revisions to the subdivision standards to require a $2,500 escrow for the first 5 years of maintenance ($500/year).

- Revisions to the drainage standards to establish uniform criteria for the development of a maintenance plan to be submitted with the preliminary plat and referenced in the subdivision agreement. A good maintenance plan will not only provide a guide for future property owners but will help ensure that maintenance responsibilities are clear when ownership is transferred from the developer.

- The development of a proactive education program by the City/NRD.

- The improvement/refinement of the City/NRD partnership to share in the responsibility of inspections on a regular rotation basis.

Opportunity Areas

Figure ES-5 is a Watershed Planning Map that overlays a wide variety of natural and built elements to support an integrated approach to watershed planning in Stevens Creek. Opportunity Areas are very general planning locations within the watershed that highlight where natural elements and/or existing or future infrastructure come together. These are areas with the potential for multiple benefits and opportunities to protect or enhance features like floodplains, natural resources, historical and cultural features, and open space.

Four Opportunity Areas are highlighted on the map along the Salt Valley Heritage Greenway, which follows the main channel of Stevens Creek. These highlighted areas generally recognize where natural features like the floodplain and drainage corridors overlap or are in the vicinity of other elements such as the East Beltway corridor, existing or future trails, NRD conservation easements, or historical and cultural resources.

As future planning continues for Stevens Creek, these areas should be referenced as a guide by City and County departments and the NRD, particularly with regard to opportunities to integrate parks, open space, and stormwater or floodplain benefits.

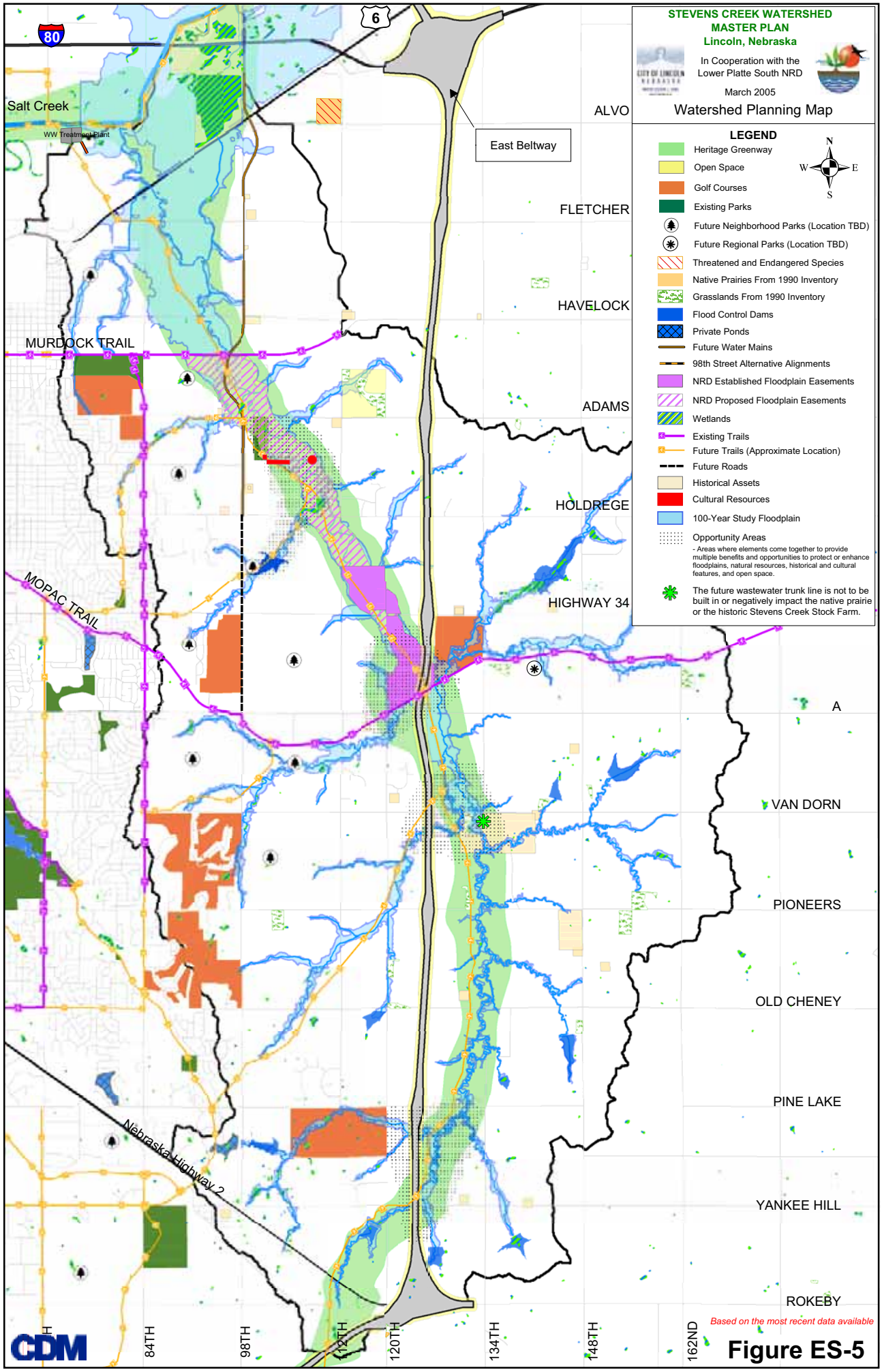

STEVENS CREEK WATERSHED
MASTER PLAN
Lincoln, Nebraska
In Cooperation with the
Lower Platte South NRD
March 2005
Watershed Planning Map
LEGEND
Heritage Greenway
Open Space
Golf Courses
Existing Parks
Future Neighborhood Parks (Location TBD)
Future Regional Parks (Location TBD)
Threatened and Endangered Species
Native Prairies From 1990 Inventory
Grasslands From 1990 Inventory
Flood Control Dams
Private Ponds
Future Water Mains
98th Street Alternative Alignments
NRD Established Floodplain Easements
NRD Proposed Floodplain Easements
Wetlands
Existing Trails
Future Trails (Approximate Location)
Future Roads
Historical Assets
Cultural Resources
100-Year Study Floodplain
Opportunity Areas
- Areas where elements come together to provide multiple benefits and opportunities to protect or enhance floodplains, natural resources, historical and cultural features, and open space.
The future wastewater trunk line is not to be built in or negatively impact the native prairie or the historic Stevens Creek Stock Farm.
N
W
E
S
80
6
Salt Creek
WW Treatment Plant
East Beltway
ALVO
FLETCHER
HAVELOCK
ADAMS
HOLDREGE
HIGHWAY 34
MURDOCK TRAIL
MOPAC TRAIL
Nebraska Highway 2
A
VAN DORN
PIONEERS
OLD CHENEY
PINE LAKE
YANKEE HILL
ROKEBY
84TH
98TH
120TH
134TH
148TH
162ND
CDM
Based on the most recent data available

Figure ES-5

Summary

The Stevens Creek Watershed Master Plan provides the City and NRD with the necessary planning tools and capital improvement projects to address flood management, water quality, and stream stability for achieving sustainable urban growth in the watershed. By using the detailed study information and applying the Master Plan elements described above, multiple goals will be achieved including:

- Protection of future homes and businesses from flood hazards
- Reduction of future impacts to water quality and stream stability due to urbanization
- Preservation of aquatic and riparian habitat
- Long-term stream stability that protects public infrastructure
- Development guidelines that address stormwater quantity and quality
- Opportunities for multiple benefits through an integrated approach to watershed planning

Section 1
Introduction and Purpose

1.1 Introduction

The City of Lincoln (City) and the Lower Platte South Natural Resources District (NRD) are in the process of developing a Comprehensive Watershed Management Plan for the City of Lincoln and its future growth areas. This comprehensive watershed plan is being developed basin by basin, through the completion of watershed master plans for individual basins. Watershed master plans are used as planning tools to be referenced in conjunction with proposed development and as a guide in the preparation of future capital improvement projects.

The City and NRD have previously adopted watershed master plans for the Beal Slough and Southeast Upper Salt Creek basins (Figure 1-1). The Stevens Creek Watershed Master Plan (Master Plan) is the third master planning effort to date and is summarized in this report, together with the study components that served as its foundation. The Master Plan for the Stevens Creek Watershed has been prepared because significant near-term growth within the basin is expected as identified in the Lincoln-Lancaster County Comprehensive Plan.

The Stevens Creek Watershed is located immediately east of the City's existing municipal limits (Figure 1-1). The watershed drains approximately 55 square miles from the headwaters near Highway 2 to its confluence with Salt Creek located just north of Highway 6. The watershed is approximately 15 miles in length with a maximum width of about 6 miles. The purpose of the Master Plan is to outline long-term planning tools and improvement projects to address water quality, flood management, and stream stability to provide guidance for sustainable urban growth in the watershed.

The project team was lead by the City and NRD, in cooperation with Lancaster County (County). The City/NRD retained the consultant team of Camp Dresser & McKee Inc. (CDM), in association with Intuition & Logic (I&L), Heartland Center for Leadership Development (HC), Kirkham Michael Consulting Engineers (KM), and E&A Consulting Group, Inc. (E&A) to provide assistance with the planning effort. Figure 1-2 shows the project organizational chart. At the outset of the study process, the project team developed a study logo depicting the over reaching theme of providing a "bridge" between preserving the watershed's natural resources while embracing future growth.

Study Logo

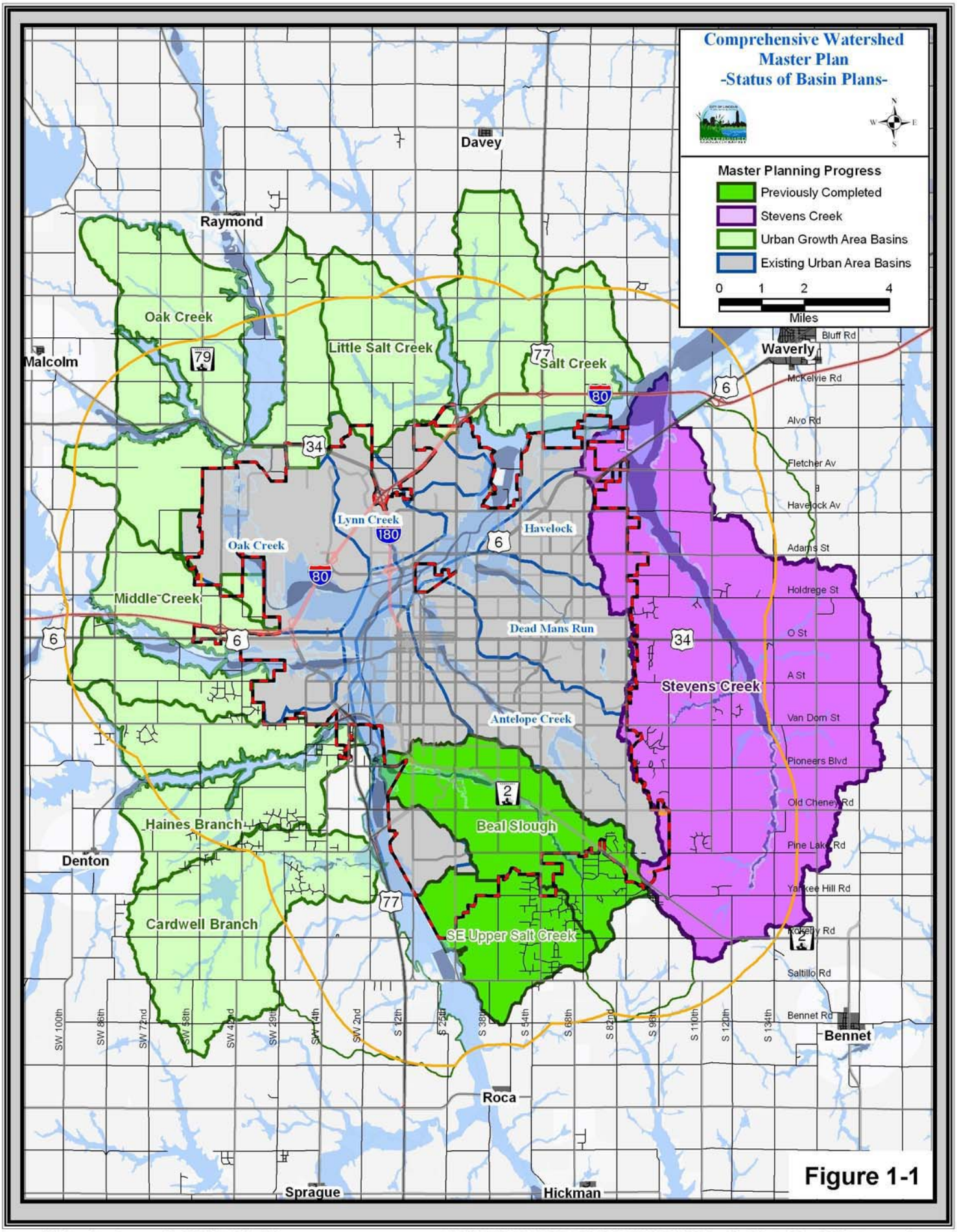

Comprehensive Watershed Master Plan
-Status of Basin Plans-
Master Planning Progress
Previously Completed
Stevens Creek
Urban Growth Area Basins
Existing Urban Area Basins
0 1 2 4
Miles
Davey
Raymond
Malcolm
Oak Creek
Little Salt Creek
Salt Creek
Waverly
Bluff Rd
McKelvie Rd
Alvo Rd
Fletcher Av
Havelock Av
Adams St
Holdrege St
O St
A St
Van Dorn St
Pioneers Blvd
Old Cheney Rd
Pine Lake Rd
Yankee Hill Rd
Rokeby Rd
Saltillo Rd
Bennet Rd
Bennet
Lynn Creek
Havelock
Oak Creek
Middle Creek
Dead Mans Run
Stevens Creek
Antelope Creek
Beal Slough
Haines Branch
Denton
Cardwell Branch
SE Upper Salt Creek
Roca
Sprague
Hickman
SW 100th
SW 86th
SW 72nd
SW 58th
SW 43rd
SW 29th
SW 14th
SW 2nd
S 12th
S 25th
S 38th
S 54th
S 68th
S 82nd
S 96th
S 110th
S 120th
S 134th

Figure 1-1

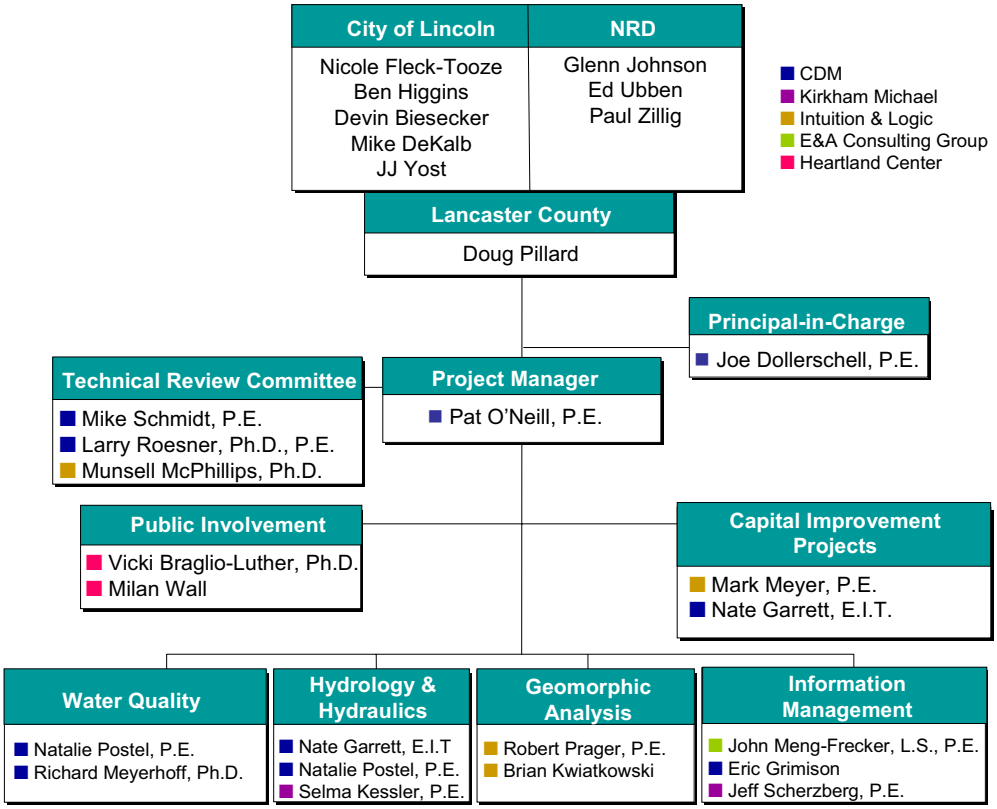


Figure 1-2
Project Organizational Chart

1.2 Goals and Objectives

The goal of the study was to develop a Watershed Master Plan with planning tools and improvement projects to address flood management, water quality, and stream stability to provide guidance for achieving sustainable urban growth in the watershed. The study included a wide range of services organized into the following major components. This approach places emphasis on preservation and prevention rather than future reactive measures that are difficult and costly to implement. The study included a wide range of services organized into the following major components:

Data Collection

- Watershed inventory to collect existing information applicable to the watershed
- Field survey to collect data describing the physical aspects of the drainage system

Hydrology and Hydraulics

- GIS based HEC-HMS and HEC-RAS computer model simulating the hydrologic and hydraulic aspects of the watershed, using subareas no larger than 150 acres at the upper reaches of the drainage system.
- Floodplain boundaries using HEC-GeoRAS that represent existing land use conditions. In addition, floodway boundaries were developed.
- Federal Emergency Management Agency (FEMA) submittal documents necessary for Digital Flood Insurance Rate Map (DFIRM) application.

Water Quality
- Stream bioassessment to characterize the current ecological health of the stream
- Stream sustainability analysis to provide guidance for providing long-term stream stability
- Watershed management evaluation to provide guidance on future development practices
- Review of the City's Drainage Criteria Manual to provide guidance on applying applicable best management practices (BMPs)

Stream Stability
- Geomorphic field investigation to document the condition of the stream
- Geomorphic analysis to diagnose the stability of the stream

Capital Improvement Projects
- Conceptual improvement projects to alleviate flooding and stream instability problems
- Integrated resource planning to provide coordination efforts with other planning initiatives within the watershed

Public Participation
- Questionnaire mailed to property owners and others to solicit input about various watershed topics and issues
- Open houses, property owner meetings, and stakeholder sessions to disememinate information and solicit feedback from the public
- Citizen advisory meetings and bus tours to receive input from various interest groups and elected officials
- Newsletters and study website designed to inform the public about the study and to post preliminary results

Geographic Information System (GIS) Services
- GIS products designed to enhance the usability of key study products. The GIS product descriptions are described in Section 11 and provided in Appendix A, located in Volume II of this report.

1.3 Public Participation Process

Through each stage of the study, active citizen participation was a hallmark of the watershed evaluation process. Citizens and stakeholders were offered a variety of ways to provide input to the study and to contribute to the development of alternative concepts and solutions. Each public involvement activity provided the project team with ideas for presenting and refining its recommendation. The following is a summary of the various components of the public participation process.

1.3.1 Questionnaire Survey

A questionnaire on the Stevens Creek Watershed was sent out in mid-December 2003 to about 4,000 Stevens Creek landowners, local and state agency staff, a broad range of interest groups, and others.

The City received responses from 74 people. The responses were categorized based on the demographics depicted on Figure 1-3. The number of years for those living or working in the watershed ranged from 1 to 70.

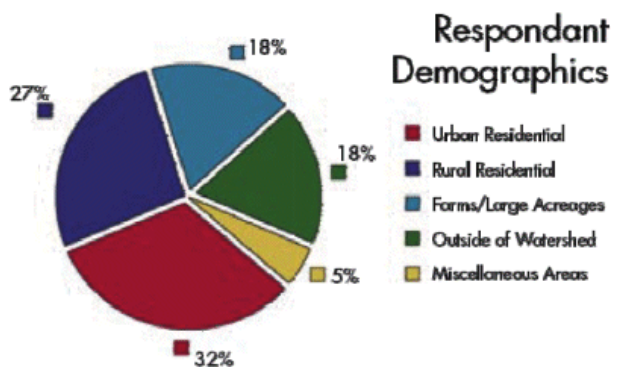


Figure 1-3
Watershed Demographics

About 20 percent of the respondents with comments had concerns about issues (potable water, wastewater, east beltway, recreation) not directly addressed by the study. Copies of those responses were forwarded to the responsible agencies for their information and reply as appropriate. Information on the responses that related to specific drainage issues was forwarded to the project team for their use.

Over half of the respondents with comments had concerns about flooding (i.e., negative impacts from development, specific issues, or general concerns). Slightly less than half stated that much of the existing area should be left in a natural condition and/or that the floodplain/floodprone areas should remain as open space or buffer area. About 10 percent recommended specific flood control structures such as dams. One respondent said that levees should be constructed. A little more than 5 percent said the flooding was minimal and not an important concern. Figure 1-4 summarizes the questionnaire responses.

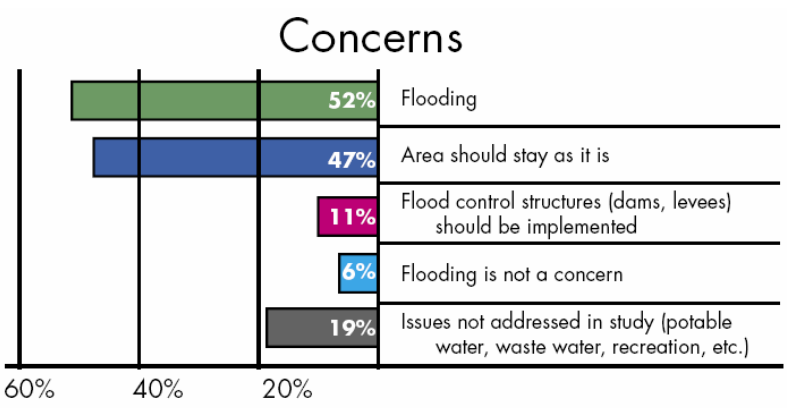


Figure 1-4
Questionnaire Responses

In regard to the natural and beneficial functions of floodplains, approximately 15 percent specifically identified stream water quality as an important issue, and over 15 percent cited multi-use of open space (e.g., trails) as an important consideration. A little less than 20 percent stated that habitat and wildlife preservation were critical for the watershed, and about a third of the respondents mentioned that up-front planning was an important component toward developing a sustainable watershed. Less than 5 percent mentioned that development should proceed without restrictions and/or that property rights were the most critical item to be considered.

Input received through the questionnaire was used by the project team in the evaluation of the watershed and development of alternative concepts for public review and comment.

1.3.2 Open House Events

A series of three open house events was held during the study to present preliminary results and solicit input from the public. All three events followed the same general format consisting of formal presentations offered at 5:30 and 7:00 p.m. Following the formal presentations, participants were encouraged to visit information stations and to discuss their concerns with representatives from the project team. The events were held at the Boy Scouts Cornhusker Council located near Walton, Nebraska. A summary of each open house event is provided below.

Open House Events were well attended and provided valuable information to the public.

Information Stations were used to display preliminary study results.

Approximately 245 citizens participated in the first open house held on September 16, 2003. The first open house was designed to provide an overview of the study, including background information, major technical themes, and the public participation process to be conducted throughout the study effort. Following the formal presentations, participants were encouraged to visit four information stations set up around the room. The four stations addressed the following major topics: major study components, NRD activities, City-County Comprehensive Plan, and Parks and Recreation activities.

Over 150 people attended the second open house held on September 13, 2004. The second open house covered the preliminary findings of the three major study themes including hydrology and hydraulics, water quality, and geomorphology. Alternative management methods to address future urbanization were also discussed at length and were included as handouts for all participants. Following the formal presentations, participants were encouraged to visit numerous information stations that provided additional detail on the alternative management methods, the draft Stevens Creek floodplain and floodway maps, and stream erosion problem areas.

Nearly 125 people attended the third open house held on January 26, 2005. The third open house focused on presenting the Master Plan recommendations consisting of four major elements: 1) Floodplain Management Tools, 2) Capital Improvements Projects, 3) Site-Specific Structural Best Management Practices, and 4) Opportunity Areas. The draft

Executive Summary and fact sheets covering the various components of the study were included as handouts for all participants. Following the formal presentations, participants were encouraged to visit information stations covering the four major Master Plan elements. In addition, participants were encouraged to fill out comment cards regarding the Master Plan recommendations. A copy of the submitted comment cards is provided in Appendix B, located in Volume II of this report.

1.3.3 Citizen Advisory Committee

An important part of the study was the participation and review process of the Citizen Advisory Committee. At the first open house event, an Expression of Interest Form was made available for those citizens interested in serving on the committee. The form was also made available on the study website.

Balancing interests, perspectives, geography, and gender resulted in a 25-member group with City/NRD/County representatives. Roughly one-third of the group represented land and homeowners from the watershed, another third the interests of conservation and preservation, and the remaining third representing the development and business community. The mission of the committee was to provide review and input on preliminary study results, offer advice and oversight, and to serve as a liaison to the rest of the community. The committee members included Ann Bleed, Andrew Campbell, Robert Christiansen, Dick Dam, Mike Eckert, Peggy Fletcher, Beth Goble, Rick Hodtwalker, Tony Koester, Marvin Lambie, Russell Miller, Kathy Newberg, Patte Newman, Brock Peters, Dean Petersen, Marleen Rickertsen, Jane Schroeder, Alan Slattery, Jason Smith, Steven Smith, Lyle Vannier, Jack Wagener, John Watson, Bob Wolf, and Bob Workman.

The project team held a series of 6 monthly committee meetings that started in May 2004 and ended in October 2004. In addition, special makeup sessions were organized for members who were unable to attend all six meetings. In response to requests for an additional session, a seventh meeting was held on January 20, 2005 to review the draft study recommendations.

As a way to disseminate study findings and draft recommendations, the project team developed a series of summary documents that addressed key findings of the study. These summary documents were distributed to the committee members during the course of the seven meetings, were also made available at the second and third open houses, and were posted on the study website.

A copy of the summary documents, meeting minutes, and attendance records are provided in Appendix B, located in Volume II of this report.

1.3.4 Property Owner Meetings and Stakeholder Sessions

Six separate property owner meetings were held at the Boy Scouts Cornhusker Council on September 8 and 9, 2004 to discuss special issues and potential impacts regarding alternative watershed management approaches. The meetings were conducted and facilitated by members of the project team.

A series of three stakeholder session meetings was held to solicit input on draft study recommendations. The first session, held on September 20, 2004, was conducted to obtain feedback from developers, realtors, and legal entities; the second session, held on September 21, 2004, was designed to obtain feedback from environmental groups; while the third session, held on October 12, 2004, was an open forum format representing all interest groups. The first two sessions were held at the F Street Community Center, while the third session was held at the Boy Scouts Cornhusker Council.

WATERSHED NEWS

NOVEMBER 2004

WATER QUALITY AND STREAM STABILITY: COST SHARING AND MAINTENANCE

The question of who bears the cost for offsetting impacts to water quality and stream stability caused by future urbanization is a policy issue that must be determined by the community. In some communities, each private development bears these costs, while other communities provide some public funding for construction and maintenance.

A proposed method of offsetting future urbanization impacts is a water quality/stream stability structural best management practice (i.e. structural BMP).

One of the issues we have heard expressed regarding this method is that consideration should be given to some cost sharing by the public sector. This approach assumes that there is both private responsibility to offset impacts from development, as well as public responsibility to ensure that best management practices (BMPs) function together as a system throughout the watershed.

The estimated construction cost to incorporate structural BMPs into the current design of detention/retention basins is approximately $200 per drainage acre that drains to the detention/retention basin. With a cost-share concept, the City and NRD would share the cost of constructing the structural BMP portion of the facility, jointly providing funding for $100 per acre of drainage area.

For example: In a 75-acre average drainage area, the construction cost for the structural BMP is estimated to be approximately $15,000. At $100 per acre, the City/NRD cost-share for construction would be $7,500. The

Integrated Detention Pond and Structural BMP

STRUCTURAL BMP COMPONENTS ARE HIGHLIGHTED

MEET THE TEAM

VICKI LUTHER

HEARTLAND CENTER FOR LEADERSHIP DEVELOPMENT
LINCOLN, NE

Q: What is your role in this project?

A: I am the Co-Director of the Heartland Center for Leadership Development, which serves as the facilitator for public involvement in the Stevens Creek Watershed Management Planning Study. Our role is to help provide citizens with information about this project and to gather input and feedback from the public that will inform the project team.

Q: How does public involvement work in a project like this one?

A: Our goal is to create opportunities for people to come together and share ideas about how future decisions will be made in the basin. The first step is to make

WATERSHED NEWS NOVEMBER 2004

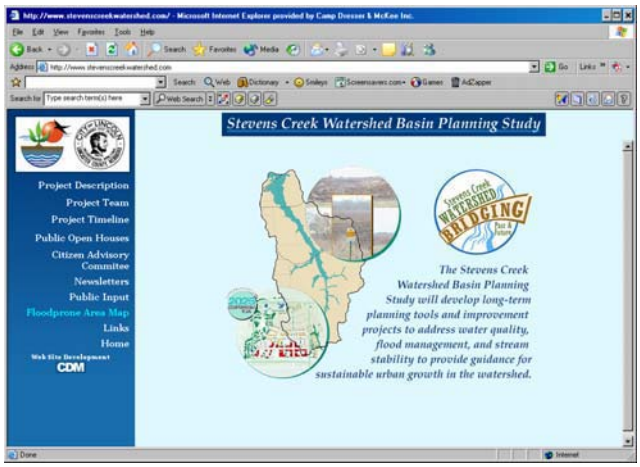
November 2004 Issue

Nearly 100 individuals provided feedback and suggestions during the three stakeholder sessions, which were recorded by the project team. The feedback was then consolidated into the nine most frequently raised issues and was utilized in developing the final Master Plan recommendations. These nine issues along with the project team's responses are provided in Appendix B, located in Volume II of this report.

1.3.5 Website and Newsletter

A series of eight newsletters (Watershed News) and a project website were used to disseminate information about the study process and Master Plan recommendations. Each newsletter edition was mailed to over 700 people and provided an effective means of informing the public about key aspects of the project. See Appendix B for a copy of each Newsletter.

The project website (www.stevenscreekwatershed.com) was another mechanism used to inform the public about the progress of the study. The website contains general background information, preliminary study results, and handout materials that were distributed at the Advisory Committee meetings and open houses. The website was regularly updated throughout the study process and was used to advertise upcoming events.



www.stevenscreekwatershed.com

1.3.6 Watershed Bus Tours

On April 15, 2004 the Citizen Advisory Committee toured the watershed on a route that highlighted stream conditions, drainage infrastructure, existing and proposed NRD projects, and cultural and historical features. A similar bus tour was conducted on October 18, 2004 for elected and appointed officials. The project team provided commentary during both bus tours.

Committee members and the project team discussed the creek's condition during the bus tour.

Section 2
Data Collection and Development

2.1 Watershed Inventory

The watershed inventory consisted of collecting, compiling, and evaluating existing data applicable to the Stevens Creek Watershed Master Plan development. A data search was conducted to identify existing information to be used by the project team. The digital and hardcopy information collected and compiled during the study is provided below.

Digital Information

- Existing and future land use data
- Comprehensive plan tiers and priority areas for future growth
- Existing and future trails, native prairies, wetlands, historical and cultural assets
- 2002 color aerial photography
- 1997 topographic contour maps with 2-foot contour intervals
- USGS LiDAR information, flown between November 2003 and January 2004
- Existing FEMA floodplain and floodway boundaries
- Land parcel information

Hardcopy Information

The hardcopy information was organized into five Project Information Notebooks, which were compiled and submitted to the City/NRD under separate cover. Table 2-1 summarizes the information contained in each information notebook.

Table 2-1
Project Information Notebooks – Summary of Data

Section	*Title*	*Date*	*Source*	*Project Notebook No.*
1	Dry Weather Stormwater Monitoring	April 29, 2001	U of N at Lincoln	I
2	Design Drawings for Ponds and Drainage Structures/Bridges	Various	NRD - Ponds Lancaster Co. - Drainage Structures/Bridge	I
3	Beltway EIS	June 14, 2002	NDOR	II
4	BMP (Best Management Practices)	Jan-Feb 2003	U of N at Lincoln	II
5	Floodplain Task Force Recommendations	Various	City of Lincoln	II
6	Stevens Creek Planning Initiative	April 2001	City of Lincoln	II
7	Stevens Creek Reconnaissance Study: Lower Channel Analysis; Open Space Preservation Lower Platte South Natural Resource District	Various	NRD	II
8	Results of the Nationwide Urban Runoff Program	December 1983	EPA	II
9	City Water Quality Data	Various	City of Lincoln	III
10	Quantity and Quality of Urban Stormwater Runoff from Selected Drainage Basins, Omaha, Nebraska, Water Resources Investigation Report 98-4168	1992-1993	USGS	III
11	Historical and Ecological Resources Survey	1985 rev 1990	Lancaster County	III
12	City of Lincoln Flood Insurance Study	Sept. 21, 2001	FEMA	III
13	Aerial Photographs 1940, 1949, 1959, and 1971	Various	City of Lincoln	III
14	Draft Master Plan Map for CIP 2002-2008, with Comprehensive Plan Tiers	April 2002	City of Lincoln	III
15	Waterway Flyer for South Basins	Various	City of Lincoln	III

Table 2-1 (Continued)

Section	Title	Date	Source	Project Notebook No.
16	Summary Report of Initial Project Investigations (Basin Planning Project-Precursor Document to Specific Basin Plans)	March 17, 1997	Olsson Assoc.	III
17	Paper on Impacts of Urbanization on Downstream Receiving Waters	Unknown	(Unknown Author)	III
18	Stevens Creek Watershed Advisory Group Comments on NRD Study of Stevens Creek	October 1996	NRD	III
19	Letter to NRD, Re: Comments on Stevens Creek dated May 10, 1996	May 1996	City of Lincoln	III
20	Interim Report, Concept Comprehensive Flood Management Plans Alpha, Delta, Epsilon and Zeta, Stevens Creek Watershed Study for NRD	Feb. 1996	NRD	III
21	Addendum to the Interim Report, Concept Comprehensive Flood Management Plan Lambda, Stevens Creek Watershed Study for NRD	June 1997	NRD	III
22	Memo from Wright Water Engineers Re: Comparison of Lincoln Stormwater Quality Data with National Urban Runoff and Other Data	Feb. 28, 1997	City of Lincoln	III
23	Matrix of Stormwater Management Issues in Selected Midwest Cities	Unknown	City of Lincoln	III
24	Urban Water Quality Data		City of Lincoln	IV
25	Lancaster County Soil Maps	1977	NRCS	IV
26	Design Criteria Manual	Feb. 22, 2000	City of Lincoln	IV
27	Land Ownership Information		City of Lincoln	IV
28	Trends in Channel Gradation-Water Resources Investigations Report 99-4103	1913-1995	USGS	V
29	2025 Comprehensive Plan, 2002 Draft Comprehensive Plan	April-May 2002	City of Lincoln	V
30	Floodplain Task Force Information	Various	City of Lincoln	V
31	Regulated National Pollutant Discharge Elimination System (NPDES) Industries and Confined Animal Feedlot Operations (CAFOs) within the Watershed	Various	Internet NRD	V
32	Soil Data from the NRCS	Various	Internet NRCS	V
33	Non Point Source News Notes	May 2003	EPA	V
34	Engaging and Involving Stakeholders in Your Watershed	Unknown	EPA TetraTech	V
35	Rain Gage Data	Various	City of Lincoln	V
36	Meeting Notes/Correspondence	Various	Various	V

As part of the study evaluation process, numerous new data sets were developed using geographic information system (GIS) technology to organize the drainage structure and geomorphic field surveys and key results of the study. A description of each GIS data set is provided in Section 11.

2.2 Drainage Structure Field Survey

A drainage structure field survey was conducted to obtain the necessary hydraulic data along the study reaches. The information was collected using a combination of Global Positioning System (GPS) and total station technology to obtain the required elevations for each drainage structure, while inventory sheets were used to graphically document the data. The drainage structures were categorized based on three types, including bridges, culverts, and detention facilities.

Highway 6 Bridge Crossing (SC05)

- **Bridges** – The types of information collected for each bridge included a stream cross section to define the upstream face of the bridge opening, centerline profile of the bridge decking, low chord elevation of the bridge, physical characteristics of the support system, and upstream and downstream photographs.

Culvert (SC040) extending beneath Havelock Avenue, just east of 70th Street

- **Culverts** – The types of information collected included a stream cross section immediately upstream of the culvert, centerline profile of the roadway crossing, upstream and downstream invert locations, opening dimensions, material type, wing-wall configuration, and upstream and downstream photographs.

Magee Detention Facility (SC642) located near 120th and Yankee Hill Road

- **Detention Facilities** – Information was collected for detention facilities located along the stream centerlines, as shown on Figure 2-1, that provided significant watershed storage or impacted floodplain elevations. The types of information collected included the location and dimensions of the inlet and outlet structures, dimensions of the emergency spillway, centerline profile of the detention embankment, a cross section of the emergency spillway at the embankment toe and crest, and representative photographs. In addition, design drawings for regional detention facilities located upstream of the stream centerline were collected.

The drainage structures were given a unique alphanumeric name with the format SC-BBB. "SC" is the two-letter code for the Stevens Creek Watershed. "BBB" is a three-digit structure number. The numbering system begins at Highway 6 with structure SC-05, and moves incrementally upstream. The drainage structures located along the Stevens Creek Overflow were named in a similar manner using a prefix of "SCOF."

Figure 2-1 graphically illustrates the approximate location of each drainage structure surveyed, along with those that contained useable design drawing information. A hardcopy printout of the electronically recorded data, inventory sheets, and photographs for each surveyed drainage structure were provided to the City/NRD under separate cover. Appendix A located in Volume II of the report, contains a CD-ROM that includes the electronically recorded survey data and photographs for each drainage structure.

2.3 Base Mapping/Triangular Irregular Network

The base mapping used for the project consisted of topographic data with 2-foot contour intervals developed from two data sources. The primary source is the 1997 topographic mapping, which was supplemented by USGS LiDAR data at specific locations. The LiDAR data were used in areas where either the 1997 contour data appeared to be inaccurate or significant development occurred since 1997 that had altered the floodplain contours. Figure 2-2 shows the specific locations where LiDAR data were used in place of the 1997 topographic data.

A triangular irregular network (TIN) was created from the base mapping data using ArcInfo technology. A TIN is a three-dimensional representation of the ground topography that was used to automate the development of input data for the hydrologic and hydraulic computer models. The TIN is also used in conjunction with other GIS tools to automate the floodplain delineation process (Section 5 - Floodplain Mapping).

2.4 Longitudinal Profile Survey

The longitudinal (long) profile is among the more important diagnostic methods in fluvial geomorphology. The locations of the thalweg survey are shown on Figure 2-2. The surveyed long profile was used to calibrate the profile layer developed in GIS throughout the watershed. The long profile is a surveyed description of the bed slope, accomplished by traversing the channel and surveying the elevation of the thalweg or deepest part of the channel. The thalweg represents the flowline as distinct from the channel centerline. The long profile is particularly useful for diagnosing and locating channel incision and reveals sudden breaks in bed slope called knickpoints and the subtler but still recognizable change in slope over a short distance, indicating a knick zone.

2.5 Geomorphic Investigation

The purpose of the geomorphic investigation was threefold: first, to evaluate the physical stability of the stream under current and past conditions; second, to make reasonable predictions about how the stream will change under the proposed future conditions; and third, to make concept-level design recommendations for managing the stream.

Geomorphology is a data-intensive endeavor. Because Stevens Creek is not in equilibrium and reliable regional data regarding channel form is not available, equilibrium conditions must be estimated using sediment transport functions, the continuity and roughness equations, and hydraulic and hydrologic conditions. This approach does not depend on current or previous channel stability for its validity; therefore, data collection focuses on stream process indicators rather than on extensive documentation of the current channel form.

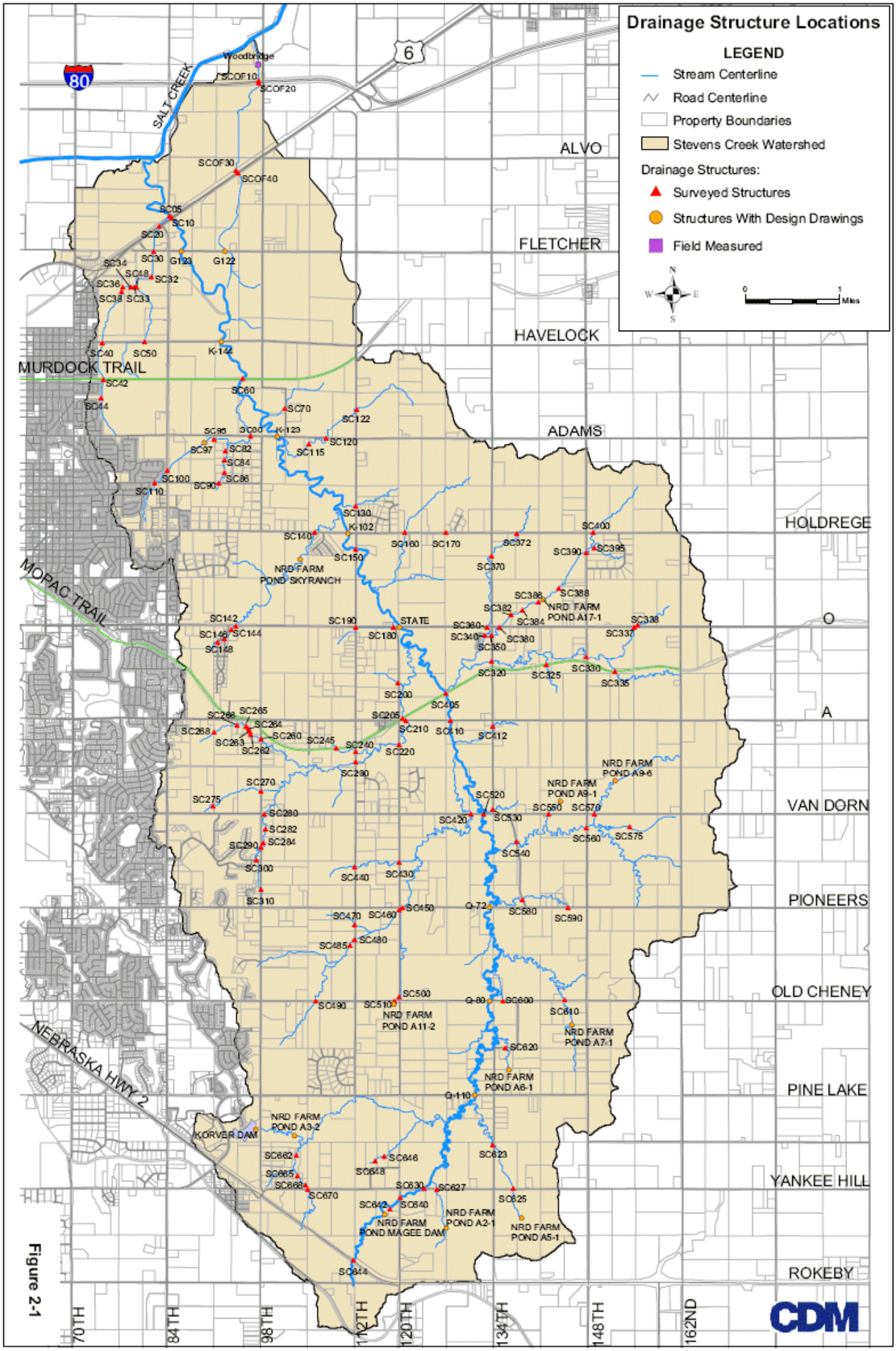

Drainage Structure Locations
LEGEND
Stream Centerline
Road Centerline
Property Boundaries
Stevens Creek Watershed
Drainage Structures:
Surveyed Structures
Structures With Design Drawings
Field Measured
0
1
Miles
N
S
E
W
80
6
SALT CREEK
Woodbridge
SCOF10
SCOF20
SCOF30
SCOF40
ALVO
FLETCHER
HAVELOCK
ADAMS
HOLDREGE
O
A
VAN DORN
PIONEERS
OLD CHENEY
PINE LAKE
YANKEE HILL
ROKEBY
MURDOCK TRAIL
MOPAC TRAIL
NEBRASKA HWY 2
NRD FARM POND SKYRANCH
NRD FARM POND A17-1
NRD FARM POND A9-6
NRD FARM POND A9-1
NRD FARM POND A11-2
NRD FARM POND A7-1
NRD FARM POND A6-1
NRD FARM POND A3-2
KORVER DAM
NRD FARM POND MAGEE DAM
NRD FARM POND A2-1
NRD FARM POND A5-1
STATE
70TH
84TH
98TH
112TH
120TH
134TH
148TH
162ND
CDM

Figure 2-1

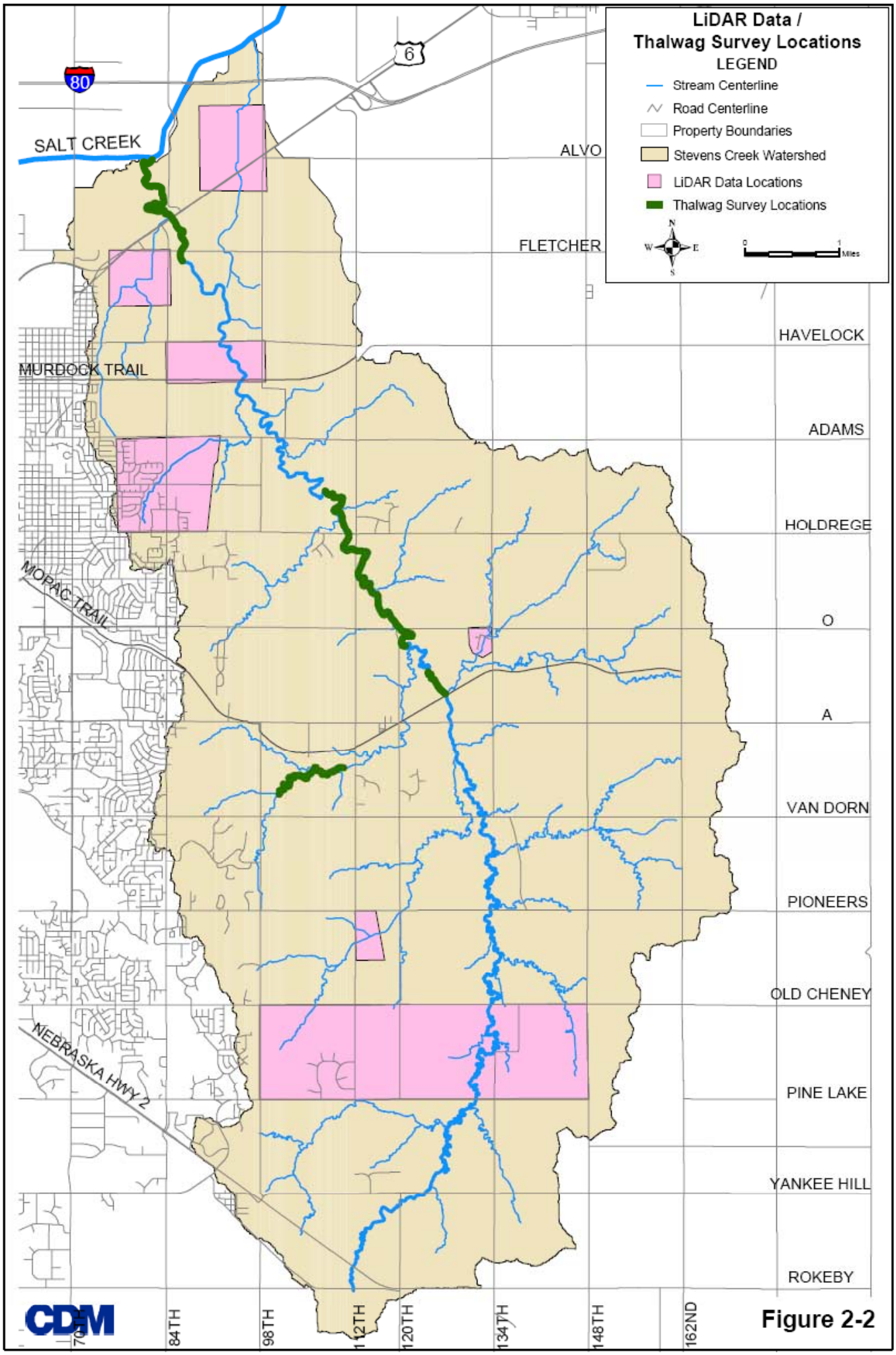

LiDAR Data /
Thalwag Survey Locations
LEGEND
Stream Centerline
Road Centerline
Property Boundaries
Stevens Creek Watershed
LiDAR Data Locations
Thalwag Survey Locations
N
W
E
S
0
1
Miles
80
6
SALT CREEK
ALVO
FLETCHER
HAVELOCK
MURDOCK TRAIL
ADAMS
HOLDREGE
MOPAC TRAIL
O
A
VAN DORN
PIONEERS
OLD CHENEY
NEBRASKA HWY 2
PINE LAKE
YANKEE HILL
ROKEBY
70TH
84TH
98TH
112TH
120TH
134TH
148TH
162ND
CDM

Figure 2-2

2.5.1 Geomorphic Background Investigation

The purpose of the background investigation is assessment of basin behavior as a whole. The elements of the evaluation were a drainage basin analysis, plan form analysis, and interpretation of historical aerial photographs. The City provided aerial photographs and GIS layers for all three analyses. Both drainage basin analysis and photo interpretation were conducted in general agreement with the methods of Lueder (1959).

The drainage basin analysis provides insight on how local geology influences stream behavior and whether one or more subareas behave in ways distinct from the basin as a whole. This may be an indication that such subareas require different methods of analysis or management.

The meander patterns for Stevens Creek reveal rough guidelines for how the geometries change throughout the watershed. The measurements were conducted in general compliance with Chang (1998), Leopold and Langbein (1969), and USACE (1993). Those areas where meander geometry, particularly radius of curvature, was substantially outside the norm for alluvial streams were noted for closer examination in the field. Other photographic evidence of active channel adjustment such as multiple in-channel bars, advancing bars, or evidence of systemic mass wasting were also noted for field examination.

The historical photo interpretation provides insight into how the land uses and channel conditions have changed over time. It also provides useful information on the relative intensity and duration of channel process for a given set of stresses. The City supplied historical aerial photographs for the years 1940, 1949, 1959, and 1971. The analysis did not include photogrammetry but did include notation of channel adjustment such as changes in meander amplitude, wavelength or radius of curvature, scour and deposition patterns, tree scrolls, and altered lag sections.

2.5.2 Geomorphic Field Investigation

Geomorphologists collected field data on approximately 426,400 linear feet of channel. Most of the data collection occurred between October 2003 and April 2004. To improve the efficiency of data collection and reduce the likelihood of transcription errors, all field data were collected in hand-held computers in ArcPad format. The City supplied base data and projection files. Immediately after field collection, all data were downloaded to ArcView files.

The following 10 themes shown in Table 2-2 represent the collected field data. The themes include 109 data parameters. An electronic version of the data is available in Appendix A, GIS Data Sets.

The data organization is a modification of the approach described by Johnson, Gleason, and Hey (1999). Dr. Johnson's team developed an approach of rapid, efficient data collection that is oriented towards assessing stability in streams affected by infrastructure. The paragraphs below detail the data collected and their relevance to channel process.

Table 2-2
Geomorphic Field Data

Bed and Bank material type (collected separately) and bed consolidation
Channel bar type and condition
Channel profile
Channel cross section
Erosion and mass wasting
Vegetative bank protection and condition of riparian corridor
Outfalls
Infrastructure crossings
Photographs
Notes

Material
The material theme consists of 12 bed and bank material parameters, including bed or bank material type, bed material shape, degree of consolidation or imbrication, and approximate bed material gradation (D90, D60, etc.). These data and their distribution through the project reach inform assessments of present and future resistance to erosion. Particle sizes, such as D90 and D50, are indicators of stream power. In addition, consolidation and imbrication of bed material is used in conjunction with bar data to evaluate sediment transport competency.

Bar
The bar theme is used primarily for developing an understanding of sediment transport, an often overlooked but critically important stream process.

The bar theme includes 16 parameters. These include extent and type of bed sorting (generally coarse to fine proceeding downstream), pattern of bar placement, bar width relative to stream width, consolidation, vegetative condition, and other indicators of potential bar advance. Assessment of bar condition is particularly useful in distinguishing between widening and meander adjustment, two stream processes associated with systemic bank failures. Bar evaluation is also helpful in temporal analysis of stream process and helps distinguish between ongoing and completed channel adjustments.

Profile Features (non-surveyed)
This theme included the location of knickpoints and the tops of pool-riffle sequences. The height of the knickpoint, bed material type, presence or absence of debris jams, and erosion patterns are all used to distinguish between active and completed channel incision. Evaluation of pool-riffle sequence, particularly relative to location in plan form, is useful in assessing potential plan form migration.

Channel Dimensions
The channel dimensions theme is essentially channel cross section information. In this theme there are 27 parameters, including bed width, bank height, bank angle, top of bank width, scour line elevation, and lower limit of woody vegetation. The combined bank height and angle data are useful in distinguishing between fluvial and geotechnical causes of bank failure and therefore the appropriate approach to management.

Erosion and Mass Wasting

The erosion and mass wasting theme includes both quantitative and qualitative data used to identify lengths of channel experiencing active erosion or mass wasting, as well as the dominant mode of failure, such as scour, toppling, flow, wedge, or circular failure. Identifying the type of mass wasting is essential to understanding the failure mode and to distinguish between systemic, local, and geotechnical failures. Scour patterns are also helpful in determining the systemic process driving the erosion.

Vegetation

The vegetation theme contains 16 elements. Vegetative data include the quality, size, and structure of the riparian forest, percent of canopy cover, and presence or absence of invasive species. Native vegetation plays a role in stabilizing stream systems through mechanical reinforcement of streambanks by plant roots, soil moisture management through evapotranspiration, and hydraulic roughness at the bank toes. Vegetative conditions such as surfed or toppled trees, freshly exposed, or barked over roots are useful in estimating the degree of instability and progress towards recovery.

Dominant and subdominant tree species and the successional status of the riparian corridor are also important to urban stream management. Invasive nonnative species can interrupt the succession of more desirable tree and understory species that would not only provide greater habitat and ecological benefits, but also provide improved bank stability and scour resistance. The timing and degree of disturbance are reflected in the same vegetation characteristics. For example, sudden changes in vegetation type often accompany localized problems, which help distinguish between systemic and local concerns. Vegetative status also indicates how well the streambanks will respond to soil biostabilization and provides insight into the potential for habitat recovery.

Outfalls and Infrastructure Crossings

The outfall and crossing themes locate in-stream or near stream infrastructure. The location of outfalls, bridges, and culverts is essential when considering design limitations and construction access. In addition, the condition of in-stream infrastructure can also provide clues to past and present channel conditions. For example, culverts and crossings can also act as process indicators. Undermined outfalls and culverts indicate the extent of channel incision while discontinuities in energy distribution and sediment transport can be inferred from the depth and consolidation of deposits in culvert or bridge bays.

Photos and Notes

The last two themes mainly include supporting or miscellaneous information. Notes generally consist of short site descriptions or information that does not otherwise fit into any of the previously mentioned themes. Photos are taken at regular intervals, not only for internal quality assurance and quality control practices, but also to provide the user with a virtual walk through of the study reach.

Section 3
Hydrologic Model Development

3.1 Introduction

This section summarizes the methodology used to develop the hydrologic model for the Stevens Creek Watershed. The modeling was performed using the USACE's Hydrologic Engineering Center's Hydrologic Modeling System program (HEC-HMS) Version 2.2.2. Both an existing conditions model and a future conditions model were developed. The hydrologic methods used to develop the HEC-HMS models are described below. The following appendix sections, located in Volume II of this report, provide detailed information on the hydrologic and hydraulic model data input and results:

- Appendix C - Hydrologic Model Input Data and Results
- Appendix D - Hydraulic Model Input Data and Results
- Appendix E - Stream Profiles
- Appendix J - Drainage Structure Design Data

3.2 Hydrology Methodology

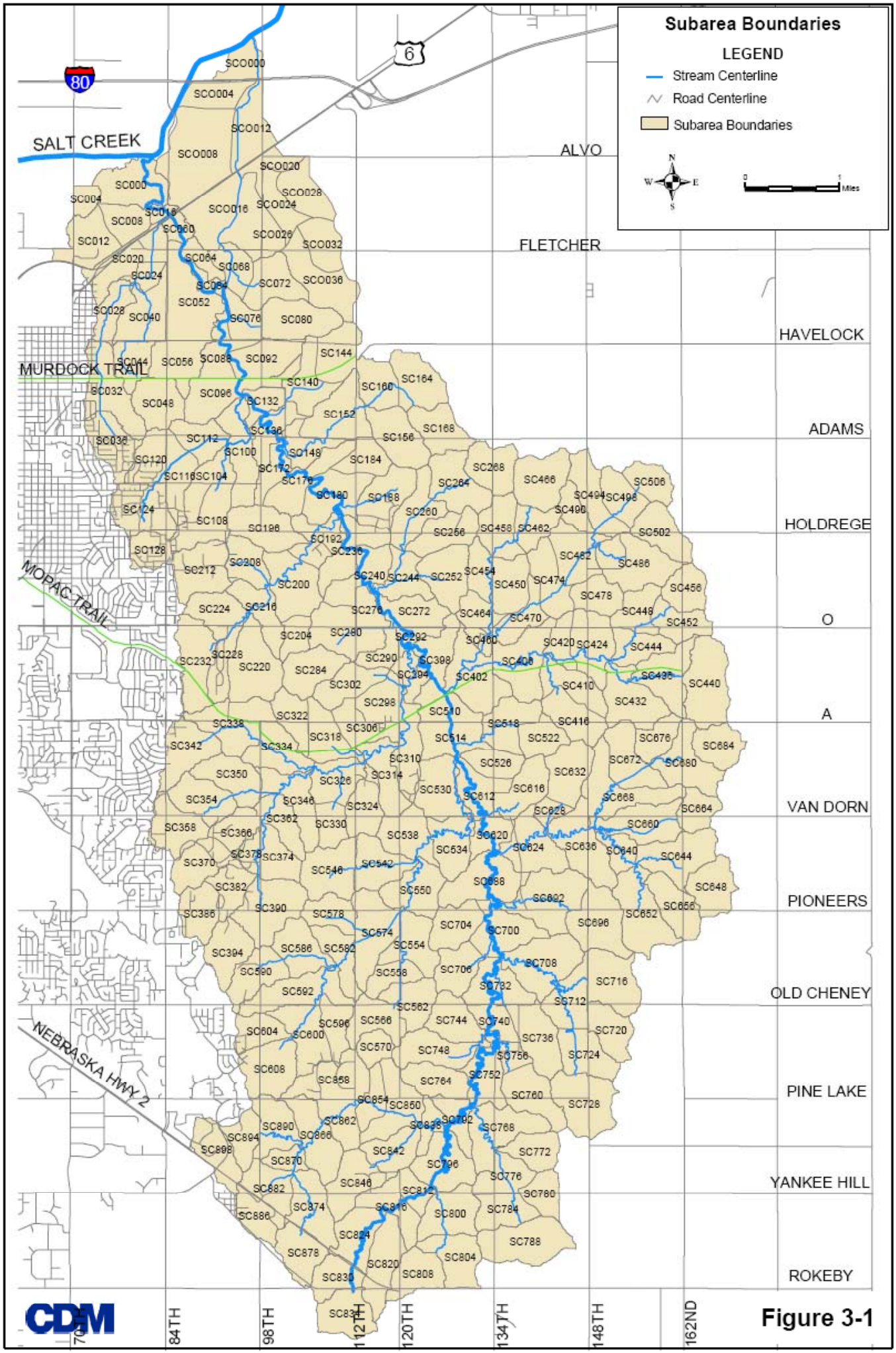
The HEC-HMS model was used to simulate the runoff volumes and hydrographs resulting from 2-, 5-, 10-, 50-, 100-, and 500-year return periods using the design storms outlined in the City's Drainage Criteria Manual dated February 22, 2000. The hydrology methodology contains six primary components including the subarea delineation, rainfall, runoff volume, runoff hydrographs, routing, watershed storage, and flow diversions.

3.2.1 Subarea Delineation

The Stevens Creek Watershed was delineated into 241 subareas with an average area of 146 acres. A map showing the subarea boundaries are shown on Figure 3-1. The subarea delineation was performed using ArcView, HEC-GeoHMS, and the digital elevation model (DEM) developed from the contour data provided by the City. The HEC-GeoHMS tool runs within ArcView and uses the DEM to delineate subareas and to determine the overland flow path for each subarea. Another major advantage of using the HEC-GeoHMS tool was that it automated the HEC-HMS model development.

Using the HEC-GeoHMS tool, the approximate locations for subarea outlets such as stream crossings, tributaries, and major lakes/ponds were located using ArcView and available GIS data. The HEC-GeoHMS tool uses these points to automatically delineate the subarea boundaries based on the DEM. The automation process was then checked against contours and drainage structure locations.

Subareas draining to Stevens Creek were given a unique alphanumeric name with the format SC-BBB. "SC" is the two-letter code for the Stevens Creek Watershed. "BBB" is a three-digit subarea number. Generally, the subarea numbers were assigned in increments of four to allow for future subdivision (e.g., SC-004, SC-008, SC-012). The subareas draining to the Stevens Creek Overflow were named in a similar manner using a prefix of "SCO."


Subarea Boundaries
LEGEND
Stream Centerline
Road Centerline
Subarea Boundaries
N
W
E
S
0
1
Miles
80
6
SALT CREEK
ALVO
FLETCHER
HAVELOCK
MURDOCK TRAIL
ADAMS
HOLDREGE
MOPAC TRAIL
O
A
VAN DORN
PIONEERS
OLD CHENEY
NEBRASKA HWY 2
PINE LAKE
YANKEE HILL
ROKEBY
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134TH
148TH
162ND
CDM

Figure 3-1

3.2.2 Rainfall

The Soil Conservation Service (SCS), now called the Natural Resources Conservation Service (NRCS), Type II storm distribution was used to simulate rainfall events for each return interval. This method requires the rainfall depth for a storm duration of 24 hours as input data. Table 3-1 summarizes the design rainfall depths for 24-hour events from the City's Drainage Criteria Manual that were used in the HEC-HMS model. The peak intensity was derived by distributing the rainfall depth over a 24-hour period using the Type II distribution and 15-minute increments. The peak intensity in inches per hour was calculated by multiplying the peak 15-minute intensity by 4. The 500-year rainfall depth was determined by extrapolating along a logarithmic curve fit to the data. Figure 3-2 shows the plotted data points and the logarithmic curve.

Table 3-1
Rainfall-Duration Depths

Return Interval	Rainfall Depth (inches)	Peak Intensity (in/hr)
2-Year	3.00	3.31
5-Year	3.93	4.34
10-Year	4.69	5.18
50-Year	6.00	6.62
100-Year	6.68	7.37
500-Year	8.18	9.03

3.2.3 Runoff Volume (SCS CN)

The SCS Curve Number Loss Rate option in the HEC-HMS model was used to generate runoff volumes for each subarea. The SCS option uses an initial abstraction value and composite curve number (CN) to estimate runoff volumes from each subarea for a particular design rainfall event.

Initial abstraction is defined as losses from rainfall before runoff begins. Initial abstraction is a function of the composite CN and is commonly calculated using Equation 3-1.

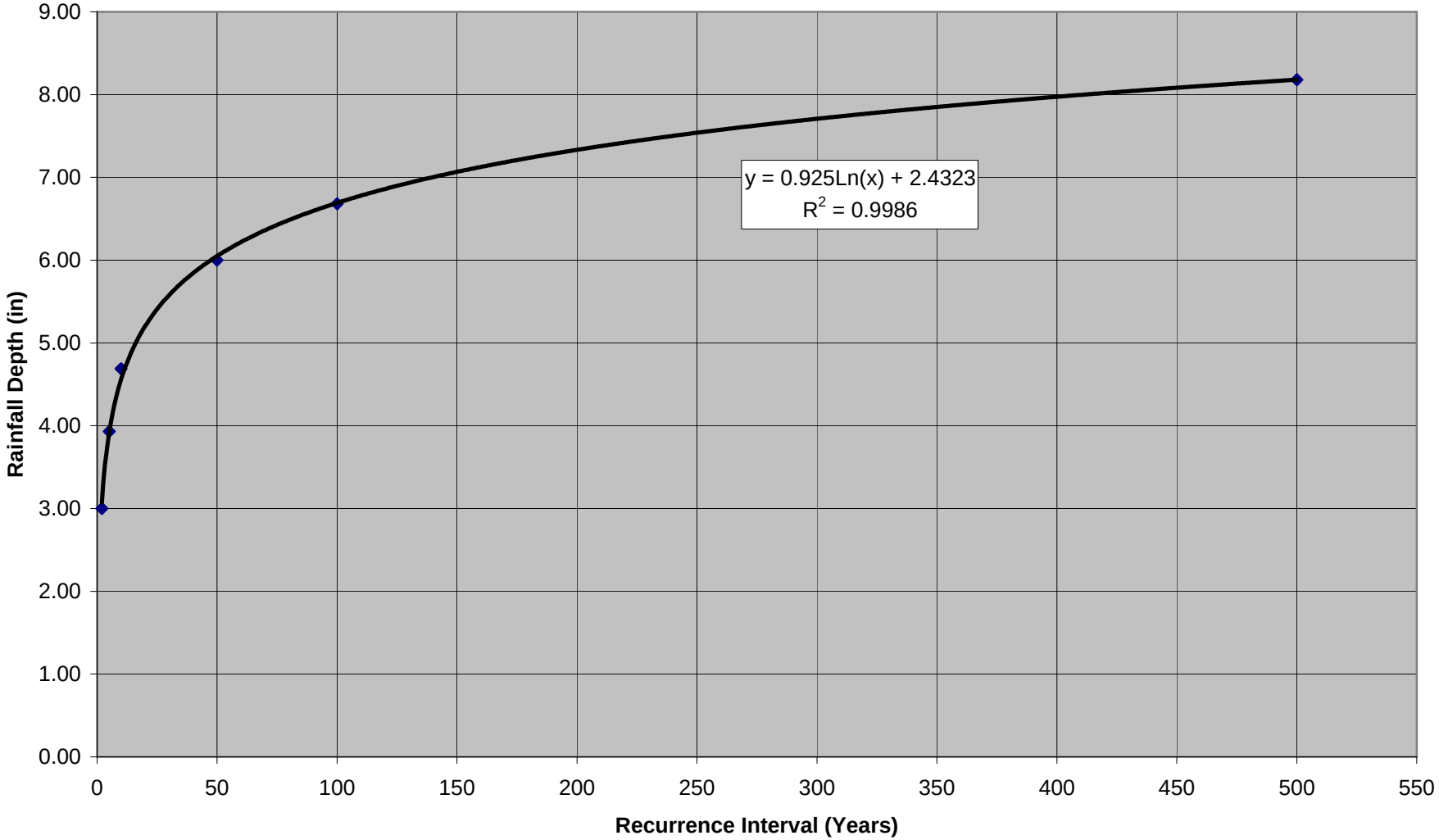
$$Ia = 0.2(1000/CN - 10) \qquad \text{Equation 3-1}$$

The CN is a function of the land use condition and hydrologic soil group (HSG). For each subarea, a composite CN was developed using the GIS by overlaying the soils and land use coverages and spatially analyzing the percent of each land use and soil condition in each subarea. Runoff CN tables from the Drainage Criteria Manual were used to assign a CN to each soil and land use combination. The runoff CN tables are provided in Appendix C, located in Volume II of this report. The CNs listed represent average antecedent moisture conditions (AMC II conditions).

Existing Land Use

For existing land use conditions, the digital land use data supplied by the City were used to determine a CN using the values in the Drainage Criteria Manual as a guideline. Figure 3-3 shows the existing land uses and Table 3-2 lists the percentage of watershed area for each existing land use category. Table 3-3 shows the land use

Figure 3-2
Recurrence Interval Versus Rainfall Depth



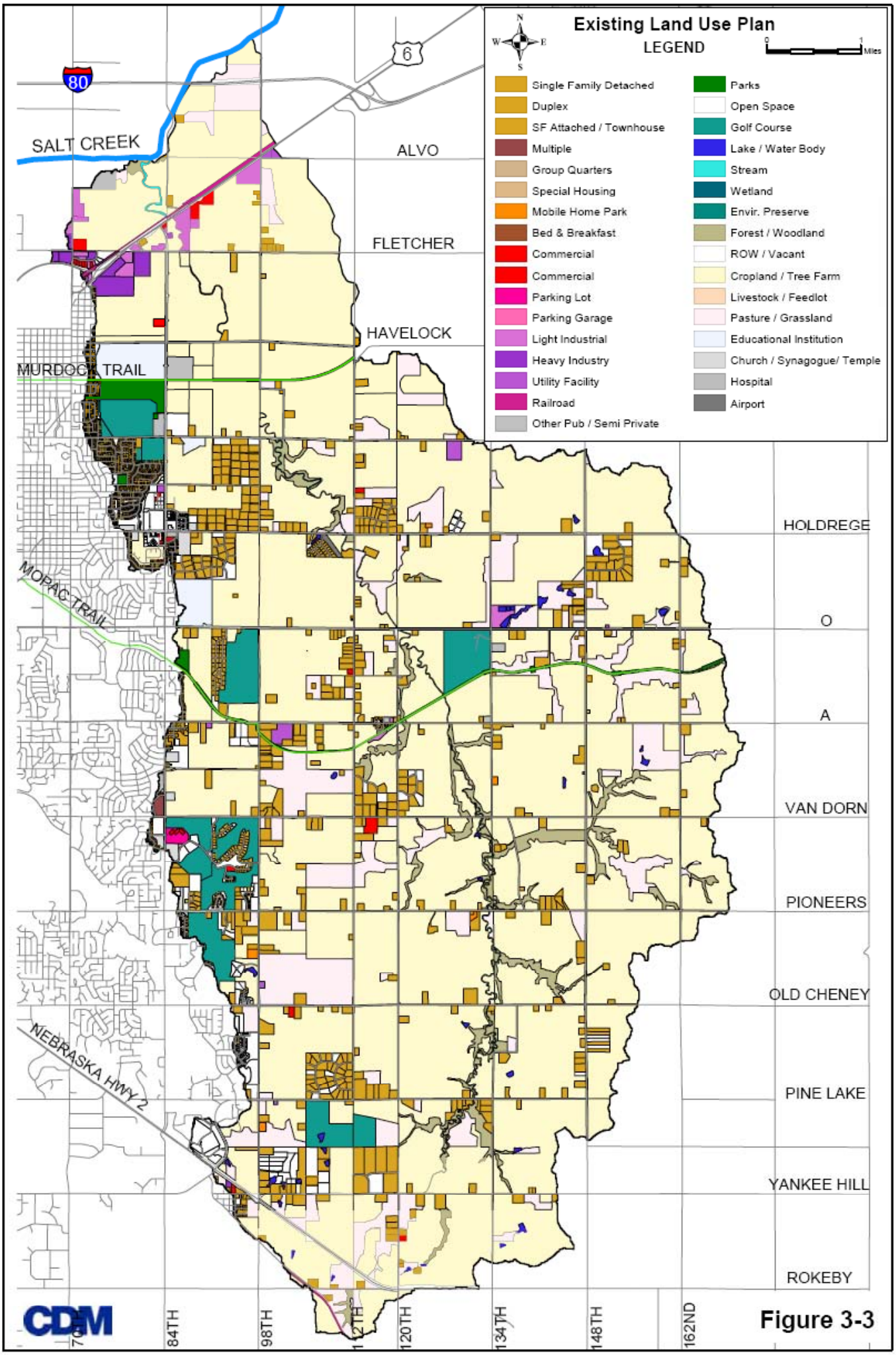

Existing Land Use Plan
LEGEND
Single Family Detached
Duplex
SF Attached / Townhouse
Multiple
Group Quarters
Special Housing
Mobile Home Park
Bed & Breakfast
Commercial
Commercial
Parking Lot
Parking Garage
Light Industrial
Heavy Industry
Utility Facility
Railroad
Other Pub / Semi Private
Parks
Open Space
Golf Course
Lake / Water Body
Stream
Wetland
Envir. Preserve
Forest / Woodland
ROW / Vacant
Cropland / Tree Farm
Livestock / Feedlot
Pasture / Grassland
Educational Institution
Church / Synagogue/ Temple
Hospital
Airport
SALT CREEK
ALVO
FLETCHER
HAVELOCK
MURDOCK TRAIL
MOPAC TRAIL
NEBRASKA HWY 2
HOLDREGE
O
A
VAN DORN
PIONEERS
OLD CHENEY
PINE LAKE
YANKEE HILL
ROKEBY
84TH
98TH
112TH
120TH
134TH
148TH
162ND
CDM

Figure 3-3

categories and the assigned CN. Several land use categories did not correspond directly with CN cover types located in the Drainage Criteria Manual. CNs for these land uses were assigned by determining an average percent impervious and calculating a composite CN.

Table 3-2
Existing Land Use Percentages

Land Use Category	*Watershed Area (%)*
Agricultural Production: Crops/Tree Farm	69.2
Airport	<0.1
Apartments (w/number of units)	<0.1
Attached Single Family (Townhouses)	<0.1
Church, Synagogue, or Temple	0.2
Commercial NEC	0.3
Duplex	<0.1
Educational Institution	0.9
Forest/Woodland	2.4
Golf Course	3.4
Heavy Industrial	0.4
Lake	0.2
Light Industrial	0.5
Mobile Home including parks, courts (w/number of unit)	0.1
Open Space	0.6
Park Land	0.7
Parking Lot (PL)	0.1
Pasture/Grassland	8.5
Public & Semi-Public NEC (e.g., cemetery)	0.3
Railroad	0.2
Single Family (detached)	9.2
Stream / Creek	0.2
Utility Facility (e.g., communication tower)	0.2
VACANT (UNDEVELOPED) LAND	2.4
Vacated ROW (retained by public entity)	<0.1
Total	**100**

As shown in Table 3-3, all agricultural land uses were designated a cover description of contour/crop residue in good hydrologic condition. Streams/Creeks, Lakes, and Wetlands were given a CN of 98. Land uses that do not correspond directly with a cover type were assigned a CN based on approximate average percent impervious and generally accepted engineering practices.

The category Single Family (detached) includes residential lots of varying sizes; however, the Drainage Criteria Manual CN tables have lot sizes broken into 1/8 acre, 1/4 acre, 1/3 acre, 1/2 acre, 1 acre, and 2 acres. Single family (detached) land use was assigned to one of these six land use CN categories based on the actual lot size. The lot size was calculated using GIS. For example, if a single family (detached) land use parcel has an area of 1 acre, it was assigned a CN for 1-acre residential.

Table 3-3
Curve Numbers for Stevens Creek Watershed Study

Lincoln/Lancaster County Land Use	*Cover Type (% Imp)*	*Hydrologic Soil Group*			
		A	*B*	*C*	*D*
Agricultural Production: Crops/Tree Farm	Row Crops – Straight Row Good Condition	67	78	85	89
Airport	Compacted Soil	72	82	87	89
Apartments (w/number of units)	Residential 1/8 acre or less (65%)	77*	85*	90*	92*
Attached Single Family (Townhouses)	Residential 1/8 acre or less (65%)	77	85	90	92
Church, Synagogue, or Temple	Churches/Schools (75%)	84*	89*	92*	94*
Commercial NEC	Commercial and business (85%)	89	92	94	95
Duplex	Residential 1/8 acre or less (65%)	77*	85*	90*	92*
Educational Institution	Churches/Schools (75%)	84*	89*	92*	94*
Forest/Woodland	Woods - Fair Condition	36	60	73	79
Golf Course	Open Space - Good Condition	39	61	74	80
Heavy Industrial	Industrial (72%)	81	88	91	93
Lake	Water	98	98	98	98
Light Industrial	Industrial (72%)	81	88	91	93
Mobile Home including parks, courts (w/number of unit)	Residential 1/8 acre or less (65%)	77*	85*	90*	92*
Open Space	Open Space - Fair Condition	49	69	79	84
Park Land	Open Space - Fair Condition	49	69	79	84
Parking Lot (PL)/Street	Impervious (100%)	98	98	98	98
Pasture/Grassland	Pasture - Fair Condition	49	69	79	84
Public & Semi-Public NEC (e.g., cemetery)	Open Space - Fair Condition	49	69	79	84
Railroad	Gravel Covered Surface	76	85	89	91
Rural Residential	Residential 2 acres (12%)	51	68	79	84
Single Family (detached)+	Residential 1/4 acre (38%)	61	75	83	87
	Residential 1/3 acre (30%)	57	72	81	86
	Residential 1/2 acre (25%)	54	70	80	85
	Residential 1 acre (20%)	51	68	79	84
Stream/Creek	Water	98	98	98	98
Urban Residential	Residential 1/3 acre (30%)	57	72	81	86
Utility Facility (e.g., communication tower)	Commercial and business (85%)	89	92	94	95
VACANT (UNDEVELOPED) LAND	Open Space - Fair Condition	49	69	79	84
Vacated ROW (retained by public entity)	Open Space - Fair Condition	49	69	79	84
Wetland	Water	98	98	98	98

+ Single Family (detached) land use includes large and small lots.
CN will be assigned based on lot size calculated using GIS.
* CN may be adjusted based on actual percent impervious versus reported standard percent impervious.

Future Land Use

For the purpose of this study, full buildout of the watershed was assumed to provide a conservative estimate of future flows. The future land use plan for the watershed is based on a 2025 planning horizon, which is illustrated on Figure 3-4. Under the 2025 planning horizon, more than 55 percent (Table 3-4) of the watershed is defined as agricultural. Therefore, to simulate full buildout conditions, a prediction of future land use conditions was required for this category.

Table 3-4
2025 Land Use Percentages

Land Use Category	*Watershed Area (%)*
Agricultural	55.7
Commercial	0.9
Industrial	4.3
Green Space	8.2
Public/Semi-Public	2.7
Residential, Low Density	3.5
Residential, Urban	17.3
Lakes and Streams	0.6
Environmental Resources	5.8
Agricultural Stream Corridor	1.0

Using data provided by the Lincoln-Lancaster County Planning Department, a surrogate future land use category was developed based on a typical square mile area of development. Table 3-5 summarizes the land use category percentages used for the surrogate future land use, which was applied to agricultural land use categories.

Table 3-5
Breakdown of Surrogate Future Land Use

Land Use Category	*Percentage (%)*
Commercial/Business	11
Parks/Open Space	11
Public/Semi-Public	3
Urban Residential	75

Using this surrogate land use breakdown, a composite CN was calculated by multiplying the fraction of each land use category by its corresponding CN and then summing the values. Using this technique, the CNs for the surrogate future land use are 69, 80, 87, and 90 for hydrologic soil groups A, B, C, and D, respectively. These surrogate future land use CNs were applied over the agricultural areas to simulate the full buildout conditions.

Hydrologic Soil Groups

HSGs by soil types were determined from the NRCS Lancaster County Soil Survey. Figure 3-5 shows the HSGs for Stevens Creek Watershed. The HSG was used to assign an appropriate CN for each subarea. Table 3-6 shows the soil types and their associated HSG for soils within the Stevens Creek Watershed. For soil types where HSGs are provided for drained and undrained conditions, the undrained HSG was used. For example, Colo soil type has an HSG designation of B/D where B is for drained conditions and D is for undrained. All Colo soils were categorized as having an HSG of D, unless available data shows that the water table was lowered in a particular area.

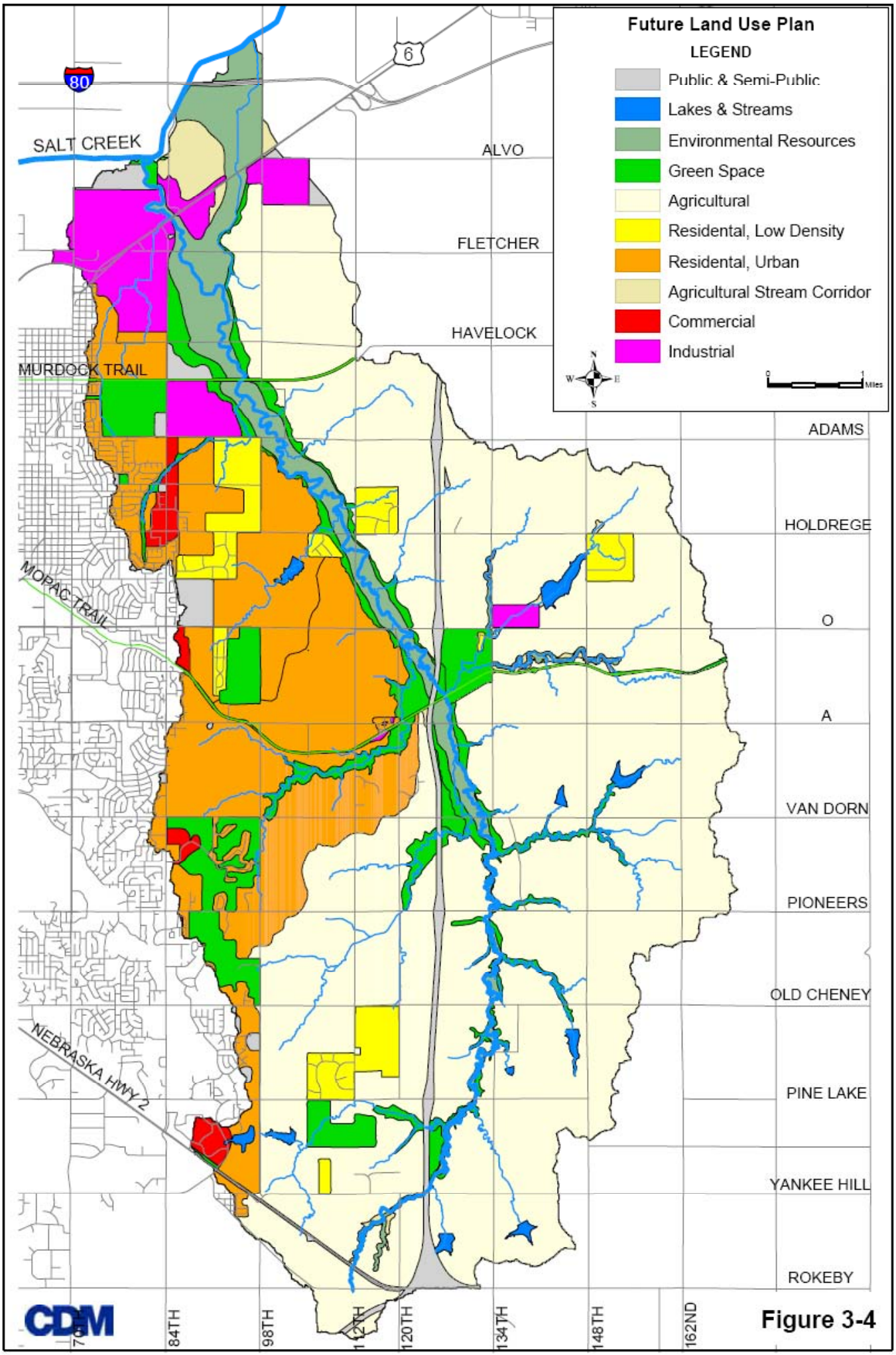

Future Land Use Plan
LEGEND
Public & Semi-Public
Lakes & Streams
Environmental Resources
Green Space
Agricultural
Residental, Low Density
Residental, Urban
Agricultural Stream Corridor
Commercial
Industrial
N
W
E
S
0
1
Miles
80
6
SALT CREEK
ALVO
FLETCHER
HAVELOCK
MURDOCK TRAIL
ADAMS
HOLDREGE
MOPAC TRAIL
O
A
VAN DORN
PIONEERS
OLD CHENEY
NEBRASKA HWY 2
PINE LAKE
YANKEE HILL
ROKEBY
84TH
98TH
112TH
120TH
134TH
148TH
162ND
CDM

Figure 3-4

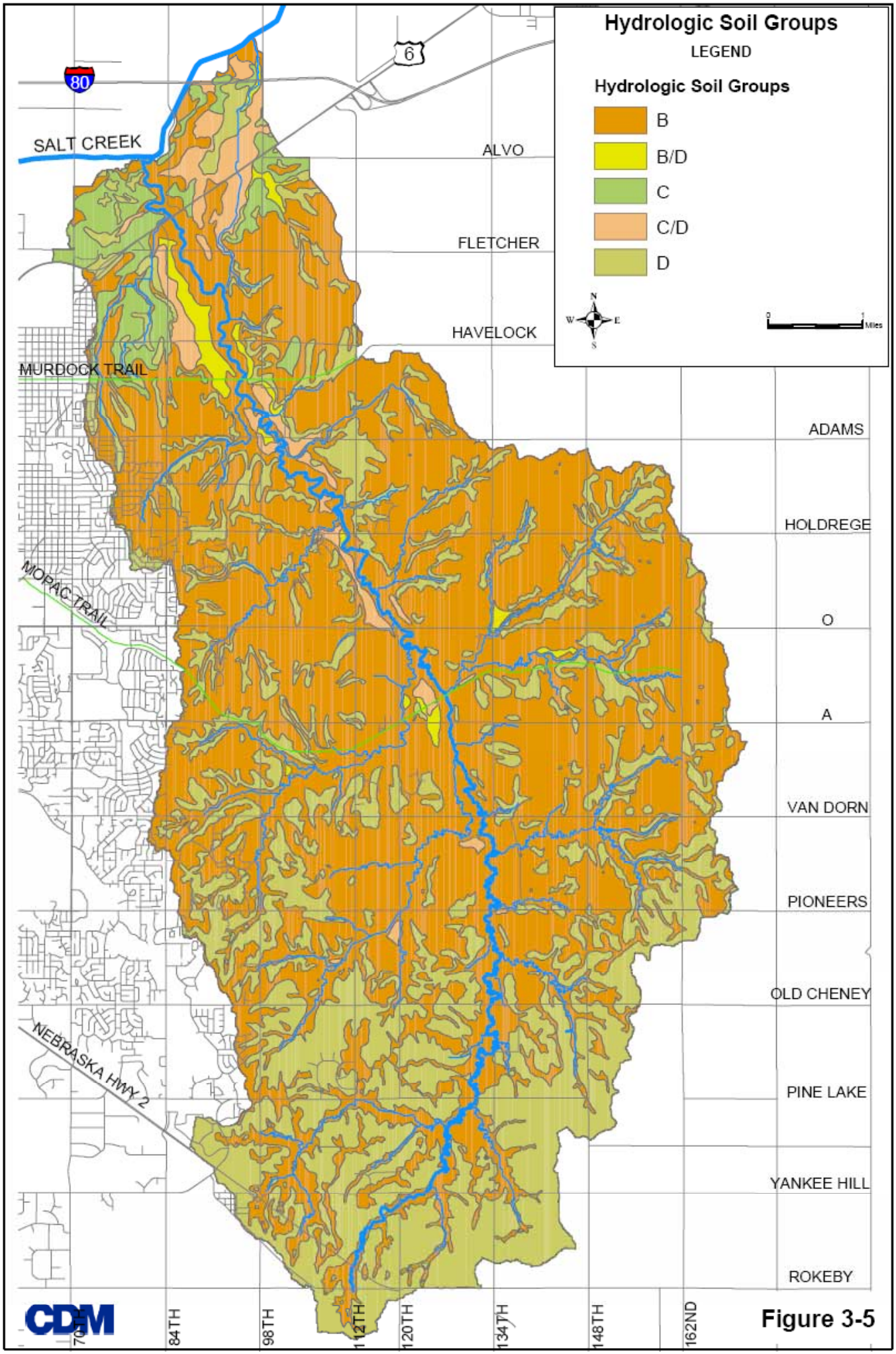

Hydrologic Soil Groups
LEGEND
Hydrologic Soil Groups
B
B/D
C
C/D
D
N
W
E
S
0
1
Miles
80
6
SALT CREEK
ALVO
FLETCHER
HAVELOCK
MURDOCK TRAIL
ADAMS
HOLDREGE
MOPAC TRAIL
O
A
VAN DORN
PIONEERS
OLD CHENEY
NEBRASKA HWY 2
PINE LAKE
YANKEE HILL
ROKEBY
70TH
84TH
98TH
112TH
120TH
134TH
148TH
162ND
CDM

Figure 3-5

Table 3-6
Lancaster County Hydrologic Soil Groups

Soil Type	HSG	Soil Type	HSG	Soil Type	HSG	Soil Type	HSG
Aksarben	B	Fillmore	D	Nodaway	B	Wabash	D
Burchard	B	Geary	B	Pawnee	D	Water	D
Butler	D	Judson	B	Salmo	C/D	Wymore	D
Colo	B/D	Kennebec	B	Sharpsburg	B	Yutan	B
Crete	C	Malmo	D	Shelby	B	Zook	C/D
Crete Variant	D	Mayberry	D	Steinauer	B		
Dickinson	B	Morrill	B	Urban Land	D		
Aksarben	B	Fillmore	D	Nodaway	B		

3.2.4 Runoff Hydrographs (Lag Time)

The SCS Dimensionless Unit Hydrograph was used to distribute the runoff volume to a unit hydrograph. The determination of an SCS lag time was required for this method. Consistent with the methodology of the SCS's *Technical Release-55 Urban Hydrology for Small Watersheds* published June 1986, the lag time for a subarea was assumed to equal 0.6 times the time of concentration. The time of concentration, in turn, was defined as the time required for water to travel to the subarea outlet from the most hydraulically distant point in the subarea.

The time of concentration for each subarea was calculated using the methodology outlined in TR-55 (SCS 1986). For each subarea, the longest flow path to the subarea outlet was determined using the DEM and ArcView/ArcInfo tools that divided the flow path into four elements:

- Sheet flow
- Shallow concentrated flow
- Secondary channel
- Primary channel

The travel times associated with each of the four elements were added to calculate the time of concentration for each subarea. The methodology described below was used to evaluate both existing and future surface conditions in the watershed. In the case of sheet flow and shallow concentrated flow, the methodology accounted for reduced travel time as undeveloped surface conditions (existing) are converted to developed surface conditions (future). Secondary and primary channels were assumed to be the same for both existing and future conditions.

Sheet Flow

Sheet flow was assumed to occur at the most hydraulically distant portion of the flow path. TR-55 recommends a maximum sheet flow length of 300 feet, and best professional judgment indicates that a length of 100 feet or less may not be appropriate for some subareas. Consequently, subarea sheet flow lengths will typically fall within the range of 100 to 300 feet. The sheet flow length was estimated using ArcView with aerial photographs and contour data.

Physical data were required to calculate the travel time associated with sheet flow using the TR-55 methodology, including flow length, slope, and overland flow roughness coefficient. The sheet flow length was calculated using GIS. A composite overland flow roughness value was estimated by calculating a weighted roughness value using typical

literature values for each surface condition and the length of sheet flow associated with each surface condition. The surface condition was determined from the aerial photos. Table 3-7 lists the overland flow roughness coefficients used for sheet flow.

Table 3-7
Sheet Flow and Shallow Concentrated Flow Values

Surface Conditions	*Overland Flow Roughness Coefficient*	*Shallow Flow Paved/Unpaved*
Business-Heavy Commercial	0.06	Paved
Business-Light Commercial	0.08	Paved
Single Family I	0.23	Unpaved
Single Family II	0.17	Paved
Multi-Family Areas	0.13	Paved
Churches and Schools	0.10	Paved
Industrial-Light Areas	0.13	Paved
Industrial-Heavy Areas	0.09	Paved
Industrial-Parks, Cemeteries	0.22	Unpaved
Industrial-Railroad Yard	0.19	Paved
Undeveloped Areas (Permanent)	0.40	Unpaved
Impervious: Asphalt, Concrete, Roofs, etc.	0.011	Paved
Turfed	0.15	Unpaved
Wet Detention Basins	0.05	NA
Unknown Developed	0.17	Paved
Cultivated Soils	0.11	Unpaved

Shallow Concentrated Flow

Shallow concentrated flow occurs between the areas of sheet flow and open channel flow. Open channel flow is commonly assumed to begin at a point where blue lines (solid or intermittent) appear on U. S. Geological Survey (USGS) quadrangle maps. USGS maps were reviewed to estimate the tributary area at which blue lines begin to occur. The results indicated that, on average, blue lines typically were shown for tributary areas of approximately 20 acres. Therefore, travel times are based on shallow concentrated flow occurring from the end of sheet flow to 20 acres along the subarea's flow path.

To calculate the travel time associated with shallow concentrated flow by the TR-55 methodology, physical data including the shallow concentrated flow length, slope, and surface conditions along the path were required. The process for calculating the time of concentration for shallow concentrated flow was the same as performed for sheet flow.

Secondary Channel Flow and Primary Channel Flow

Secondary and primary channel flow occur between the end of shallow concentrated flow and the subarea outlet. Secondary channel flow occurs between the end of shallow concentrated flow and the flow path intersection with the primary stream network, while primary channel flow occurs along the primary stream network to the subarea outlet. The primary stream network is defined as the main channel of Stevens Creek and it's tributaries that receive runoff from areas approximately 150 acres in size and greater. This network was evaluated with the HEC-RAS model. Depending upon location, a subarea may have one or both of these channel flow features. For example, a headwater subarea will probably include only flow length associated with the secondary stream network and none associated with the primary stream network.

For both types of channel flow, travel time was calculated based on channel length and velocity for the 2-year storm. The velocity, in turn, was estimated based on channel slope and assumed flow depth and cross-sectional geometry. All of these data were developed from the GIS. Slope data were calculated by using the upstream and downstream elevations and the stream length in GIS. Cross-section geometries were assigned based on review of stream geometry data developed by using GIS tools and DEM.

3.2.5 Routing (Muskingum-Cunge)

The Muskingum-Cunge Routing method was used to route runoff through the watershed. An eight-point channel cross section was developed for each routed reach using the ArcView profiler tool and the elevation contours. The channel length and slope was also determined using ArcView and DEM.

3.2.6 Watershed Storage

Areas of significant storage were simulated in HEC-HMS as a reservoir hydrologic element. In general, storage areas were simulated if the storage volume to runoff volume ratio was greater than 0.20 for the 100-year design event. Under existing land use conditions, the hydrologic model includes five small high-hazard flood control structures designed by the NRD. The model also includes two additional ponds, the first (Magee Dam) located at the intersection of Yankee Hill Road and 120th Street and the second (Korver Dam) located between Pine Lake Road and Highway 2 west of 98th Street. In addition, channel storage affects along the main channel of Stevens Creek was simulated, including the area between Highway 6 and Havelock Avenue and directly upstream of Murdock Trail.

Under future land conditions, the model includes the seven ponds and channel storage locations from the existing conditions model as well as five additional ponds designed by the NRD, which will be constructed over the next few years. The storage areas that were simulated under existing and future land use conditions are depicted on Figure 3-6.

3.2.7 Flow Diversions

The Stevens Creek main channel diverts flow at two locations during flooding conditions as depicted on Figure 3-7. During high flows, a portion of the main channel flow is diverted in the easterly direction to the Stevens Creek Overflow channel. The overflow channel was included in both the hydrologic and hydraulic models to accurately define the Stevens Creek floodplain and floodway.

Flow diversion also occurs near the confluence of Tributary 5 and the Stevens Creek main channel (Figure 3-7). A portion of the flow from Tributary 5 enters the Stevens Creek main channel between Fletcher and Highway 6. The Tributary 5 flow diversion was also included in both the hydrologic and hydraulic models.

Diversion nodes in HEC-HMS were used to simulate the diverted flow. The diversion node required defining a relationship between the primary channel flow and the diverted flow. The procedure included using the HEC-RAS models to determine the flow rate that the primary channel and the diversion channel could convey that resulted in the same water surface elevation. To develop the peak flow diversion table, a range of flow rates were

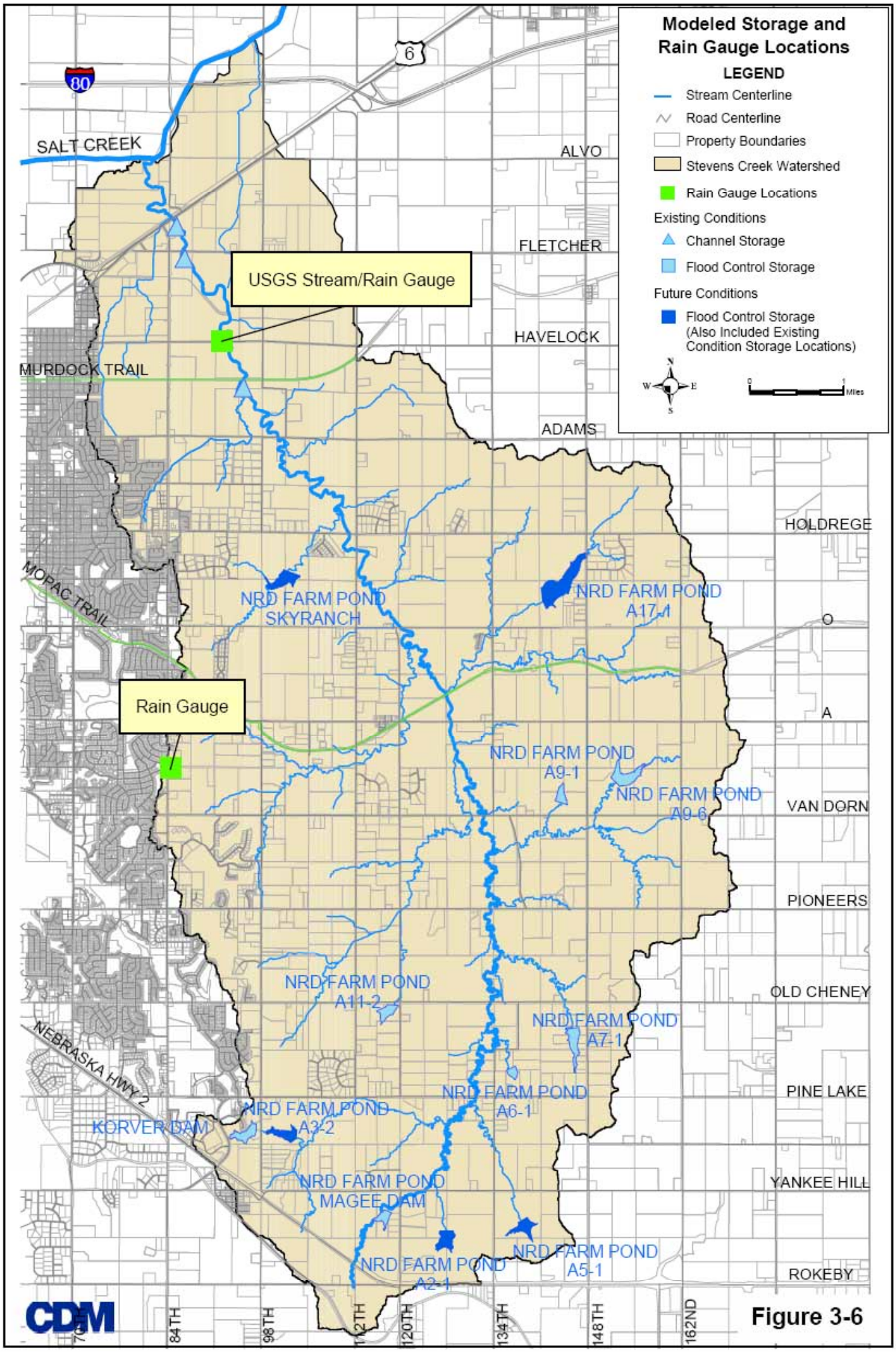

Modeled Storage and Rain Gauge Locations
LEGEND
Stream Centerline
Road Centerline
Property Boundaries
Stevens Creek Watershed
Rain Gauge Locations
Existing Conditions
Channel Storage
Flood Control Storage
Future Conditions
Flood Control Storage (Also Included Existing Condition Storage Locations)
N
W
E
S
0
1
Miles
80
6
SALT CREEK
ALVO
FLETCHER
HAVELOCK
ADAMS
HOLDREGE
O
A
VAN DORN
PIONEERS
OLD CHENEY
PINE LAKE
YANKEE HILL
ROKEBY
USGS Stream/Rain Gauge
Rain Gauge
MURDOCK TRAIL
MOPAC TRAIL
NEBRASKA HWY 2
NRD FARM POND SKYRANCH
NRD FARM POND A17-1
NRD FARM POND A9-1
NRD FARM POND A9-6
NRD FARM POND A11-2
NRD FARM POND A7-1
NRD FARM POND A6-1
NRD FARM POND A3-2
KORVER DAM
NRD FARM POND MAGEE DAM
NRD FARM POND A2-1
NRD FARM POND A5-1
84TH
98TH
112TH
120TH
134TH
148TH
162ND
CDM

Figure 3-6

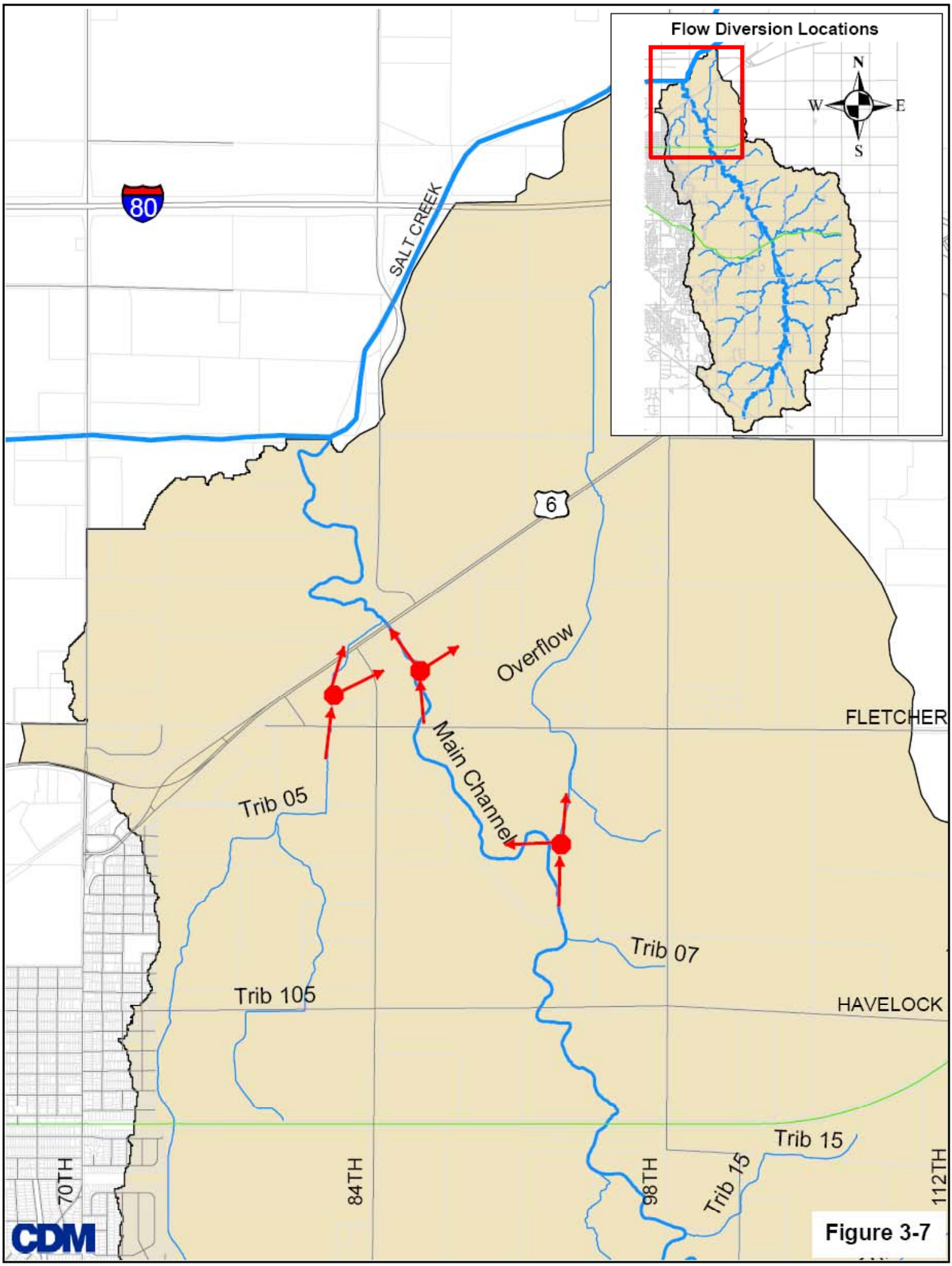

Flow Diversion Locations
N
W
E
S
80
SALT CREEK
6
Overflow
Main Channel
FLETCHER
Trib 05
Trib 07
Trib 105
HAVELOCK
Trib 15
Trib 15
70TH
84TH
98TH
112TH
CDM

Figure 3-7

inputted into both HEC-RAS models. The HEC-RAS models were then run to simulate the water surface elevation (WSE) through this area. The WSEs were then matched to determine the flow rate that the primary channel and overflow channel could convey for various WSEs. The same general procedure was used for the three flow diversion locations.

3.3 Model Calibration

The calibration process included two components, including historical storm event calibration and peak flow verification, using FEMA published flows and regression equation flow estimates.

3.3.1 Historical Storm Event Calibration

Historical storm event calibration requires stream gauge data and a distribution of rain gauges located in the watershed. Figure 3-6 shows the location of one stream gauge and two rain gauges within the watershed.

A USGS gauge (06803520) is located on the main channel of Stevens Creek at Havelock Avenue and contains both hourly stream flow and rainfall data. This gauge has available information from October 1, 1968, through December 2002. A review of data identified the September 8, 1989 storm event with the highest recorded peak discharge for the period of record, which was approximately 12,900 cubic feet per second (cfs). The existing FEMA Lancaster County Flood Insurance Study (FIS), dated September 21, 2001, 10-year flow rate is 9,400 cfs.

The other rain gauge is located along 84th Street between Van Dorn and A Street. This gauge contains hourly rainfall data from 1992 to 2003, which does not correspond to the September 8, 1989 flood event.

The HEC-HMS model was used to estimate a runoff hydrograph for the September 8, 1989 rain storm using only the recorded precipitation data from the Havelock gauge. Figure 3-8 shows the hydrographs from both the HMS model and the stream flow data recorded at the USGS gauge.

Typically, for a watershed of this size, six or more rain gauges distributed throughout the watershed are needed to properly calibrate the model. As shown in the Figure 3-8, the HEC-HMS peak flow estimate is approximately 30 percent lower than the recorded value. Due to insufficient rainfall data distributed across the watershed, it was concluded the HEC-HMS model could not be properly calibrated using historical data.

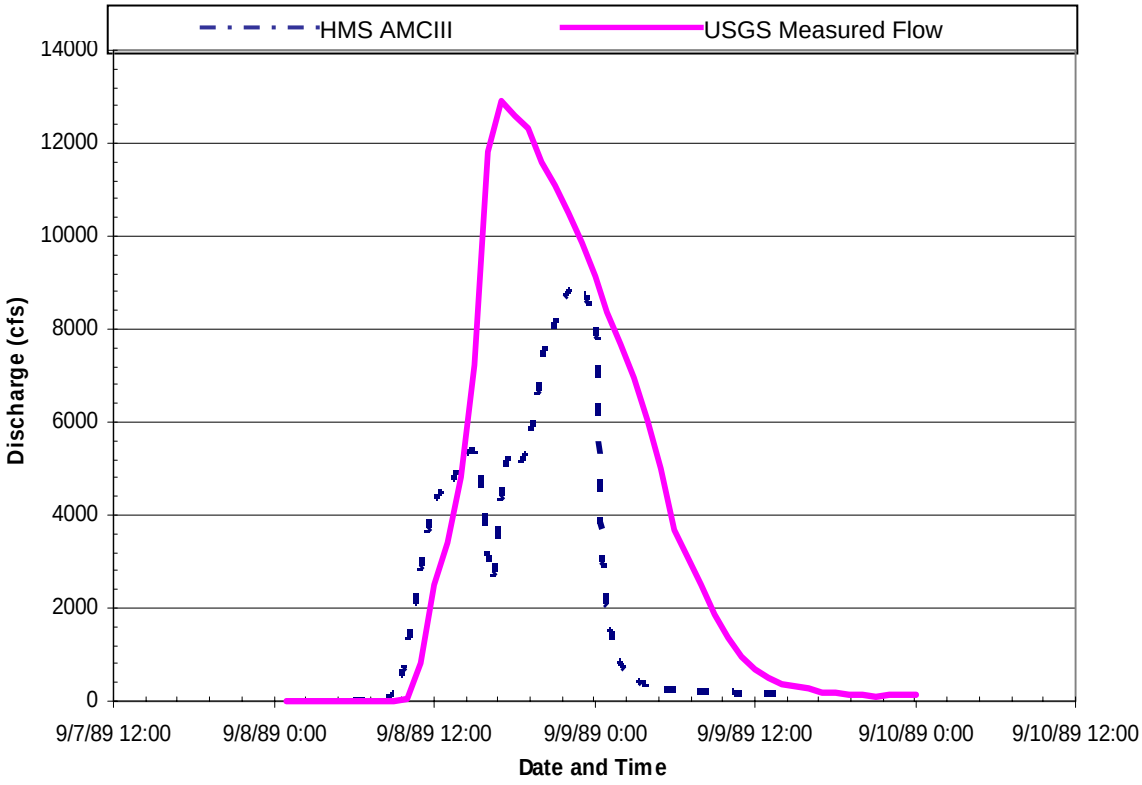


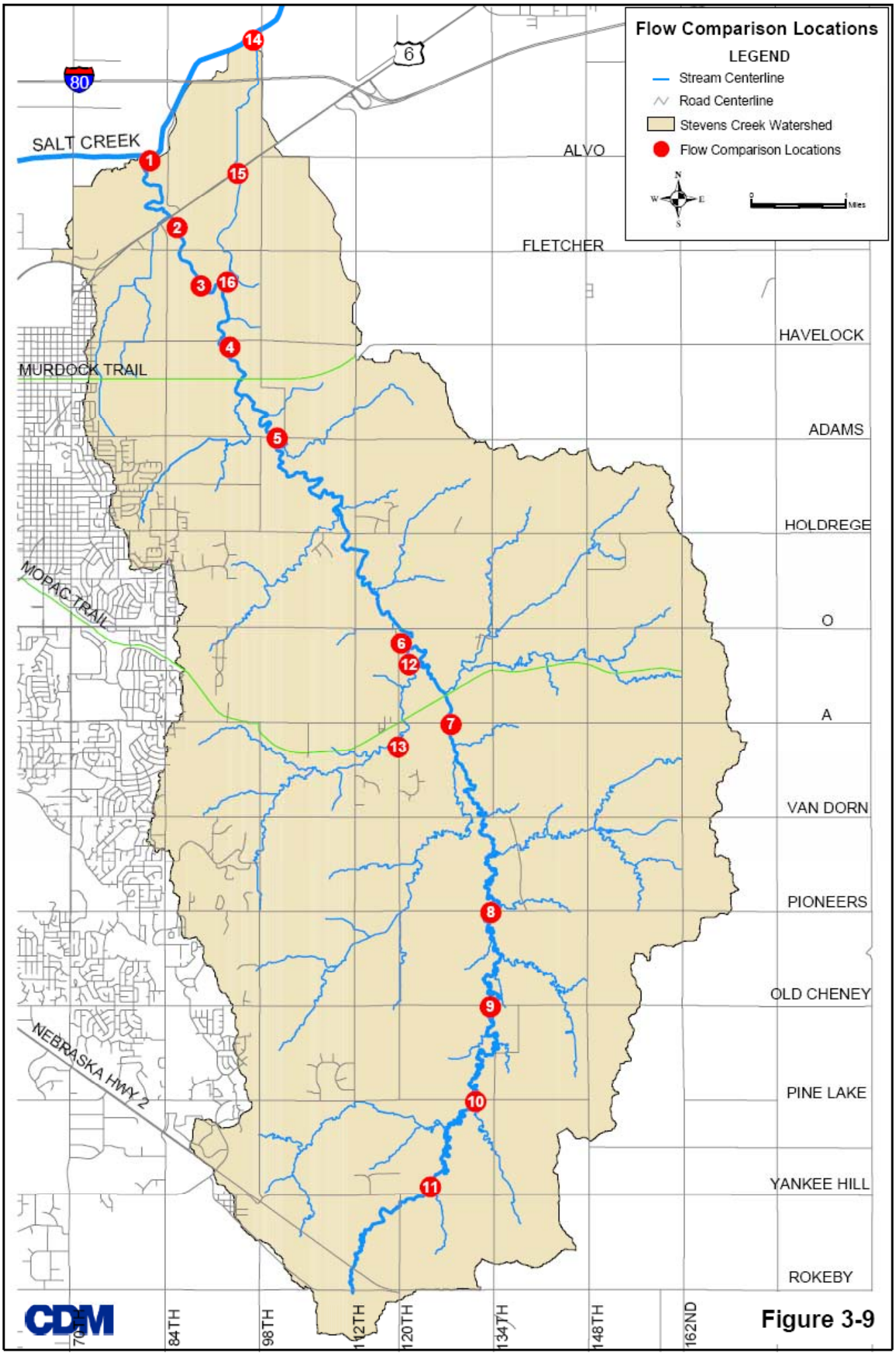
Figure 3-8
Stevens Creek - Havelock Street
9-8-89 Calibration Event

3.3.2 Peak Flow Verification

The HEC-HMS model results were compared to the Lancaster County FIS and peak flows derived using the Nebraska USGS regression equations. Table 3-8 illustrates the flow rates used in the verification process, while Figure 3-9 illustrates the location.

Other data were used in the verification process, including historical photos and eyewitness accounts of flooding during storm events. The project team used a questionnaire mailer and public meetings to facilitate the gathering of this information.

On average, the peak runoff rates estimated by the HEC-HMS model under existing land use conditions are 2 percent higher than the flow rates published by FEMA. At the Havelock Avenue location, the HEC-HMS is within 5 percent of both the FEMA published flows and the minimum regression equation estimate.


Flow Comparison Locations
LEGEND
Stream Centerline
Road Centerline
Stevens Creek Watershed
Flow Comparison Locations
Miles
SALT CREEK
80
6
ALVO
FLETCHER
HAVELOCK
ADAMS
HOLDREGE
O
A
VAN DORN
PIONEERS
OLD CHENEY
PINE LAKE
YANKEE HILL
ROKEBY
MURDOCK TRAIL
MOPAC TRAIL
NEBRASKA HWY 2
70TH
84TH
98TH
112TH
120TH
134TH
148TH
162ND
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CDM

Figure 3-9

Table 3-8
100-Year Flow Comparisons

Location Number	Description	FEMA	HMS Model[1]	Regression Minimum	Regression Maximum
Stevens Creek Locations					
1	At mouth	8,100	9,730	NA[2]	NA[2]
2	Upstream of Hwy 6	8,000	9,687	NA[2]	NA[2]
3	D/S of Stevens Creek Overflow	13,100	11,482	NA[2]	NA[2]
4	Havelock Avenue	17,400	18,331	19,570	34,191
5	Adams Street	17,700	19,372	NC	NC
6	D/S of Trib 45	19,800	20,407	NC	NC
7	A Street	14,000	13,298	NA[3]	NA[3]
8	Pioneers Boulevard	7,660	6,769	NC	NC
9	At Old Cheney	6,050	6,259	NA[3]	NA[2]
10	Pine Lake Road	5,790	6,266	NC	NC
11	At Yankee Hill	2,090	2,443	NA[3]	NA[3]
12	Trib45 - at Mouth	3,900	4,134	6,760	11,810
13	Trib45 - U/S of 120th Street	4,000	4,918	6,270	10,950
Stevens Creek Overflow Channel Locations					
14	At mouth	8,300	7,367	NA[2]	NA[2]
15	Upstream of Hwy 6	8,300	7,430	NA[2]	NA[2]
16	D/S of Stevens Creek	6,500	6,310	NA[2]	NA[2]

1 Peak flow rates based on existing land use conditions.
2 Regression equations are not applicable due to the reduction in peak flow caused by flow diversions at these locations.
3 Regression equations not applicable for A Street, Old Cheney, and Yankee Hill. Basin slope variable outside of applicable range.

NC: Not calculated.

3.4 Stream Gauge Statistical Analysis

In addition to the calibration and verification process described above, the feasibility of performing a flood flow frequency analysis using the historical stream data at the USGS Havelock gauge was evaluated. The review of the gauge data found that the two highest recorded flow rates (12,900 and 9,760 cfs) were approximately a 10-year event. In addition, an examination of the yearly recorded peak discharges found that over 87 percent was less than 5,000 cfs and 71 percent less than 3,000 cfs.

The stream gauge is located within very mild terrain with significant overbank conveyance capacity that may have affected the historical gauge data. This was confirmed with historical photos of this area during a flood event. Therefore, this gauge was found to lack the necessary extreme events (>10 year event) and quality of data to perform a flood flow frequency analysis.

3.5 Modeling Results

Table 3-9 presents the HEC-HMS modeling results under existing and future land use conditions. The stormwater peak flow rates are provided at the same major locations as reported in the Lancaster County FIS. The 100-year peak flow rates under existing conditions were used to delineate the floodplain/floodprone areas as depicted in Section 5. Model input data and results are included in Appendix C, located in Volume II. Peak flow rates for each structure included in the hydraulic model are presented in Appendix J, located in Volume II.

Table 3-9
Peak Flow Modeling Results

Location No.	Description	2-year		5-year		10-year	
		Exist	Future	Exist	Future	Exist	Future
1	At mouth	4,507	5,456	6,695	6,975	7,388	7,548
2	Upstream of Hwy 6	4,493	5,450	6,668	6,948	7,354	7,512
3	D/S of Stevens Creek Overflow	4,464	5,454	6,829	7,061	7,539	7,852
4	Havelock Avenue	4,529	5,570	7,645	8,099	9,337	10,250
5	Adams Street	4,602	5,846	8,086	9,109	10,927	12,197
6	D/S of Trib 45	5,046	6,626	8,331	10,111	11,314	12,974
7	A Street	3,460	4,541	5,698	7,209	7,760	9,385
8	Pioneers Boulevard	2,233	2,106	3,192	3,134	4,032	4,298
9	At Old Cheney	2,030	1,860	2,934	2,665	3,718	3,671
10	Pine Lake Road	2,105	2,283	3,002	3,138	3,704	3,857
11	At Yankee Hill	727	822	1,111	1,192	1,438	1,445
12	Trib45 - at Mouth	1,063	1,636	1,767	2,397	2,350	3,027
13	Trib45 - U/S of 120th Street	1,096	1,730	1,842	2,716	2,573	3,606
Stevens Creek Overflow Channel Locations							
14	At mouth	893	1,393	1,269	2,174	1,871	2,870
15	Upstream of Hwy 6	700	1,268	1,202	2,001	1,888	2,556
16	D/S of Stevens Creek	0	0	696	1,001	1,737	2,265

Location No.	Description	50-year		100-year		500-year	
		Exist	Future	Exist	Future	Exist	Future
1	At mouth	8,679	9,033	9,730	9,982	11,511	11,567
2	Upstream of Hwy 6	8,641	8,997	9,687	9,942	11,452	11,509
3	D/S of Stevens Creek Overflow	9,896	10,426	11,482	11,950	14,252	14,512
4	Havelock Avenue	15,408	16,480	18,331	19,301	24,678	25,187
5	Adams Street	16,311	17,653	19,372	20,669	26,381	27,288
6	D/S of Trib 45	17,048	19,127	20,407	22,540	28,064	30,009
7	A Street	11,247	13,563	13,298	15,892	17,819	20,565
8	Pioneers Boulevard	5,783	5,961	6,769	6,833	8,633	8,777
9	At Old Cheney	5,348	5,071	6,259	5,855	8,066	7,531
10	Pine Lake Road	5,352	5,093	6,266	5,765	8,245	7,529
11	At Yankee Hill	2,101	1,941	2,443	2,206	3,196	2,801
12	Trib45 - at Mouth	3,441	4,406	4,134	5,170	5,726	7,046
13	Trib45 - U/S of 120th Street	4,046	5,474	4,918	6,477	6,916	8,745
Stevens Creek Overflow Channel Locations							
14	At mouth	5,709	6,299	7,367	7,909	11,787	12,033
15	Upstream of Hwy 6	5,786	6,272	7,430	7,858	11,850	11,942
16	D/S of Stevens Creek	4,962	5,412	6,310	6,707	9,979	10,144

Section 4
Hydraulic Model Development

4.1 Introduction

This section provides a description of the methodology used to develop the hydraulic model for the Stevens Creek Watershed. The hydraulic modeling was performed using the Army Corps of Engineer's (USACE) Hydrologic Engineering Center's (HEC) River Analysis System program (HEC-RAS) Version 3.1.1 steady state option. Both an existing and future conditions model was developed. The following appendix sections, located in Volume II of this report, provide detailed information on the hydrologic and hydraulic model data input and results:

- Appendix C - Hydrologic Model Input Data and Results
- Appendix D - Hydraulic Model Input Data and Results
- Appendix E - Stream Profiles
- Appendix J - Drainage Structure Design Data

4.2 HEC-RAS Model Development

The HEC-RAS data requirements are categorized into 10 data sets as shown in Table 4-1. The model parameters were developed using a combination of manual procedures and automation tools using ArcInfo, ArcView GIS, and HEC-GeoRAS in conjunction with GIS data. All GIS data were in Lincoln/Lancaster County projection.

Table 4-1
HEC-RAS Model Data Sets

HEC-RAS Model Parameter	*Development Method*	*Data Requirements*
Stream network	ArcView GIS	Stream centerline coverage with unique stream reach names
Cross sections (river station and geometry data)	ArcInfo and HEC-GeoRAS	Triangular irregular network (TIN), cross section cut line coverage
Downstream reach lengths (channel and overbanks)	ArcInfo and HEC-GeoRAS	Stream centerline and overbank (left and right) flow path coverage
Manning's n-values	ArcInfo	Mannings n-value coverage created from orthophotos and future development plans
Roadway crossings	Manually input using field survey data	Roadway profile and bridge or culvert opening
Dams	Manually input using field survey data	Control structure dimensions and embankment profile
Expansion and contraction coefficients	Manually input using standard values and engineering judgment	Contours and cross section cut line coverage
Normal depth boundary conditions	ArcView GIS	Contours, stream centerline, and cross section cut line coverage
Ineffective flow areas	Manually input using standard procedures and engineering judgment	Contours and cross section cut line coverages
Channel bank stations	Manually input using standard procedures and engineering judgment	Cross section geometries (station and elevation data)

A separate HEC-RAS model was developed for the main channel, each tributary, and the overflow channel. The paragraphs below describe the HEC-RAS model development procedures.

4.2.1 Stream Network, Cross Sections, and Reach Lengths

The first step in developing the HEC-RAS model was to create a HEC-RAS geometry file containing the stream network, cross section river stations and geometries, and channel and overbank downstream reach lengths. The stream network defines the extent of the model and can be defined as the main channel and its tributaries that receive runoff from areas approximately 150 acres in size and greater. Cross section river stations define the location of the cross section along the stream in miles measured from the confluence with Salt Creek, and cross section geometry includes station and elevation data. Downstream reach lengths define the distance to the next downstream cross section along the stream reach and the along the left and right overbanks.

Automation tools were used to develop the model input data described above, including HEC-GeoRAS Version 1.0 in conjunction with ArcInfo Version 7.3 and ArcView GIS Version 3.3. These tools were used to prepare an ASCII text file that was directly imported into the HEC-RAS model, creating a geospatially referenced HEC-RAS geometry file. HEC-GeoRAS is a free software program developed by the USACE HEC.

HEC-GeoRAS uses the following data to create the ASCII text import file:

Triangular Irregular Network (TIN)

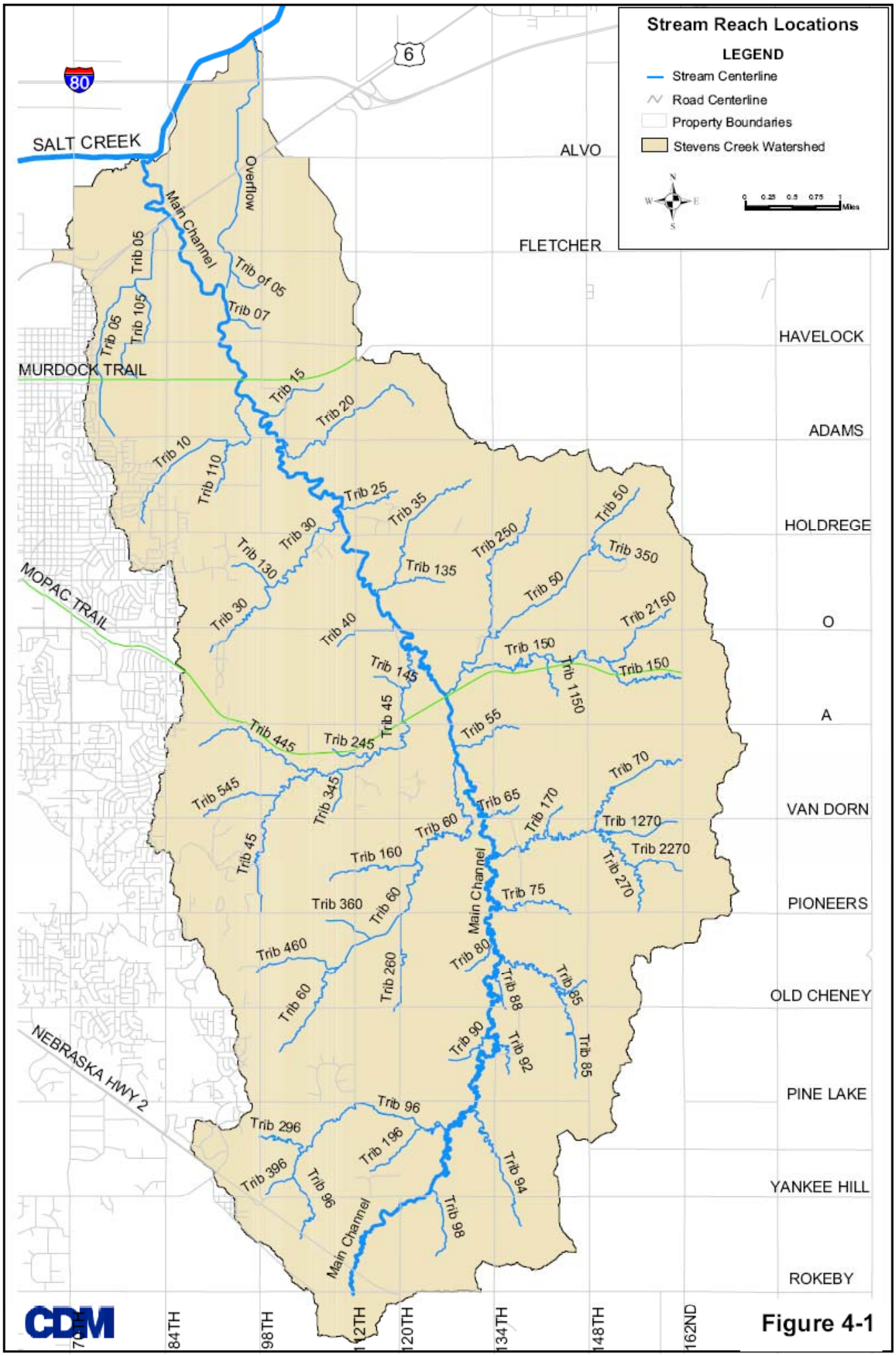
As discussed in Section 2, a TIN was created from the Lincoln/Lancaster County contour information using ArcInfo in conjunction with LiDAR. A TIN is a surface representing the ground topography and is used in conjunction with the cross section cut line coverage to develop station and elevation information for cross section geometry data. A surface elevation was recorded at each station along the cross section cut line that crosses the TIN edge.

Stream Centerline Coverage

The stream centerline coverage was created in ArcView GIS using the existing Lincoln/Lancaster County hydrography GIS coverage. The stream centerline coverage represents the Stevens Creek stream network, which includes a separate line segment for the main channel, overflow channel, and each of the 51 tributaries. HEC-GeoRAS requires a river name and reach name be assigned to each line segment. For the purpose of this study, each segment was assigned Stevens Creek as the river name. Figure 4-1 shows the location of each stream and its associated reach name.

Cross Section Coverage

The cross section coverage is a GIS line coverage that identifies the location and extent of each cross section. The cross section coverage was generated in ArcView GIS. Cross section cut lines were located along the stream centerline at points that represent the average geometry of the stream reach, and at changes in geometry, slope, channel, overbank roughness, and discharge. Available aerial photographs and contour information were used to layout the cross section locations. The FEMA 500-year floodplain boundary was used as a guide in determining the extent of the cross sections. The average distance between cross sections was approximately 400 feet, with less distance between cross sections in the vicinity of structures and abrupt changes in channel geometry.



CDM

Figure 4-1

The cross sections are oriented from left to right looking downstream. Each cross section is identified by the stream name, reach name, and river station. The river station for each cross section is the cumulative distance in miles to the confluence of Salt Creek.

Overbank Flow Path Coverage

The overbank flow path coverage is a GIS line coverage that represents the average left and right overbank flow paths between each cross section. The overbank flow path coverage was used to determine the downstream reach lengths for the left and right overbanks. The FEMA 500-year floodplain boundary and the contour information were used as guides to locate the overbank flow paths. In general, the overbank flow path was located on each side of the stream halfway between the 500-year floodplain boundary and the channel bank. In areas with no existing floodplain, the location of the overbank flow path was estimated based on the width of the nearest floodplain.

4.2.2 Manning's n-Values

The Manning's n-values at each cross section were estimated using digital aerial and field photographs. A polygon coverage was created using ArcView GIS to represent land surface characteristics and the associated n-values. These values are shown in Table 4-2.

Table 4-2
Land Surface Characteristics and Associated Manning's n-Values[1]

Land Surface Type	*Initial n-Value*	*Range of n-Value*
Grass, urban and maintained	0.030	0.025–0.035
Trees and brush	0.090	0.035–0.160
Brush	0.060	0.035–0.160
Residential areas[2]	0.150	0.035–10
ADF Plant - (developed area)[2]	0.100	0.035–10
Agricultural, Pasture	0.035	0.025–0.050
Pavement	0.020	0.013–0.025
Lake	0.025	0.0160–0.033

1 Source: Open Channel Hydraulics, Chow 1959.
2 These n-values will be used in developed areas to account for the loss of conveyance caused by buildings.

The initial n-values were used as a model starting point and were adjusted within the provided ranges during calibration. The horizontal extent of each type of land cover and the associated n-value for each cross section were determined by intersecting the land surface coverage with the cross section coverage. Multiple n-values across the cross section were imported using a customized ArcInfo tool that generates the data in HEC-RAS ASCII format.

The n-values were increased where buildings are located within the floodplain to account for conveyance loss. The n-values in these areas may range from 0.030 for areas with few buildings to 0.15 for fully developed areas. If significant blockage is caused by buildings in the flood fringe, the developed areas were modeled as ineffective flow.

Channel n-values were manually adjusted using the HEC-RAS cross section data editor. A combination of digital aerial photos, field photographs, and site visits were used to select an appropriate n-value. Table 4-3 lists channel descriptions and associated ranges of n-values that were used for Stevens Creek.

Table 4-3
Channel Descriptions and Associated Manning's n-Values[1]

Channel Description	Initial n-Value	Range of n-Value
Clean, straight	0.030	0.025 - 0.033
Straight channels, weeds	0.035	0.030 - 0.040
Clean, meandering	0.040	0.033 - 0.045
Meandering, weedy	0.045	0.045 - 0.050
Sluggish, weedy	0.070	0.050 - 0.080
Very weedy, floodways with heavy timber and underbrush	0.100	0.075 - 0.150

1 Source: Open Channel Hydraulics, Chow 1959

4.2.3 Roadway Crossings and Dams

Bridge and culvert openings and roadway profiles were developed from data collected during field surveys. Field data were collected based on monument and GPS controls using standard field survey collection forms. These data were manually entered into the HEC-RAS model.

HEC-RAS requires four cross sections to be entered to define each drainage structure. The four cross sections include a downstream cross section where flow is fully expanded, a cross section at the downstream face of the structure, a cross section at the upstream face of the structure, and an upstream cross section prior to flow contraction. Three cross sections were cut from the TIN to model each hydraulic structure. These three cross sections include the downstream cross section at fully expanded flow, the upstream face, and the upstream cross section prior to flow contraction. The upstream face cross section was copied downstream to represent the downstream face.

The flow lengths between the bridge cross sections and the upstream and downstream cross sections were determined using ArcView GIS. The drainage structure location in river miles was estimated by intersecting the stream network coverage with the roadway coverage. A unique identifier was given to each structure for ease in identification. In instances where County IDs have been assigned to structures, the County ID was documented in the cross section description in the HEC-RAS model.

4.2.4 Expansion and Contraction Coefficients

The expansion and contraction coefficients were estimated based on the ratio of expansion and contraction of the effective flow area in the floodplain occurring at cross sections and at roadway crossings. Typical coefficients used in the model are listed in Table 4-4. The expansion and contraction coefficients were manually coded into the HEC-RAS cross section data editor.

Table 4-4
Expansion and Contraction Coefficients[1]

Transition Type	Expansion Coefficient	Contraction Coefficient
Gradual	0.3	0.1
Roadway Crossing	0.5	0.3
Abrupt	0.8	0.6

1 Data from HEC-RAS Hydraulic Manual, Page 3-20

4.2.5 Boundary Conditions

Normal depth was used as the downstream boundary condition for all modeled reaches. This boundary condition requires the input of the energy grade line (EGL) slope at the downstream boundary of each reach. The downstream EGL slope can be approximated as the channel invert slope from the contour data. Therefore, the slope between the two most downstream cross sections was used to calculate the normal depth boundary condition for each reach. This slope was calculated in ArcView GIS using the elevation contour data, cross section

cut line coverage, and stream centerline coverage. For the main channel, the normal depth was calculated in ArcView GIS using the thalweg survey, cross section cut line coverage, and stream centerline coverage.

4.2.6 Ineffective Flow Areas

Ineffective flow areas were determined using the cross section plots and contour information. The following situations required the use of the ineffective flow area option:

- Floodplain areas significantly below the top of the channel bank that are not hydraulically connected to the channel downstream.
- Floodplain areas within the hydraulic shadow of roadway encroachments caused by contraction and expansion of flow through the bridge or culvert openings. These were estimated using 4:1 expansion and 1:1 contraction ratios.
- Floodplain areas within the hydraulic shadow of other obstructions or irregularities in the stream valley floodplain.
- Floodplain areas that are significantly blocked by buildings.

Ineffective flow areas were manually coded into the HEC-RAS cross section data editor.

4.2.7 Channel Bank Stations

The bank stations were located and entered manually by graphically editing the cross sections within HEC-RAS. The bank stations were verified by comparing samples of channel bank stations from the field survey, the GIS generated cross section geometries, and conditions during field reconnaissance.

4.3 Special Modeling Cases

During the development of the HEC-RAS model, unique hydraulic situations were encountered that required supplemental calculations as described below.

4.3.1 Stevens Creek Overflow Channel

Two flow diversions occur along the Stevens Creek main channel between Highway 6 and Fletcher Avenue, and one diversion exists along Tributary 5. As described in Section 3.2.7, the HEC-HMS and HEC-RAS models were used to develop the appropriate flow diversions between the primary and overflow channel. At locations where the flow is within both the primary and overflow channel, cross sections were truncated in both models at the ridge to avoid double counting channel conveyance.

4.3.2 Split Flow Occurrences

On the western side of the watershed, the stream at times drains parallel to the roadway before draining into the roadway culvert crossings. During flooding conditions, if the roadway profile is low enough, flow can be released across the road creating a split flow situation. This occurs at two locations during flooding conditions:

- Upstream of drainage structure SC180 (8’ x 5.5’ RCB, tributary 40) along Highway 34

- Immediately upstream of drainage structure SC290 (twin 8′ x 3′ RCB, tributary 45) along 98th Street

For these two cases, spreadsheet calculations were used to estimate the amount of flow released across the roadway, referred to as split flow. For both cases, the split flow was subtracted from the primary channel, which resulted in a reduced flow rate at each drainage structure. At the next cross section downstream from the culverts, the split flow was added back to the primary channel flow rate.

4.4 Floodway Determination

A floodway was determined for each of the modeled reaches. The floodway is determined from the floodplain model by encroaching the left and right overbanks of each cross section to produce a target rise in water surface elevation. The encroachments simulate fill within the floodplain that reduces conveyance of flood flows.

A 1-foot rise criterion was used to determine the encroachment stations at each cross section. Initially, Encroachment Method 4 was used to estimate encroachment stations at each cross section. Encroachment Method 4 automates the floodway modeling process by computing the encroachment station so that conveyance within the encroached cross section (with a target water level) is equal to the conveyance of the natural cross section at the natural water level. The higher water level for the encroached cross section is specified as a fixed amount above the natural profile. A target increase of 1.0 foot was used for this analysis.

Once the initial encroachment stations were determined by HEC-RAS using Encroachment Method 4, each cross section was reviewed and adjusted if necessary to meet the target 1-foot rise. The downstream boundary condition for the floodway model was set at 1.0 foot above the 100-year water surface elevation.

4.5 Model Verification

The HEC-RAS model was verified by comparing the results to existing FEMA floodplain maps, historical high water marks, and aerial photos showing past flooding. For example, the June 1984 flood event caused a significant amount of building damage along Highway 6. During this flood event, the owners reported that the Telex building had 14 inches of floodwater in the main building, which equates to flood elevation of approximately 1,135.60 feet. In 1984, no NRD farm ponds were constructed. In comparison, the study HEC-RAS 100-year flood elevation under existing land use conditions is approximately 1,135.00 feet. Five NRD farm ponds were simulated under existing conditions, which may account for the slightly lower flood elevation at the Telex building location as estimated by the HEC-RAS model. In addition, information obtained from public meetings and questionnaires were used to verify the model results.

Section 5
Floodplain Management Tools

5.1 Floodprone Areas

One of the major elements of the Master Plan is updated 100-year floodplain and floodway boundary maps. This information will provide a planning tool to protect future homes and businesses from flood hazards and provide guidance for sustainable urban growth in the watershed. In addition, this component of the Master Plan reflects the conclusions of the Mayor's Floodplain Task Force, which recommended that the City continue to develop a comprehensive watershed approach to floodplain mapping using the latest technology and data available to keep the City's FEMA floodplain maps as accurate and reliable as possible.

The current FEMA Stevens Creek floodplain maps were based on a study completed by the Natural Resources Conservation Service (NRCS) in 1978 and were officially adopted for regulatory purposes on February 3, 1982. Through the City's Cooperating Technical Partnership (CTP) program with FEMA, the floodplain maps were updated as part of the Stevens Creek Watershed Master Plan study process. The study updated the floodplain boundary in areas already mapped, and delineated the floodplain boundary along stream reaches not previously studied or mapped by FEMA. The study floodplains are referred to as "floodprone areas." These floodprone areas will be reflected on the FEMA floodplain maps at some time in the future when FEMA finalizes the Flood Insurance Rate Map Physical Map Revision and it is adopted by the City.

The study floodplain maps were submitted to FEMA in December 2004 for preliminary review and comment. The FEMA review process could potentially take several months to more than a year following the final submittal to FEMA and will include a public comment period. The comment period will include a FEMA-hosted public meeting before the maps become officially adopted. In the interim, the City will use study floodplains for the purposes of regulating the floodprone areas until the FEMA approval adoption process is finalized.

The floodprone areas are being used as best available information for City regulatory purposes, in accordance with the *Flood Standards for New Growth Areas* adopted by the City in May 2004. On December 20, 2004, the Lincoln City Council passed a formal resolution authorizing the use of Stevens Creek floodprone areas within the City 3-mile jurisdiction for regulatory purposes.

5.1.1 Flood Insurance Certificates

Flood elevation certificates were prepared by certified land surveyors to verify whether habitable buildings located near the outer edge of the flood fringe were in fact located within the study floodplain. The survey crews obtained first floor elevations to make the determination. The completed flood elevation certificate provides the property owner with some of the necessary documentation to obtain a FEMA Letter of Map Amendment (LOMA). A flood certificate survey was offered to the properties listed in Table 5-1.

Table 5-1
Properties Offered a Flood Certificate

Address
341 Anthony Lane
417 Anthony Lane
330 Anthony Lane
11800 Holdrege
2536 N. 83rd Street
2524 N. 83rd Street
2518 N. 83rd Street
7331 Havelock
7333 Havelock Avenue
7332 Ballard Place
7328 Ballard Place
7321 Morrill Avenue
7410 E. Colfax
7411 E. Colfax
7401 E. Colfax Circle
7325 Yosemite Drive
3550 N. 75th Street
3530 N. 75th Street
9341 A Street
7301 Ballard

5.1.2 Floodplain Delineation Process

HEC-GeoRAS Version 1.0 is a package of ArcInfo macros specifically designed to view and manipulate geospatial data for use in the HEC-RAS model. HEC-GeoRAS was used to create geometric input data for use in the HEC-RAS model and to generate spatially accurate water surface profiles. The HEC-GeoRAS macros are written in the arc macro language (AML) and require the ArcInfo program with the TIN extension.

Stream confluences were not simulated with the HEC-RAS computer model. Per FEMA requirements, stream confluences are to be simulated with HEC-RAS only if coincident peaks occur, which was not the case within this watershed. To accurately map the floodplain at stream confluences, a level pool process was performed. Table 5-2 lists the WSEs at the downstream end of each stream reach, which formed the basis of the floodplain boundary at each confluence location. Reach names are shown on Figure 4-1.

The floodplain boundaries were delineated based on the GIS data and other model parameters. A manual quality control review was conducted to verify the accuracy of the automated process.

5.1.3 Study Floodplain and Floodway Maps

Figure 5-1 represents an overview map depicting the entire watershed divided into 15 floodplain maps. The study floodplain maps are based on existing land use and infrastructure as described in Section 3. Each floodplain map is shown in more detail on Figures 5-2 through Figure 5-16. In addition, four sets of floodplain maps depicting the 100- and 500-year floodplain boundaries and floodway boundary were provided to the City under separate cover at a scale of 1 inch = 400 feet.

Stream profiles for each modeled channel reach were developed depicting the 10-, 50-, 100-, and 500-year water surface elevations. Each floodplain map provides information on the naming convention used to organize the stream profiles. The stream profiles are located in Appendix E, located in Volume II of the report.

5.2 Floodplain Management Strategy

The Master Plan also includes a strategy for adopting design standards needed to address stormwater volume and timing issues of individual detention basins within the larger watershed to avoid adverse downstream flooding impacts. As described in Section 6.7.2, this will involve using the HEC-HMS and HEC-RAS computer model, which were developed as part of the Master Plan study process, during the design of stormwater detention facilities. In addition, the Master Plan assumes the goals and objectives of the Comprehensive Plan regarding floodplain management and the Flood Standards for New Growth Areas will be implemented. These include designating areas for future urban development generally outside of the floodplain and applying No Net Rise, Compensatory Storage, and preservation of Minimum Flood Corridors where development encroaches into the floodplain.

Table 5-2
Stevens Creek Confluence Level Pool Elevations (NAVD 88)

*Reach Name**	*10-year*	*50-year*	*100-year*	*500-year*
Main Channel **	1125.32	1129.82	1131.32	1132.02
Overflow **	1119.82	1122.82	1124.22	1125.32
Tributary 07	1140.42	1141.06	1141.34	1141.83
Tributary 10	1150.08	1151.31	1151.77	1152.55
Tributary 105	1139.56	1140.17	1140.43	1140.82
Tributary 110	1161.59	1162.47	1162.76	1163.29
Tributary 1150	1218.98	1219.50	1219.71	1220.17
Tributary 1270	1236.31	1237.54	1237.98	1238.79
Tributary 130	1188.80	1189.41	1189.70	1190.27
Tributary 135	1174.84	1175.92	1176.23	1176.92
Tributary 145	1186.35	1187.69	1188.20	1188.89
Tributary 15	1150.75	1151.81	1152.25	1153.05
Tributary 150	1189.43	1190.26	1190.63	1191.31
Tributary 160	1221.90	1223.52	1224.31	1225.73
Tributary 170	1215.88	1217.30	1217.91	1219.02
Tributary 185	1250.81	1251.51	1251.86	1252.41
Tributary 196	1277.24	1278.08	1278.47	1279.19
Tributary 20	1154.51	1155.34	1155.68	1156.16
Tributary 2150	1246.69	1247.42	1247.75	1248.40
Tributary 2270	1262.01	1262.78	1263.12	1263.78
Tributary 245	1202.37	1203.88	1204.47	1205.44
Tributary 25	1163.65	1164.41	1164.81	1165.61
Tributary 250	1202.33	1202.80	1203.05	1203.51
Tributary 260	1240.83	1241.31	1241.55	1242.28
Tributary 270	1229.44	1231.69	1233.05	1236.66
Tributary 296	1322.98	1323.50	1323.74	1324.25
Tributary 30	1164.91	1165.67	1166.06	1166.84
Tributary 345	1212.93	1215.66	1216.01	1216.52
Tributary 35	1173.31	1174.23	1174.68	1175.56
Tributary 350	1249.01	1249.66	1249.90	1250.44
Tributary 360	1251.76	1252.23	1252.47	1253.02
Tributary 396	1335.88	1336.14	1336.25	1336.50
Tributary 40	1177.59	1178.65	1179.11	1180.06
Tributary 445	1218.64	1219.85	1220.46	1221.90
Tributary 45	1181.65	1182.60	1183.04	1183.97
Tributary 460	1267.38	1268.09	1268.37	1269.10
Tributary 5	1125.74	1129.50	1131.00	1131.70
Tributary 50	1187.73	1188.46	1189.02	1189.83
Tributary 545	1234.72	1235.61	1236.02	1236.76
Tributary 55	1192.75	1193.63	1193.92	1194.51
Tributary 60	1194.15	1195.35	1195.82	1196.57
Tributary 65	1201.48	1203.71	1204.33	1205.09
Tributary 70	1205.49	1207.67	1208.61	1210.15
Tributary 75	1214.24	1216.27	1217.11	1218.80
Tributary 80	1221.10	1223.04	1223.98	1225.47
Tributary 85	1222.98	1225.00	1226.00	1227.70
Tributary 88	1227.16	1229.14	1230.11	1231.85
Tributary 90	1240.22	1241.98	1242.84	1244.36
Tributary 92	1242.65	1244.65	1245.61	1247.41
Tributary 94	1263.00	1264.38	1265.20	1266.29
Tributary 96	1269.90	1272.19	1272.95	1274.04
Tributary 98	1293.82	1294.54	1294.67	1294.93
Tributary OF 05	1137.08	1137.80	1138.03	1138.65

* Reach names are shown on Figure 4-1.
** Obtained from Salt Creek backwater surface elevations published in the current FIS.

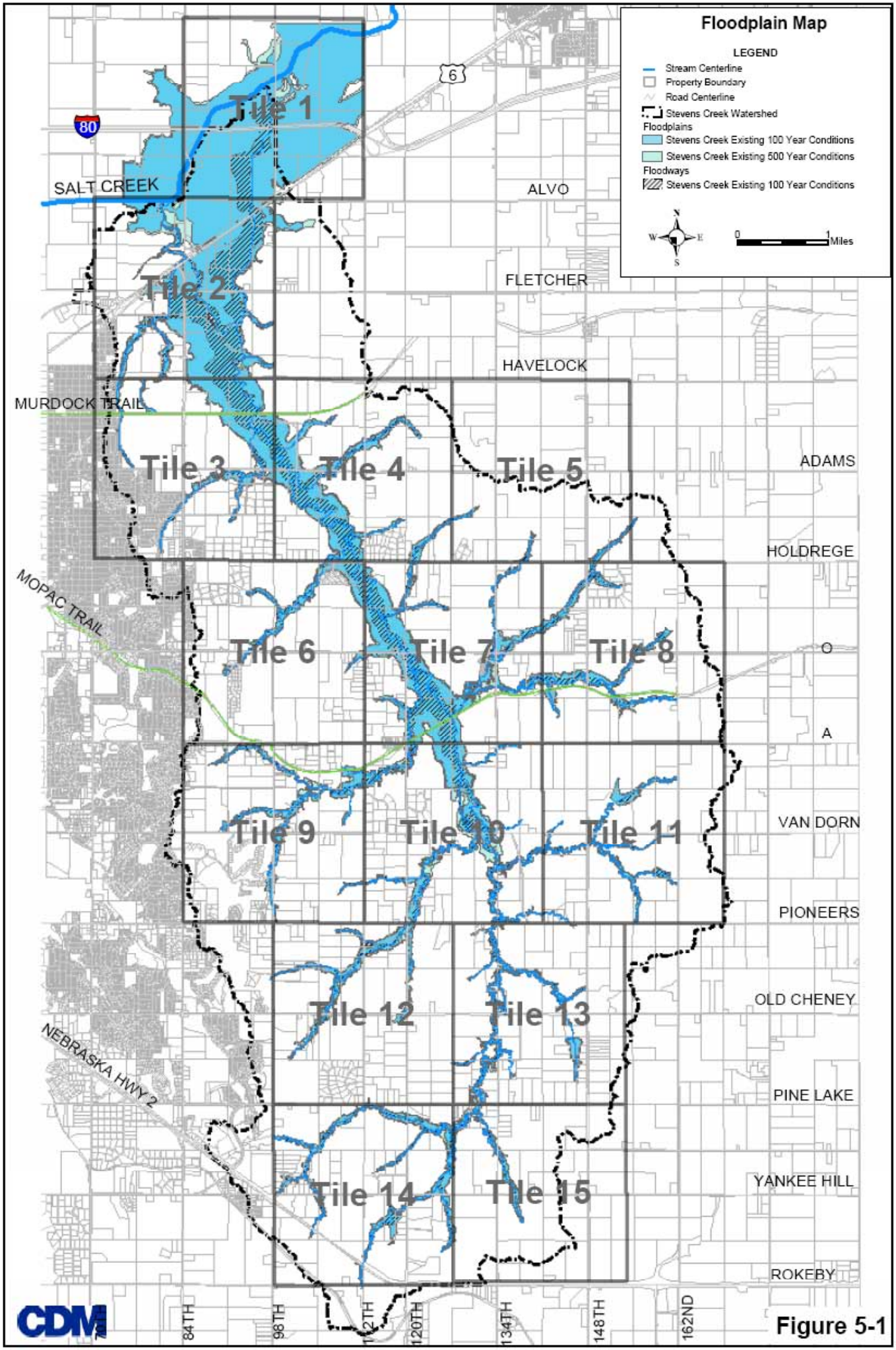

Floodplain Map
LEGEND
Stream Centerline
Property Boundary
Road Centerline
Stevens Creek Watershed
Floodplains
Stevens Creek Existing 100 Year Conditions
Stevens Creek Existing 500 Year Conditions
Floodways
Stevens Creek Existing 100 Year Conditions
N
W
E
S
0
1
Miles
Tile 1
Tile 2
Tile 3
Tile 4
Tile 5
Tile 6
Tile 7
Tile 8
Tile 9
Tile 10
Tile 11
Tile 12
Tile 13
Tile 14
Tile 15
SALT CREEK
ALVO
FLETCHER
HAVELOCK
MURDOCK TRAIL
ADAMS
HOLDREGE
MOPAC TRAIL
O
A
VAN DORN
PIONEERS
OLD CHENEY
NEBRASKA HWY 2
PINE LAKE
YANKEE HILL
ROKEBY
84TH
98TH
112TH
120TH
134TH
148TH
162ND
80
6
CDM

Figure 5-1

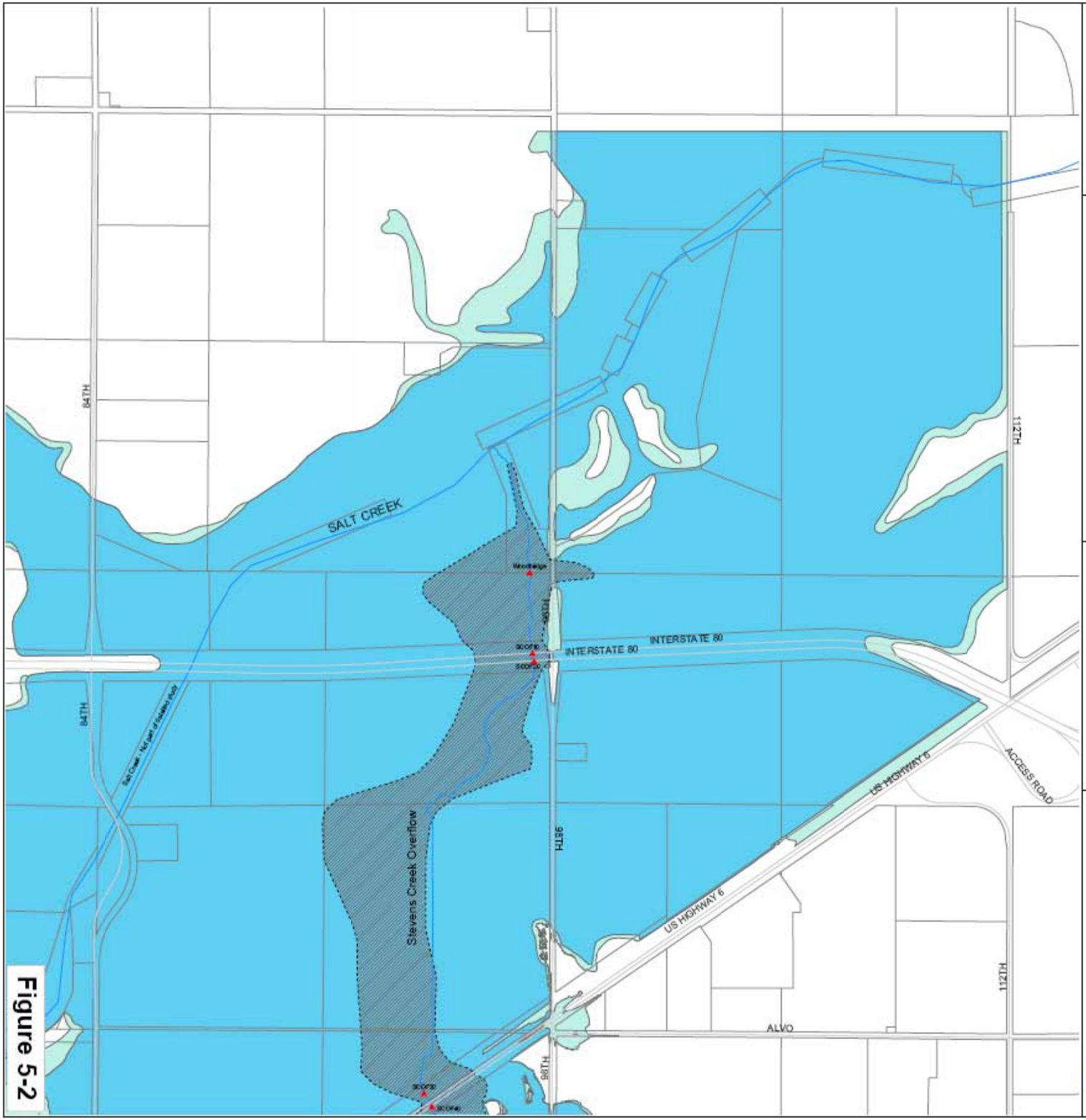


Figure 5-2

STEVENS CREEK WATERSHED MASTER PLAN
Lincoln, Nebraska

In Cooperation with the Lower Platte South NRD

Floodplain Maps

February, 2005

LEGEND

- Modeled Drainage Structures
- Stream Centerline
- Property Boundary
- Road Centerline
- Limit of Detailed Study
- 100 Year Floodplain - Existing Conditions
- 500 Year Floodplain - Existing Conditions
- 100 Year Floodway - Existing Conditions

MAP PROJECTION AND DATUMS:

Lincoln Custom Projection,
Transverse_Mercator
False_Easting: 164041.6666
False_Northing: 0
Central_Meridian: -96.6680
Scale_Factor: 1.00005
Latitude_Of_Origin: 40.25
Unit: Foot_US

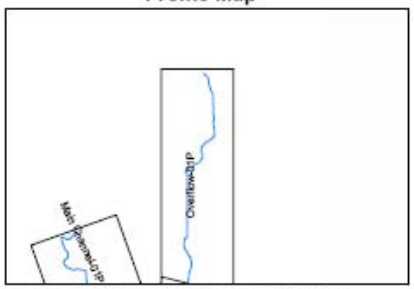
DATA SOURCES / DATE:

Contours: City of Lincoln, 1997
USGS LIDAR, 2003

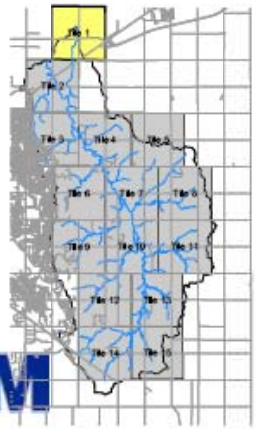
N W E S

0 1,600 Feet

Profile Map *



* For stream profiles, see the Stevens Creek Watershed Planning Study Report, Volume II, Appendix E



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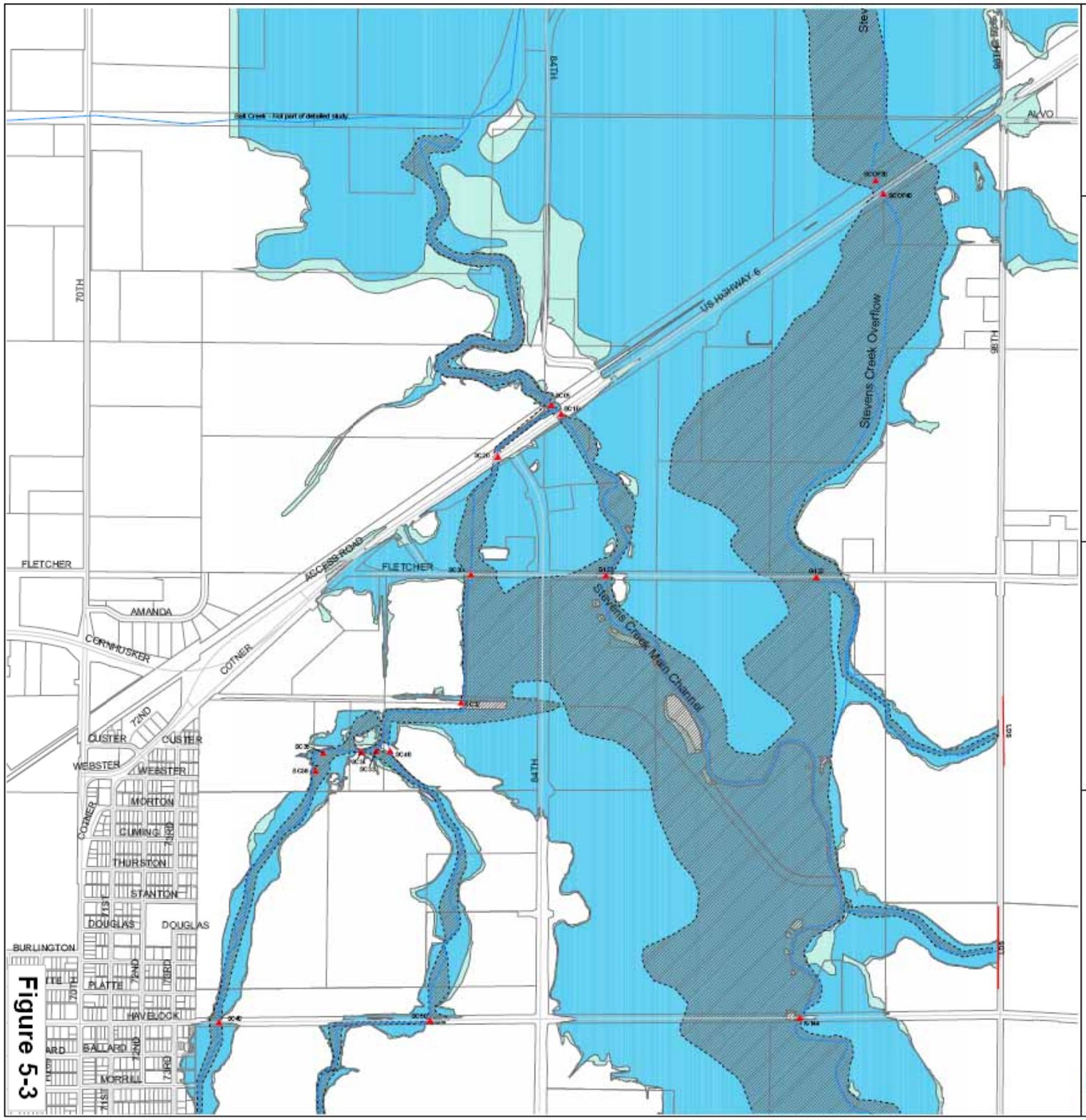

Figure 5-3

STEVENS CREEK WATERSHED MASTER PLAN
Lincoln, Nebraska

In Cooperation with the Lower Platte South NRD

Floodplain Maps

February, 2005

LEGEND

- Modeled Drainage Structures
- Stream Centerline
- Property Boundary
- Road Centerline
- Limit of Detailed Study
- 100 Year Floodplain - Existing Conditions
- 500 Year Floodplain - Existing Conditions
- 100 Year Floodway - Existing Conditions

MAP PROJECTION AND DATUMS:

Lincoln Custom Projection,
Transverse_Mercator
False_Easting: 164041.6666
False_Northing: 0
Central_Meridian: -96.6880
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Latitude_Of_Origin: 40.25
Unit: Foot_US

DATA SOURCES / DATE:

Contours: City of Lincoln, 1997
USGS LIDAR, 2003

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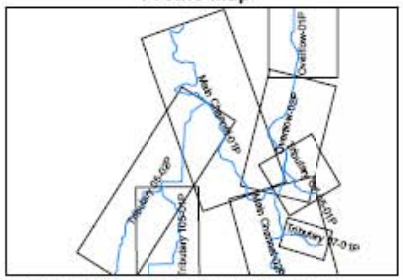
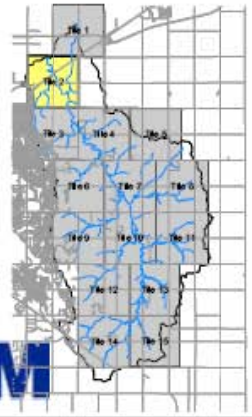


* For stream profiles, see the Stevens Creek Watershed Planning Study Report, Volume II, Appendix E



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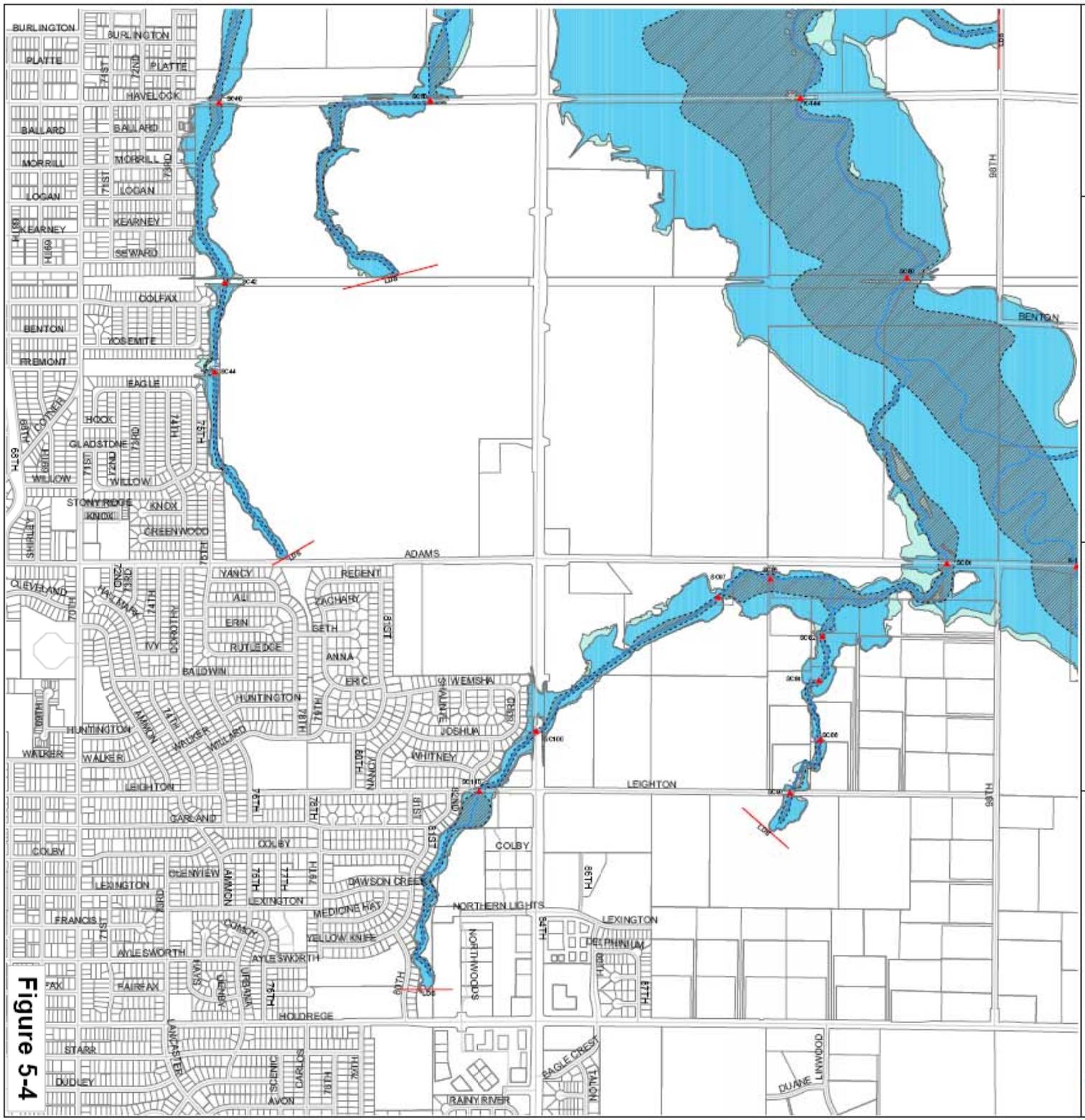


STEVENS CREEK WATERSHED MASTER PLAN
Lincoln, Nebraska

In Cooperation with the Lower Platte South NRD

Floodplain Maps

February, 2005

LEGEND

- Modeled Drainage Structures
- Stream Centerline
- Property Boundary
- Road Centerline
- Limit of Detailed Study
- 100 Year Floodplain - Existing Conditions
- 500 Year Floodplain - Existing Conditions
- 100 Year Floodway - Existing Conditions

MAP PROJECTION AND DATUMS:

Lincoln Custom Projection,
Transverse_Mercator
False_Easting: 164041.6666
False_Northing: 0
Central_Meridian: -96.6680
Scale_Factor: 1.00005
Latitude_Of_Origin: 40.25
Unit: Foot_US

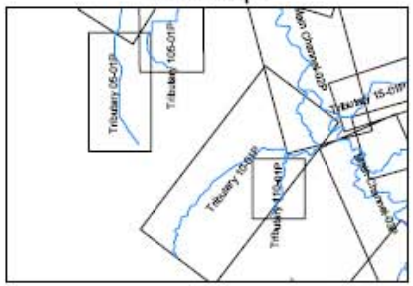
DATA SOURCES / DATE:

Contours: City of Lincoln, 1997
USGS LIDAR, 2003

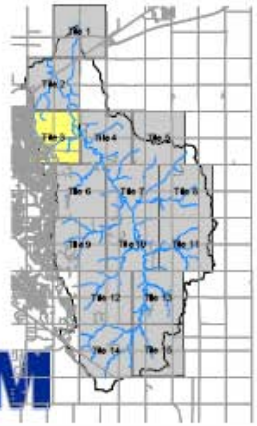
N W E S

0 1,600 Feet

Profile Map *



* For stream profiles, see the Stevens Creek Watershed Planning Study Report, Volume II, Appendix E



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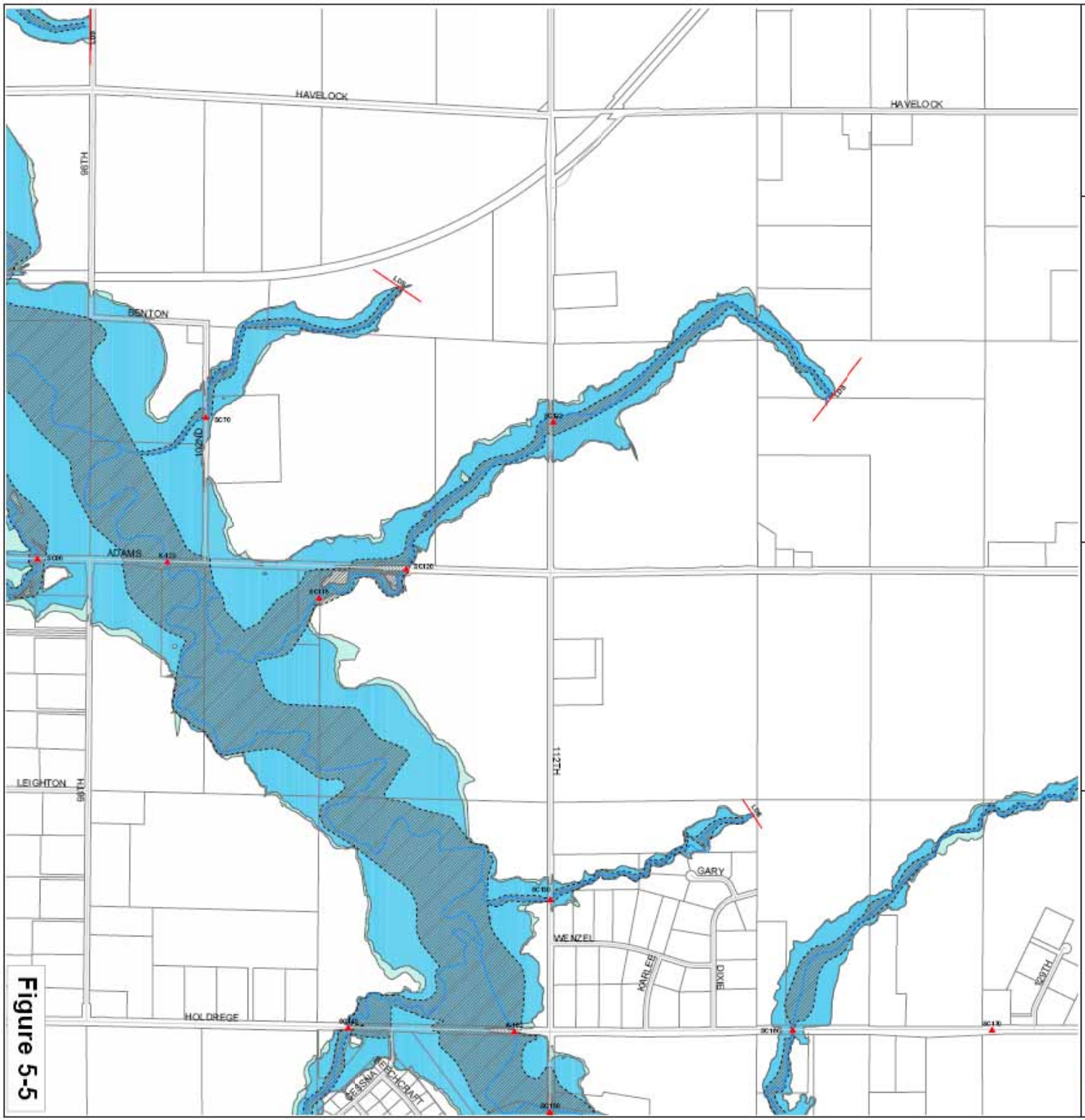

Figure 5-5

STEVENS CREEK WATERSHED MASTER PLAN
Lincoln, Nebraska

In Cooperation with the Lower Platte South NRD

Floodplain Maps

February, 2005

LEGEND

- Modeled Drainage Structures
- Stream Centerline
- Property Boundary
- Road Centerline
- Limit of Detailed Study
- 100 Year Floodplain - Existing Conditions
- 500 Year Floodplain - Existing Conditions
- 100 Year Floodway - Existing Conditions

MAP PROJECTION AND DATUMS:

Lincoln Custom Projection,
Transverse_Mercator
False_Easting: 164041.6666
False_Northing: 0
Central_Meridian: -96.6680
Scale_Factor: 1.00005
Latitude_Of_Origin: 40.25
Unit: Foot_US

DATA SOURCES / DATE:

Contours: City of Lincoln, 1997
USGS LIDAR, 2003

N
W E
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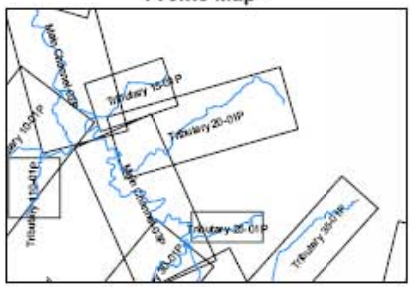
0 1,600 Feet

Profile Map *



* For stream profiles, see the Stevens Creek Watershed Planning Study Report, Volume II, Appendix E

CDM

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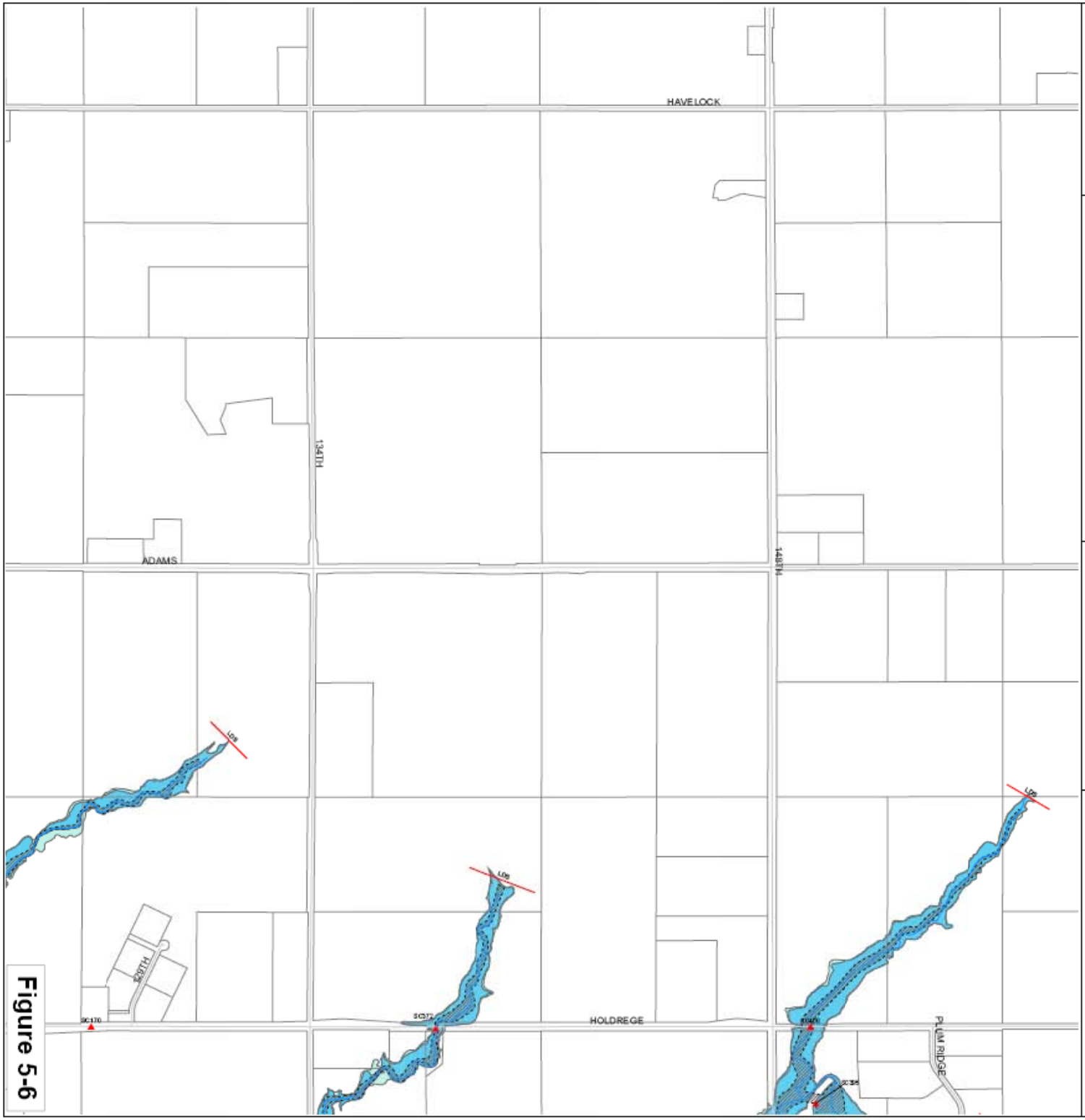


Figure 5-6

STEVENS CREEK WATERSHED MASTER PLAN
Lincoln, Nebraska

In Cooperation with the Lower Platte South NRD

Floodplain Maps

February, 2005

LEGEND

- Modeled Drainage Structures
- Stream Centerline
- Property Boundary
- Road Centerline
- Limit of Detailed Study
- 100 Year Floodplain - Existing Conditions
- 500 Year Floodplain - Existing Conditions
- 100 Year Floodway - Existing Conditions

MAP PROJECTION AND DATUMS:

Lincoln Custom Projection,
Transverse_Mercator
False_Easting: 164041.6666
False_Northing: 0
Central_Meridian: -96.6680
Scale_Factor: 1.00005
Latitude_Of_Origin: 40.25
Unit: Foot_US

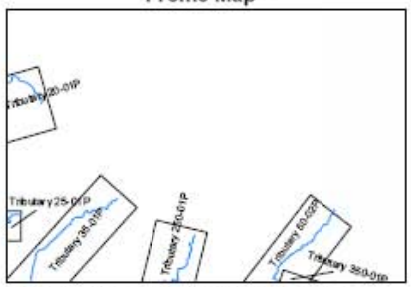
DATA SOURCES / DATE:

Contours: City of Lincoln, 1997
USGS LIDAR, 2003

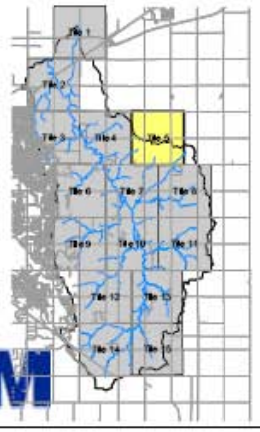
N W E S

0 1,600 Feet

Profile Map *



* For stream profiles, see the Stevens Creek Watershed Planning Study Report, Volume II, Appendix E



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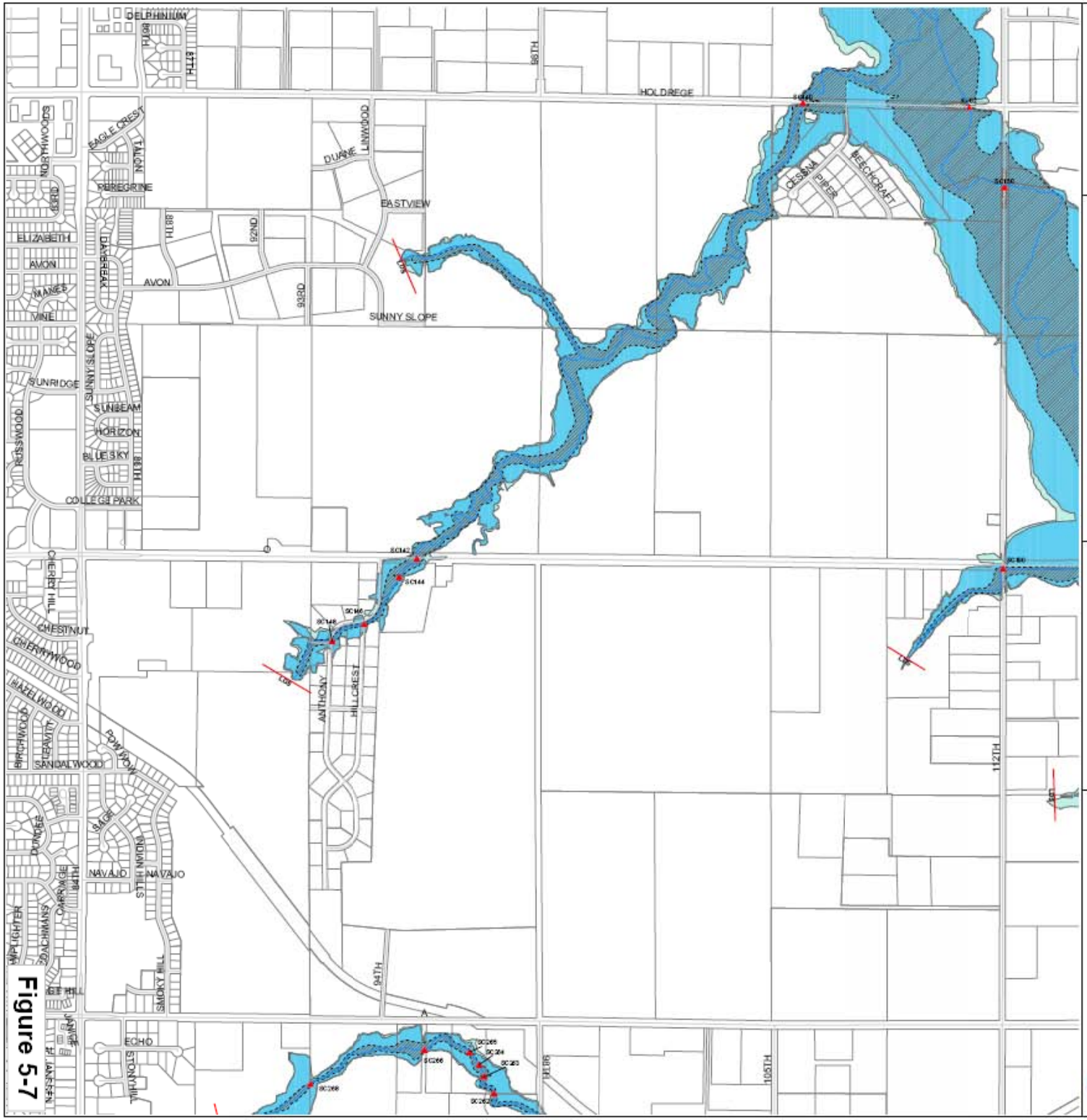


Figure 5-7

STEVENS CREEK WATERSHED MASTER PLAN
Lincoln, Nebraska

In Cooperation with the Lower Platte South NRD

Floodplain Maps

February, 2005

LEGEND

- Modeled Drainage Structures
- Stream Centerline
- Property Boundary
- Road Centerline
- Limit of Detailed Study
- 100 Year Floodplain - Existing Conditions
- 500 Year Floodplain - Existing Conditions
- 100 Year Floodway - Existing Conditions

MAP PROJECTION AND DATUMS:

Lincoln Custom Projection,
Transverse_Mercator
False_Easting: 164041.6666
False_Northing: 0
Central_Meridian: -96.6680
Scale_Factor: 1.00005
Latitude_Of_Origin: 40.25
Unit: Foot_US

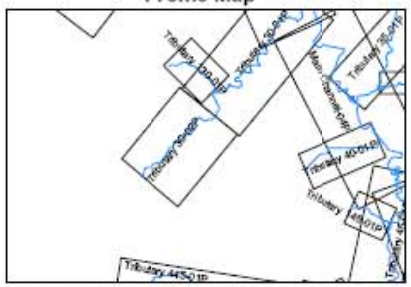
DATA SOURCES / DATE:

Contours: City of Lincoln, 1997
USGS LDAR, 2003

N
W E
S

0 1,600 Feet

Profile Map *



* For stream profiles, see the Stevens Creek Watershed Planning Study Report, Volume II, Appendix E

CDM

Tile No.: 6

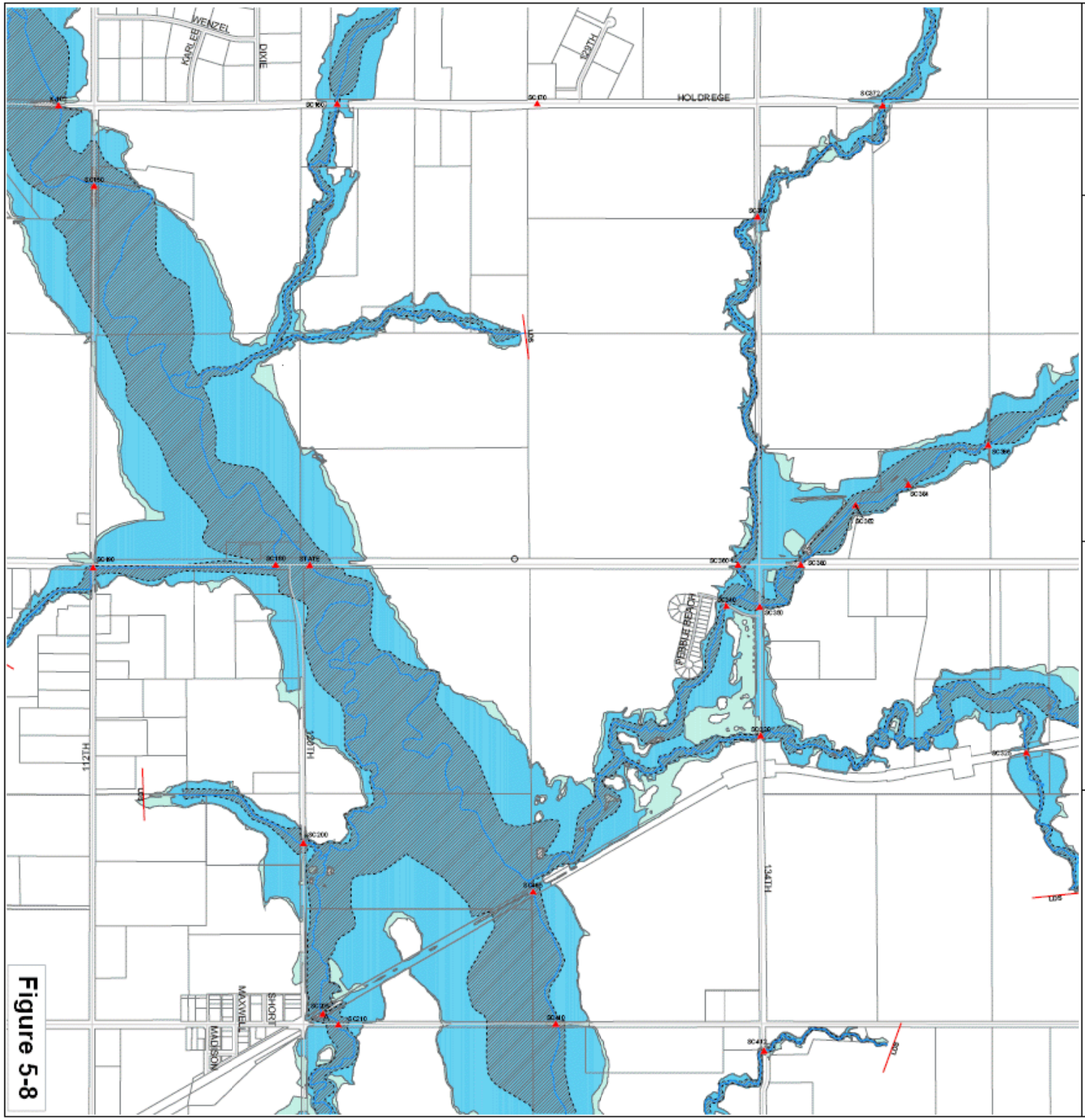


Figure 5-8

STEVENS CREEK WATERSHED MASTER PLAN
Lincoln, Nebraska

In Cooperation with the Lower Platte South NRD

Floodplain Maps

February, 2005

LEGEND

- Modeled Drainage Structures
- Stream Centerline
- Property Boundary
- Road Centerline
- Limit of Detailed Study
- 100 Year Floodplain - Existing Conditions
- 500 Year Floodplain - Existing Conditions
- 100 Year Floodway - Existing Conditions

MAP PROJECTION AND DATUMS:

Lincoln Custom Projection,
Transverse_Mercator
False_Easting: 164041.6666
False_Northing: 0
Central_Meridian: -96.6880
Scale_Factor: 1.00005
Latitude_Of_Origin: 40.25
Unit: Foot_US

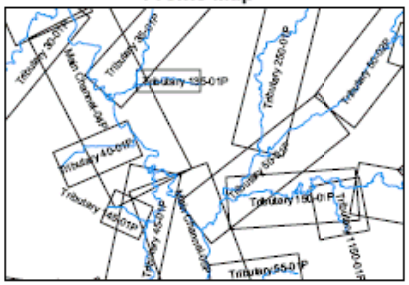
DATA SOURCES / DATE:

Contours: City of Lincoln, 1997
USGS LIDAR, 2003

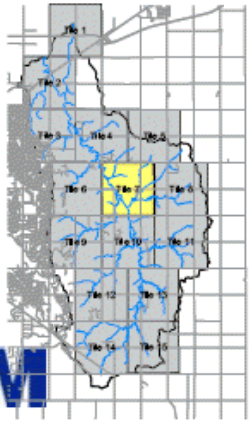
N W E S

0 1,600 Feet

Profile Map *



* For stream profiles, see the Stevens Creek Watershed Planning Study Report, Volume II, Appendix E



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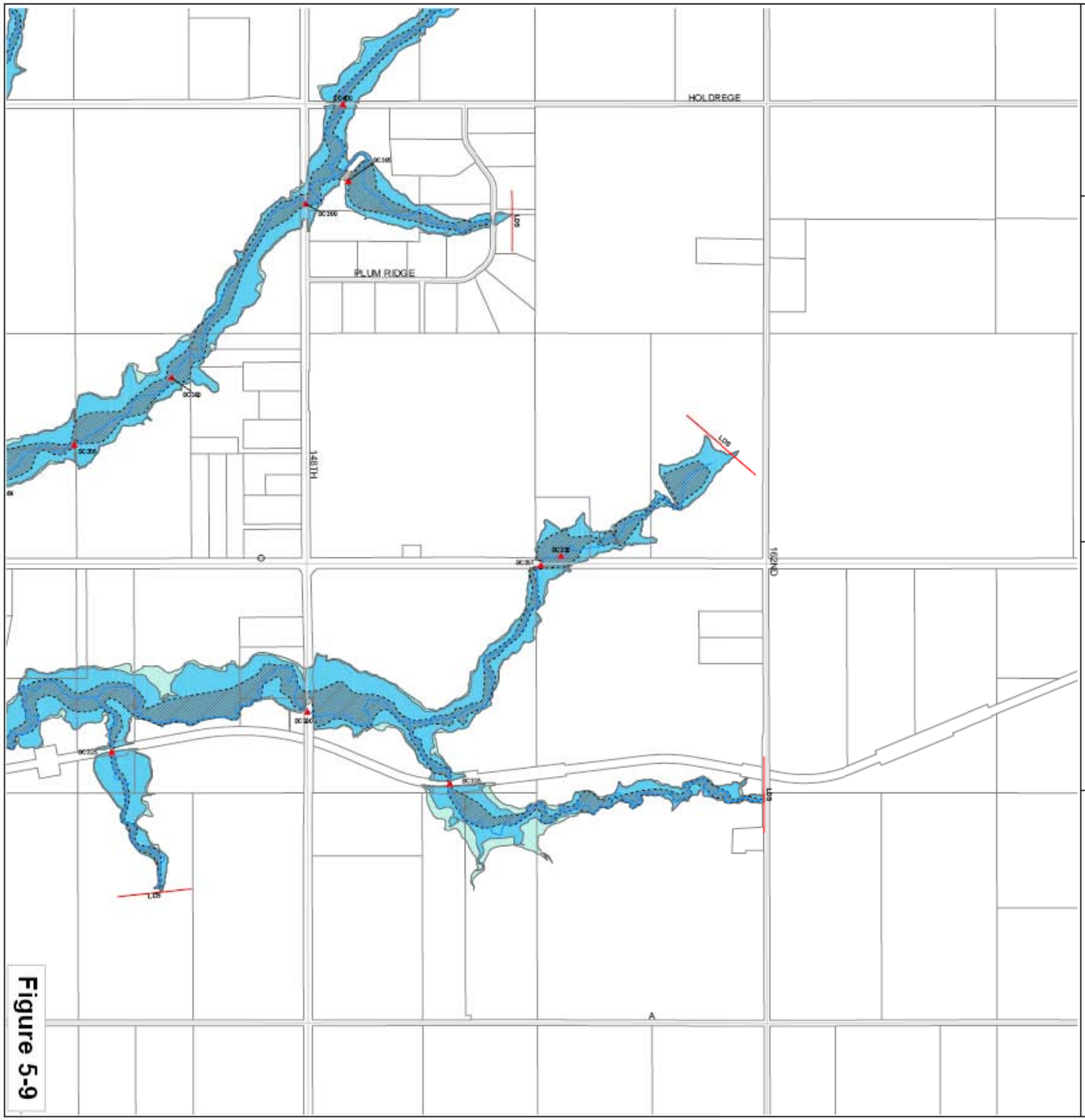


STEVENS CREEK WATERSHED MASTER PLAN
Lincoln, Nebraska

In Cooperation with the Lower Platte South NRD

Floodplain Maps

February, 2005

LEGEND

- Modeled Drainage Structures
- Stream Centerline
- Property Boundary
- Road Centerline
- Limit of Detailed Study
- 100 Year Floodplain - Existing Conditions
- 500 Year Floodplain - Existing Conditions
- 100 Year Floodway - Existing Conditions

MAP PROJECTION AND DATUMS:

Lincoln Custom Projection,
Transverse_Mercator
False_Easting: 164041.6666
False_Northing: 0
Central_Meridian: -96.6680
Scale_Factor: 1.00005
Latitude_Of_Origin: 40.25
Unit: Foot_US

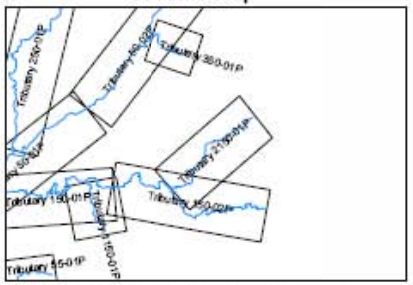
DATA SOURCES / DATE

Contours: City of Lincoln, 1997
USGS LIDAR, 2003

N W E S

0 1,600 Feet

Profile Map *



* For stream profiles, see the Stevens Creek Watershed Planning Study Report, Volume II, Appendix E

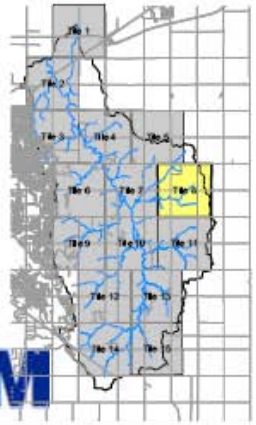


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Figure 5-9

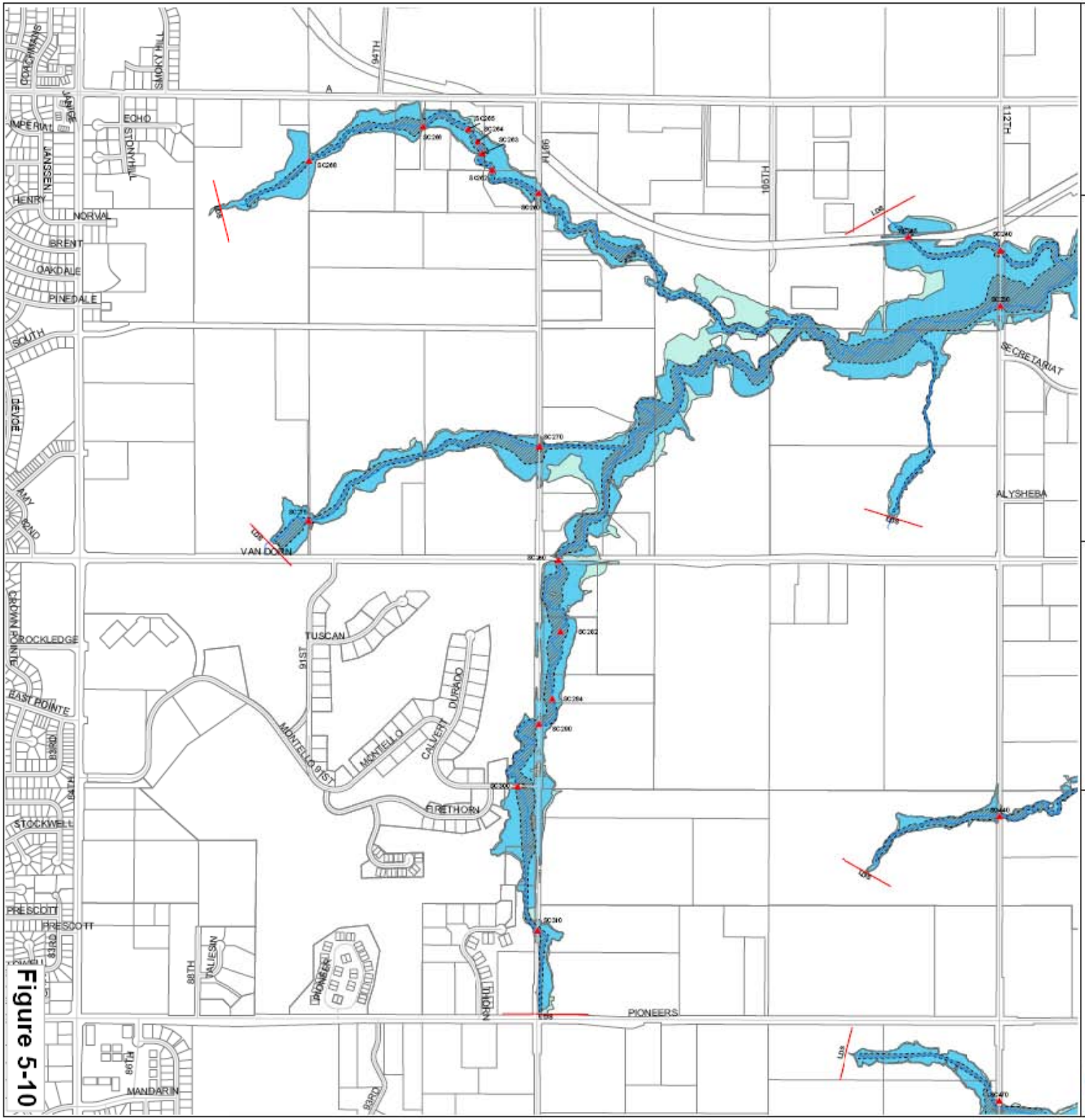


Figure 5-10

STEVENS CREEK WATERSHED MASTER PLAN
Lincoln, Nebraska

In Cooperation with the Lower Platte South NRD

Floodplain Maps

February, 2005

LEGEND

- Modeled Drainage Structures
- Stream Centerline
- Property Boundary
- Road Centerline
- Limit of Detailed Study
- 100 Year Floodplain - Existing Conditions
- 500 Year Floodplain - Existing Conditions
- 100 Year Floodway - Existing Conditions

MAP PROJECTION AND DATUMS:

Lincoln Custom Projection,
Transverse_Mercator
False_Easting: 164041.6666
False_Northing: 0
Central_Meridian: -96.6680
Scale_Factor: 1.00005
Latitude_Of_Origin: 40.25
Unit: Foot_US

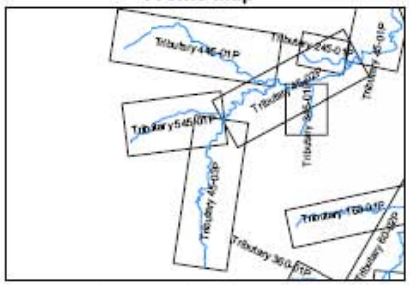
DATA SOURCES / DATE:

Contours: City of Lincoln, 1997
USGS LIDAR, 2003

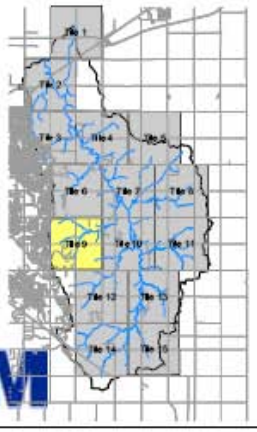
N W E S

0 1,600 Feet

Profile Map *



* For stream profiles, see the Stevens Creek Watershed Planning Study Report, Volume II, Appendix E



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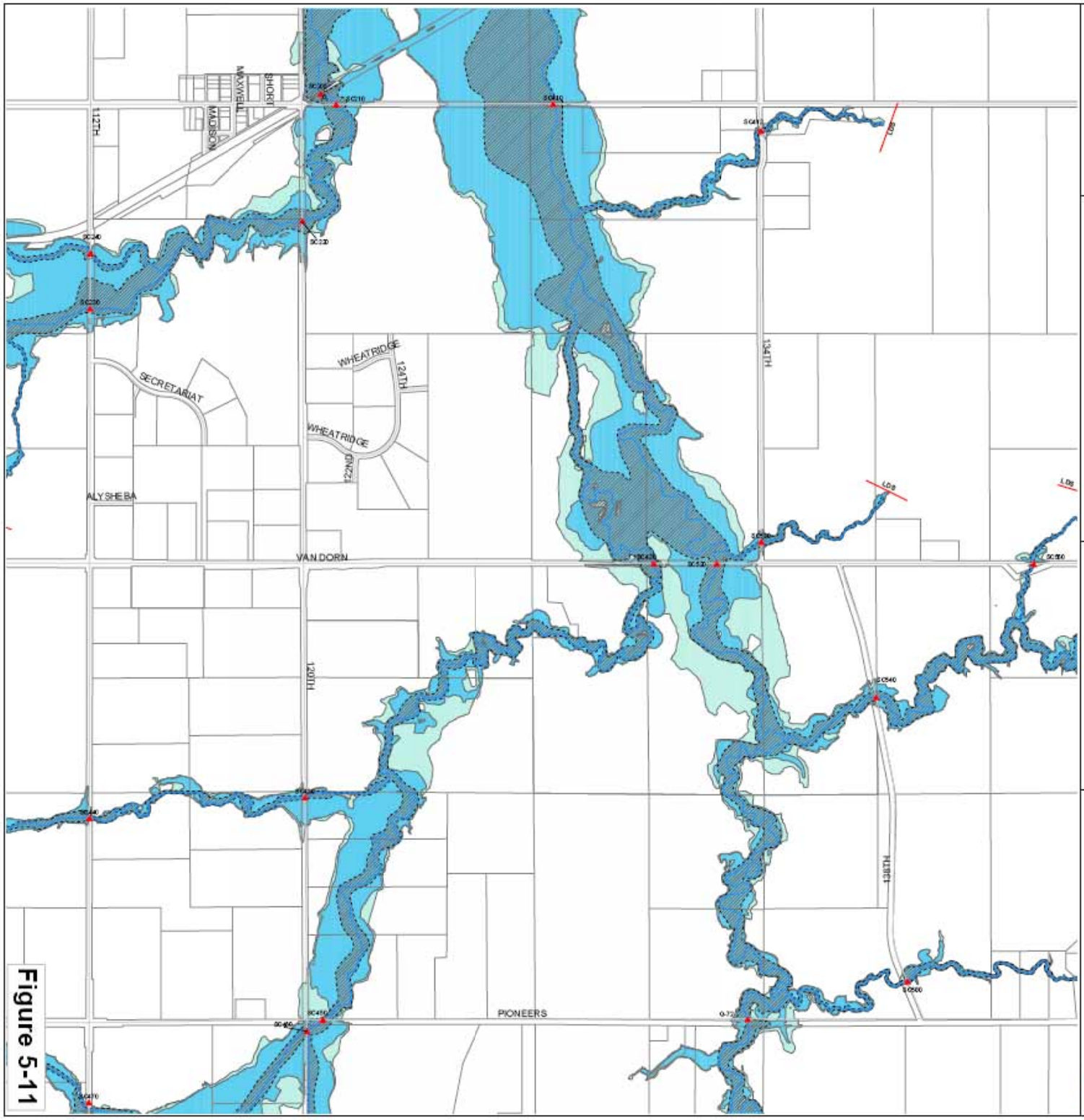


Figure 5-11

STEVENS CREEK WATERSHED MASTER PLAN
Lincoln, Nebraska

In Cooperation with the Lower Platte South NRD

Floodplain Maps

February, 2005

LEGEND

- Modeled Drainage Structures
- Stream Centerline
- Property Boundary
- Road Centerline
- Limit of Detailed Study
- 100 Year Floodplain - Existing Conditions
- 500 Year Floodplain - Existing Conditions
- 100 Year Floodway - Existing Conditions

MAP PROJECTION AND DATUMS:

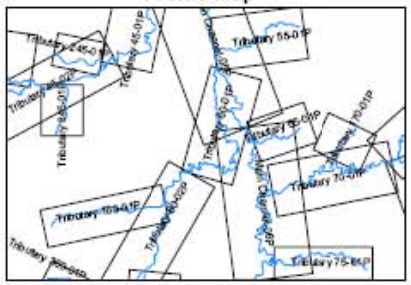
Lincoln Custom Projection,
Transverse_Mercator
False_Easting: 164041.6666
False_Northing: 0
Central_Meridian: -96.6680
Scale_Factor: 1.00005
Latitude_Of_Origin: 40.25
Unit: Foot_US

DATA SOURCES / DATE:

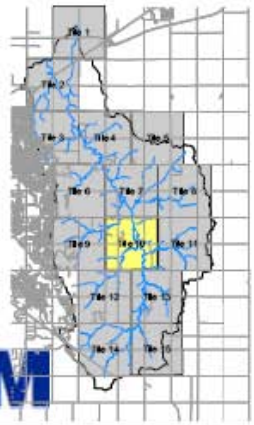
Contours: City of Lincoln, 1997
USGS LDAR, 2003

0 1,600 Feet

Profile Map *



* For stream profiles, see the Stevens Creek Watershed Planning Study Report, Volume II, Appendix E



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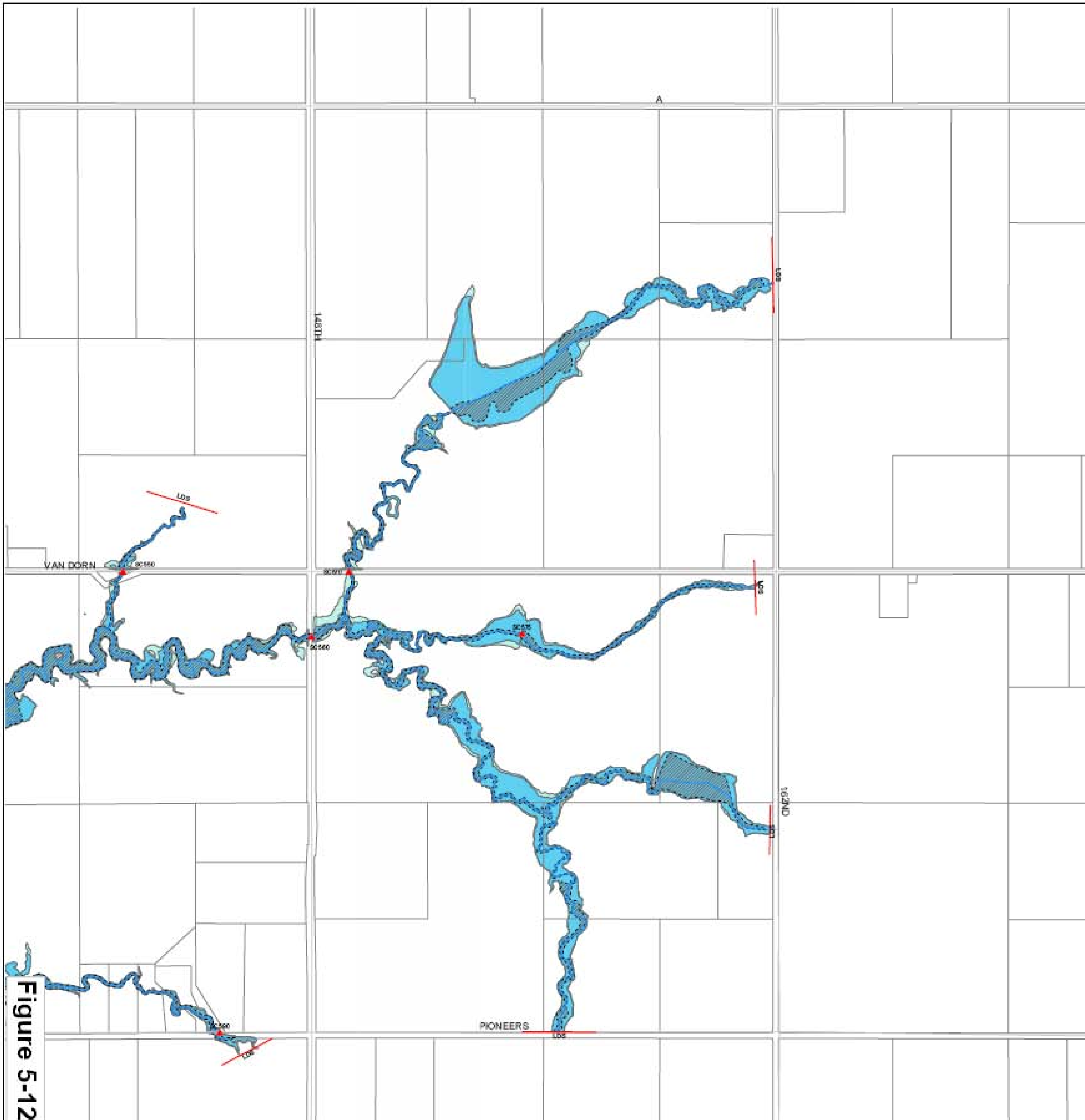


STEVENS CREEK WATERSHED MASTER PLAN
Lincoln, Nebraska

In Cooperation with the Lower Platte South NRD

Floodplain Maps

February, 2005

LEGEND

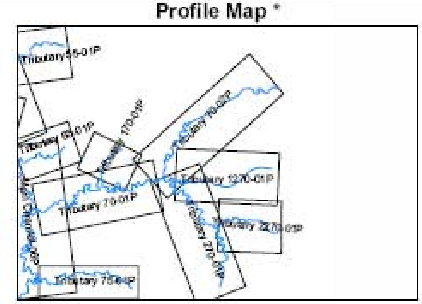
- ▲ Modeled Drainage Structures
- Stream Centerline
- Property Boundary
- Road Centerline
- Limit of Detailed Study
- 100 Year Floodplain - Existing Conditions
- 500 Year Floodplain - Existing Conditions
- 100 Year Floodway - Existing Conditions

MAP PROJECTION AND DATUMS:
Lincoln Custom Projection,
Transverse_Mercator
False_Easting: 164041.6666
False_Northing: 0
Central_Meridian: -96.6880
Scale_Factor: 1.00005
Latitude_Of_Origin: 40.25
Unit: Foot_US

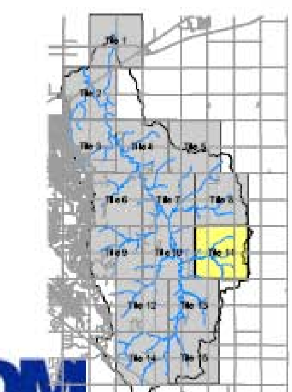
DATA SOURCES / DATE
Contours: City of Lincoln, 1997; USGS LIDAR, 2003

0 — 1,600 Feet

Profile Map *



* For stream profiles, see the Stevens Creek Watershed Planning Study Report, Volume II, Appendix E



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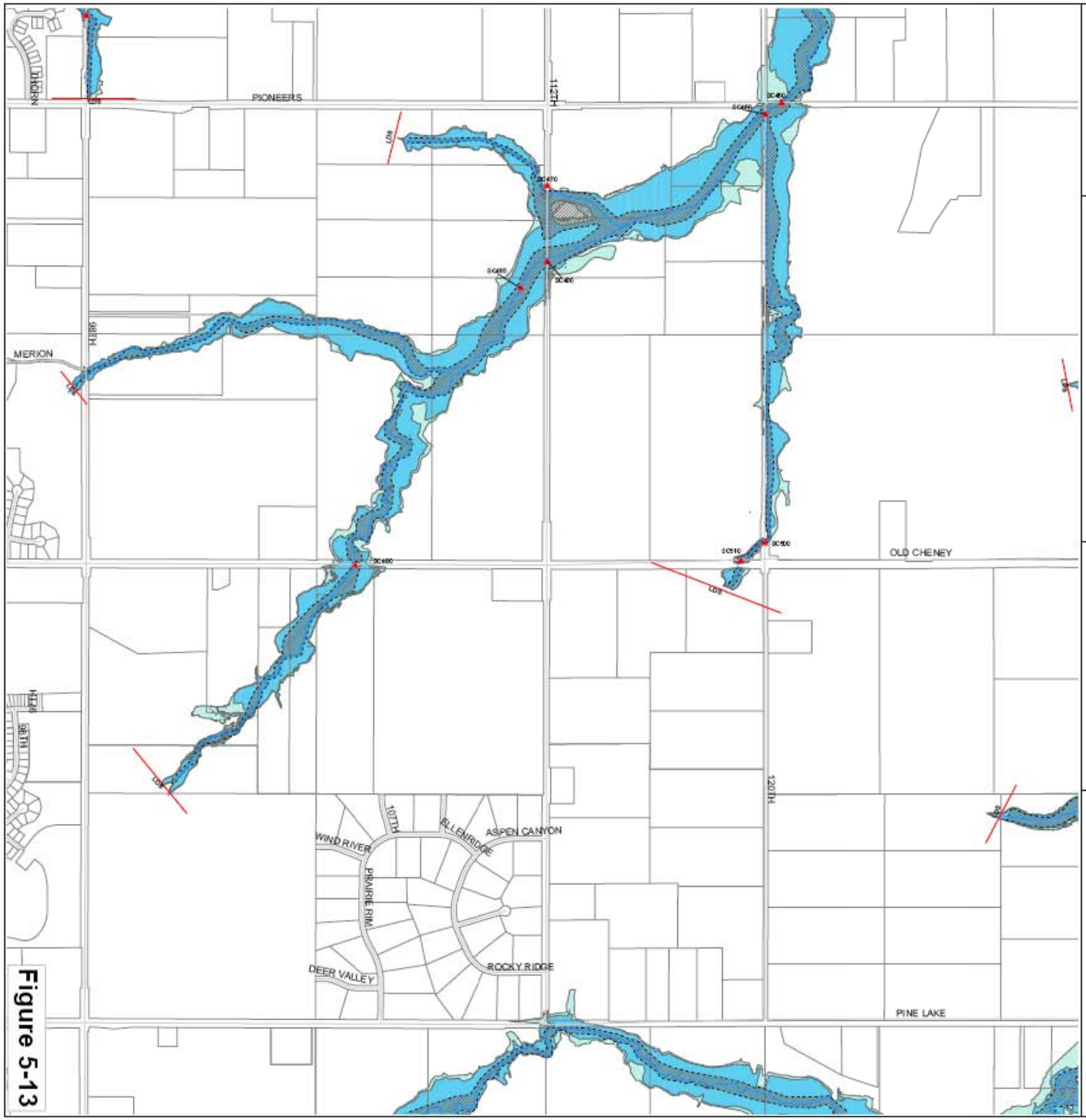
Tile No.: 11

Figure 5-12



STEVENS CREEK WATERSHED MASTER PLAN
Lincoln, Nebraska

In Cooperation with the Lower Platte South NRD

Floodplain Maps

February, 2005

LEGEND

- Modeled Drainage Structures
- Stream Centerline
- Property Boundary
- Road Centerline
- Limit of Detailed Study
- 100 Year Floodplain - Existing Conditions
- 500 Year Floodplain - Existing Conditions
- 100 Year Floodway - Existing Conditions

MAP PROJECTION AND DATUMS:

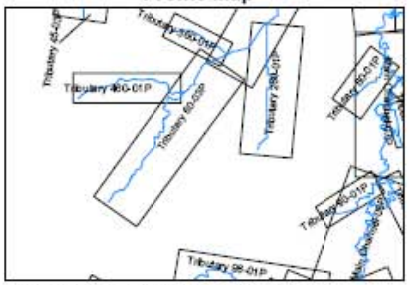
Lincoln Custom Projection,
Transverse_Mercator
False_Easting: 164041.6666
False_Northing: 0
Central_Meridian: -96.6680
Scale_Factor: 1.00005
Latitude_Of_Origin: 40.25
Unit: Foot_US

DATA SOURCES / DATE:

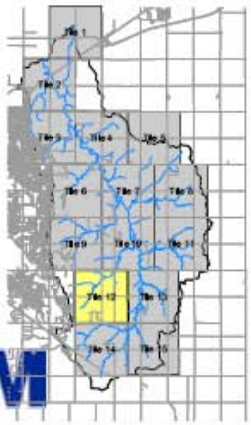
Contours: City of Lincoln, 1997
USGS LIDAR, 2003

0 1,600 Feet

Profile Map *



* For stream profiles, see the Stevens Creek Watershed Planning Study Report, Volume II, Appendix E



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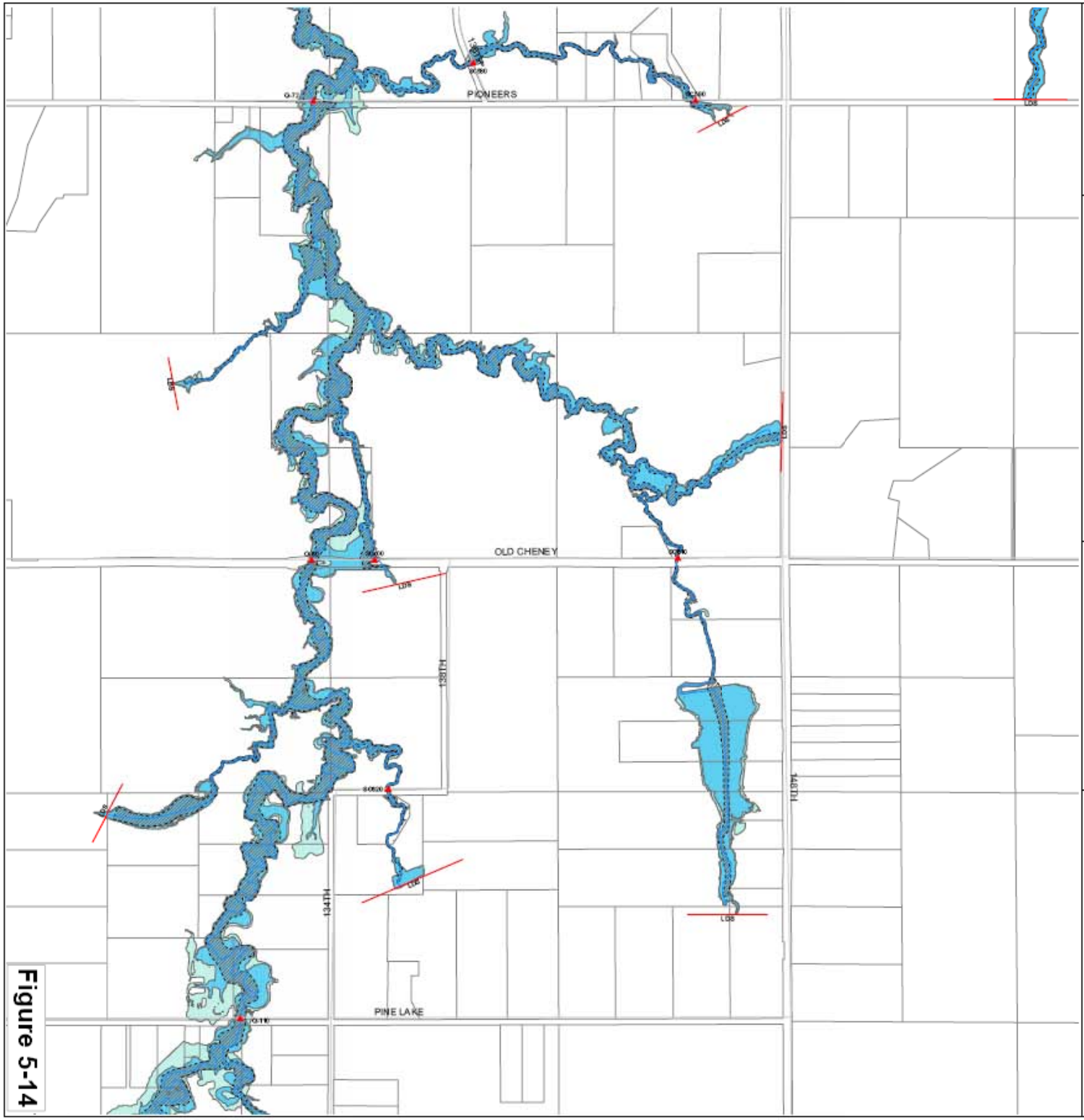
Tile No.: 12

Figure 5-13



STEVENS CREEK WATERSHED MASTER PLAN
Lincoln, Nebraska

In Cooperation with the Lower Platte South NRD

Floodplain Maps

February, 2005

LEGEND

- Modeled Drainage Structures
- Stream Centerline
- Property Boundary
- Road Centerline
- Limit of Detailed Study
- 100 Year Floodplain - Existing Conditions
- 500 Year Floodplain - Existing Conditions
- 100 Year Floodway - Existing Conditions

MAP PROJECTION AND DATUMS:

Lincoln Custom Projection,
Transverse_Mercator
False_Easting: 164041.6666
False_Northing: 0
Central_Meridian: -96.6680
Scale_Factor: 1.00005
Latitude_Of_Origin: 40.25
Unit: Foot_US

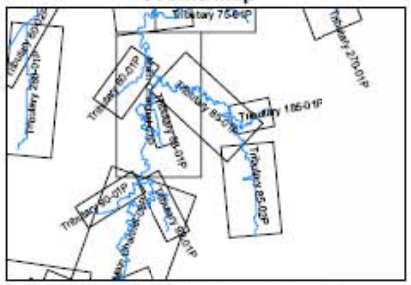
DATA SOURCES / DATE:

Contours: City of Lincoln, 1997
USGS LDAR, 2003

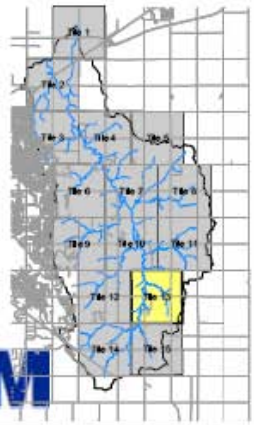
N W E S

0 1,600 Feet

Profile Map *



* For stream profiles, see the Stevens Creek Watershed Planning Study Report, Volume II, Appendix E



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Tile No.: 13

Figure 5-14

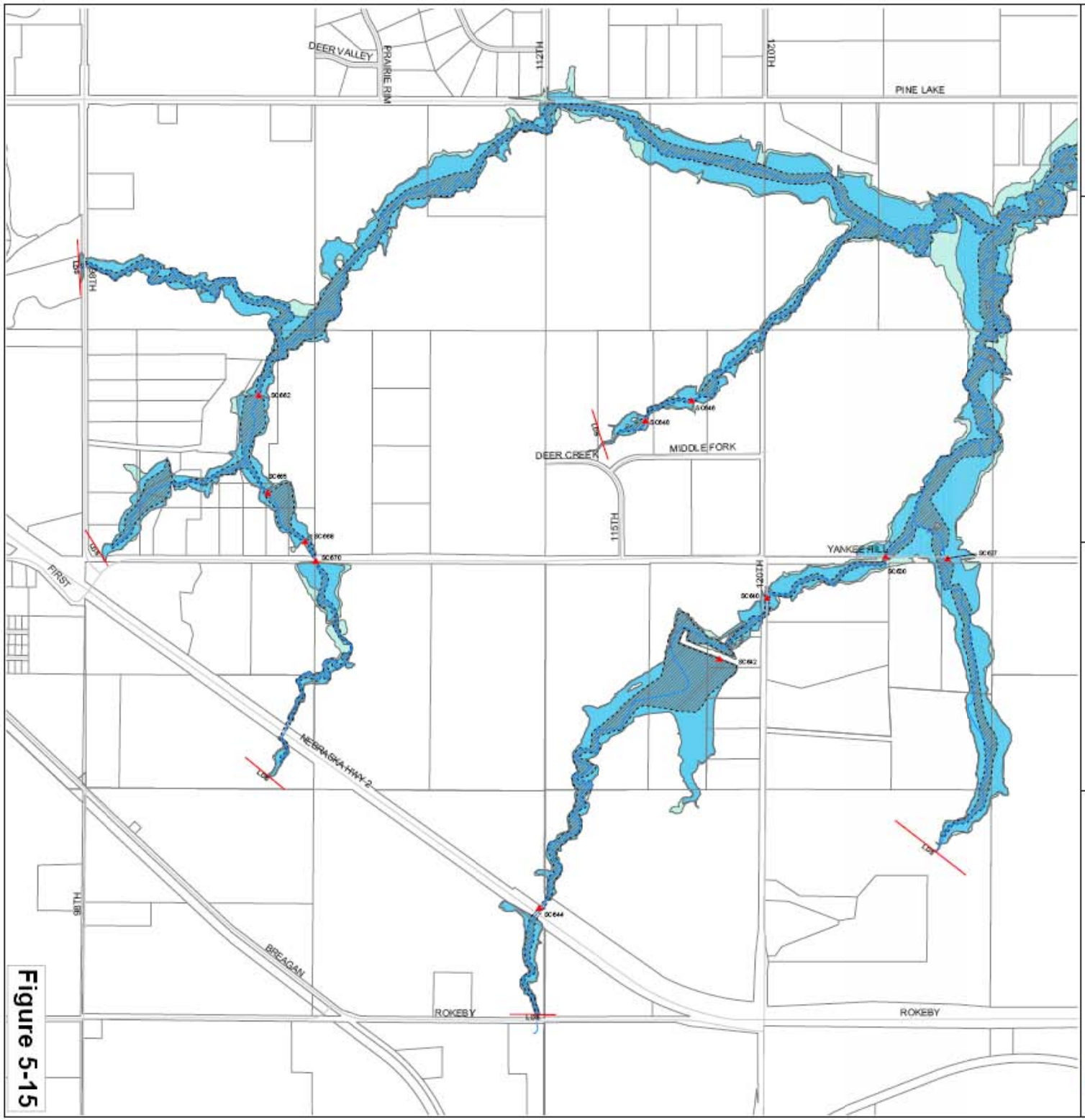


Figure 5-15

STEVENS CREEK WATERSHED MASTER PLAN
Lincoln, Nebraska

In Cooperation with the Lower Platte South NRD

Floodplain Maps

February, 2005

LEGEND

- Modeled Drainage Structures
- Stream Centerline
- Property Boundary
- Road Centerline
- Limit of Detailed Study
- 100 Year Floodplain - Existing Conditions
- 500 Year Floodplain - Existing Conditions
- 100 Year Floodway - Existing Conditions

MAP PROJECTION AND DATUMS:

Lincoln Custom Projection,
Transverse_Mercator
False_Easting: 164041.6666
False_Northing: 0
Central_Meridian: -96.6680
Scale_Factor: 1.00005
Latitude_Of_Origin: 40.25
Unit: Foot_US

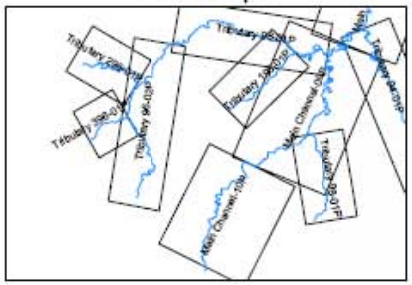
DATA SOURCES / DATE

Contours: City of Lincoln, 1997
USGS LIDAR, 2003

N W E S

0 1,600 Feet

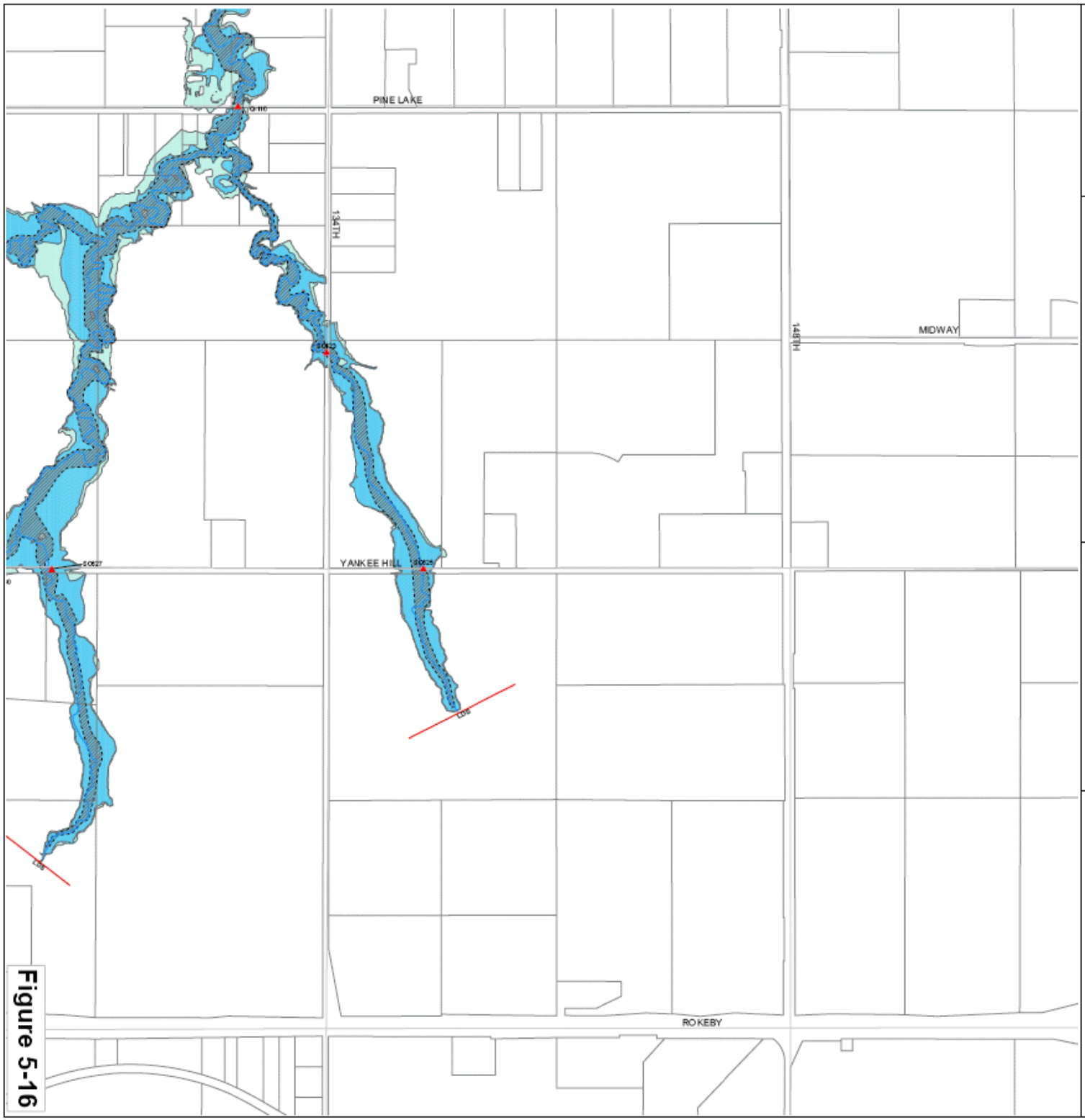
Profile Map *



* For stream profiles, see the Stevens Creek Watershed Planning Study Report, Volume II, Appendix E

CDM

Tile No.: 14



STEVENS CREEK WATERSHED MASTER PLAN
Lincoln, Nebraska

In Cooperation with the Lower Platte South NRD

Floodplain Maps

February, 2005

LEGEND

- Modeled Drainage Structures
- Stream Centerline
- Property Boundary
- Road Centerline
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MAP PROJECTION AND DATUMS:

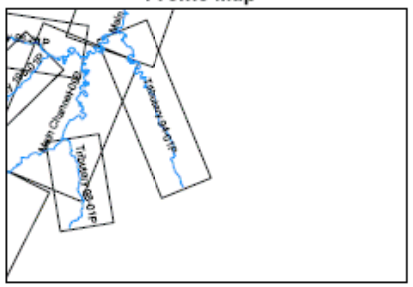
Lincoln Custom Projection,
Transverse_Mercator
False_Easting: 164041.6666
False_Northing: 0
Central_Meridian: -96.6880
Scale_Factor: 1.00005
Latitude_Of_Origin: 40.25
Unit: Foot_US

DATA SOURCES / DATE:

Contours: City of Lincoln, 1997
USGS LIDAR, 2003

0 1,600 Feet

Profile Map *



* For stream profiles, see the Stevens Creek Watershed Planning Study Report, Volume II, Appendix E

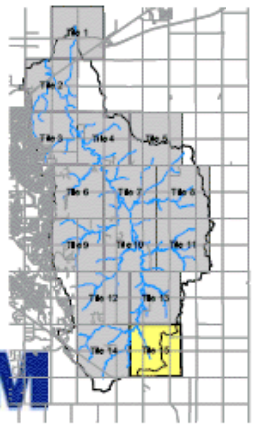


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Figure 5-16

Section 6
Water Quality and Stream Stability

6.1 Background

Land use changes that result from transitioning a watershed from undeveloped to agricultural to fully urbanized conditions can have significant impacts on runoff hydrology and consequently on the aquatic environments of the streams to which that runoff drains. The urbanization process alters the hydrologic characteristics of a watershed, which can potentially degrade the water quality and ecological health of the receiving waters. However, if proper watershed management practices are followed as development progresses, long-term stream sustainability can be achieved.

The hydrologic effects of urbanization on a watershed are illustrated on Figure 6-1. Undeveloped land has very little stormwater runoff. In an undeveloped watershed, rainfall that contributes to direct stormwater runoff typically ranges from nearly zero to 20 percent; most of the rainfall infiltrates into the soil and is held there by capillary action, transpired back to the atmosphere by vegetation, migrates slowly through the soil mantle as interflow to the nearest stream or lake, or infiltrates to the deeper aquifer system as recharge. The result of this process is that effects of short rainfall bursts are typically averaged out over longer periods of time as indicated on Figure 6-1 and thus do not have a strong impact on the peak flow rates in the receiving waters.

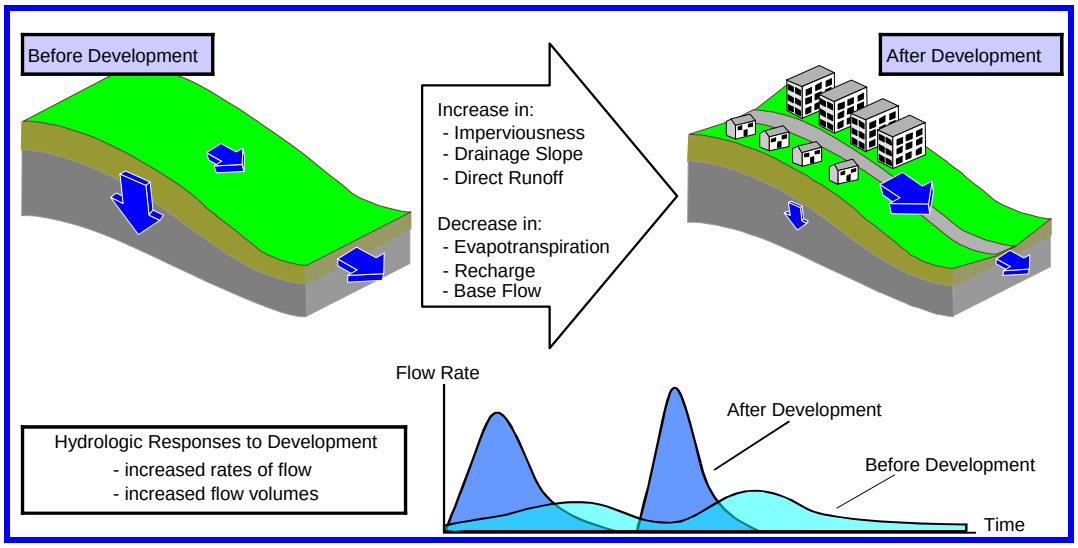


Figure 6-1
Hydrologic Responses to Development (Roesner et al. 2001)

But, as a watershed develops, the land is covered over with impervious surfaces such as roads, parking lots, roofs, driveways, and sidewalks that prevent rainfall from infiltrating into the ground. Even the remaining open ground (pervious surfaces) cannot infiltrate rainfall into the ground as rapidly as it did before development because during construction, the topsoil is removed, compacted, and/or mixed with the underlying less permeable soil. The combined result is that infiltration is greatly reduced or halted by urbanization, and 40

to 90 percent of the rainfall (depending upon land use) is directly converted to stormwater runoff. This causes an increase in stormwater runoff flow rate, volume, and velocity, which increases erosion and sediment deposition. Altering the magnitude, frequency, and duration of stormwater runoff and sediment loads to streams causes impacts to water quality and loss of aquatic life and habitat through a wide variety of geomorphic mechanisms. These mechanisms include changes in channel bed material, increased suspended sediment loads, loss of riparian habitat due to streambank erosion, and changes in the variability of flow and sediment transport characteristics relative to aquatic life cycles.

Section 8 of this report discusses fluvial geomorphology, or the science of how moving water shapes the land, and the geomorphic processes occurring in Stevens Creek. The key geomorphic observation in Stevens Creek is the presence of highly erodible soils within the channel, which makes the creek susceptible to erosion even under the slightest changes in land use. As a result, some locations along the stream are experiencing channel downcutting and widening even though urban development has barely begun. This situation makes it even more critical that the hydrologic changes caused by the urbanization process are properly managed in the future to provide long-term stream stability.

Channel downcutting in Stevens Creek

In addition to the adverse impacts caused by increased erosion and sediment deposition, the aquatic environment and habitat is also affected by pollutants transported by stormwater runoff. During dry weather, impervious surfaces collect pollutants such as oil and grease that leak from automobiles and sand and salt deposits along roadways. Then when precipitation falls, the stormwater runoff carries the pollutants into the stormwater system that eventually drains into streams and lakes. These pollutants have the potential to adversely impact the habitats of aquatic plants and animals. Other types of harmful pollutants that are carried by stormwater runoff include fertilizers, pesticides, and pathogens.

6.2 Regulatory Compliance

Stormwater quality is regulated under the National Pollutant Discharge Elimination System (NPDES) Program. Specifically, the 1987 amendment to the Clean Water Act (CWA) introduced regulations pertaining to stormwater, which are enforced by EPA and individual states and tribes. Because the State of Nebraska is a delegated state, the stormwater program is implemented by the Nebraska Department of Environmental Quality (NDEQ). To comply with the NPDES program, the City is required to develop, implement, and enforce a program to address the quality of stormwater runoff. The program must involve the implementation of Best Management Practices (BMPs), which are actions and practices designed to preserve the quality and integrity of streams and lakes. In general, BMPs can be classified as nonstructural and structural.

Nonstructural BMPs consist of pollution prevention techniques designed to prevent the pollutants from entering the drainage system rather than trying to control pollutants with constructed facilities (structural BMPs). In addition, these measures include requirements to protect the natural resources within a given area. Using the treatment train concept as shown on Figure 6-2, nonstructural BMPs should be the first step in protecting the receiving stream.

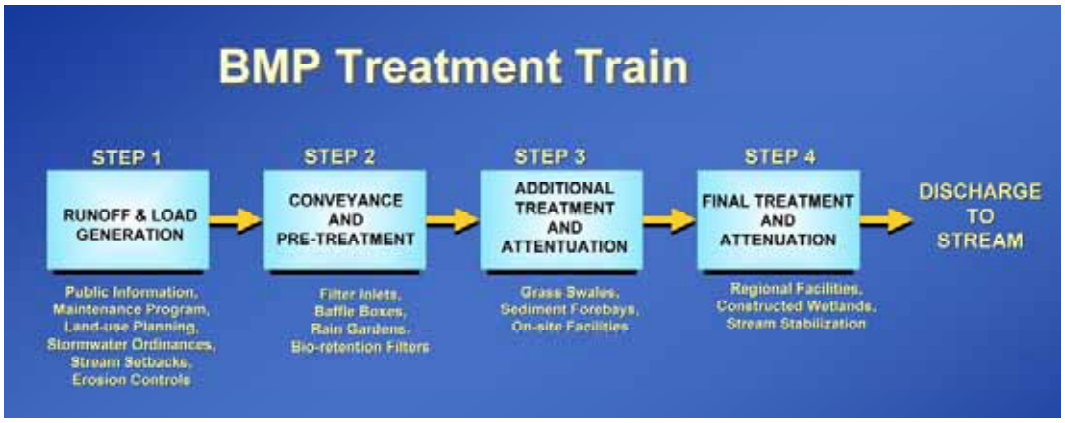


Figure 6-2
BMP Treatment Train

Structural BMPs are constructed facilities designed to remove pollutants and slow down the runoff before the stormwater enters the receiving stream (Steps 2, 3, and 4 on Figure 6-2). Structural BMPs are designed to address the smaller more frequent rainstorms that carry the majority of pollutants and are believed to cause the greatest amount of erosion and sediment deposition, which directly impacts the aquatic and riparian habitat. In designing structural BMPs, the smaller rainstorms are defined by the water quality control volume (WQCV), which is the initial amount of stormwater runoff from the development site. Numerous methods are available to estimate the WQCV, which is discussed in more detail in Section 7.2.3. The use of specific structural BMPs depends on the site conditions and objectives such as pollutant removal, stream stability, and flood control. In many cases, there are multiple goals or needs for a given project. Therefore, BMPs can be "mixed and matched" to develop a "treatment train" approach, which maximizes the use of available site conditions and promotes flexibility within any given development site.

As part of the City's NPDES program, stormwater quality data were collected at a total of seven sites along Beal Slough and Salt Creek between 1992 and 1995. The pollutants most frequently observed to be elevated above national average concentrations included: total suspended solids (TSS), carbonaceous oxygen demand (COD), oil and grease, and nutrients (Wright Water Engineers, Inc. 1997). These constituents are an indication of the types of pollutants that would need to be addressed with appropriate BMPs as development progresses in the Stevens Creek Watershed.

6.3 Evaluation Approach

For this study, the focus was to recommend watershed management practices that protect the biological environment and stream sustainability by controlling the hydrology. Through implementation of these recommendations, the water quality goals and objections as required by the EPA NPDES program will be addressed along with providing treatment for the types of pollutants listed above.

The study evaluation included two main components: a biological assessment and a stream sustainability analysis. The objective of the biological assessment was to determine the general ecological health of the watershed and identify known or potential sources of ecological stress to the stream habitat. The stream sustainability analysis focused on minimizing the identified ecological stressors through the use of watershed management practices that preserve and protect the stream integrity and aquatic habitat within the watershed.

6.4 Biological Assessment

Biological assessments, or bioassessments, provide an effective means to evaluate the cumulative impacts from land use activities on biological communities (i.e., macro-invertebrates, fish, algal) that live in streams. Once a baseline has been established, bioassessments can be a useful tool to evaluate the effectiveness of implementing watershed management practices to minimize land use impacts.

Bioassessments may be conducted at different levels of complexity or detail. The Stevens Creek bioassessment included a field level screening of the macroinvertebrate community that included insects, crustaceans, worms, and clams. The following is a brief summary of the methodology and key results, while Appendix F located in Volume II of this report, provides additional information.

Mesh net being used in Stevens Creek

6.4.1 Methodology

The bioassessment was based on field observations at 12 sites within the Stevens Creek Watershed as shown on Figure 6-3. The sites were chosen to depict a range of current land use within the watershed, including urban development, cropland, and pastureland. At each site, both a habitat assessment and biological survey were conducted.

Sorting trays being used in Stevens Creek

A habitat assessment was performed to document the general health of the stream and adjacent vegetation, known as the riparian corridor. Using guidelines developed by EPA, the assessment was based on numerous habitat components, including the overall condition of the streambank, streambed, and vegetation bordering the stream. Each sampling site was given a habitat score. The higher the score, the better suited the site is for sustaining aquatic species.

A field level biological survey was conducted to document the relative abundance of the primary macroinvertebrate community present. The process involved sweeping the water using a mesh net and then pouring the sample into sorting trays as shown in the above pictures. The samples were evaluated using common biological indicators generally related to the relative abundance and diversity of the macroinvertebrate community.

The results indicated the primary factor that appears to influence the macroinvertebrate communities is the quality of the habitat. Sites located in areas with minimal development,

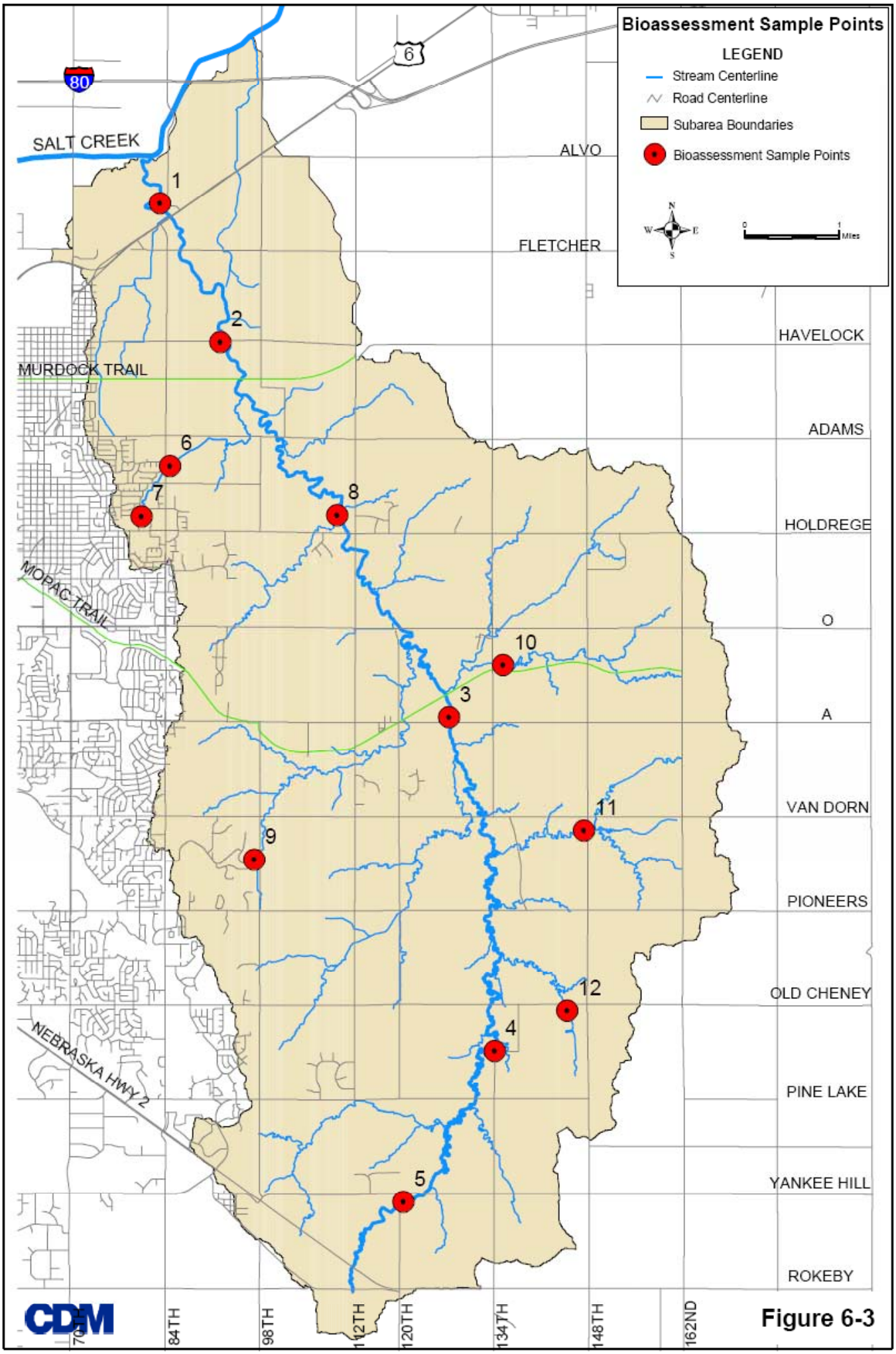

Bioassessment Sample Points
LEGEND
Stream Centerline
Road Centerline
Subarea Boundaries
Bioassessment Sample Points
N
W
E
S
0
1
Miles
80
6
SALT CREEK
ALVO
FLETCHER
HAVELOCK
ADAMS
HOLDREGE
O
A
VAN DORN
PIONEERS
OLD CHENEY
PINE LAKE
YANKEE HILL
ROKEBY
MURDOCK TRAIL
MOPAC TRAIL
NEBRASKA HWY 2
1
2
3
4
5
6
7
8
9
10
11
12
70TH
84TH
98TH
112TH
120TH
134TH
148TH
162ND
CDM

Figure 6-3

such as Site 11, had healthy biological communities with high habitat scores. The key habitat components that influenced the macroinvertebrate community were the degree of streambank stability and the presence of pools and riffles along the streambed.

6.4.2 Summary and Recommendations

The ecological health of the Stevens Creek Watershed appears to be best in areas with minimal development. Adverse channel impacts from development were apparent in developed areas such as Sites 6 and 7. However, channel erosion and resulting sediment deposition were found to be a common concern throughout the watershed and should be considered the primary threat to the health of the biological community.

The most sensitive areas of the watershed are the streams that have retained many of their natural characteristics, which are especially difficult to restore once lost. The three sources of ecological stress that have the greatest potential to threaten the long-term health of these natural streams include:

- **Future Development** – Construction activities need to be monitored to minimize the amount of trash and sediment discharged to natural streams.
- **Channel Encroachment** – Stream setback distances need to be enforced to preserve the riparian corridor.
- **Stormwater Runoff** – As development progresses, it will be critical to implement structural and nonstructural BMPs that minimize pollutant sources and reduce stormwater runoff flow rates that cause erosion.

6.5 Stream Sustainability Analysis

The biological assessment identified three key sources of ecological stress, including future development, channel encroachment, and stormwater runoff. The City's floodplain standards for new growth areas will be applied within the Stevens Creek Watershed, which includes a minimum stream buffer along streams that drain 150 acres or more, and/or have a defined bed and bank. The stream buffer requirement will help preserve the stream riparian habitat that will reduce adverse impacts caused by channel encroachment. To address the potential adverse effects caused by future development that directly alters the volume, velocity, and quality of stormwater runoff, a stream sustainability analysis was conducted.

As discussed previously, urbanization of a watershed increases impervious area resulting in larger stormwater runoff volumes and higher peak flow rates, which causes channel degradation in the form of sediment deposition, incision, and lateral migration. Recent research in urban hydrology and geomorphology indicates the key to providing long-term stream sustainability is to install stormwater facilities (example: detention basins) that control the full range of hydrologic conditions, including the 2-, 10-, and 100-year design storms, plus the small rainstorms that occur many times per year. The City's existing detention standard focuses solely on water quantity by controlling the 2-, 10-, and 100-year design storms. It is the more frequent rainstorms that carry the majority of pollutants and are believed to cause the greatest amount of erosion and sediment deposition, which directly impacts the aquatic and riparian habitat. There is a direct measurable relationship

between the increased flow of stormwater runoff and the erosive shear stress applied to the stream channels. Understanding the impacts of this relationship was the overall goal of the stream sustainability analysis.

The focus of the stream sustainability analysis was to provide recommendations on how to control the full range of hydrology to replicate pre-development hydrology with the goal of preserving water quality and maintaining stream geomorphic stability. The following subsections provide an overview of the methodology and results of the analysis.

6.5.1 Methodology

The following paragraphs provide a description of the prototype watershed and the computer modeling that was used for the analysis.

Watershed Characteristics

The prototype watershed selected for the analysis is depicted on Figure 6-4. The prototype is 483 acres (0.75 square miles) in size and located in the western half of the Stevens Creek Watershed, north of Pioneers Boulevard and west of 98th Street. This watershed was selected based on its inclusion in the City's future service limit, but having minimal development presently, and the available geomorphic data along the tributaries that drain the area. For the purposes of this analysis, the prototype watershed was considered to be 100 percent undeveloped (agricultural conditions), even though small portions of the watershed contain residential development. This assumption was made to provide a baseline for comparing various watershed management scenarios.

The watershed was delineated into 12 subareas ranging from 19 to 74 acres, each of which drain into a tributary of Stevens Creek. The tributary, bounded by Van Dorn and 98th Street, was divided into two stream reaches based on their unique geomorphic characteristics and are labeled Reach 1 and Reach 2 on Figure 6-4. The tributary area into the headwaters of Reach 2 is approximately 170 acres. Based on the City's flood corridor management standards for new growth areas, both stream reaches shown on Figure 6-4 must remain in their natural condition, since the upper area into Reach 2 is greater than 150 acres. The analysis focused on preserving the long-term stream stability along these two natural stream reaches. For the purpose of this analysis it was assumed that all streams draining less than 150 acres did not contain a defined bed or bank.

A detailed geomorphic analysis was performed for the two stream reaches between Van Dorn and 98th Street. Several debris jams were observed in the lower portion of Reach 1. These jams are spaced similar to riffles and are the dominant geomorphic feature within Reach 1. Reach 2 is characterized by a silty clay bed and banks. The NRCS soils data indicate a low erodibility factor and a moderate value for the plasticity index. The results of the geomorphic analysis are further discussed in Section 8 of this report.

As part of the geomorphic analysis, field observations were used to define critical shear stress values for Reaches 1 and 2. Critical shear stress is the threshold at which the fluid flow around a sediment particle exerts a force that is balanced with the resisting force of the particle weight. Movement of streambed and bank materials (i.e., erosion) occurs when the shear stress in the channel exceeds the critical shear stress.

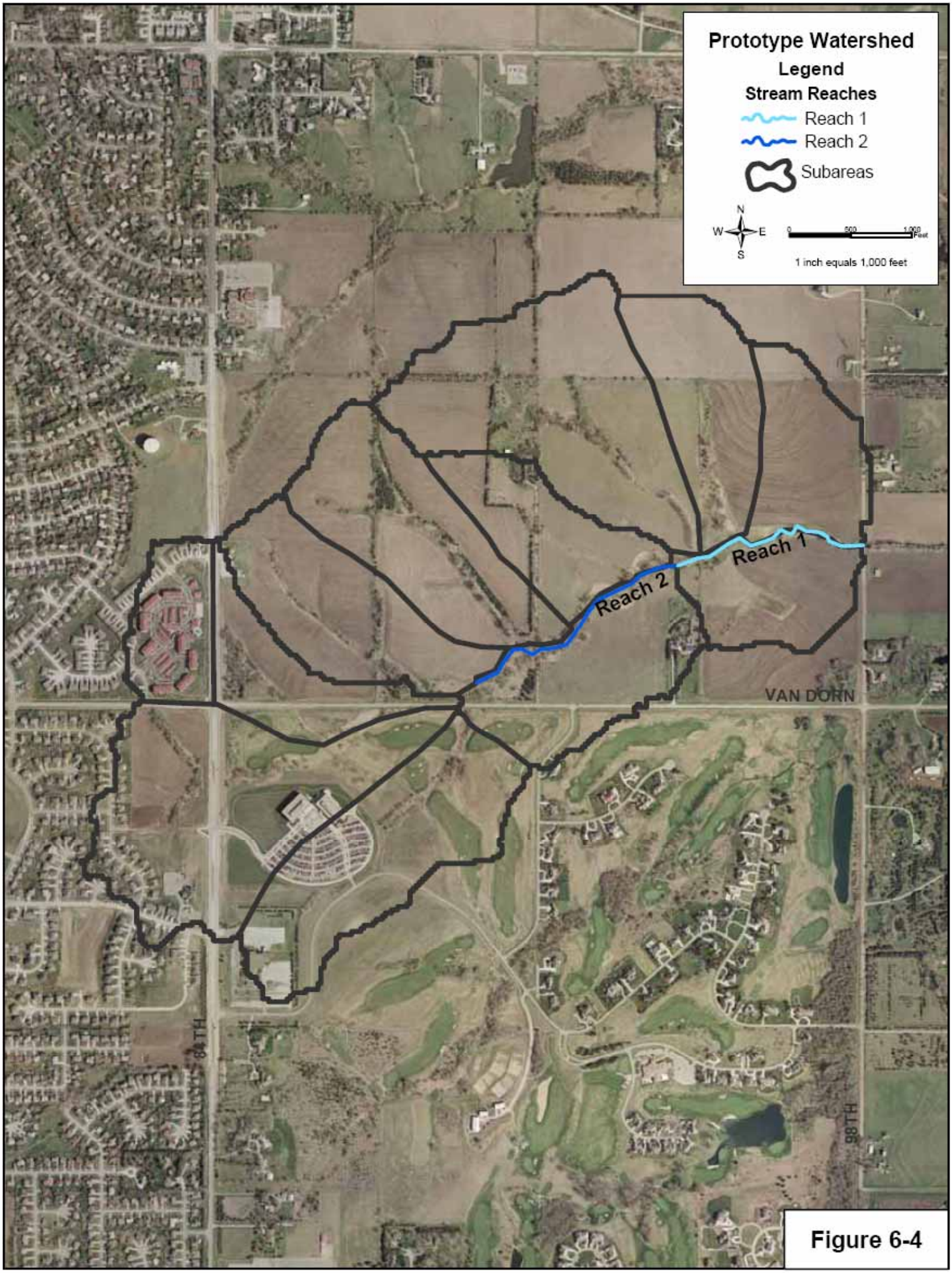

Prototype Watershed
Legend
Stream Reaches
Reach 1
Reach 2
Subareas
N
W
E
S
0
500
1,000
Feet
1 inch equals 1,000 feet
Reach 1
Reach 2
VAN DORN
88TH
98TH

Figure 6-4

The debris jams found in Reach 1 pond water flattens the hydraulic slope and limits shear stress. A critical shear stress value of 3 lb/ft^2 was assigned to Reach 1. This value is often used for streams with large woody debris. A critical shear stress value of 0.26 lb/ft^2 was assigned to Reach 2 based on experience and a comparison with known shear stress values for similar soil types. These values were validated using reach average slopes from 2-foot aerial topography and other indicators of effective discharge.

Computer Modeling

A six-step approach was used for the computer modeling, using programs primarily contained in the EPA Stormwater Management Model (SWMM) suite of tools. The following is a brief description of the six-step process.

- Step 1 – The watershed was divided into subareas, and hydrologic properties of each subarea was determined.
- Step 2 – A 20-year precipitation record of hourly rainfall amounts was developed using local rain gauges and applied to the watershed.
- Step 3 – Design storms for the 2-, 10-, and 100-year return intervals, as listed in the Drainage Criteria Manual, were used by the SWMM runoff model to compute runoff hydrographs for predevelopment and developed surface conditions.
- Step 4 – Detention basins were sized for each subarea to control peak runoff flows for developed conditions to match peak flows for predevelopment conditions.
- Step 5 – Continuous 20-year simulations were performed to develop flow-frequency curves for four watershed management scenarios as described in Section 6.3.2.
- Step 6 – Continuous stream flows estimated for Reaches 1 and 2 were used to compute flow duration frequency and shear stress duration frequency curves to analyze the geomorphic affects of each of the four watershed management scenarios.

Precipitation Data

Twenty years of continuous precipitation data were used to simulate the impacts of development on the two natural stream reaches shown on Figure 6-4. The precipitation data were obtained from the USGS Stevens Creek Gauge located at Havelock Avenue. Table 6-1 summarizes the historical precipitation data.

As shown in the Table 6-1, several data gaps were identified during the review of the historical record. The precipitation data from the Lincoln Airport gauge was used to fill the gaps at the Havelock gauge by applying a ratio of the rainfall totals for the months preceding and following each data gap. The ratio was calculated by totaling the rainfall amounts for 1 month preceding the data gap and 1 month following the data gap for each gauge and then dividing the Havelock totals by the Airport totals. The Airport data spanning the dates of the data gaps were multiplied by the ratio to provide a precipitation estimate at the Havelock gauge.

Table 6-1
Summary of Historical Rainfall Data - USGS Havelock Gauge

Year	Total (in)	Number of Rain Storms	Data Gaps
1983	16.50	25	
1984	34.64	40	140 day gap preceding 4/20/1984
1985	26.62	47	
1986	40.93	54	99 day gap preceding 2/7/1986
1987	24.58	42	156 day gap preceding 4/12/1987
1988	21.67	30	138 day gap preceding 4/1/1988
1989	23.86	32	123 day gap preceding 3/29/1989
1990	20.69	38	125 day gap preceding 3/3/1990
1991	25.82	56	
1992	30.55	56	
1993	42.67	68	
1994	22.11	44	
1995	23.24	42	
1996	27.09	40	
1997	16.95	31	
1998	29.86	41	145 day preceding 3/27/1998
1999	25.93	36	
2000	18.05	33	121 day gap preceding 3/23/2000
2001	21.48	35	
2002	22.94	32	150 day gap preceding 4/4/2003

Model Parameters

SWMM produces hydrographs for each specified subarea. The primary input data included rainfall, tributary area, runoff width, watershed slope, percent directly connected impervious area, and channel characteristics such as slope, cross section geometry, and channel roughness. Pervious area losses due to soil infiltration were estimated using the Green-Ampt equation. Table 6-2 lists the tributary area size and percent impervious for both predevelopment and developed surface conditions.

Predevelopment land use conditions were based on the watershed consisting primarily of agricultural property with portions of green space. The developed land use conditions were based on the watershed as primarily residential property with the exception of subarea SC11, which is currently developed as commercial property.

Table 6-2
Subarea Land Surface Characteristics

Subarea	Area (acres)	Percent Impervious Area	
		Predevelopment Land Surface Conditions	Developed Land Surface Conditions
SC1	74	4	58
SC2	19	4	71
SC3	25	4	47
SC4	40	1	38
SC5	48	1	32
SC6	39	5	36
SC7	71	5	35
SC8	26	1	32
SC9	28	2	32
SC10	34	4	35
SC11	53	4	60
SC12	27	7	37
Total	**484**		

6.5.2 Watershed Management Scenarios

Four watershed management scenarios were analyzed to examine the full range of potential long-term impacts to the two natural stream reaches. The scenarios include "predevelopment," "developed uncontrolled," "developed controlled," and "developed fully controlled." Each scenario is described below.

Scenario 1 - Predevelopment. This is based on predevelopment land surface conditions with no stormwater detention basins. Table 6-2 lists the percent impervious values used for this scenario. The subareas were drained by natural channels. Results from this scenario were used as the baseline for replicating existing hydrologic conditions.

Scenario 2 - Developed Uncontrolled. This is based on the watershed as developed with typical stormwater facilities consisting of concrete pipes that drain to one of the two natural channels, but with no stormwater detention basins. Under this scenario, the percent imperviousness values were based on developed land surface conditions (Table 6-2).

Scenario 3 - Developed Controlled. This is based on the watershed as developed with stormwater detention facilities in place that meet the detention requirements currently outlined in the Drainage Criteria Manual. The Drainage Criteria Manual requires developers to control the post-development runoff rates from the 2-, 10-, and 100-year design storms to match predevelopment peak runoff rates for the same return intervals. The detention facilities modeled in this scenario generally consisted of an orifice to control the 2-year peak flow and the use of rectangular weirs to control the 10- and 100-year peak runoff stormwater flows. The basins were designed to limit the 100-year depth to 10 feet. As in Scenario 2, the percent imperviousness values for developed land surface conditions were used (Table 6-2). The subareas were drained by concrete storm sewer pipes that discharge to detention basins before being released to one of the two natural stream reaches. This scenario is consistent with the Drainage Criteria Manual.

Scenario 4 - Developed Fully Controlled. This scenario is the same as Scenario 3, with the addition of controlling the small frequent storms. This was accomplished by integrating a structural BMP with the detention basins to capture the WQCV and to control the 2-, 10-, and 100-year design storms. For the purposes of this analysis, the WQCV was calculated as the first 0.50 inch of runoff applied over the prototype watershed, which is consistent with the City's Drainage Criteria Manual. The WQCV was released using an orifice with a 40-hour drawdown time.

6.5.3 Modeling Results

Flow frequency, flow duration, and shear stress duration exceedance curves were developed for each watershed management scenario based on the 20-year precipitation record. A comparison analysis between the four watershed management scenarios was conducted to determine the relative stream stability impacts.

Flow Frequency Curves

Figures 6-5 and 6-6 show the flow frequency curves for each scenario at the downstream end of Reaches 1 and 2, respectively. Flow frequency curves provide a statistical representation of the long-term hydrologic response in the watershed. These curves are used as a tool to evaluate the effectiveness of various watershed management controls in replicating predevelopment hydrology. As shown in the figures, the flow frequency curves for the "developed controlled" and "developed fully controlled" scenarios closely match the "predevelopment" flows for the 2- and 10-year return periods. This result is expected since the control of the 2- and 10-year design storms is a requirement stipulated by the City's Drainage Criteria Manual.

However, as shown on Figures 6-5 and 6-6, the "developed controlled" curve begins to diverge significantly from the "predevelopment" curve for return frequencies below the 2-year return interval, while the "developed fully controlled" curve closely matches the "predevelopment" scenario until about the 3-month return interval. At approximately the 3-month return interval, the peak stormwater runoff rate for the "developed controlled" scenario is two to three times greater than the "developed fully controlled" scenario. For the 1-month return interval (0.08 return period), which occurs 12 times per year, the difference approaches a magnitude of 10. The 3-month, 2-year, and 10-year peak flow rates for each scenario are shown in Table 6-3.

Table 6-3
Peak Flow Rates

Scenario	*3-Month Peak Flow Rate (cfs)*	*2-Year Peak Flow Rate (cfs)*	*10- Year Peak Flow Rate (cfs)*
Reach 1			
1. Predevelopment	30	400	600
2. Developed Uncontrolled	200	700	900
3. Developed Controlled (City Criteria)	100	400	600
4. Developed Fully Controlled	30	400	600
Reach 2			
1. Predevelopment	30	200	400
2. Developed Uncontrolled	100	400	600
3. Developed Controlled (City Criteria)	60	200	400
4. Developed Fully Controlled	20	200	400

As shown on the table above, the predevelopment hydrology for the smaller rainstorms (less than 2-year return interval) can be closely replicated under urbanized conditions if structural BMPs are installed in the watershed.

Flow Duration Curves

Figures 6-7 and 6-8 show the flow duration curves for each scenario at the downstream end of Reaches 1 and 2, respectively. Flow duration curves provide a statistical representation of how often a particular flow rate is equaled or exceeded. As shown in the figures, the flow duration curves for "developed uncontrolled," "developed controlled," and "developed fully developed" all exceed the "predevelopment" scenario curve.

When using detention basins to control stormwater runoff, the flow durations are expected to increase due to the extended time period required to release the stormwater

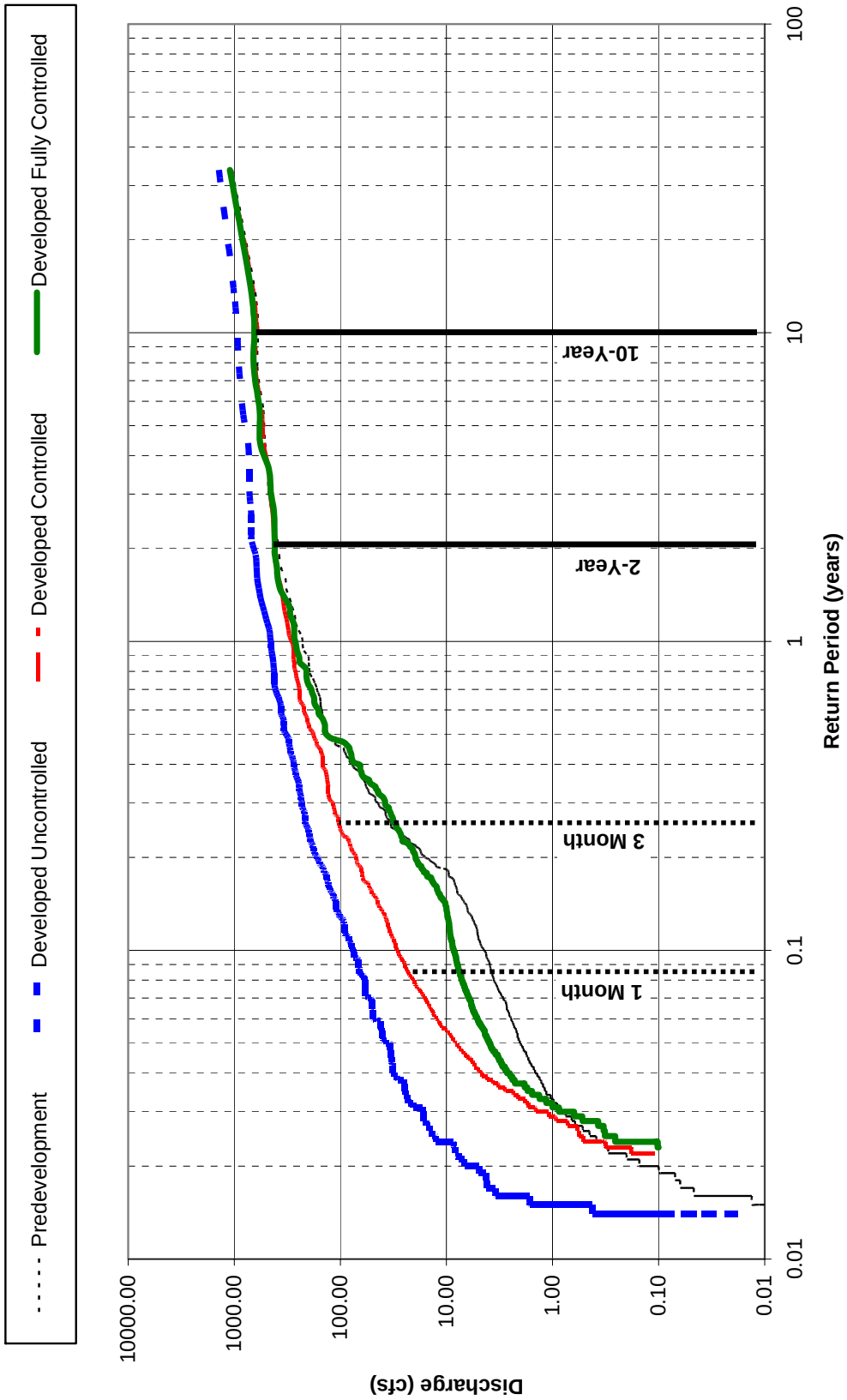


Figure 6-5
Reach 1 - Flow Frequency Curve

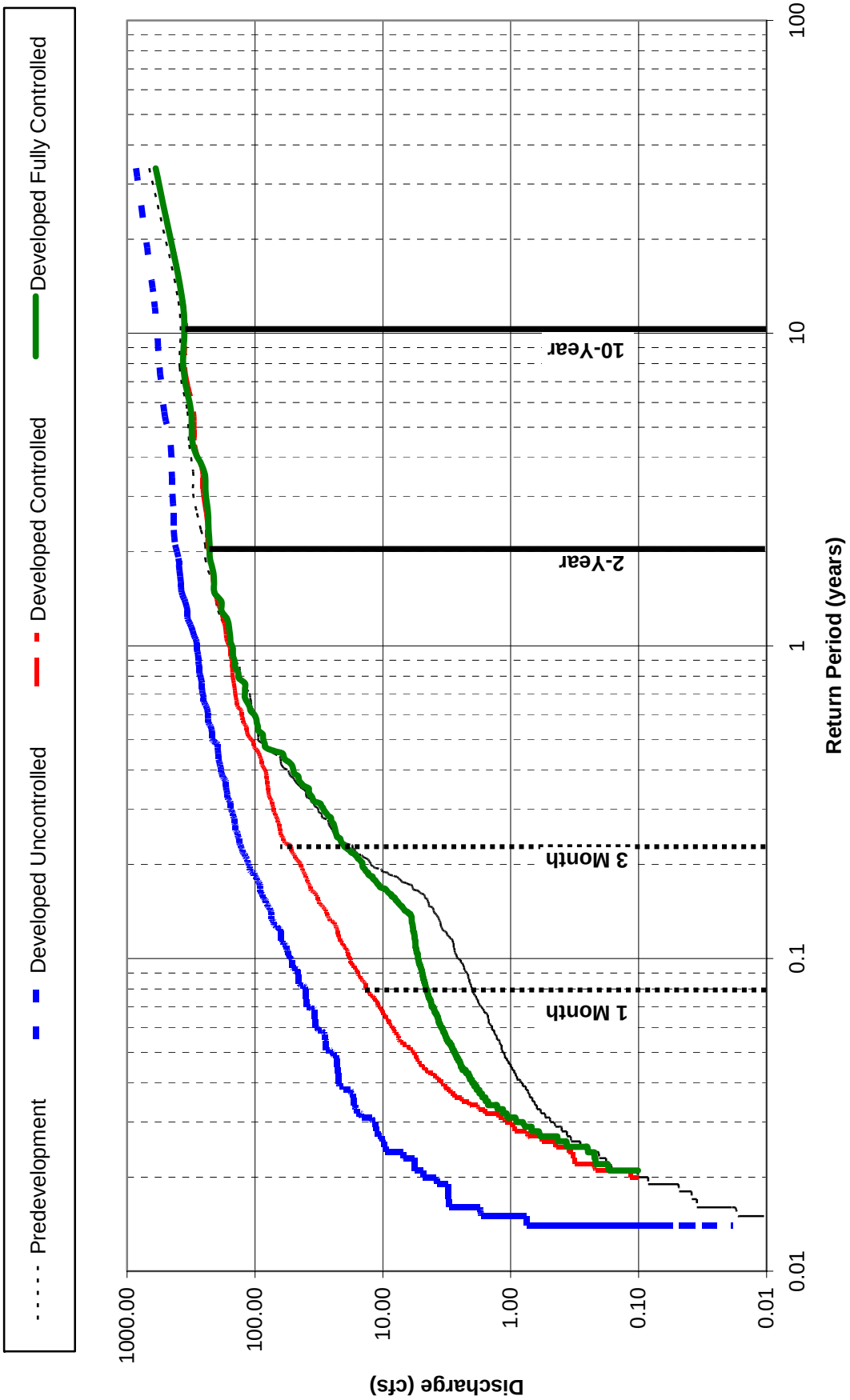


Figure 6-6
Reach 2 - Flow Frequency Curve

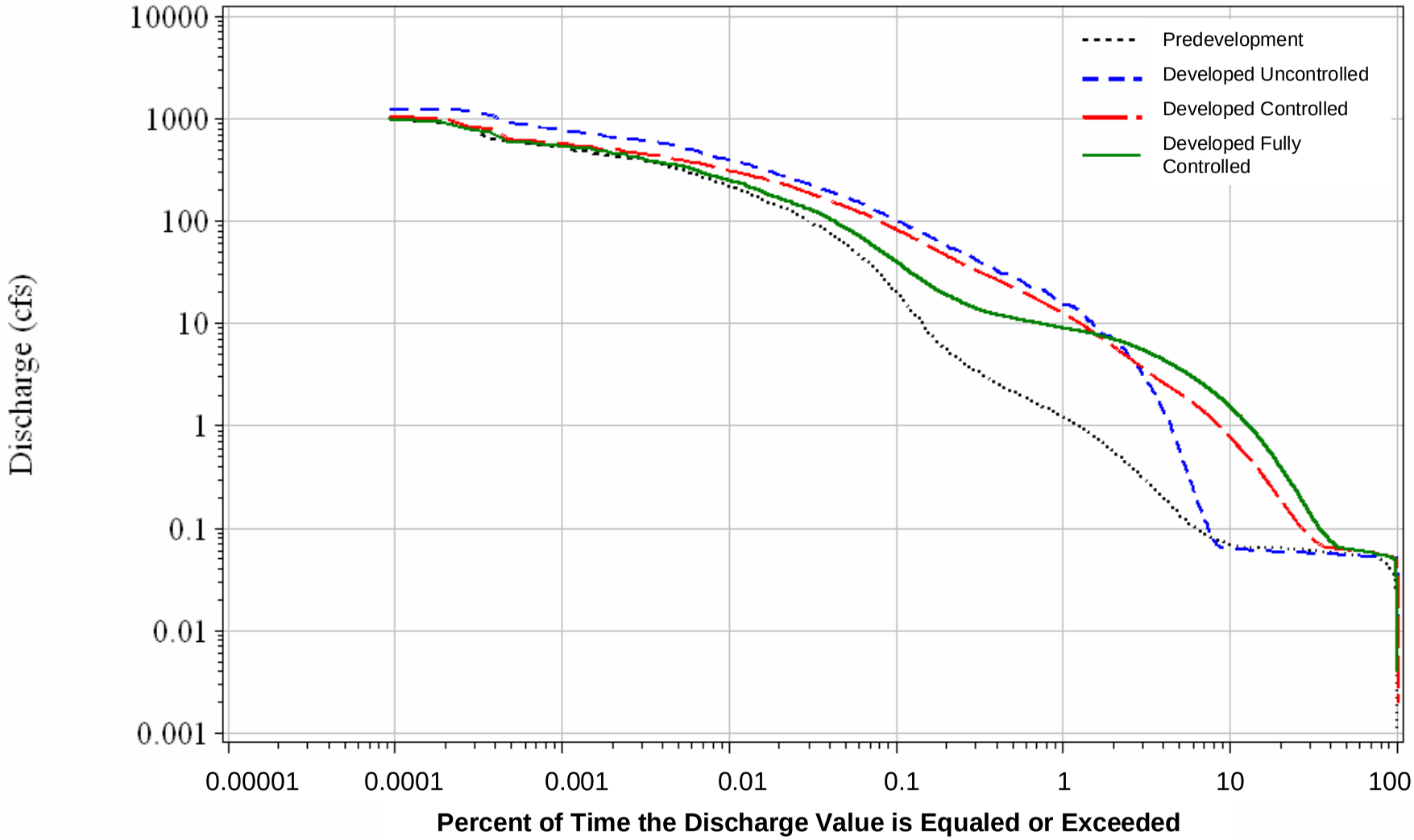


Figure 6-7
Reach 1 – Flow Duration Frequency Curves

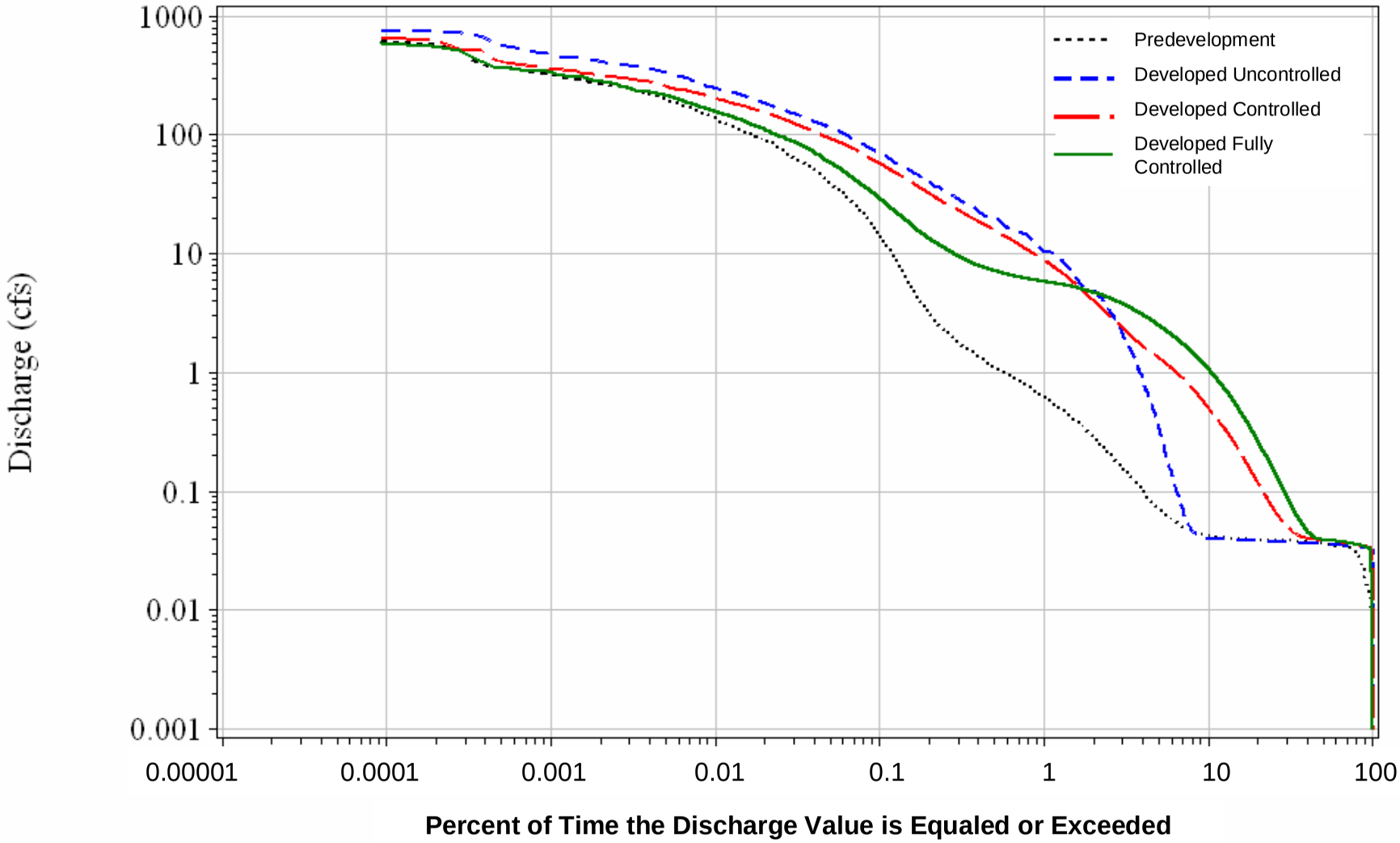


Figure 6-8
Reach 2 – Flow Duration Frequency Curves

runoff into the stream system. However, the key to providing long-term stream stability is to determine whether the increase in the flow duration will adversely affect the shear stress within the stream. Shear stress is the key geomorphic indicator for stream stability.

Shear Stress Curves

Figures 6-9 and 6-10 show the shear stress curves for each scenario at the downstream end of Reaches 1 and 2, respectively. The shear stress curves provide a statistical representation of how often a particular shear stress value is equaled or exceeded. As discussed previously, the critical shear stress for Reaches 1 and 2 was estimated to be 3.0 and 0.26 lb/ft^2, respectively. When shear stress values exceed the critical shear stress, stream instability begins to occur in the form of incision, lateral migration, and sediment deposition.

As shown on Figures 6-9 and 6-10, once the shear stress values reach approximately 0.80 lb/ft^2 and 0.20 lb/ft^2 for Reaches 1 and 2 respectively, the shear stress curve for the "developed fully controlled" drops below the "developed controlled" curve and begins to converge towards the "predevelopment" curve. This indicates that the "developed fully controlled" scenario provides the best opportunity for preserving existing geomorphic conditions by reducing the percentage of time the critical shear stress is exceeded during the simulation period.

Long-Term Cumulative Excess Shear Stress

To quantify the long-term stream sustainability over the 20-year simulation period, the cumulative excess shear stress applied to each stream reach was estimated for the four watershed management scenarios. The cumulative excess shear stress is the sum of the excess shear over the simulation period. Excess shear is calculated by subtracting the critical shear from the total shear at each time step. The resultant value represents the shear stress that causes stream instability. Table 6-4 summarizes the results.

Table 6-4
Cumulative Excess Shear Stress

Scenario	Reach 1			Reach 2		
	3-Month Peak Flow Rate (cfs)	Cumulative Excess Shear (lb/ft^2)	Percent Increase	3-Month Peak Flow Rate (cfs)	Cumulative Excess Shear (lb/ft^2)	Percent Increase
1. Predevelopment	30	320	-	30	152	-
2. Developed Uncontrolled	200	1,716	436	100	516	239
3. Developed Controlled (City Criteria)	100	1,307	308	60	326	114
4. Developed Fully Controlled	30	536	67	20	193	27

As shown in the table above, there is a direct measurable relationship between the increased flow rate from the smaller more frequent runoff events (less than 2-year storm) and the cumulative erosive shear stress applied to the stream channel. Scenario 4 (Developed Fully Controlled) provides the best opportunity to replicate predevelopment hydrology and reduce the long-term erosive impacts from future urbanization by providing structural BMPs to control the smaller rainstorms.

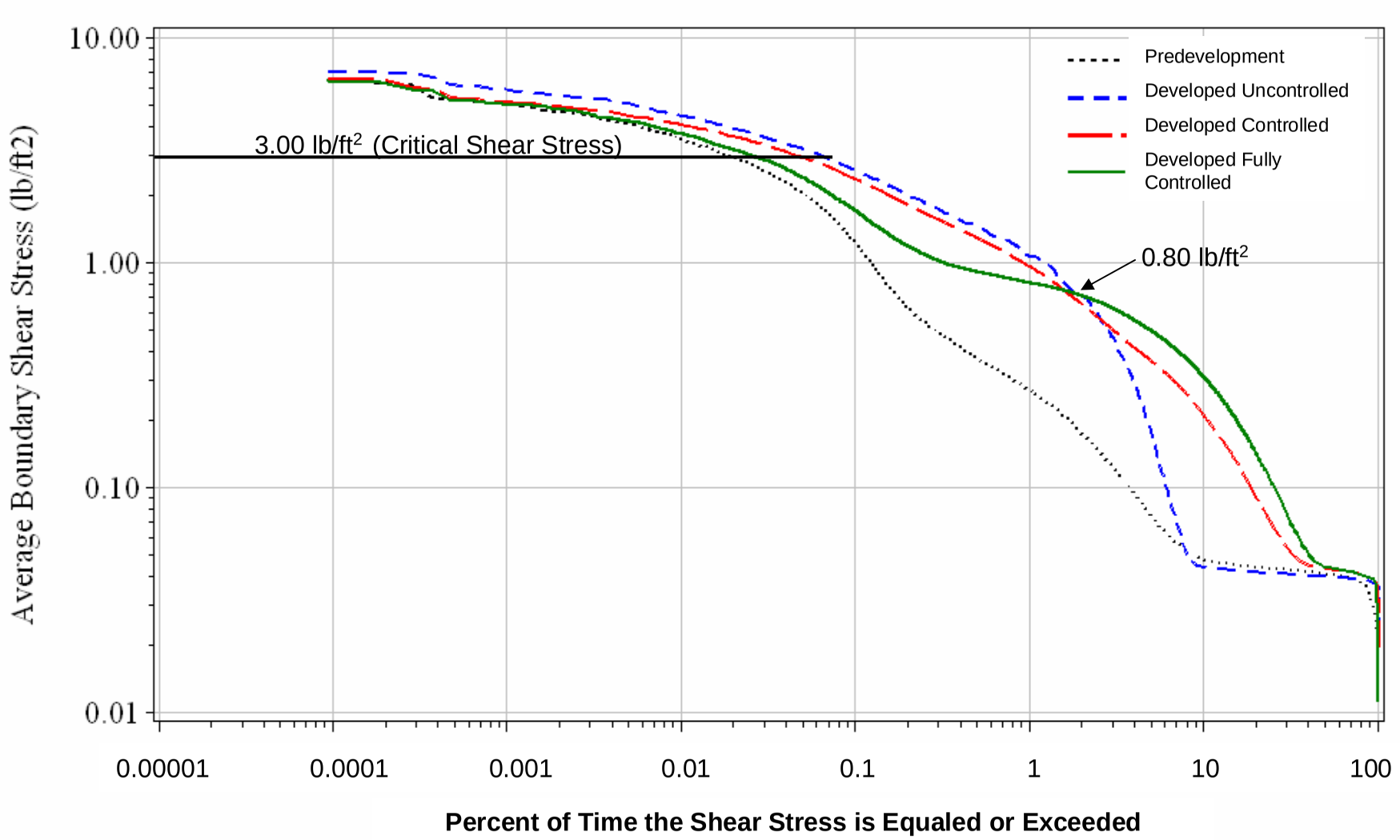


Figure 6-9
Reach 1 – Shear Stress Duration Curves
Critical Shear Stress = 3 lb/ft^2

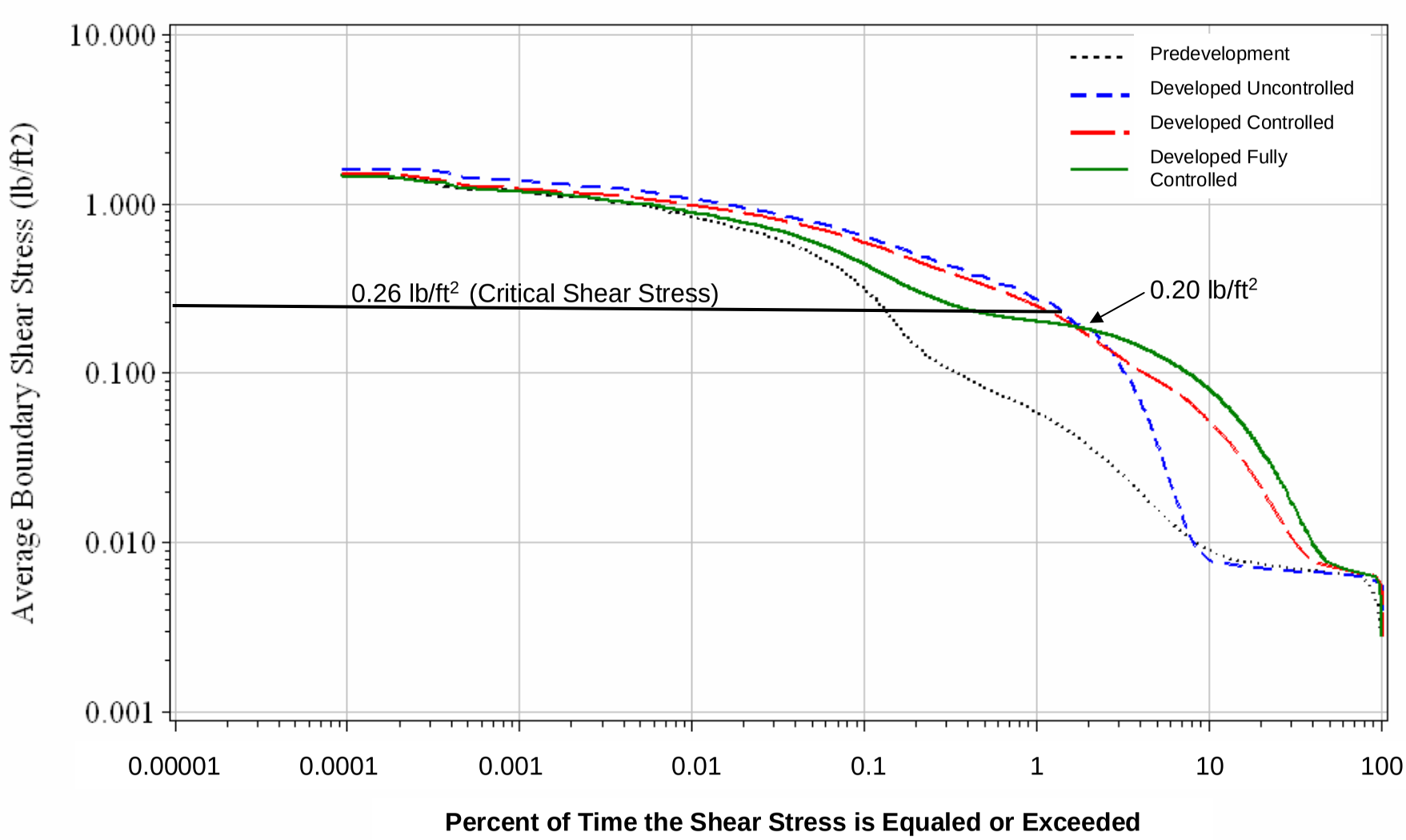


Figure 6-10
Reach 2 – Shear Stress Duration Curves
Critical Shear Stress = 0.26 lb/ft^2

6.6 Evaluation Results

The major conclusions and recommendations resulting from the biological assessment and stream sustainability analysis are summarized below.

6.6.1 Major Conclusions

The major conclusions are summarized below:

- Preserving the stream riparian habitat along the stream corridor is critical to preserving the ecological health of the stream. This should be combined with floodplain storage protection.
- Reducing the source of pollutants transported by stormwater runoff during construction will help preserve the aquatic stream habitat.
- Stormwater facilities should be designed to control the full range of hydrologic conditions, including the WQCV, and the 2-, 10-, and 100-year design storms to maintain predevelopment hydrologic conditions.
- By controlling the WQCV using a 40-hour drain time, the cumulative excess shear stress applied to the natural streams can be properly managed to provide long-term stream stability.
- By controlling the WQCV using a 40-hour drain time, the first flush is captured and detained, which will provide water quality benefits by allowing time for settling of particulates and absorption of soluble pollutants.

6.6.2 Recommendations

A series of watershed management recommendations are provided below that addresses water quality and stream stability to provide long-term sustainable urban growth in the watershed. The recommendations include enforcing key nonstructural and structural BMPs and constructing stream stabilization projects to strengthen the natural system prior to development.

Nonstructural BMPs

The most effective method of reducing stormwater pollution and preserving the natural resources in the watershed is to implement nonstructural BMPs. The more nonstructural BMPs that are implemented in a watershed, the less burden is placed on structural BMPs to preserve the natural stream corridor environment. For the Stevens Creek Watershed, enforcing the following key nonstructural BMPs will be critical as development progresses in the coming years.

Stream Buffers

The primary ecological stressor identified during the biological assessment was the potential loss of stream riparian habitat due to channel encroachment during development. The City's floodplain standards for new growth areas include a stream buffer ordinance that provides a minimum setback distance from the stream that must be

preserved in its natural conditions. This would include streams draining 150 acres or more and streams draining less than 150 acres with a defined bed and bank. As development occurs in the watershed, it will be critical that this ordinance be strictly enforced to preserve the aquatic habitat within the natural streams.

Erosion and Sediment Control

Another key stressor identified during the biological assessment was sediment and trash related to construction activities. Enforcing the erosion and sediment control provisions as outlined in the Drainage Criteria Manual will be an integral component of preserving the aquatic habitat within the streams. Aggressive enforcement of sediment and erosion control practices using inspections during construction can reduce the amount of sediment and trash delivered to the stream. EPA recommends inspections during the rainfall season once every 14 calendar days and within 24 hours after any storm event greater than 0.5 inches.

All approved erosion and sediment control plans approved should comply with the seven technical principles for controlling erosion as described in Section 9.3 of the Drainage Criteria Manual and are listed below:

- Plan the development projects to fit the particular topography, soils, drainage pattern, and natural vegetation to the extent practicable
- Minimize the extent and duration of soil exposure
- Apply erosion control practices to prevent excessive sediment production
- Apply perimeter control practices to protect the disturbed area from offsite runoff and prevent sedimentation damage to areas below the construction site
- Keep runoff velocities low and retain runoff on the site
- Stabilize disturbed areas immediately after final grading has been attained
- Implement a thorough maintenance and follow-up program

Land Development Planning

One of the most effective nonstructural BMPs that can be used to preserve the water quality of runoff after development is land development planning. Land use planning tools such as subdivision regulations, zoning ordinances, and master planning can be used to ensure consistent watershed management practices are followed. As part of this planning process, it is very important to establish who will be responsible for maintaining the structural BMPs. Without proper maintenance, the effectiveness of the structural BMPs will decrease over time.

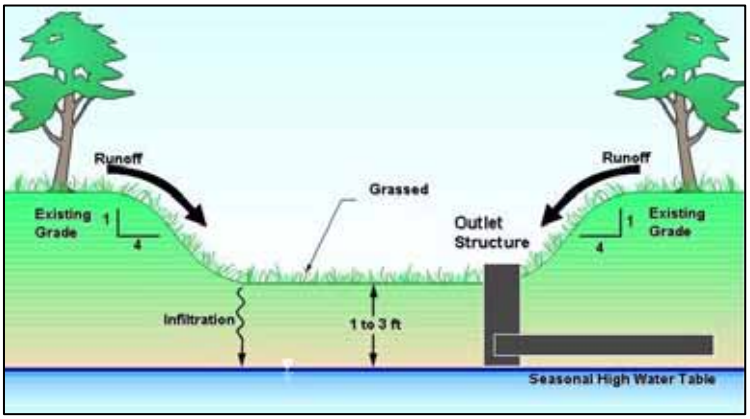
Structural BMPs

One of the major conclusions from the stream sustainability analysis is to install stormwater facilities that control the WQCV to provide long-term stream stability and pollutant removal benefits. This will require the implementation of structural BMPs to address the smaller

more frequent rainstorms that carry the majority of pollutants and are believed to cause the greatest amount of erosion and sediment deposition. Structural BMPs can be implemented using a regional or site-specific approach, each having its own advantages and disadvantages. These two implementation methods are discussed in Section 6.7. The following types of structural BMPs are recommended for the Stevens Creek Watershed.

Extended Dry Detention Basins

Extended dry detention basins are well suited for removing suspended constituents (sediment), and therefore may be a good application for this watershed. In addition, these types of BMPs can be easily configured to become an integral part of the urban landscape by supplementing landscape features, park amenities, and passive and active recreation facilities. These types of detention facilities can be located in a variety of locations, including residential developments, commercial property, open space lots, and adjacent to stream corridors.

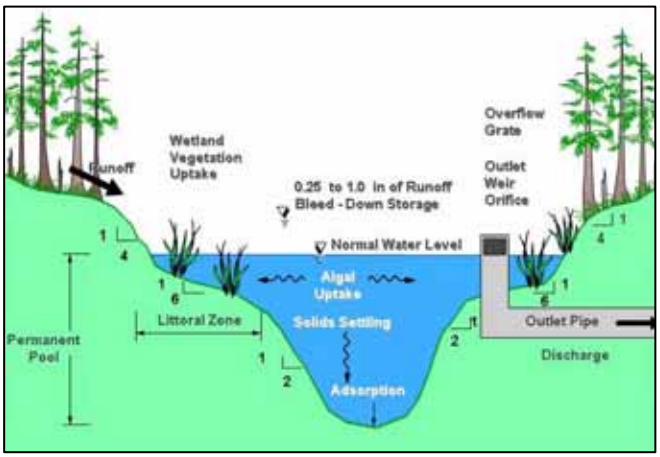


Example Extended Dry Detention Pond

The vegetation within the basin provides erosion control and sediment entrapment. The basin can be planted with native grasses or with turf grasses depending on the design intent and its other intended uses, such as recreation. Sediment deposition, along with frequent and prolonged periods of inundation, makes it difficult to maintain healthy grass cover on the bottom of the basin. Other alternatives are available, including marshy wetland bottoms, riparian shrub, or other types of vegetation that can survive conditions found at the bottom of the basin (WEF, ASCE). Section 7.2.1 of this report provides additional details regarding the design of extended dry detention basins.

Extended Wet Detention Basins

Extended wet detention basins are similar to extended dry detention basins, except they are designed to have a permanent pool of water that is surrounded by emergent wetland vegetation. The permanent pool provides a mechanism for the settling of solids between storms and the removal of nutrients and dissolved pollutants. The wetland vegetation bench is called the littoral zone and provides aquatic habitat and enhances pollutant removal. Wet



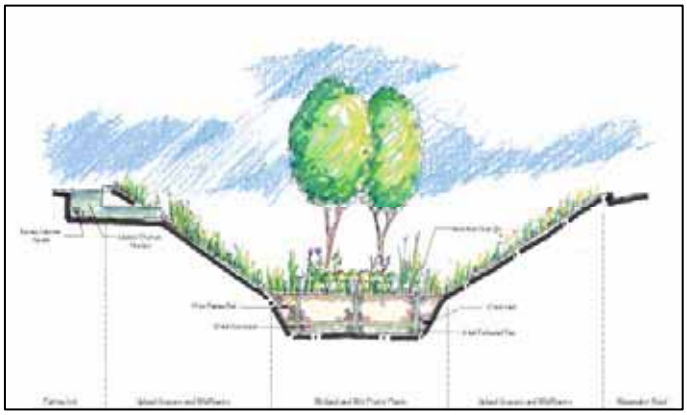
Example Extended Wet Detention Basin

basins are superior to extended dry detention basins in their ability to remove a variety of pollutants, including sediment, nutrients, and dissolved pollutants (WEF, ASCE). The City's Drainage Criteria Manual refers to this type of BMP as Retention (Wet) Ponds.

Extended wet detention basins offer a number of aesthetic advantages. Typically, wet basins are more attractive than dry detention basins and are considered property value amenities in many areas. This is primarily because the sediment and debris accumulate within the permanent pool, hiding it from public view. Section 7.2.2 of this report provides additional details regarding the design of extended wet detention basins.

Vegetated Swales

The City's Drainage Criteria Manual provides design guidance for using grass swales primarily to convey stormwater and provide some water quality benefits. The current design could be easily modified to control the full range of hydrology and enhance water quality benefits. The modifications would include installation of an underlying permeable soil mixture that would promote infiltration and provide water quality treatment. A perforated drain system installed beneath the soil mixture would transport excess runoff to the downstream drainage system. In addition, a series of stand pipes located at regular intervals along the grass swale would provide overflow outlets for larger rain events.



Example Vegetated Swale (Rendering by Patti Banks Associates)

The grass swales can be installed in a variety of applications, including parallel to roadways, within roadway mediums, adjacent to parking lots, and within parking lot islands. Underdrain grass swales are also sometimes referred to as bio-retention facilities. Landscape features such as shrubs, trees, native grasses, flowers, and park benches can be incorporated into these designs to make them a decorative and useful addition to any development.

Constructed Wetlands

Constructed wetlands can be an effective means of providing both flood control and water quality treatment. However, specific site conditions are critical for the proper design of a wetland, including soils, hydroperiod, and plant species and density. In addition, the depth to the confining layer or groundwater is important to ensure that the wetland does not dry up during extended dry periods. A terrace design allows for a variety of wetland vegetation with varying water levels (WEF, ASCE). Constructed wetlands create wildlife habitat and act to filter pollutants from runoff. In addition, education signage and walking paths can turn constructed wetlands into a valuable public amenity and educational tool.

Stream Stabilization

The installation of structural BMPs to control the changes in hydrology will reduce the impacts of erosion. However, it will be very difficult to exactly replicate historical stream flows and velocities with structural BMPs; therefore, stream stabilization projects will be required in critical areas that already contain severe erosion or are vulnerable to future erosion.

For areas that are already showing signs of severe erosion, stream stabilization projects using bioengineering techniques are recommended to improve ecosystem health and to prevent the problem from migrating to adjacent streams. The recommended stream improvement projects are discussed in Section 9 of this report.

6.7 Implementation Methods

As summarized above, the key to preserving water quality and providing long stream stability is to install stormwater facilities that control the full range of hydrologic conditions, including not only the 2-, 10-, 100-year storm events, but also the smaller rainstorms. The structural BMPs described above are designed to control the smaller rainstorms that carry the majority of pollutants and are believed to cause the greatest amount of erosion and sediment deposition, which directly impacts the aquatic and riparian habitat. A range of approaches were discussed with the advisory committee which were refined and assembled into two alternative implementation methods. These included: 1) Regional Structural BMPs, and 2) Site-Specific Structural BMPs.

The study utilized the Tier 1 growth area identified in the Comprehensive Plan to compare the application of the two alternative methods, with the intent that the recommended method would be applied across the entire watershed as development progresses in other portions of the basin. A brief summary of each method is provided in the following paragraphs.

6.7.1 Method 1 – Regional Structural BMPs

Method 1 is based on constructing City/NRD owned and operated regional structural BMPs that provide downstream environmental benefits. The regional structural BMPs would likely consist of a shallow pond 5 to 7 feet deep with surrounding wetland vegetation that is designed to filter out pollutants and reduce the erosive impacts from smaller rainstorms. In addition, structural BMP components would be integrated into the Sky Ranch NRD farm pond, which is expected to be constructed in the near future. This method also includes stream stabilization improvement projects to offset long-term erosive impacts to streams that would not receive water quality and stream stability benefits from the regional facilities. This method still requires privately owned and operated detention ponds for new developments to provide 2-, 10-, and 100-year flood control benefits, as required under the City's existing stormwater standards.

The approximate locations of the regional structural BMPs were based on suitable surrounding topography, maximize the protection of the natural streams, and avoid existing habitable buildings and major roadways. Eight regional structural BMPs were sited based on these criteria as shown on Figure 6-11. The stream sustainability analysis (Section 6.5) concluded that severe degradation will likely occur to those natural streams that do not

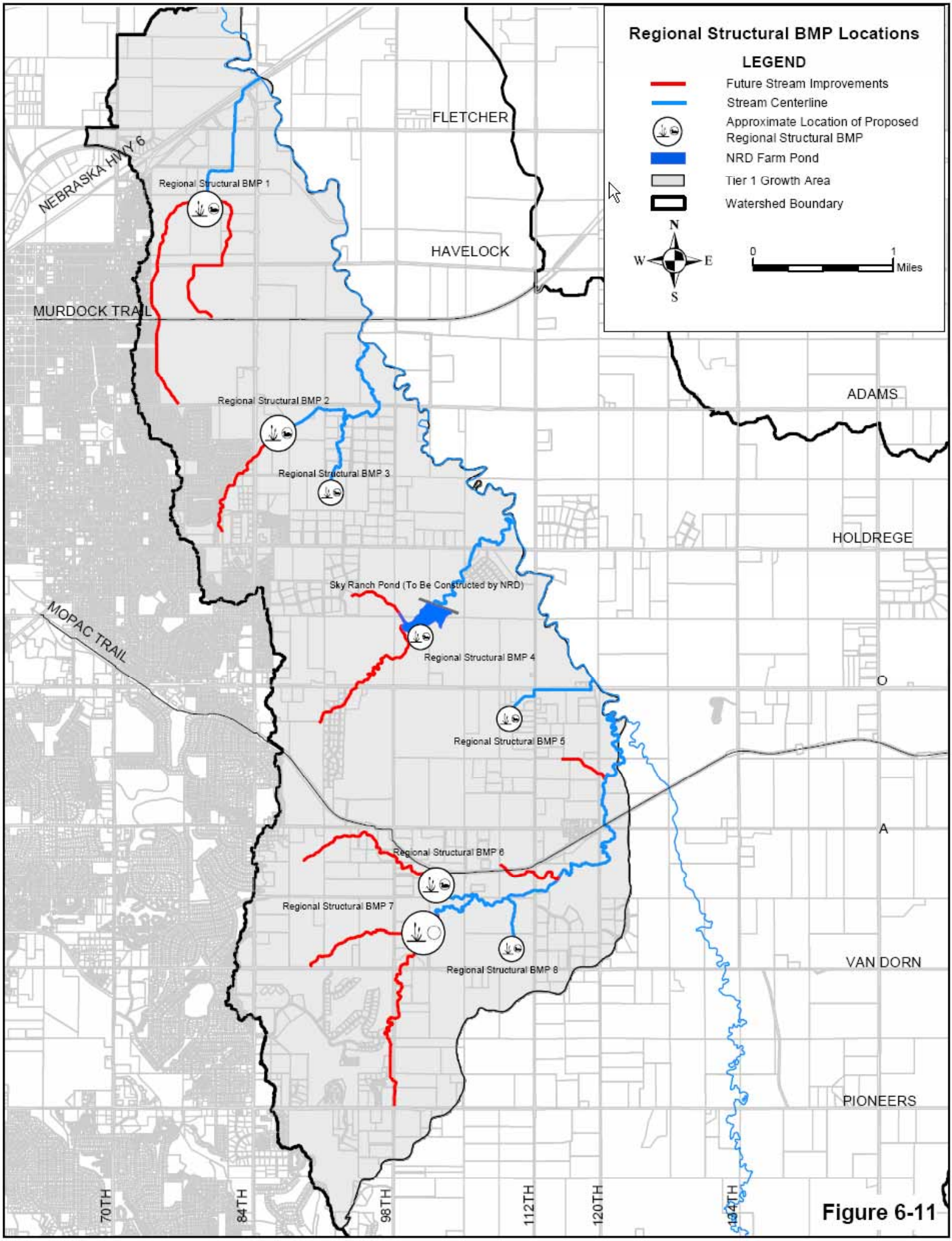

Regional Structural BMP Locations
LEGEND
Future Stream Improvements
Stream Centerline
Approximate Location of Proposed Regional Structural BMP
NRD Farm Pond
Tier 1 Growth Area
Watershed Boundary
N
W
E
S
0
1
Miles
FLETCHER
HAVELOCK
ADAMS
HOLDREGE
O
A
VAN DORN
PIONEERS
NEBRASKA HWY 6
MURDOCK TRAIL
MOPAC TRAIL
Regional Structural BMP 1
Regional Structural BMP 2
Regional Structural BMP 3
Sky Ranch Pond (To Be Constructed by NRD)
Regional Structural BMP 4
Regional Structural BMP 5
Regional Structural BMP 6
Regional Structural BMP 7
Regional Structural BMP 8
70TH
84TH
98TH
112TH
120TH
134TH

Figure 6-11

receive water quality benefits from structural BMPs. Under this method, this includes tributaries located upstream of the eight regional structural BMPs and those tributaries located in drainage basins where regional structural BMPs could not be feasibly located. These streams, which are shown in "red" on Figure 6-11, are expected to require future stream stabilization improvements. For the purposes of this alternative method evaluation, natural streams were defined as those channels that drain a minimum of 150 acres.

Conceptual Cost Estimate

The conceptual cost estimate to apply this method to the Tier I growth area is shown in Table 6-5. The cost estimate includes capital costs, operations and maintenance (O&M) costs, and stream stabilization costs. The capital cost includes design fees, construction management services, construction materials and installation (regional facilities and stream improvements), and easement acquisition for the seven regional facilities. In addition, structural BMP components are included for the Sky Ranch NRD farm pond. The stream stabilization costs are based on repairing approximately 62,000 feet of channel that is expected to degrade over the coming years.

Table 6-5
Method 1: Conceptual Cost Estimate

Item	*Estimated Cost**	*Funding Entity*
Eight Regional Structural BMPs	$7,000,000	City/NRD
Future Stream Stabilization Improvements	$12,400,000	Private/Public ?
Total Capital Cost	**$19,400,000**	
Average Yearly O&M per Regional Water Quality Facility	$7,000	City/NRD

***** Estimates were based on 2004 construction and maintenance costs.

The capital costs were based on 2004 construction unit prices, even though the actual construction would be staged over several years if Method 1 was implemented. This cost basis was made in order to provide a direct comparison to Method 2.

6.7.2 Method 2 –Site-Specific Structural BMPs

Method 2 is based on upgrading the standards for privately owned and operated detention ponds on each individual development site. The detention ponds would be designed to control not only the 2-, 10-, and 100-year storm events (current City standards), but also include a structural BMP to provide long-term stream stability and pollutant removal benefits. This integrated facility would provide both quantity and quality benefits**.**

As shown on Figure 6-12, the upgrades required to integrate a structural BMP into the detention ponds include sediment forebays and slight modifications to the outlet structure. This method would also include additional design requirements to address stormwater volume and timing issues of the individual detention ponds, relative to the watershed computer model, to avoid adverse downstream flooding impacts. This would involve using the HEC-HMS and HEC-RAS computer models, which were developed as part of this study, during the design of stormwater facilities.

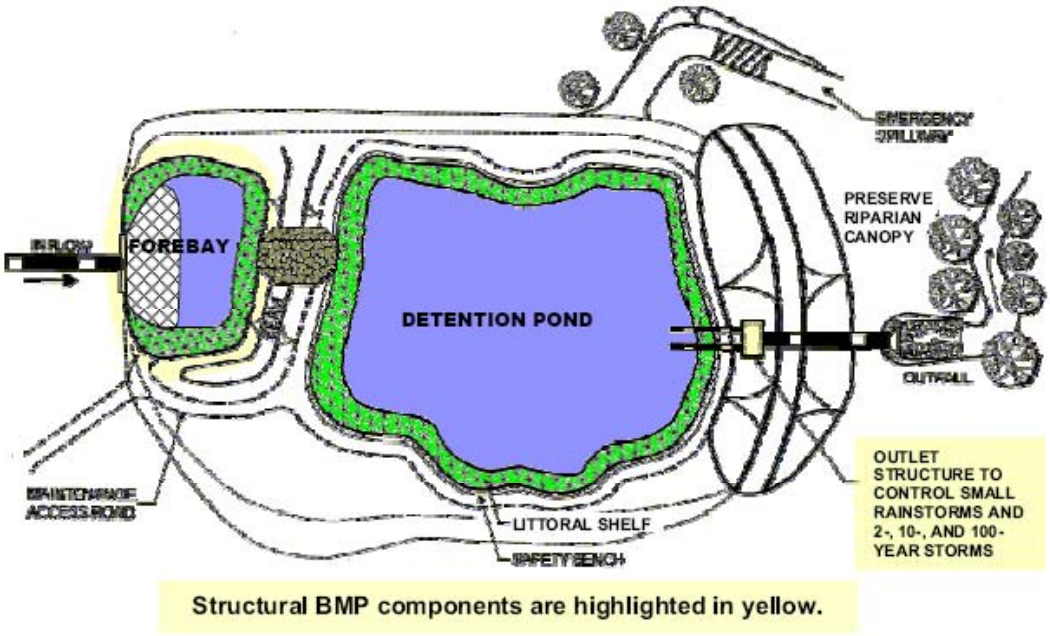


Figure 6-12
Integrated Detention Pond and Structural BMP

This method was based on constructing structural BMPs to serve a typical development site of 75 acres within the Tier I growth area, which is approximately 9,960 acres. This equates to constructing 133 structural BMPs to provide site-specific stormwater quality benefits for this area. For cost estimating purposes, the probable conceptual capital and O&M costs only reflect those additional improvements required to integrate a structural BMP into the City's current detention pond design requirements. The water quantity capital and O&M costs are already being borne by the private developers, as required by current requirements.

The estimated cost to implement Method 2 is summarized in Table 6-6, which includes capital and O&M costs. Total capital cost includes design fees, construction materials installation, and land costs for 133 structural BMPs required within the Tier I growth area.

Table 6-6
Method 2: Conceptual Cost Estimate

Item	*Estimated Cost**	*Funding Entity*
133 Site-Specific Structural BMPs	$2,100,000 ($210/acre)	Public/Private Developer**
Future Stream Stabilization Improvements	$0	---
Total Capital Cost	**$2,100,000**	
Average Yearly O&M Cost for Only Structural BMP	$500	Owning Entity

***** Estimates were based on 2004 construction and maintenance costs.
** See Potential Cost Share Program in Section 6.7.4

The cost was based on constructing all 133 structural BMPs in year 2004, even though the actual construction would be staged as development progresses in the coming years. This cost basis was made in order to provide a direct comparison to Method 1.

6.7.3 Comparison Evaluation

A list of advantages and disadvantages were evaluated to compare the two alternative methods. Tables 6-7 and 6-8 summarize the major issues that were identified.

Table 6-7
Method 1 - Regional Structural BMPs

Advantages	*Disadvantages*
▪ Increases reliability of facilities. The regional facilities would be designed, operated, and maintained by the City/NRD to ensure the facilities are properly designed and maintained.	▪ Higher overall costs. The capital and O&M costs are significantly higher than Method 2. This would require the City/NRD to identify additional revenue sources to finance the design, construction, and long-term maintenance of the regional ponds.
▪ Provides limited benefits to downstream reaches. The regional ponds would provide flood protection and limited water quantity benefits to stream reaches located downstream of the facilities.	▪ Adverse impacts to the environment. Due to the limited number of feasible regional pond locations, several stream reaches would not receive water quality benefits. The long-term effect would be stream instability and loss of aquatic and riparian habitat that is costly and difficult to replace once lost.
▪ No increase in City staff review time. City staff would not be burdened with additional review time to verify water quality features and hydrograph volume, and timing issues were properly integrated into new site developments.	▪ Future Stream Stabilization Improvements. Those stream reaches that do not receive water quality benefits would eventually require expensive stream stabilization improvements to address severe erosion problems, which would be financed by private citizens.
▪ No change in City design requirements. The City/NRD would not be required to alter their current design requirements for new developments.	▪ Sequence difficult to predict. The regional ponds would need to be constructed prior to new development to avoid adverse impacts to the natural streams. Since development patterns are difficult to predict, knowing the sequence and timing of construction for the six regional ponds would be difficult to implement in advance of new development.
▪ No increase in private developer's construction costs. The construction cost to comply with the City's stormwater requirements for new developments would not increase.	▪ Unfair land impact distribution. Since construction of the regional ponds would require acquiring land from only a few property owners, land impacts would not be equally distributed to everyone who contributes to the stormwater problems associated with urbanization.
▪ No increase in O&M costs for private citizens. This method would not increase O&M costs associated with stormwater detention ponds on each individual development.	▪ Requires FEMA floodplain map revision. Construction of the regional ponds would require a FEMA submittal to update the floodplain boundaries as a result of the dam construction.

Table 6-8
Method 2 - Site-Specific Structural BMPs

Advantages	*Disadvantages*
▪ Lower capital costs. The total capital costs are significantly lower than Method 1 (less than half).	▪ Higher maintenance cost. A higher emphasis on regular maintenance would be required to ensure the structural BMPs are functioning properly. This would likely require maintenance agreements between the City/NRD and the owning entity.
▪ Protects natural streams. This method will preserve the aquatic and riparian habitat within the natural streams and provide long-term stream stability.	▪ Higher cost to developers. The capital costs to construct onsite detention ponds would slightly increase as a result of adding water quality enhancements.
▪ Minimal cost to private citizens. The need for expensive, privately funded stream stabilization and flood improvements in future years will be avoided.	▪ Increase City staff review time. The staff time required to review design submittals that included water quality features and addressed hydrograph volume and timing would increase. Additional staff may also be required for maintaining the watershed computer models and to increase inspections of the detention ponds to effectively enforce the maintenance agreements.
▪ Fair land impact distribution. By requiring each new development to provide onsite flood control and water quality benefits, the land impacts are equally distributed to those stakeholders developing land parcels within the watershed.	▪ City policy revision. This method would call for a revision of City policy to require structural BMPs for each new development.
▪ Minimizes adverse downstream impacts. By requiring the development community to design detention ponds to account for hydrograph volume and timing issues, the no-net rise floodplain standard will be maintained and adverse downstream flooding impacts will be avoided.	
▪ Similar to City current standards. The City currently requires each new development to provide onsite detention ponds for the control of water quantity. Method 2 would maintain this same onsite approach, with the addition of relatively inexpensive water quality enhancements.	

6.7.4 Recommendations

Site-specific structural BMPs, as described in Method 2, is the approach embodied by the Master Plan for preserving water quality and providing long-term stream sustainability as the urbanization process continues in the watershed. This method is a cost-effective approach towards maintaining the integrity of the natural streams, preserving water quality, and can be efficiently integrated with the City's current standards for flood control.

The integration approach would require detention basins to have staged outlet control structures to control the 2-, 10-, and 100-year design storms, and detain the WQCV using a 40-hour drain time. In addition, sediment forebays and energy dissipaters are recommended to capture sediment and reduce the velocity of the stormwater runoff before draining into the pond. While this would require changing the City's Drainage Criteria Manual from a voluntary to mandatory program for structural BMPs, it will result in significantly increasing the protection of natural streams and support the requirements of EPA NPDES Stormwater Programs. The details of the integration approach are provided in Section 7.2.

Alternative Design Approaches

The site-specific structural BMPs can be integrated with the City's current stormwater detention basins. However, this integrated approach is one of many site-specific design concepts that can be employed to achieve the desired results. Section 7.3 provides additional details on how structural BMPs can be separated from detention basins to provide site-specific water quality and quantity benefits.

Potential Cost Share Program

One of the key concerns expressed about site-specific structural BMPs during the stakeholder sessions and Citizen Advisory Meetings was the question of who should bear the cost for offsetting the impacts to water quality and stream stability caused by future urbanization. While this is a policy issue that must be consciously determined by the community, many Midwest communities have faced similar challenges, including Kansas City. They concluded that each private development should bear the cost of offsetting impacts to water quality and stream stability, similar to widely accepted practices for offsetting flooding impacts caused by that development, while other communities have provided some funding support with construction and maintenance costs.

In response to this input, a cost share concept was investigated that would address both construction and maintenance of site-specific structural BMPs. This approach assumes that there is both private responsibility to offset impacts from development and public responsibility relative to how the structural BMPs function together as a system to address water quality and stream stability throughout the watershed. The cost share concept is described below.

Using the site-specific structural BMP approach, the estimated construction cost to incorporate structural BMPs into the current design of detention basins is approximately $200 per acre of drainage area (Table 6-5) and an average annual cost of $500 per year per basin to perform the required maintenance (for the additional structural BMP). The cost share concept would be for the City and NRD to share in the cost of constructing the BMP portion of the facility with the private developer, jointly providing funding for $100 per acre of drainage area. ***Example***: if a 75-acre average drainage area is assumed, the total construction cost would be approximately $15,000. At $100 per acre, the City/NRD cost share for construction would be $7,500. The remaining cost would be funded by the developer. To address maintenance, a subdivision agreement could potentially require the developer to set up a $2,500 escrow for the first five years of maintenance ($500/year).

City/NRD funding would be provided on a first-come, first-serve basis and would be contingent upon City/NRD approval of the proposed cost share program. In addition, the cost share program would be subject to yearly budget approvals, voter approval of GO bonds, and NRD board approval.

Maintenance Plan

To implement site-specific structural BMPs, the City would need to revise its standards for maintenance. This would include uniform criteria for a maintenance plan that would be submitted with the preliminary plat and referenced in the subdivision agreement.

A good maintenance plan would provide a guide for future property owners, and would help ensure that maintenance responsibilities are clear when ownership is transferred from the developer. The required maintenance escrow would ensure that funding for maintenance is set aside from the beginning.

To implement this site-specific structural BMP, the City/NRD would jointly sponsor a proactive education program and share in the responsibility of regular inspections on a rotation basis. This will ensure adequate long-term operation and maintenance of structural BMPs, as required by the City's NPDES permit. Section 7.4 provides additional information regarding suggested maintenance programs.

Section 7
Drainage Criteria Manual Review

7.1 Background

As discussed in Section 6, urbanization increases impervious areas, which reduces the amount of rainfall that infiltrates into the ground. As a result, more rainfall is directly converted to stormwater runoff. This causes an increase in stormwater runoff flow rate, volume, and velocity, which increases erosion and sediment deposition.

Altering the magnitude, frequency, and duration of stormwater runoff and sediment loads to streams causes impacts to water quality, stream stability, and loss of aquatic life and habitat through a wide variety of geomorphic mechanisms. These mechanisms include changes in channel bed material, increased suspended sediment loads and loss of riparian habitat due to streambank erosion. In addition, the aquatic environment and habitat are also affected by pollutants transported by stormwater runoff. However, as shown in Section 6, if predevelopment hydrologic conditions can be replicated using stormwater facilities, the impacts to water quality, stream stability, and aquatic habitat can be minimized.

Given the variability of rainfall and the resulting stormwater runoff volumes and discharge rates, the statistical probabilities of runoff events must be considered in the sizing of stormwater facilities to meet both water quality and water quantity goals. However, conventional stormwater facilities are typically sized to achieve flood control objectives for the rare storm events (i.e., 10- and 100-year return periods). Therefore, stormwater facilities must be designed for the full range of hydrologic events, from the relatively frequent small storms for water quality control and stream stability to the rare large storms for flood control.

Chapters 6 and 8 of the City's Drainage Criteria Manual revised May 10, 2004, address regulatory requirements and design principles for stormwater detention facilities and stormwater BMPs. The Drainage Criteria Manual requires adequate detention volume to attenuate the post development peak discharge rates to predevelopment discharge rates for the 2-, 10-, and 100-year return intervals. The Drainage Criteria Manual encourages the use of BMPs on a voluntary basis, and recommends a design WQCV of 0.5 inches with a 24-hour drawdown time. The WQCV is calculated by multiplying the inches of runoff by the contributing drainage area and dividing by 12.

The key issues described in the following paragraphs include:

- Design features that integrate water quantity and quality into a single integrated facility
- Outlet control structure design guidance to achieve the required release rate
- Design guidance in determining the appropriate WQCV and release rates
- Alternative design approaches
- Guidance on necessary maintenance activities, ordinances, agreements, and inspection reports
- Conservation culvert design approach

7.2 Integrating Stormwater Detention with Structural BMPs

The benefits of integrating water quality features with flood control facilities is discussed in Section 8.3.3 of the City's Drainage Criteria Manual:

> *For many BMPs, combining the water quality facility with a flood control facility is practical and cost effective. Specifically, the water quality control volume (WQCV) that is recommended for control is the first half inch (0.5 inches) of runoff from the basin tributary to the BMP. For facilities that combine water quality control with flood control, the runoff from the design storms for the flood control criteria should be "stacked" on top of the water quality control volume. The water quality control volume should be detained over at least a 24-hour period, and preferably for longer.*

The purpose of this section is to provide design guidance to integrate structural BMPs with the City's current stormwater detention basin control requirements to provide both water quantity and quality benefits. This integrated approach offers a cost-effective method towards preserving water quality, maintaining the stability of natural streams, and achieving flood control objectives.

The City's current detention policy (Section 6 of the Drainage Criteria Manual) focuses on controlling the 2-, 10-, and 100-year design storms to predevelopment conditions. The more frequent rainstorms (e.g., less than 2-year return interval) carry the majority of pollutants and generally cause the greatest amount of erosion and sediment deposition, which directly impacts the aquatic and riparian habitat. As noted in Section 6, recent research and application in urban hydrology and geomorphology indicate the key to providing long-term stream sustainability is to control the full range of hydrologic conditions. Among the conclusions from the biological assessment and stream sustainability analysis:

- Stormwater detention basins should be designed to control the full range of hydrologic conditions, including the WQCV and the 2-, 10-, and 100-year design storms to maintain predevelopment hydrologic conditions.
- By controlling the WQCV using a 40-hour drain time, the cumulative excess shear stress applied to the natural streams can be properly managed to provide long-term stream stability.

For the purposes of this report, the following terms are defined:

- Extended dry detention basin: An extended dry detention basin provides flood control and water quality treatment and is a dry storage facility. The term "extended" means the entire WQCV is treated by slowly releasing the runoff over a specified period of time until the facility completely drains. The primary pollutant removal mechanism is sedimentation, which is achieved through an appropriate detention time.
- Extended wet detention basin: An extended wet detention basin provides flood control and water quality treatment and contains a permanent pool. The term "extended" means the entire WQCV is treated above the permanent pool by slowly releasing it over a specified period of time. The permanent pool provides a mixing

volume for the settling of solids and the removal of dissolved pollutants (e.g., nutrients). Section 8.3.4.2 of the Drainage Criteria Manual refers to these basins as "Retention (Wet) Ponds."

Table 7-1 summarizes the key design criteria for the two types of stormwater facilities. For extended wet detention basins, the permanent pool provides a holding volume for continued settling of particulate pollutants and uptake of dissolved pollutants by aquatic plants, with a residence time between 2 and 4 weeks. The permanent pool represents the portion of the basin that normally holds water (i.e., between the normal water level and the pond bottom). For extended dry detention basins, the micropool is an optional, relatively shallow impoundment intended to reduce the potential for resuspension during runoff events.

Table 7-1
Design Criteria for Stormwater Basins

Type of Basin	Permanent Pool Volume	Storage Volume	
		Water Quality	Flood Control
Extended Dry Detention	Micropool (optional)	WQCV (40-hr drawdown)	Predevelopment 2-, 10-, 100-yr release rate
Extended Wet Detention	1 to 2*WQCV (2-4 week residence time)	WQCV (40-hr drawdown)	Predevelopment 2-, 10-, 100-yr release rate

The volume required for extended detention basins (both dry and wet) is a function of the basin geometry and outlet control structure. As mentioned above, controlling the WQCV with a 40-hour drawdown time provides both water quality treatment and long-term stream stability.

The following paragraphs provide a summary of key design features, outlet control recommendations, and other issues that should be considered when designing extended dry and wet detention basin facilities. This discussion is followed by various approaches to calculate the WQCV.

7.2.1 Extended Dry Detention Basin

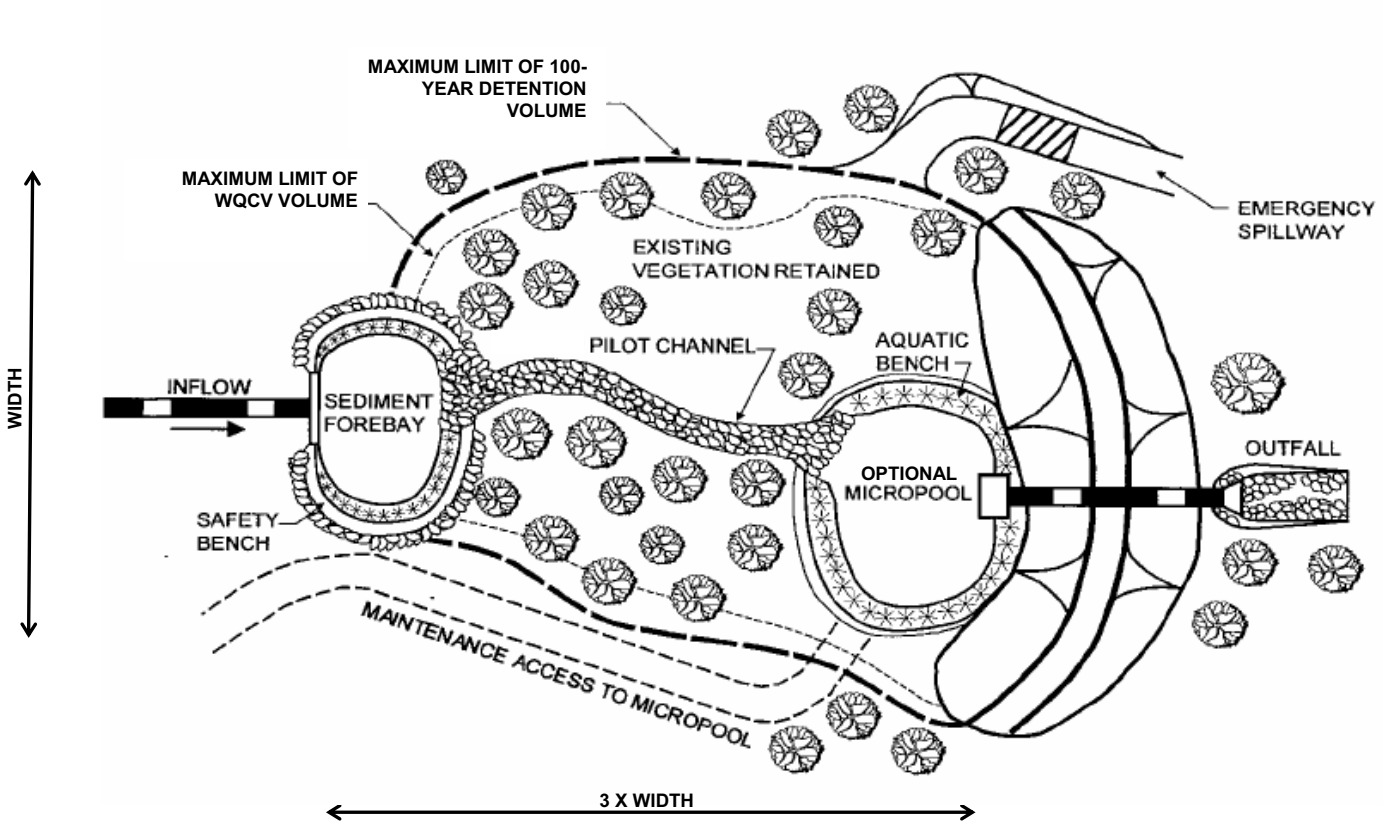
Figure 7-1 shows a schematic plan and profile view of an extended dry detention basin with a micropool (adapted from Figure 3-1 of the *Maryland Stormwater Design Manual*, Maryland Dept of the Environment, 2000). The profile view shows the various volume components listed in Table 7-1, including the water levels corresponding to the WQCV, 2-, 10-, and 100-year design storm events.

The advantages of extended dry versus extended wet detention basins include:

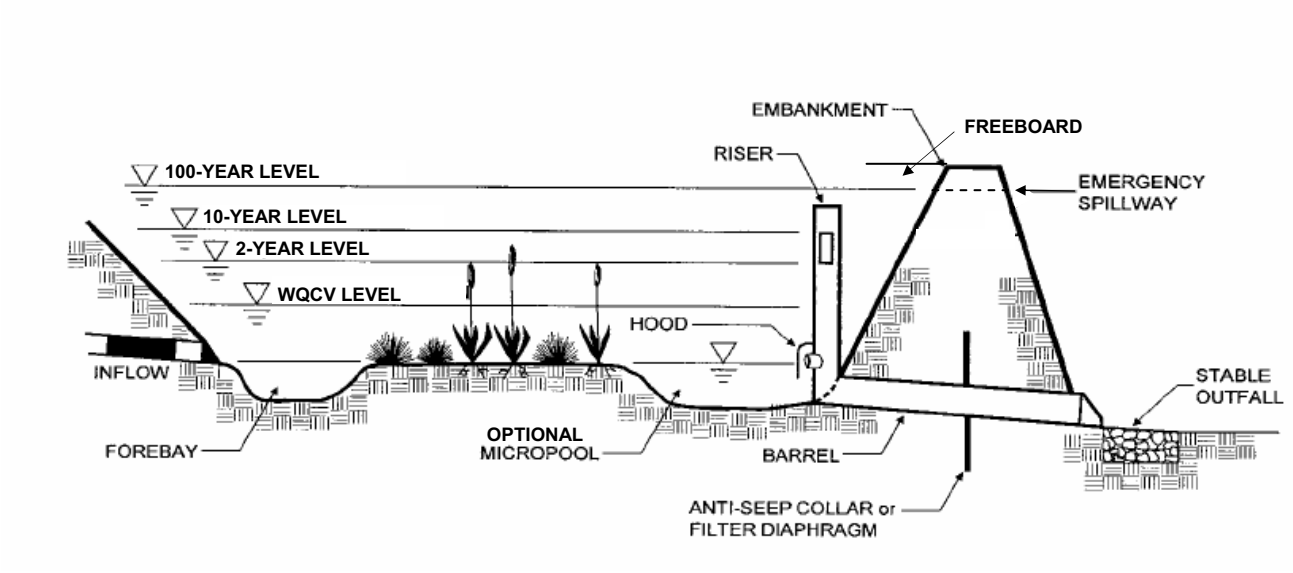
- Algae growth problems are not a concern, unless design includes a micropool.
- Recreational amenities (e.g., athletic fields) can be accommodated.

The disadvantages of extended dry versus extended wet detention basins include:

- Less aesthetically pleasing if amenities are not included due to dry, bare areas.
- Little pollutant removal for nutrients and soluble pollutants.
- Resuspension of settled material is more likely.
- Debris and silt buildup are seen.



Plan



Profile

Figure 7-1
Schematic of an Extended Dry Detention Basin
(Adapted from Maryland Department of Environment, 2000)

Design Features

The performance of extended dry detention basins can be maximized by addressing key design features including sediment forebay, length-to-width ratio, recommended side and bottom slopes, micropool design, storage volume, and vegetation.

Sediment Forebay

A sediment forebay is a pretreatment feature that can increase the pollutant removal efficiency of the facility by trapping sediment and trash at all basin inlets. Generally it is recommended that the forebay represent at least 10 percent of the WQCV to be effective. The forebay can also facilitate maintenance by concentrating sediment in an accessible location. The forebay consists of a separate cell, formed by an acceptable barrier such as a vegetated earthen weir.

To make sediment removal easier, the bottom and side slopes of the forebay are generally lined with concrete. This area should be designed to minimize aesthetic problems associated with sediment and debris accumulation and saturated soils in this portion of the basin. Additional design inlet considerations should include energy dissipaters to reduce inflow velocity, scour potential, and the turbulence and mixing currents that disturb sedimentation.

Length-to-Width Ratio

Increasing the length-to-width ratio of the facility increases the water quality treatment potential by providing additional detention time for settling, infiltration, and possibly biological uptake. As a result, a 3:1 length-to-width ratio or greater is generally recommended. Basins should be wedge-shaped, narrowest at the inlet and widest at the outlet. Greater flow lengths can be accommodated by relocating the basin inlet or outlet where possible, or by installing berms or baffles within the basin to the full depth of the WQCV to avoid short circuiting and increase travel time to the outlet.

Side and Bottom Slopes

Side slopes for extended wet detention facilities should be no steeper than 4:1 (horizontal to vertical). A bottom slope of 2 percent is required to prevent ponding and prolonged standing water.

Micropool

The micropool is an optional feature for extended dry detention basins; a relatively shallow impoundment intended to concentrate sediment and reduce the potential for resuspension during runoff events. Vegetation in the micropool can help stabilize the trapped sediment. A micropool also helps prevent clogging of the outlet.

Storage Volume

The storage volume for an extended dry detention facility includes the WQCV and flood control volume to control the 2-, 10-, and 100-year peak flow rates. Chapter 6 of the City's Drainage Criteria Manual describes the calculations required to determine the storage needed for the flood control volume. Section 7.2.3 of this report describes the methodology for calculating the WQCV. A portion of the WQCV can be included in the sediment forebay.

Based on the results of the stream sustainability analysis that is described in Section 6 of this report, it is not recommended that the flood control volumes be "stacked" on top of the WQCV. Stacking the volumes is overly conservative and reduces peak flows below predevelopment levels.

To account for sediment deposition, an additional volume equal to 20 percent of the WQCV should be included in the overall storage volume for the entire facility. This sediment storage volume is generally located near the outlet control structure of the basin. Similar to the forebay, the bottom and side slopes near the outlet structure are generally lined with concrete to make sediment removal easier. This area should be designed to minimize aesthetic and other impacts associated with sediment and debris accumulation and saturated soils in this portion of the basin.

Vegetation

The type of vegetation appropriate for extended dry detention facilities is greatly dependent upon where the facility will be used for recreational purposes. Vegetation in the basin bottom must be able to withstand prolonged periods of standing water during the WQCV drawdown. Native grasses increase infiltration capacities when planted at the bottom of the basin. If the facility is designed to provide recreational amenities, a conventional turf grass may be desired.

Embankments should be planted with native grasses and wildflowers to provide aesthetic benefits. Native grasses typically have a more robust root structure than turf grasses and reduce erosion along the banks. Trees or shrubs should not be planted along the embankment to avoid long-term maintenance problems.

Outlet Control Structure

The outlet control structure for an extended dry detention basin includes both water quality and water quantity controls. The outlet should be configured such that the WQCV is released over 40 hours and that peak discharge rates for post development conditions do not exceed predevelopment peak runoff rates for the 2-, 10-, and 100-year discharges. Determination of the WQCV drawdown period is addressed in Section 7.2.3.

Figure 7-2 shows a sample outlet structure detail of an extended dry detention basin without a micropool. The water quality and water quantity controls are included in the same structure located in the basin embankment. The WQCV is controlled by a v-notch weir located at the bottom of the detention basin. The weir top corresponds to the WQCV level shown on Figure 7-2. The 2-year peak flow rate is controlled by the v-notch weir and transverse weir that extends on each side of the v-notch weir. The 10-year peak flow rate is controlled by the overflow grate in the same structure. This grate should be designed to be removable and normally kept locked. The 100-year peak flow rate is controlled by the spillway in the basin embankment. Outlet control structures are generally located in the embankment for ease of access, maintenance, and aesthetic reasons.

Maintenance considerations for outlet structure design are described in Section 8.3.4.1 of the Drainage Criteria Manual. The following recommendations are provided to reduce the potential for clogging:

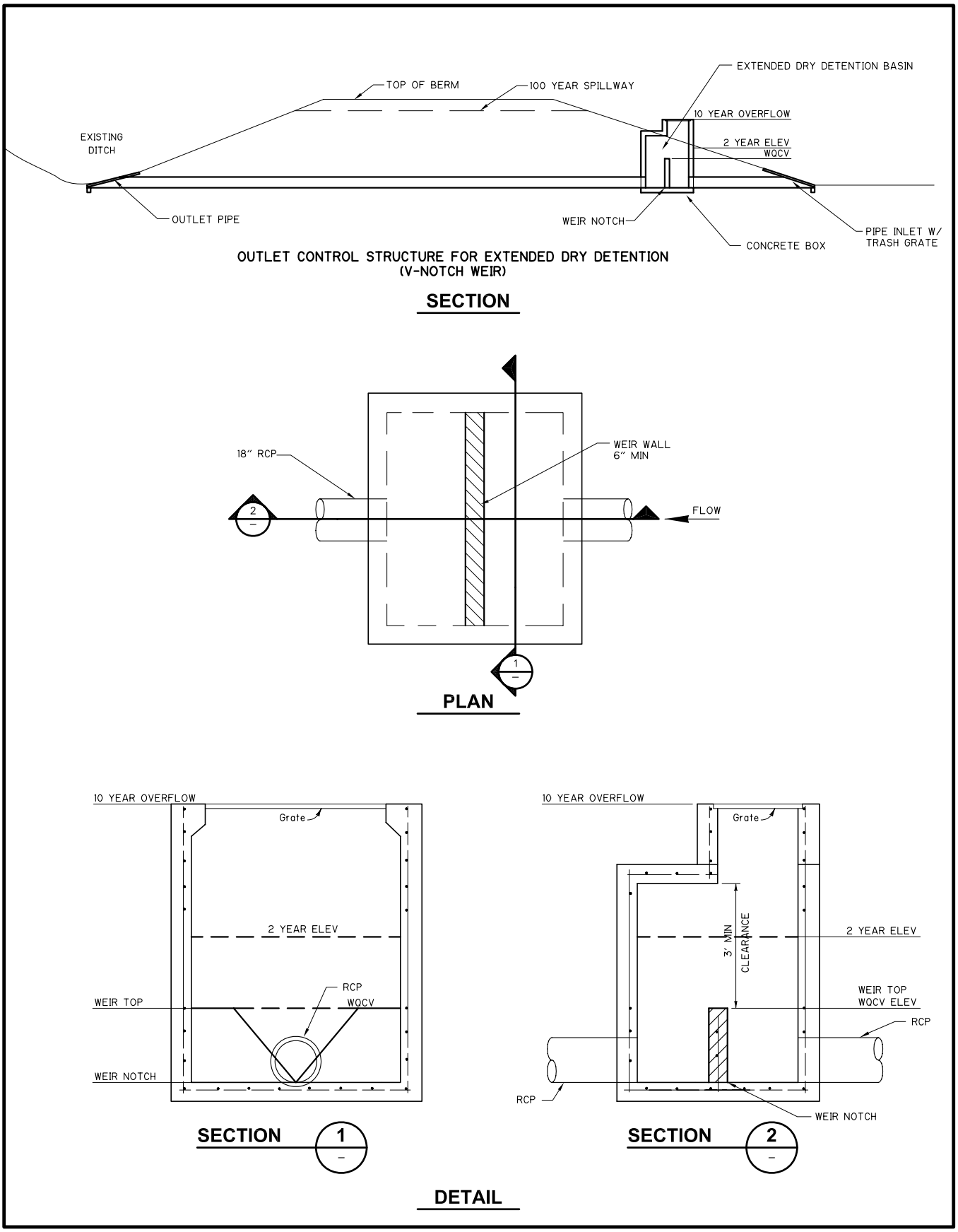


Figure 7-2
Outlet Structure Details
Extended Dry Detention Basin

CDM

- Single orifice outlets should not have an equivalent diameter less than 4 inches.
- As stated in Section 6.4.5 of the Drainage Criteria Manual, slotted riser pipes are discouraged due to clogging problems. If slotted riser pipes are used for the WQCV (Figure 8-2 of the Drainage Criteria Manual), a filter fabric is recommended rather than packed sand and gravel.
- V-notch weir outlets should not have a weir angle less than 15 degrees.
- A trash rack or other acceptable means should be incorporated to protect the outlet structure.

Integration of Recreational Amenities

The preferred design of an extended dry detention basin incorporates amenities that include landscaped features with native vegetation and/or recreational amenities (e.g., athletic fields). Passive recreation features include walking and biking trails, benches, and picnic areas. Surrounding land uses and facility access should be considered when choosing the type of recreational facility. Walking trails with benches and picnic tables work well in office park settings, while athletic fields are well suited in residential areas that can be safely accessed by children.

7.2.2 Extended Wet Detention Basin

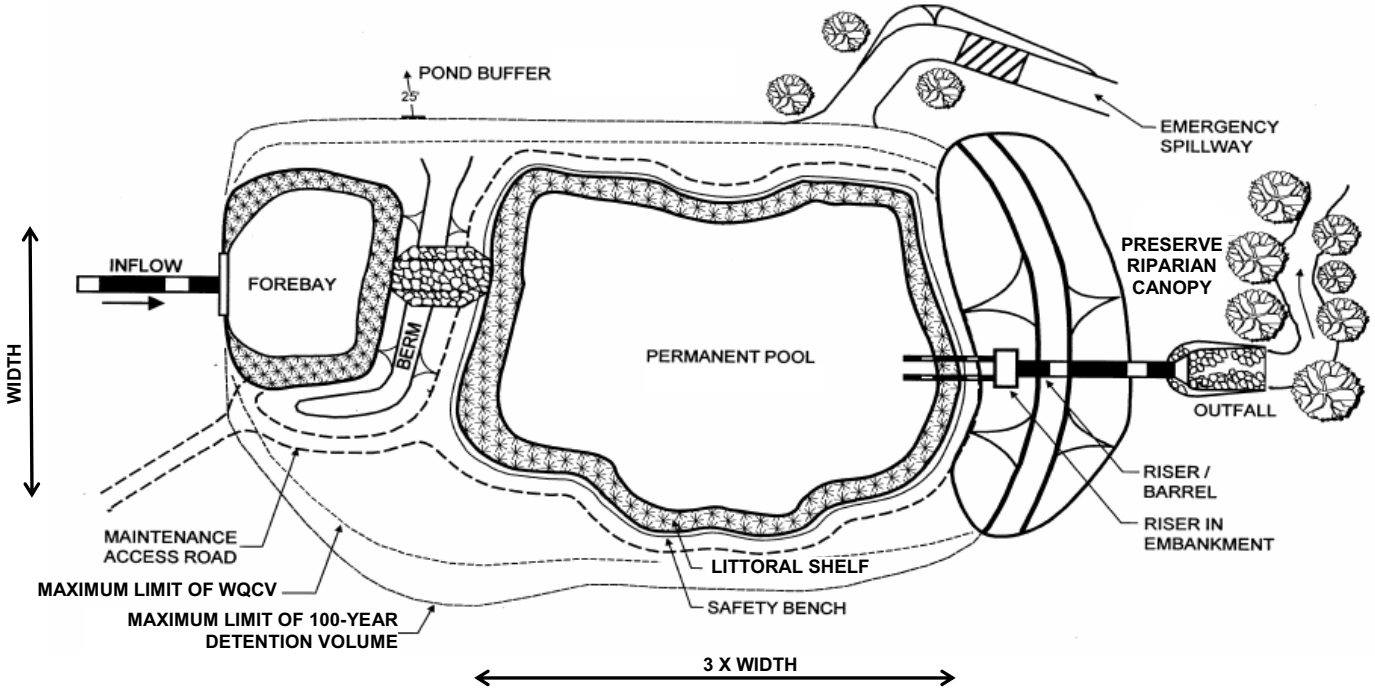
Figure 7-3 shows a schematic plan and profile view of an extended wet detention basin (adapted from Figure 3-3 of the *Maryland Stormwater Design Manual*, Maryland Dept of the Environment, 2000). The profile view shows the various volume components listed in Table 7-1 including the water levels corresponding to the WQCV, 2-, 10-, and 100-year design storm events.

The advantages of extended wet versus extended dry detention basins include:

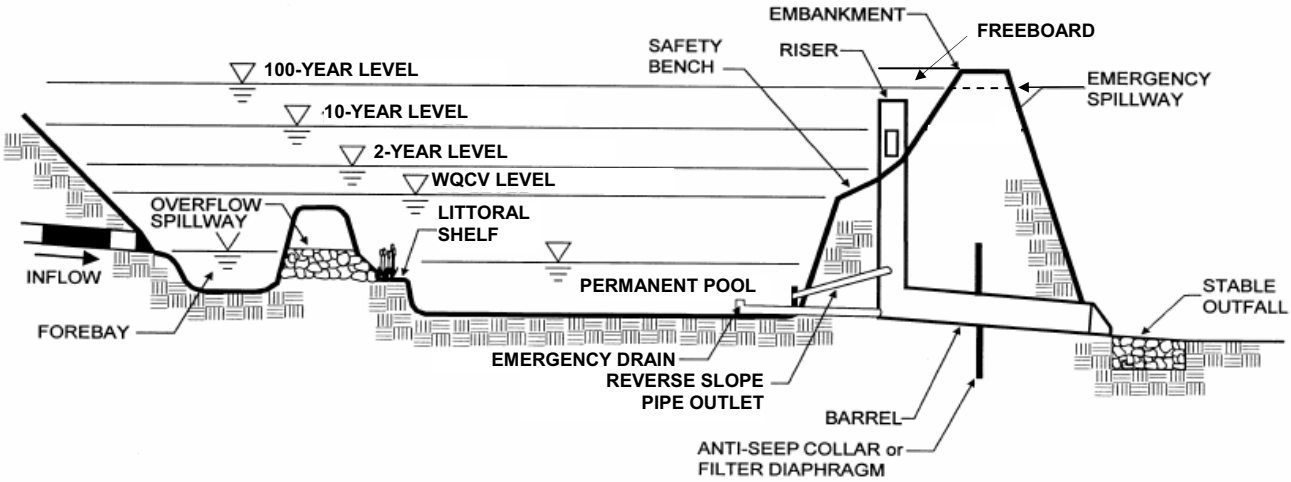
- Generally they are more aesthetically pleasing and considered more of an amenity, as well as providing more opportunities for wildlife and aquatic habitats.
- Higher pollutant removal efficiency through enhanced sedimentation, filtration, and biological uptake.
- Resuspension of settled material is less likely.

The disadvantages of extended wet versus extended dry detention basins include:

- Although they are more attractive since sediment and debris accumulation are generally hidden from public view within the permanent pool, maintaining the permanent pool and controlling algae growth can result in higher maintenance.
- Higher potential safety risks due to open impoundments.
- Recreational amenities such as athletic fields are better suited for dry basins.



Plan



Profile

Figure 7-3
Schematic of an Extended Wet Detention Basin
(Adapted from Maryland Department of Environment, 2000)

Design Features

The performance of extended wet detention basins can be maximized by addressing key design features including the sediment forebay, length-to-width ratio, permanent pool, littoral zone, and storage volume.

Sediment Forebay

Section 7.2.1 describes sediment forebay design considerations for extended dry detention basins. The same considerations apply for forebays in extended wet detention. For wet basins, the forebay helps to reduce the frequency of dredging the larger permanent pool.

Length-to-Width Ratio

Similar to extended dry detention basins, increasing the length-to-width ratio for wet facilities will increase the water quality treatment by providing additional detention time for settling, infiltration, and biological uptake. The minimum length-to-width ratio of 3:1 specified in the City's Drainage Criteria Manual is appropriate, though it should be noted that higher ratios are preferred for extended wet detention basins. Section 7.2.1 provides recommendations on ways to increase the length-to-width ratio.

Side Slopes

Side slopes above the permanent pool should be 6:1, and can be 4:1 below the littoral zone to maximize permanent pool volumes where needed. Slopes steeper than 3:1 will be susceptible to erosion.

Permanent Pool

The permanent pool provides a holding volume between runoff events for continued settling of particulate contaminants and nutrient uptake by aquatic plants. As discussed in Section 6.11.2 of the City's Drainage Criteria Manual, water budget calculations are required for all permanent pool stormwater facilities to demonstrate that a permanent pool will be achieved given the average annual site hydrologic conditions. If the permanent pool cannot be maintained under normal conditions, infiltration losses in the permanent pool can be minimized using various methods, including compaction, incorporating clay into the base materials, and installing an impermeable liner.

There are a variety of methods for determining the design volume of the permanent pool. Sizing criteria have been developed based on solids settling and nutrient removal mechanisms. Due to limited empirical evidence to support these designs, a simplified method of three to five times the WQCV is suggested (Table 7-1). The permanent pool depth should be between 5 to 10 feet, which is consistent with City's Drainage Criteria Manual guidance.

Littoral Zone

An aquatic and safety bench around the perimeter of the basin is called the littoral zone. Incorporating rooted vegetation in this bench serves several functions, including:

- Enhanced removal of dissolved pollutants
- Bank erosion protection
- Reduced formation of floating algal mats

- Reduced drowning hazard
- Enhanced habitat for insects, aquatic life, and wetland wildlife

The littoral zone should be gently sloped (i.e., maximum 6 (horizontal):1 (vertical) side slopes) below the permanent pool elevation to provide a littoral shelf and safety bench around the perimeter of the basin. The littoral zone should extend 2 feet below the permanent pool elevation, which equates to a 12-foot wide littoral shelf around the perimeter of the facility. In general, the littoral zone vegetation should occupy 20 to 30 percent of the permanent pool surface.

Storage Volume
The storage volume for an extended wet detention facility includes the WQCV and flood control volume to control the 2-, 10-, and 100-year peak flow rates. The storage volume is provided above the permanent pool elevation. Chapter 6 of the City's Drainage Criteria Manual describes the calculations required to determine the storage required for the flood control volume. Section 7.2.3 of this report describes various approaches for calculating the WQCV. A portion of the WQCV can be included in the sediment forebay.

As is the case with extended dry detention, stacking of the flood control volume on top of the WQCV is not recommended. However, an additional volume equal to 20 percent of the WQCV should be included in the overall storage volume for the entire facility to account for sediment deposition. In addition, the WQCV level should generally not exceed 18 inches above the permanent pool unless the littoral zone vegetation is sufficiently hardy to withstand prolonged inundation.

Vegetation
Wetland vegetation should be planted or seeded along the littoral zone. Plant species should vary along the side slopes according to the expected flooding duration between the normal water level and the maximum elevation associated with the WQCV.

Embankment areas above the WQCV elevation should be planted with native grasses and wildflowers to provide aesthetic benefits. Native grasses typically have a more robust root structure than turf grasses and reduce erosion along the banks. Trees or shrubs should not be planted along the embankment.

Outlet Control Structure

The outlet structure for the extended wet detention basin includes both water quality and water quantity controls. The release rate requirements for the 2-, 10-, and 100-year return intervals are described in Section 6.4.2 of the City's Drainage Criteria Manual, while the WQCV release rate is discussed in Section 7.2.3. The main types of outlet structures include:

- Single orifice. In extended wet detention basins, the orifice can be located at the permanent pool elevation. The drawdown example in Section 7.2.3 uses a single orifice.
- Riser with perforated holes. This allows a relatively uniform bleed down and should be designed according to the criteria in Section 8.4.3.2 of the Drainage Criteria Manual.
- V-notch weir. The v-notch weir equation is given in Section 6.7.4 of the Drainage Criteria Manual.

Figure 7-4 shows a sample outlet structure detail of an extended wet detention basin. The water quality and water quantity controls are included in the same structure located in the basin embankment. The WQCV is controlled by a v-notch weir located at the permanent pool elevation. The weir top corresponds to the WQCV level shown on Figure 7-4. The 2-year design water level is located above this and is controlled by the v-notch weir and the transverse weir that extends on each side of the v-notch weir. The 10-year peak flow rate is controlled by the overflow grate in the same structure. This grate should be designed to be removable and normally kept locked. The 100-year peak flow rate is controlled by the spillway in the basin embankment.

Many of the maintenance considerations for extended wet detention design are the same as those for extended dry detention as described in Section 7.2.1. Other maintenance considerations include:

- A manually operated valve can be added to the outlet structure to prevent basin discharge in case of an accidental spill upstream.
- A manually operated emergency drain can be added to the outlet structure to allow for the drawdown of the permanent pool for dredging, harvesting of the vegetation, maintenance if the primary outlet becomes clogged, and for cold weather operations (i.e., empty or reduced permanent pool elevation during winter).
- A submerged, reverse-slope pipe water quality control structure can be designed to reduce clogging potential. Such outlets draw water from below the permanent pool elevation and are therefore less likely to be clogged by floating debris.

Mosquito Control Design Considerations

Mosquito populations associated with stormwater facilities can be controlled using the proper design concepts.

- **Basin Geometry** - Using the proper basin geometry as previously discussed, flow through systems will be provided to encourage distributed flow with no standing water, which will prevent stagnant zones that are susceptible to mosquito breeding.
- **Promote Desirable Biology** - Incorporating the proper littoral zone width will provide habitat for mosquito predators. In addition, the littoral shelf provides a shallow depth that surrounds the basin making the facility safer for children. If the permanent pool is large enough, carp or macroinvertebrate population can be stocked to assist in consuming the mosquito larvae.
- **Perimeter Lining** - A concrete or brick curb lining along the perimeter of the pond will eliminate the soggy zone near the pond's edge, which will eliminate potential breeding areas for mosquitoes. In addition, the curb lining will minimize erosion along the edge of the pond.

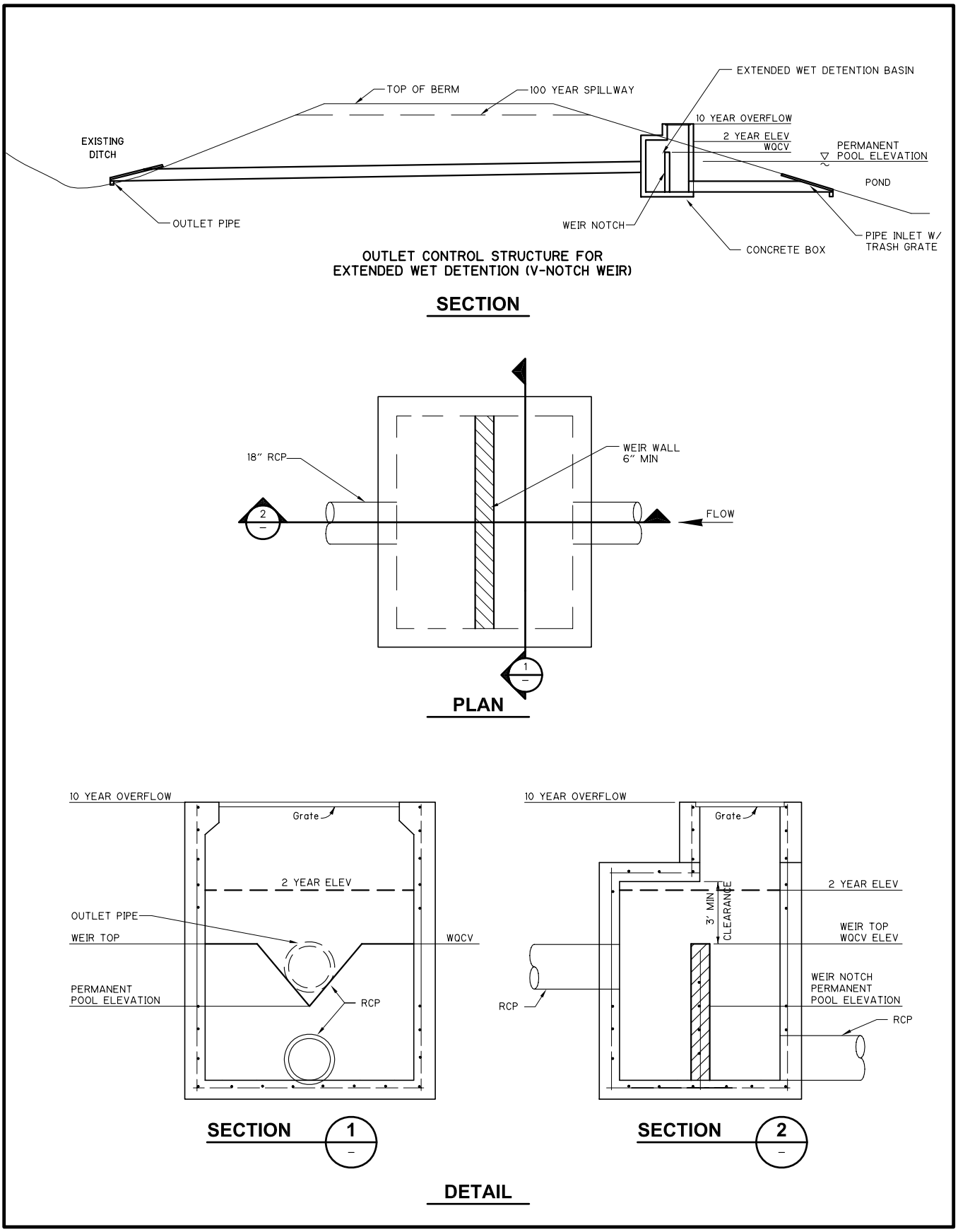


Figure 7-4
Outlet Structure Details
Extended Wet Detention Basin

CDM

7.2.3 Water Quality Control Volume

There are a variety of methods for determining the WQCV storage requirements. The WQCV is generally defined as the volume of water that is retained and slowly released to remove pollutants and reduce erosion. The optimum methods consider the local long-term rainfall characteristics as well as the land use characteristics of the contributing drainage area to the facility.

The City's Drainage Criteria Manual Section 8.1.1 references the first flush approach for estimating the WQCV storage requirements. However, recent research suggests that the first flush concept does not sufficiently address the control of pollutants over the long term (WEF/ASCE 1998). Using a percent capture approach better addresses long-term pollutant loading and stream stability since it considers the full range of runoff events, including those that are smaller than and greater than the first flush runoff volume. In addition, percent capture approaches account for the increase in runoff volume from developments with high impervious areas. By designing for the 90-percent capture volume, the majority of runoff volume and pollutants will be captured, and long-term stream stability will be achieved. This section compares three commonly used methods, including:

- First flush approach (City Drainage Criteria Manual)
- Percentage capture approach
- Percentage capture with drawdown and interevent times

These three approaches are discussed in detail below.

Approach 1 - First Flush

The first flush approach is based on the assumption that the majority of pollutants that have accumulated between rain events are washed off during the first 0.5 inches of runoff. This approach applies to all development sites regardless of the type of land use. Thus, if a facility is designed using this approach, particularly in areas with high impervious surfaces, it will not adequately treat for water quality or protect streams from erosion.

This approach to calculating the WQCV is easily used by developers to determine the volume of the water quality control portion of the stormwater pond. The WQCV is determined by multiplying 0.5 inches by the tributary area to determine a volume. The 0.5 inches is applied broadly over the entire tributary area regardless of percent imperviousness. This approach does not require a larger volume of runoff to be treated for high density developments, nor does it provide incentives to developers to construct low impact developments with open spaces. In addition, this approach does not account for basin drawdown times or small interevent times. The interevent time is the period of no precipitation between rainstorms.

Using Approach 1, the WQCV for a 100-acre development would be calculated as follows:

WQCV = 0.5 in x 100 acres x 1 foot/12 inches = **4.2 acre-feet**

Because this method does not account for the percentage of impervious area, the WQCV for a 100-acre residential, commercial, or industrial site would all equal 4.2 acre-feet.

Approach 2 - Percentage Capture

The percent capture approach is based on capturing a certain percentage (90 percent recommended) of the average annual runoff volume. For example, using a 90 percent capture criteria, the WQCV is equal to the storage required to capture and treat approximately 90 percent of the average annual stormwater runoff volume. To determine the WQCV, the 90 percent storm event is based on all 24-hour storms on an annual basis using historical precipitation records. Using the 20 years of precipitation data available at the Havelock USGS rain gauge, the 90 percent rainfall depth was determined to be 1.3 inches.

Once the 90 percent rainfall is estimated, the resulting runoff volume is calculated based on the percent imperviousness of the contributing area to the stormwater facility. The equation below is used to calculate the WQCV using the 90 percent storm event.

WQCV = P* Rv (Clayton and Schueler 1996)

P = 90 percent storm event (1.3 inches for Lincoln, Nebraska)

Rv = Volumetric Runoff Coefficient (0.05+0.009*I)

I = Percent Imperviousness

The advantage to this approach is that the basin size relates directly to the amount of impervious area in the contributing drainage area. This provides an incentive for developers to reduce imperviousness and provide green space. However, it does not account for loss of basin storage volume due to long draindown times coupled with short interevent times. For example, if the average interevent time is less than or equal to the WQCV drawdown time, then the basin is not allowed to empty before the next storm occurs. Therefore, in geographic areas where this commonly occurs, the drawdown and interevent time should be considered when calculating the WQCV.

Using Approach 2, the WQCV for a 100-acre residential development with 38 percent imperviousness would be calculated as follows:

Rv = 0.05+0.009*38 = 0.392

WQCV (inches) = P*Rv = 1.3*0.392 = 0.51 inches

WQCV (acre-feet) = 0.51 in x 100 acres x 1 foot/12 inches = **4.2 acre-feet**

Using this same approach for a 100-acre commercial development with 79 percent imperviousness, the WQCVs would be calculated as follows:

Rv = 0.05+0.009*79 = 0.761

WQCV (inches) = P*Rv = 1.3*0.761 = 0.99 inches

WQCV (acre-feet) = 0.99 in x 100 acres x 1 foot/12 inches = **8.3 acre-feet**

Approach 3 - Percentage Capture with Drawdown and Interevent Times
Incorporating the drawdown time and interevent time into the WQCV calculation provides the most comprehensive approach to determining the necessary WQCV. One of the easiest ways to do this is to use modeling software to produce WQCV look-up curves.

WQCV look up curves are generated using historical precipitation data, tributary area percent imperviousness or runoff coefficient, an estimated WQCV, and required drawdown time. Figure 7-5 shows WQCV look up curves that were generated for the City of Lincoln using software developed by CDM called NetSTORM and historical precipitation data from the Havelock USGS gauge. NetSTORM incorporates the calculation procedures that are included in the USACE's STORM program. The curves were developed for a 40-hour drawdown. The look-up curves provide a simple method of determining the WQCV based on projected land use.

Using Approach 3, the WQCV for a 100-acre residential development with a C value of 0.4 would be calculated as follows:

WQCV (inches) for 90 percent capture from Figure 7-5 = 0.50 inches

WQCV (acre-feet) = 0.50 in x 100 acres x 1 foot/12 inches = **4.2 acre-feet**

Using this same approach, the WQCV for a 100-acre commercial development with C value of 0.80 would be calculated as follows:

WQCV (inches) for 90 percent capture from Figure 7-5 = 0.98 inches

WQCV (acre-feet) = 0.98 in x 100 acres x 1 foot/12 inches = **8.2 acre-feet**

Approach Comparison and Recommendation
In summary, Table 7-2 compares the WQCV calculated using the three approaches for residential and commercial development sites. For residential developments, the results provide the same answers. However, WQCVs increase significantly for higher density developments (commercial) when using a 90 percent capture calculation (Approach 2 and 3) compared to the first flush approach. Comparing the results from Approach 2 and 3 shows that the interevent time did not reduce annual storage capacity of basins with a drawdown of 40 hours.

Table 7-2
Comparison of WQCV Calculation Approaches

Approach	WQCV (acre-feet)	
	Residential	Commercial
Approach 1 - First Flush	4.2	4.2
Approach 2 - 90 Percent Capture	4.2	8.3
Approach 3 - 90 Percent Capture w/40-hr Drawdown	4.2	8.2

The project team recommends the City adopt Approach 2 for calculating the WQCV for structural BMPs. This approach can be easily implemented by developers and City staff. In addition, it provides incentive for developers to limit impervious area.

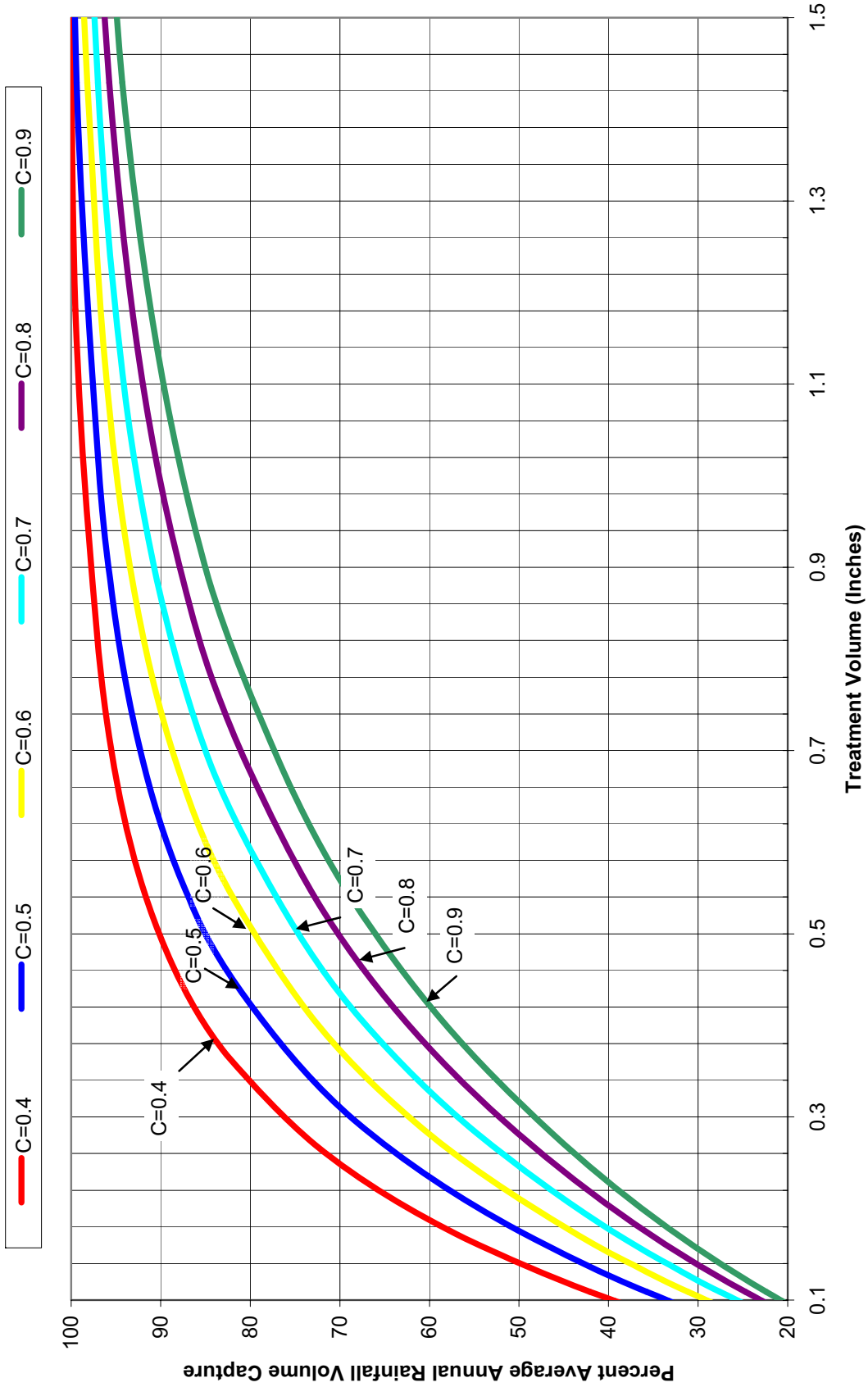


Figure 7-5
Lincoln, Nebraska
Average Annual Rainfall Volume Capture

Drawdown Calculations

Section 6.1.4 of the Drainage Criteria Manual requires all storage facilities to be analyzed using reservoir routing calculations, either performed manually or using HEC-HMS. Section 6.9 of the Drainage Criteria Manual provides a procedure and examples of storage routing calculations for 2- and 10-year storm events. To incorporate the water quality benefits in storage facility design, a 40-hour drawdown of the WQCV should be provided. Below are examples of calculating the drawdown time for a depth of water equal to the WQCV using an orifice outlet structure. Both a manual calculation and HEC-HMS example are provided.

Manual Calculations of the WQCV Drawdown

The first step in calculating the drawdown for the WQCV is determining the depth in the basin at which the WQCV is satisfied (or the WQC depth). This WQC depth can be determined by estimating storage volume in the basin at incremental depths using topographic maps and preliminary grading plans, and interpolating the depth associated with the WQCV. Once the WQC depth is determined, the procedure outlined in Drainage Criteria Manual Section 6.9 can be used to determine the drawdown time.

Step 1 - Choose an appropriate routing time step (the example uses 0.1 hours).

Step 2 - Set up the stage-storage-discharge table. The discharge column (Q) should be calculated using the appropriate equation for the hydraulic control of the WQCV.

Step 3 - Set up the storage routing table for the WQCV. The inflow hydrograph is 0 cfs for all time steps, and the starting depth is the WQC depth.

Step 4 - Continue with routing calculations until Q=0. The time step associated with Q=0 is the drawdown time.

Step 5 - Modify the outlet structure (Q column in the stage-storage-discharge table) or the storage volume and WQC depth until the time step at which Q=0 is 40 hours.

Appendix G located in Volume II of this report provides example calculations to determine WQCV drawdown using the method above.

HEC-HMS Calculations for WQCV Drawdown

The following steps can be used to determine WQCV drawdown in HEC-HMS. The same basin parameters as used in the manual routing example are used for this example.

Step 1 - Set up a new basin model that contains only one reservoir element. Do NOT include a Subbasin in the same basin model.

Step 2 - Populate the reservoir element with stage-storage-discharge data or stage-storage data and an outlet structure. Set the initial elevation equal to the WQC depth.

Step 3 - Set up a new meteorological model and choose the “No Precipitation” method.

Step 4 - Set up new control specifications and make certain the runtime extends beyond 40 hours.

Summary

Figure 7-6 shows that the results from the HEC-HMS model and the manual calculations closely match. The manual calculations are greatly simplified by the use of a spreadsheet.

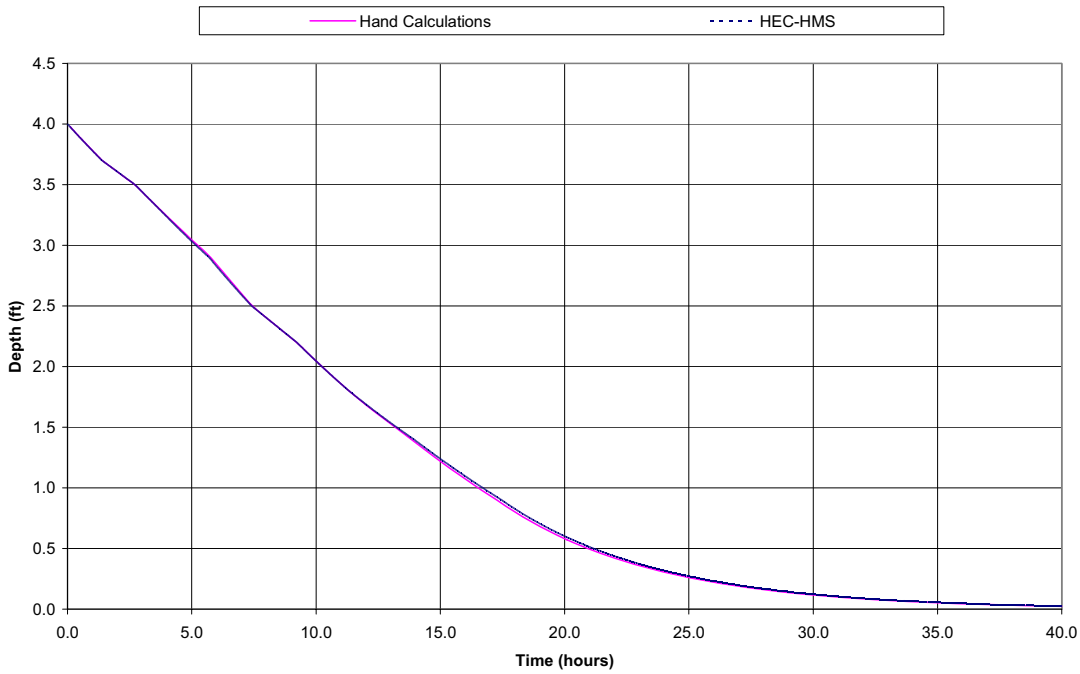


Figure 7-6
Example WQCVs Drawdown

7.3 Alternative Design Approaches

The design approach described above combines the water quantity (2-, 10-, and 100-year controls) requirements with the water quality component (structural BMP) into a single integrated facility. This integrated approach is one of many design concepts that can be employed to achieve the desired results. When revised design standards are drafted, all low cost options providing the same or greater water quality benefits should be considered and included as options for the developer. The following paragraphs provide other alternative design approaches that can be implemented to achieve the same overall goals and objectives.

As discussed above, the purpose of the structural BMP is to treat the WQCV using a 40-hour release time. To accomplish this goal, the structural BMP can be designed to take many different forms, including grass swales and bioretention filters. Figure 7-7 depicts a typical development site that contains a structural BMP separated from the detention basin. In this example, the parking lot and buildings are drained by typical stormwater conveyance components (curb/surface grates/pipeline), which discharge to the grass swale adjacent to the parking lot. For the smaller rainstorms, the stormwater runoff is treated and detained within the grass swale, and slowly released offsite using an outlet structure, such as a v-notch weir, designed to release the WQCV over a 40-hour period. For rainstorms that exceed the WQCV, the stormwater spills into the detention basin via the overflow spillway.

Figure 7-8 illustrates another alternative design using the same site layout. In this example, bioretention filters (landscape swales) are used within the parking lot to provide water quality benefits. For the smaller rainstorms, the runoff infiltrates into a natural soil media, and eventually drains into a perforated pipeline system. The pipeline transports the runoff to a flow splitter box that contains two outlet pipes. The pipeline that drains directly to the stream is sized only to convey the WQCV. All excess flow is diverted to the detention basin. For the rainstorms that exceed the WQCV, standpipes located within the bioretention filters act as overflow structures that transport the larger rainstorms to the pipeline system. The flow splitter box then directs the higher flows to the detention basin.

There are numerous other variations to the concepts presented on Figures 7-7 and 7-8, which allows the site designer the flexibility for achieving both water quantity and water quality benefits. In considering other alternatives, the following two key design concepts need to be followed: The structural BMP must be placed upstream of the detention basin to properly regulate the smaller rainstorms and provide water quality treatment. Outlet control structures need to be designed for both the structural BMP and the detention basin.

One of the key advantages of separating the structural BMP from the detention basin is the ability to enhance the usability of the facility. Using the approaches described above, the detention basin bottom only becomes saturated for storms greater than the water quality storm, which equates to a rainfall depth of approximately 1.3 inches. This allows the basin to be dry for prolonged periods of time, allowing the facility to be used for passive recreation and doubling as a parkland dedication area in some cases. In addition, the structural BMPs can be designed with landscape features, especially within bioretention filers, adding aesthetic value to the site.

7.4 Facility Ownership and Maintenance

Stormwater facilities, including both structural BMPs and storage facilities, must be regularly inspected and properly maintained to meet their expected level of performance. In addition to achieving their design functions, the proper maintenance of facilities can extend their design life and possibly reduce the costs of repairs and rehabilitation in the future.

The clear identification of ownership responsibility is critical for ensuring proper maintenance. Section 6.1.6 of the Drainage Criteria Manual describes ownership and maintenance requirements of storage facilities:

> *Storage facilities proposed in a development, along with all inlet and outlet structures and/or channels, are to be owned and maintained by the developer or a property-owners' association unless a different ownership/maintenance arrangement has been approved by the Director of Public Works and Utilities. Because the downstream storm sewer system will be designed assuming detention storage upstream, a storage facility in the storm sewer system shall remain functional as a storage facility site permanently. Provisions shall be made in the approval of development by the Planning Commission and City Council for the permanence of the storage facilities and ongoing maintenance of the storage facilities.*

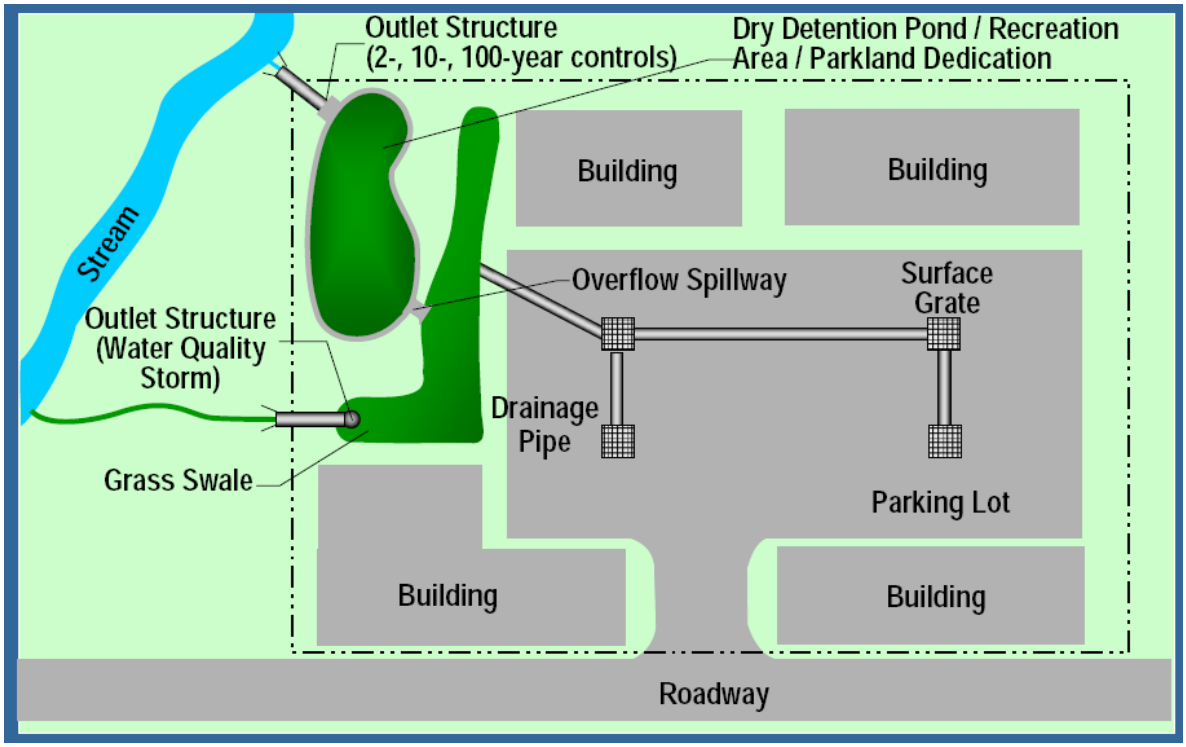


Figure 7-7
Design Alternative No. 1 - Incorporating Structural BMPs and Detention Basins

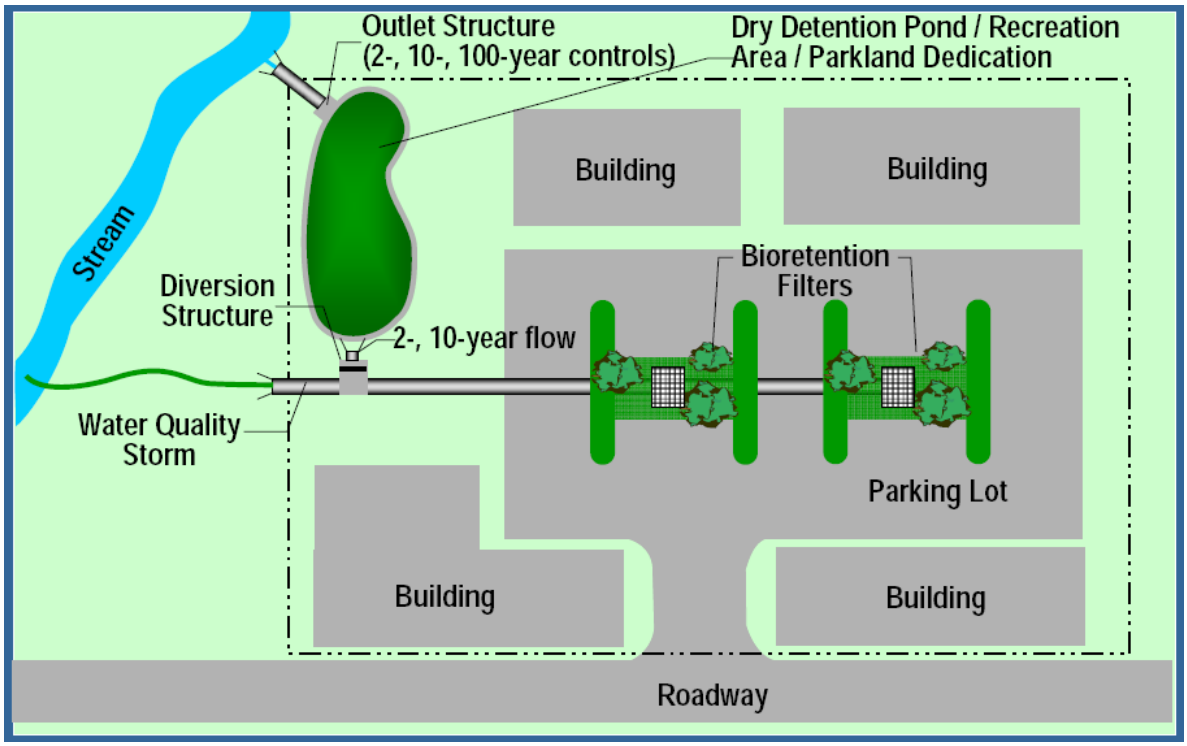


Figure 7-8
Design Alternative No. 2 - Incorporating Structural BMPs and Detention Basins

In addition, the City's NPDES Stormwater Permit, effective September 1, 2002, requires the City to "ensure adequate long-term operation and maintenance of BMPs," which is discussed in Chapter 9 of the Drainage Criteria Manual.

While the Drainage Criteria Manual provides useful information on some of the inspection and maintenance activities required of stormwater facilities, there are areas of the manual that can be strengthened to ensure that the facilities function as designed. For example, maintenance ordinances and formal maintenance agreements with the facility owner would enforce maintenance activities. In addition, a maintenance plan that outlines specific work activities should be submitted as part of the approval process. The maintenance plan would also include inspection and maintenance checklists to assist the owner in implementing the maintenance plan.

This section discusses maintenance ordinances and agreements, outlines key components of an effective maintenance plan, and recommends updates to the Drainage Criteria Manual. Design considerations for stormwater facilities that include maintenance are addressed in Section 7.2. Appendix H located in Volume II of this report includes a model maintenance ordinance, example maintenance agreement, and example inspection and maintenance checklists.

7.4.1 Maintenance Requirements

One way to ensure adequate operation and maintenance of stormwater facilities is to adopt higher standards for the design, maintenance, and inspection of facilities. Design standards referenced in the subdivision ordinance can specify inspection frequency, maintenance responsibilities, and recordkeeping procedures to be followed by facility owners. At a minimum, maintenance standards should include the following:

- Identification of the facility owner responsible for long-term maintenance and inspection of the facility
- An inspection and maintenance plan that outlines specific work activities for each type of facility
- Inclusion of the maintenance plan in the subdivision agreement
- Penalties for noncompliance

A model maintenance ordinance from the Stormwater Manager's Resource Center is provided in Appendix H.

7.4.2 Maintenance Agreement

The City currently requires a subdivision agreement between the City and the owner. Through this agreement, the owner (or his successor) is required to maintain the private improvements. Language requiring a stormwater facility maintenance plan should be added to the subdivision agreement to clearly identify who is responsible for proper installation and maintenance of the stormwater facility.

The City should obtain legally binding agreements with property owners stating that the stormwater facilities for the site will not be altered and will be maintained as needed to

achieve their original design intent. Example maintenance agreements from various communities are included in Appendix H.

7.4.3 Maintenance Plan

Maintenance plans for stormwater facilities on private residential, commercial, or industrial development sites should be developed by the facility owner and submitted to the City during the project design approval phase.

The maintenance plan should outline activities to maintain the facility's hydraulic storage and discharge release capacity, vegetative cover, and other connected structural components such as inlets, outlets, and tile lines that are tied to the same stormwater management system. In addition, the facility owners should be held responsible for damage to downstream or nearby property as a result of poorly designed or maintained facilities.

The key items to consider in a maintenance plan include:

- Identification of the facility owner responsible for long-term maintenance and inspection of the facility
- Definition of the specific maintenance and inspection activities to be performed
- Maintenance and inspection checklists and schedules
- Annual report to the City from the facility owner

The paragraphs below identify each of the key components of an effective maintenance plan for various types of stormwater facilities.

Maintenance and Inspection Activities

Maintenance and inspection activities can be divided into routine and as-needed activities. Examples of routine and as-needed activities are discussed in more detail below.

Routine Maintenance and Inspection

Routine or preventative maintenance is performed on a regular basis and includes mowing, debris removal, minor silt/sediment removal, erosion repair, nuisance control, and clearing of vegetation around the outlet control structures to prevent clogging.

At a minimum, routine inspection should be performed on an annual basis with additional inspections of problematic areas following large storm events (e.g., rainfall greater than one inch). Routine inspections can be performed in a systematic manner using the checklists described in this section. For inspections following a major storm, the inspector should visit the site within 2 days after the specified drawdown period to ensure that the outlet control structures are performing properly.

In some cases, inspection and maintenance activities can be combined, such that inspections are arranged to coincide with scheduled maintenance visits to minimize site visits and to ascertain that maintenance activities are performed satisfactorily. At the time of all site inspections, the inspector should check the accumulation of debris and sediment. If applicable, the weir or controlling structure and side slopes of the facility should be checked to ensure that they do not show signs of erosion, settlement, slope failure, or vehicular damage. Vegetated littoral zones should be inspected to ensure that

water level elevations are appropriate to enhance vegetative growth, support desirable aquatic habitats, maintain acceptable survival rates for planted species, and to confirm that vegetative cover is acceptable.

Standing water or soggy conditions within a "dry" stormwater facility can create nuisance conditions for nearby residents. Odors, mosquitoes, weeds, and litter can all be potential problems in stormwater facilities. However, wetland plants established in wet extended detention ponds can harbor birds and predacious insects and fish that serve as a natural check on mosquitoes, and regular maintenance to remove debris and ensure control structure functionality will help control these potential problems.

As-Needed Maintenance
As-needed maintenance includes major silt/sediment removal on a 5- to 10-year cycle, control structure replacement, removal of log jams, or a major harvesting of aquatic vegetation.

Sediment removal is a very important maintenance activity for extended detention ponds because these facilities are designed to primarily remove pollutants by sedimentation. Sediments collect at the bottom of the basin, reducing storage volume and increasing the likelihood of clogging the outlet structure. Sediment deposition should be regularly monitored in the routine inspections, and dry ponds may have to be cleaned out more frequently than wet ponds for aesthetic reasons. The detention facility will generally need sediment removal if greater than 10 percent of the storage is filled with silt. The typical frequency of sediment removal is 5 to 10 years, sometimes even longer if a forebay is incorporated into the design.

Floatables and trash should be cleaned from the sediment forebay on an as-needed basis. Yearly inspections should be performed to determine if sediment needs to be removed from the forebay. The typical frequency of sediment removal is 5-10 years.

Sediments removed from detention ponds, especially in highly urbanized areas, may contain high levels of toxins (e.g., heavy metals and organics). In addition to monitoring sediment deposition rates, core samples from detention ponds every few years could be used to monitor the buildup of pollutants. If bottom sediment concentrations approach levels that would restrict disposal onsite or in local landfills, clean out may be required on a more frequent basis.

Side slopes, emergency spillways, and embankments all may periodically suffer from slumping and erosion. This should not occur often if the soils are properly compacted and vegetated during construction. Regrading and revegetation may be required to correct problems that develop. Areas of erosion and slope failure should be filled and compacted, if necessary, and reseeded (or sodded) as soon as possible. Eroded areas near the inlet or outlet should be revegetated and, if necessary, be filled, compacted, and revegetated or lined with riprap. Damaged side slopes and embankments should be repaired using fill with adequate permeability. Major damage to outlet structures (e.g., cracks, leaks, or failure) should be repaired as soon as possible.

Control structures will eventually deteriorate and must be replaced. Control structures should be inspected at least annually. In the case of exfiltration/infiltration trenches, sand filters, and porous pavement, part or all of the facility may need replacement when the trench, filter, or pavement becomes clogged.

Tables 7-3 through 7-8 provide suggested maintenance activities and frequency for various BMPs to be used by developers and homeowners for maintaining BMPs. These maintenance activities are typically used by the City/NRD during inspections.

Tables 7-3 through 7-5 show suggested maintenance activities and schedules for extended dry detention basins, extended wet detention basins, and constructed wetlands. These types of stormwater facilities can be used for water quality protection and flood control.

Table 7-3
Suggested Maintenance Activities for Extended Dry Detention Basins

Activity	*Schedule*
▪ Note erosion of pond banks or bottom.	Semiannual inspection
▪ Inspect for damage to the embankment. ▪ Monitor for sediment accumulation in the facility and forebay. ▪ Examine to ensure that inlet and outlet/overflow spillway devices are free of debris and are operational. ▪ Inspect fences/accessways for needed repair. ▪ Check for standing water within 72 hours of major storm; remove standing water as necessary to control mosquito populations. Remove and replace any existing media filters that have been exposed to standing water for longer than 72 hours.	Annual inspection and after major storms
▪ Repair undercut or eroded areas. ▪ Manage pesticide and nutrients. ▪ Mow side slopes (frequency is dependent on type of vegetation). ▪ Check for both adequate and undesirable vegetation growth. ▪ Remove litter, debris, and floatables from the sediment forebay. ▪ Inspect for and repair any depressions on the pond bottom.	Monthly
▪ Monitor for presence of mosquito larvae populations.	Weekly during peak seasons
▪ Seed or sod to restore dead or damaged ground cover.	Annual maintenance (as needed)
▪ Remove sediment from the forebay.	5- to 10-year maintenance
▪ Monitor sediment accumulations in the pond, remove sediment when pond volume has been reduced by 10 percent (as determined by depth compared to design depth).	25- to 50-year maintenance

Adapted from: WMI 1997

Table 7-4
Suggested Maintenance Activities for Extended Wet Detention Basins

Activity	*Schedule*
▪ Note erosion of pond banks or bottom ▪ If wetland components are included, inspect for invasive vegetation and remove where possible	Semiannual inspection
▪ Inspect for damage to the embankment ▪ Monitor for sediment accumulation in the facility and forebay ▪ Examine to ensure that inlet and outlet devices are free of debris and are operational ▪ Inspect fences/accessways for needed repair ▪ Inspect principal and emergency spillways	Annual inspection and after major storms
▪ Repair undercut or eroded areas	Maintenance as needed
▪ Manage pesticide and nutrients ▪ Remove debris from inlet, outlet structures ▪ Mow side slopes (frequency is dependent on type of vegetation) ▪ Monitor undesirable vegetative growth ▪ Remove litter, debris, and floatables from the sediment forebay	Monthly maintenance
▪ Monitor for presence of mosquito larvae populations	Weekly during peak seasons
▪ Seed or sod to restore dead or damaged ground cover on upland areas ▪ Manage and harvest wetland plants	Annual maintenance (if needed)
▪ Remove sediment from the forebay	5- to 10-year maintenance
▪ Remove sediment when the pool volume has become reduced significantly or the pond becomes eutrophic	20- to 50-year maintenance

Adapted from: WMI 1997

Table 7-5
Suggested Maintenance Activities for Constructed Wetlands

Activity	*Schedule*
▪ Replace vegetation to maintain 50 percent surface area coverage in wetland plants	One time after the second growing season
▪ Inspect for invasive vegetation and remove where possible	Semiannual inspection
▪ Inspect for, repair damage to embankment and inlet/outlet structures ▪ Monitor for sediment accumulation in the facility and forebay ▪ Examine to ensure that inlet and outlet devices are free of debris and are operational	Annual inspection and after major storms
▪ Repair undercut or eroded areas	Maintenance as needed
▪ Remove debris from inlet, outlet structures ▪ Mow side slopes (frequency is dependent on type of vegetation)	Frequent (3 to 4 times/year) maintenance
▪ Monitor for presence of mosquito larvae population	Weekly during peak seasons
▪ Manage and harvest wetland plants	Annual maintenance (if needed)
▪ Remove sediment from the forebay	5- to 7-year maintenance
▪ Remove sediment when the pool volume has become reduced significantly or the pond becomes eutrophic	20- to 50-year maintenance

Adapted from: WMI 1997

Tables 7-6 through Table 7-8 show suggested maintenance activities and schedules for bioretention areas, vegetated swales, and open channels. These types of stormwater facilities are typically used to provide only water quality benefits.

Table 7-6
Suggested Maintenance Activities for Bioretention Filters

Activity	Schedule
▪ Remulch void areas ▪ Treat diseased trees and shrubs ▪ Mow turf areas	As needed/Monthly
▪ Water plants daily for 2 weeks	At project completion
▪ Inspect soil and repair eroded areas ▪ Remove litter and debris ▪ Check dewater rate after storm	Monthly and after major storms
▪ Remove and replace dead and diseased vegetation	Semiannually
▪ Add mulch ▪ Replace tree stakes and wires ▪ Inspect dams, energy dissipators, sumps, outlets and overflow spillways ▪ Remove sediment when the structure's design depth has been reduced by 20 percent	Annually and after major storms

Source: ETA & Biohabitats 1993 and WMI 1997

Table 7-7
Suggested Maintenance Activities for Vegetated Swales

Activity	Schedule
▪ Inspect pea gravel diaphragm (if applicable) for clogging, correct problem. ▪ Inspect, repair erosion in grass along side slopes and bed. Inspect outlets/overflow spillways (if applicable). Check dams or energy dissipators.	Annual (twice the first year) and after major storms
▪ Rototill or cultivate the surface of the sand/soil bed of dry swales if the swale does not draw down within 48 hours. ▪ Remove sediment buildup within the bottom of the swale once it has accumulated to 25 percent of the original design volume (as determined by design depth). ▪ Debris cleanout.	Monthly or as needed (may be infrequent)
▪ Mow grass to maintain a height of 3 to 4 inches.	As needed (frequent, seasonally)

Source: WMI 1997

Table 7-8
Suggested Maintenance Activities for Open Channels

Activity	Schedule
▪ Mow grass so as not to exceed minimum depth	As needed/Monthly
▪ Remove litter and debris ▪ Inspect, repair areas of erosion ▪ Check for dewatering rate after storms	Monthly and after major storms
▪ Check dams, energy dissipators, outlets, and overflow spillways ▪ Check for areas of excessive sediment deposition	Annually and after major storms

Source: New York State Stormwater Management Design Manual, August 2003

Maintenance and Inspection Checklists

Many communities track routine maintenance and inspections in a systematic manner using checklists. An example inspection and maintenance checklist from the *New York State Stormwater Management Design Manual* is provided in Appendix H of this report. Some communities have found it beneficial to track maintenance activities using an electronic database.

Annual Report from the Facility Owner

Many communities require the facility owner to submit an annual report detailing inspection and maintenance activities of their stormwater facilities. The annual report should include completed inspection and maintenance checklists, scheduled maintenance activities, and future inspection and maintenance schedules.

7.5 Conservation Culvert Design

The installation of new drainage structures should take into account the natural channel configuration at the location of the improvement. Long-term observations of stream channels and structures have shown that natural channels once modified will return to their original size and shape without routine maintenance. Therefore, by accounting for this natural tendency during design, long-term maintenance cost can be reduced.

Typically, natural channels have a two-stage configuration. The first stage handles flows up to the 1.5- to 2-year flood. This stage is typically referred to as the primary channel or flow-way. The second stage handles flows from larger flood events and is better known as the floodway.

Accounting for the natural channel configuration in the design of improvements translates to the construction of nonsymmetrical structures. Using the traditional approach, a culvert designed with three parallel box culverts would be designed around all three culverts being constructed with the same invert, requiring the channel bed to be artificially widened to match the new opening width. Figure 7-9 shows an example of a typical traditional installation. Typically, structures constructed with this approach have siltation problems that either require a significant amount of maintenance and/or significantly reduce the flow capacity of the structure.

This problem can be avoided by accounting for the natural channel configuration in the design. Through this approach, the inverts and shape of parallel culverts would be adjusted to match the shape of the natural channel. The primary culvert would be set at the natural channel invert and any secondary culverts would be set at a higher elevation, matching the flow line of the flood channel. This type of configuration is referred to as a conservation culvert design, which is shown on Figure 7-10. Through applying this design concept, flood flow capacity of the structure can be maintained while reducing the amount of routine maintenance (i.e., pipe cleaning). However, when applying this approach, the engineer should be careful to verify that the flow capacity of the modified design is contained below the peak flood elevation.

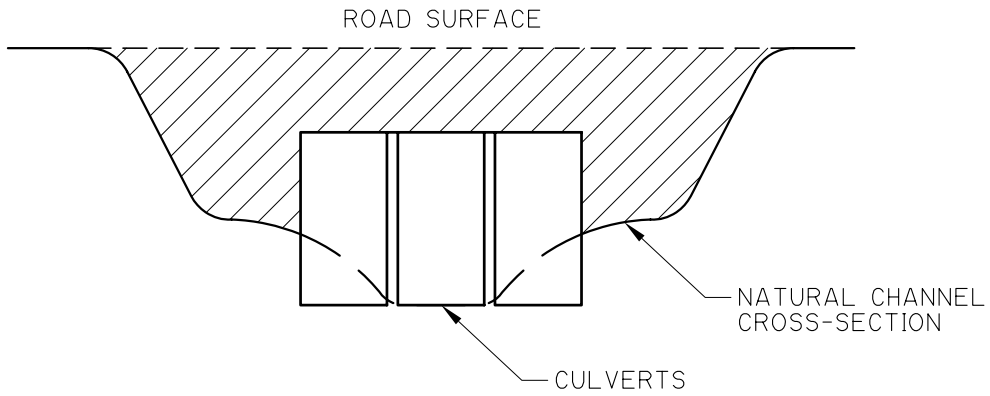


Figure 7-9
Traditional Culvert

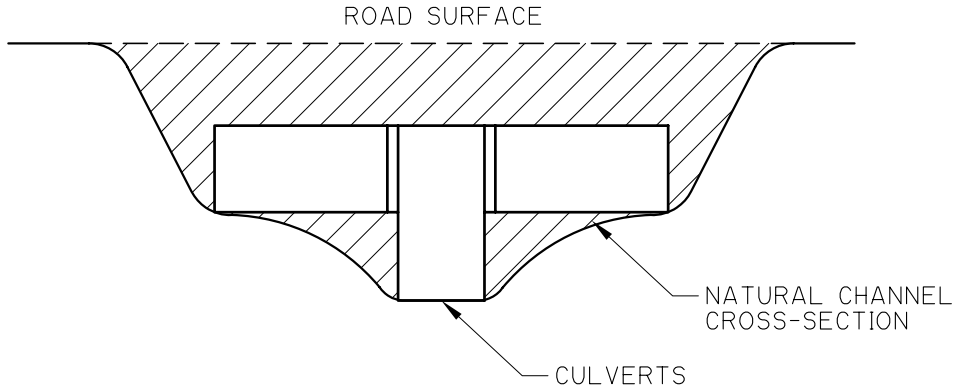


Figure 7-10
Modified Culvert

Section 8
Geomorphic Evaluation

8.1 Fundamentals of Fluvial Geomorphology

Fluvial geomorphology is the science of how moving water shapes the land. It is the fundamental discipline of river science and allows the quantitative description of stream behavior now and reasonable predictions of future behavior under specified conditions. Fluvial geomorphology and the related disciplines of hydrology and hydraulic engineering, geology and soil science together provide the technical underpinnings for sound watershed management. The paragraphs that follow are a brief overview of geomorphic principles with emphasis on their application to stream and watershed management.

8.1.1 Major Models

Streams exist in a state of dynamic equilibrium in which the forces driving channel form are balanced by the resisting forces. The driving force is gravity and acts on the stream as the rate at which water and sediment move through a stream while the resisting forces are the strength of the channel boundary materials and friction expressed as the channel shape. When the driving forces exceed the resisting forces, the stress applied by water or sediment exceeds the channel strength. The stream channel responds by altering its shape in plan, profile and cross section to accommodate the change in flow volume and applied shear. Once disturbed, the processes by which streams respond are: 1) incision or degradation, 2) widening, 3) aggradation or deposition and 4) plan form adjustments. Through these processes, streams eventually re-establish equilibrium. Determining which process is dominant and the likely progression of stream processes is one of the principle challenges of stream management.

While gravity and friction are first principles and drivers of channel form at the most fundamental levels, stream managers grapple with their many manifestations including sediment source, sizes and abundance, varying hydrologic conditions, vegetative influences and a broad range of geological influences. Given the large number of independent variables and the complex relationships between the many dependent variables, it is reasonable to seek robust, relatively straightforward models that organize these variables. In disturbed systems such as Stevens Creek, the chosen approach evaluates each channel process separately then develops an integrated assessment using energy relationships.

Although there are three commonly recognized approaches to stream design, each with advantages and limitations (Skidmore et al. 2001), the two simplest approaches, often called analog and empirical methods, explicitly assume equilibrium conditions regarding hydrology and sediment transport. Because Stevens Creek is not in equilibrium, the analytical approach is used.

Lane's Relationship

In 1955, E. W. Lane expressed the relationships between the driving and resisting forces for channel change in the following simple proportionality. The expression is also illustrated in Figure 8-1.

$$QS\ D50 \propto S\ QW$$

Where QS = Rate of sediment flow
D50 = Median size of mobile particles
S = Slope of the channel bed
QW = Rate of water flow

(Sediment LOAD) x (Sediment SIZE) ∝ (Stream SLOPE) x (Stream DISCHARGE)

(Adapted from Lane, E. W., *The Importance of Fluvial Geomorphology in Hydraulic Engineering*, 1955)

Figure 8-1
Lane's Stable Channel Balance

Here the D_{50} stands as proxy for boundary strength and S for channel shape. From this relationship, it is clear that a change in any of these parameters will, once a threshold is exceeded, induce a change in one or more of the others. The familiar increase in Q_w associated with urban development illustrates this point well. The response to this increase is some combination of the following: a decrease in channel bed slope (incision), an increase in sediment load (increased erosion) and an increase in the median size of mobile particles. When considering all four parameters, these responses often occur in sequence as described below:

- Initial change: $Q_W \uparrow$; response: $Q_S \uparrow$. Often the bed slope remains relatively unchanged at first, so to maintain the proportionality, Q_s increases. The increase in sediment load is generated by down cutting of the channel bed (incision), scour of the streambanks or both. The incision locally steepens the channel slope, compounding the driving force for more erosion. This local steepening of bed slope is called a knickpoint. Knickpoints migrate upstream liberating sediment as they progress. When the

streambanks exceed their critical height, mass failure ensues. This reconfiguring of the channel geometry continues until the equilibrium described by Lane is reestablished.

- Initial change: $Q_W \uparrow$; response: $D_{50} \uparrow$. This condition occurs when there is little sediment initially available in the bed or banks. So, to maintain Lane's proportionality, the size of the median mobile particles increases. Under this condition, rock armor that previously protected a structure becomes mobile as the D_{50} increases. Subsequently, the service life of the infrastructure declines. Moreover, the natural bed armoring aggregate, previously mobile only during less frequent floods, becomes mobile during more frequent events and the underlying, more erosion-prone bed and bank materials are exposed to greater and more frequent erosive force.

- Initial change: $Q_W \uparrow$; response: $S \downarrow$. If the channel bed is relatively resistant to incision, the stream may respond to increased flows by decreasing its slope. The stream accomplishes this decrease in slope by meandering or increasing the channel length over the same change in elevation. The downstream progression of point bars (crescent-shaped sediment deposited on the inside bank of stream bends) opposite the downstream progression of eroding and failing cut banks (steeper outside banks of stream bends) are classic signs of meandering.

- Initial change: $S \uparrow$; response: $Q_S \uparrow$. Increasing channel slope is often accomplished through channel straightening to achieve greater flood conveyance or to optimize land development. This increase in slope causes an increase in sediment load, in mobile D_{50} size or both. Bed and banks erode to generate the sediment that deposits downstream where channel slopes are flatter. The effective change in water surface slope may extend upstream well beyond the actual channel straightening, extending the accelerated erosion. The sediment eroded from upstream of the channelization and deposited downstream counteracts the effect of the channelization and improvements in flood conveyance are often less than anticipated.

Lane's Relationship is useful for broad conceptual understanding of stream behavior. The following models more specifically address stream process.

Channel Evolution – Evaluating Channel Changes in Cross Section

When considering streams from a management perspective, it is especially helpful to note that streams trend toward the equilibrium condition. Schumm (1984) and most recently Simon (1989) have described a process by which streams reacquire equilibrium after a disturbance in the watershed. Simon separates changes in channel morphology into six stages: I) Pre-Disturbance, II) Disturbance, III) Incision, IV) Widening, V) Deposition, and VI) Recovery and Reconstruction. Determining the phase of channel evolution in the various project reaches was an important part of the analysis.

Widening followed by meander advance on the Lower Main Stem of Stevens Creek

At Stage I, the channel is stable and transports the water and sediment delivered to it without significant adjustment. Although not a universal feature, internal floodplains are common in stable streams including those in the Central Midwest. Bankfull floodplains occur at the elevation corresponding to the dominant discharge. The dominant discharge is the flow that, over time, accomplishes the most work on the stream channel. In undisturbed streams, the dominant discharge typically occurs every 1.5 to 2 years. The bankfull floodplain performs a valuable function by lowering the bank shear during higher flows and effectively managing the stream energy.

During Stage II, natural or manmade events disturb the channel. In disturbed systems, the dominant discharge often occurs far more frequently and may not support the development of internal floodplains. Common forms of manipulation include increases in the rate, volume or timing of flow, or direct alteration of channel dimensions or alignment.

Incision arrested by tree roots on Stevens Creek (Tributary 45)

In Stage III, the stream cuts downward, lowering its channel slope to redistribute energy. This incision process migrates upstream. The migrating face of an incision front is referred to as a knickpoint or knickzone. The typical shape of these channels is V- shaped or narrow U-shaped. In soils such as loess, incision may proceed rapidly; migration rates exceeding 1,000 feet/year occur in the Central Midwest. Incision proceeds until the channel has reached a stable slope, the incision reaches a more resistant layer or the streambanks begin failing because of mass wasting.

Channel widening through mass wasting of the streambanks, Stage IV, follows incision. There are two common mechanisms of bank failure. Fluvial action erodes soil away from the toe of the slope resulting in a cantilevered bank, which eventually fails through toppling. Alternatively, the incision cuts deeply enough into the bed that the streambanks exceed their critical height and fail. Both mechanisms may operate in a stream.

The next phase of channel evolution is Stage V, when the channel has sufficiently widened and begun depositing sediment eroded from upstream reaches in the bed. The deposits occur as channel bars and occasionally as internal floodplains.

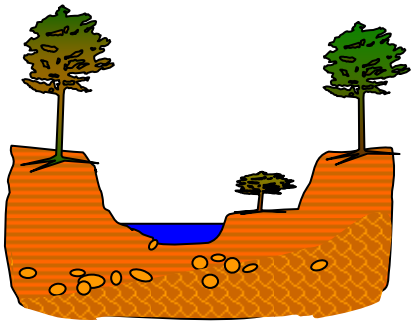
Deposition on Stevens Creek (Tributary 45)

In Stage VI, the channel regains the equilibrium condition and efficiently transports both water and sediment. If a substantial increase in Q_w precipitated the adjustment, final dimensions of the channel will probably be larger than the pre-disturbance condition.

Each of these phases is depicted on Figure 8-2.

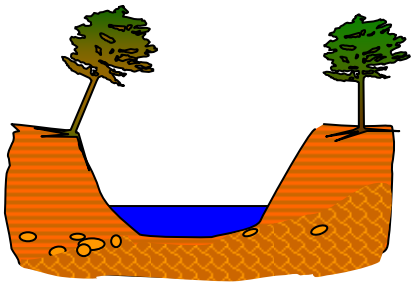
Stage I - Pre-Disturbance

- Bed and bank materials balanced with erosive forces
- Permanent woody vegetation near the water line
- Two-stage channel shape evident at about 1.8 year return interval



Stage II - Disturbance

- Channel altered, hydrology or sediment inputs modified
- Removal of permanent woody vegetation near the water line
- Two-stage channel shape eliminated or no longer supported by flow conditions



Stage III - Incision

- Downcutting liberates sediment
- Lost or perched bankfull floodplains
- "U" shaped channel
- Woody vegetation high on bank with many "surfer" trees

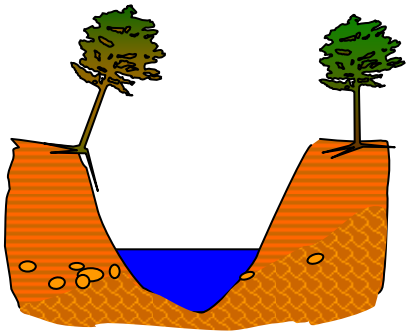
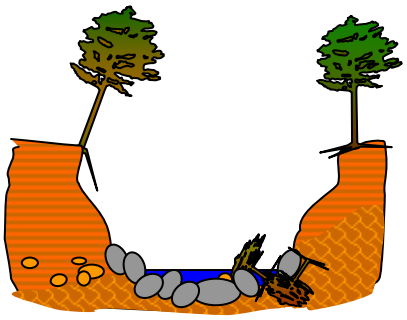


Figure 8-2
Channel Evolution Model (Simon 1989)

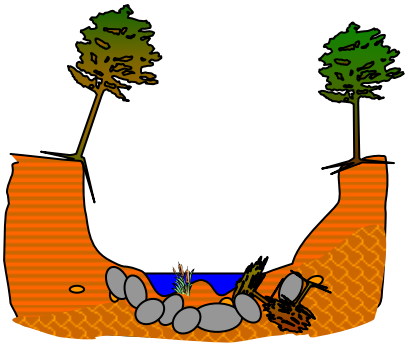
Stage IV - Channel Widening

- Widespread bank failures as banks exceed critical height or were undercut by toe scour
- Channel adjusts to new flow regime
- Significant sediment loads generated; most significant erosion hazard in this phase
- Bank armoring generally ineffective, rocks fall into channel



Stage V - Deposition

- Deposition begins from liberated sediment
- Vegetation establishes near water line



Stage VI - Recovery and Reconstruction

- Bankfull floodplains may be reconstructed from liberated sediment
- Woody vegetation establishes near water line
- Stability re-established

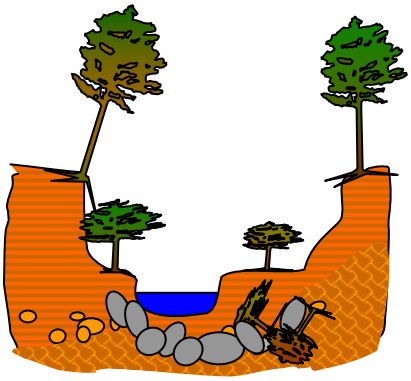


Figure 8-2
Channel Evolution Model (cont.)

Meander Formation and Migration – Evaluating Channel Change in Plan Form

Adjustments in plan form are common and have an important influence on the sustainability of a stormwater system as well as on the safety and service life of near-stream infrastructure. Some plan form adjustments can liberate significant sediment and present major erosion hazards. The management requirements of plan form adjustment differ from those of an incising or widening stream. Consequently, distinguishing between these processes was an important part of the investigation and analysis.

Meander advance on Stevens Creek (Tributary 96)

Straight stream channels are rare and require a narrow set of circumstances to maintain dynamic equilibrium in a natural setting. Like all other open systems, streams adjust their form to minimize the expenditure of energy. The formation of pool-riffle patterns and meanders are consistent with this trend towards maintaining an equilibrium condition. Meanders are complex in both formation and behavior. Meander formation graphically demonstrates the principle of cause and effect in stream mechanics. The cause is the force applied by moving water and sediment and the effect is the shape of stream channel.

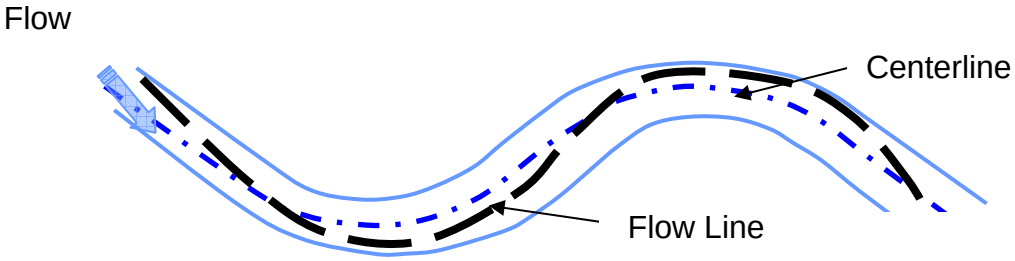


Figure 8-3
Meander Formation and Migration

To describe the basic process of meander formation, the distinction between the meander flow or discharge centerline and the channel centerline is important. As illustrated on Figure 8-3, the channel centerline (effect) lags the discharge flowline (cause). The flow in a stream does not progress in straight lines parallel to the stream channel. Rather the flow is comprised of a primary flow oriented downstream and transverse flows oriented perpendicular to the primary flow. Along the discharge flow path, these inward and outward transverse flows are balanced. However, along the channel flow path, there is considerable asymmetry. Because of the variable turbulence and secondary flow patterns, the flow velocity, sediment transport and boundary shear stress are non-uniform across the channel. These areas of turbulence produce alternating pulses of sediment, scour, and deposition.

Areas of scour and deposition alternate along the axis of discharge flow producing a pool along the outer bend and a corresponding point bar on the inner bend. As the pattern of scour and deposition alternates from one side of the channel to the other, the thalweg (deepest portion of the channel cross section) and maximum flow velocity cross over the center of the channel. These cross-over points become the riffles. The alternating pattern of bar building and bank scour causes straight streams to evolve into meandering ones with a sinuous pattern. Specifically, this is how channelized reaches eventually reacquire a sinuous shape.

Although the process of creating riffles and pools encompasses highly variable processes, the riffles and pools occur at generally predictable intervals. The spacing of these riffles or pools along the thalweg relates closely to the width of the stream at the elevation of dominant discharge. Figure 8-4 illustrates riffle geometry in plan form. Further, the spacing of the pools, which are near the outside bend and slightly downstream of the maximum curvature of the meander, have essentially the same relationship to channel width as the riffles.

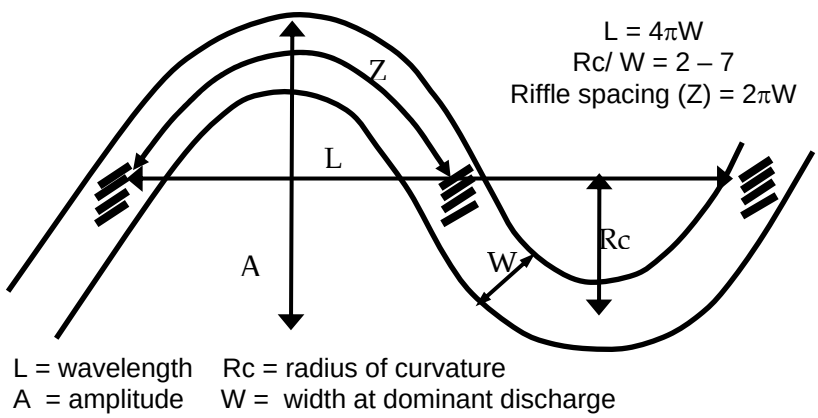


Figure 8-4
Meander Geometry

In alluvial streams of homogeneous material, meanders take the form of sine-generated curves. Leopold and Langbein (1969) demonstrated that this shape is the most hydraulically efficient form for turning water. Further, Chang (1998) presents a more analytical assessment of this meander plan geometry. These relationships between stream width, riffle spacing, meander wavelength and radius of curvature are remarkably consistent for streams and rivers throughout the world.

Most stable relationships in channel geometry include the channel width at the elevation corresponding to the dominant discharge. Riffle spacing (Z) generally occurs every 6.3 bank widths (W) where W is the width at the dominant discharge, this spacing is essentially 2πW. Meander wavelength is approximately 12 bank widths, which approaches 4πW.

The radius of curvature is also related to the channel width at dominant discharge elevation. The ratio of meander radius of curvature (R_c) to channel width (W) generally ranges between 2 and 7. Bagnold's (from Thorne et al. 1997) investigation of energy

losses at bends confirmed the empirical observations by determining that flow energy losses are minimized through this shape. A tighter radius causes a flow separation and severe energy losses, a hydraulic inefficiency that is not persistent. In natural rivers, channel bends erode to an R_c/W ratio from 2 to 5 and then maintain that form, which indicates that the hydraulic efficiency is optimized by this form.

In streams containing heterogeneous media and in confined channels, the meander pattern is interrupted by variations in bank structure, infrastructure, confluences, geologic features, and channel manipulation. Streams out of equilibrium also display distortions in meander pattern and growth. Nevertheless, the fundamental relationships describing these patterns remain broadly applicable.

Consistent with the location of peak stress downstream of each bend apex, meander waveforms migrate downstream. In stable streams, the meander migration generally occurs at a rate that does not affect infrastructure. However, accelerated migration may pose a substantial risk. A rapid increase in sediment load delivered from an incising or widening reach upstream is the most likely trigger for accelerated migration in Stevens Creek.

Profile Analysis

Stevens Creek flows through erodible soils and has a low threshold for incision. A profile analysis reveals reaches where, by virtue of bed slope and material strength, incision is likely. Abrupt changes in channel profile indicate areas where incision is occurring now or where the degradation is arrested by manmade or natural structures. In Stevens Creek debris jams are the most common natural structures restraining the advance of incision. The advancing front of incision is known as a knickpoint or where slope changes are slightly less abrupt, knickzone. It is especially important to identify and manage incision because it usually precedes processes that are more destructive.

Energy Relationships

Other fundamental relationships used to understand stream mechanics are energy, continuity, and loss relationships. Remembering that energy can neither be created nor destroyed, that mass is conserved, and that all dynamic systems have losses, we can calculate flood elevations and erosive stresses.

First, the total energy in a system can be expressed as:

$$E = w + v^2/(2g) + z - L$$

Where:
- E = energy (ft-lb/lb)
- w = work per unit mass
- $v^2/(2g)$ = kinetic energy
- z = potential energy
- L = losses

The total energy at any point is equal to the total energy at any other point and is expressed as:

$$w_1 + v_1^2/(2g) + z_1 = w_2 + v_2^2/(2g) + z_2 - L$$

Additional equations such as continuity[1] and Manning's loss equation[2] allow the designer to calculate the depth and velocity at any point in the system. Energy, continuity, and Manning's equations are the bases for programs such as HEC-RAS. Bringing these concepts together in the context of stream mechanics, work is the movement of sediment by water, kinetic energy is the movement of water, potential energy is the depth of the water, and losses are friction and sound. HEC-RAS does not include a separate calculation of work. The energy exchange of work moving sediment is included by default in losses and kinetic energy.

Some designers consider sediment transport competency for major projects by establishing a sediment budget to analyze sediment movement through the designed intervention. More sophisticated techniques include computer based analyses. For small projects, it is usually difficult to justify a sophisticated model. The designer, however, can achieve a basic understanding of sediment transport competency and erosion hazard from data and analyses used to determine water surface elevations. The designer estimates area of erosion and deposition from the continuity of the stream power or boundary shear stress. Routines in the HEC-RAS model calculate stream power and boundary shear stress. The values of either stream power or boundary shear stress are plotted against the longitudinal profile. The designer compares the zones of highest and lowest values to his field observations of size and distribution of bed material and the location of scour and erosion. The designer then establishes threshold values from these observations. Improved sediment transport competency results from using these threshold values in design. Boundary shear stress is the product of density, depth and slope. The designer predicts areas of scour and erosion by comparing the boundary shear stress to the shear resistance of the bed or bank toe materials. The shear resistance for granular materials is calculated using empirical relationships. The shear resistance for cohesive materials is usually compared to measured or tabulated values.

Lane's proportionality allows the designer to understand and predict the effect of forces on a stream. Energy and continuity equations allow the designer to predict the depth and average velocity at any point. The energy and continuity equations are the bases for understanding the exchange of energy modes. Perhaps the simplest useful way to apply these principles is to think of energy as either kinetic or potential. For the purposes of stormwater, flooding occurs when potential energy is higher than we can accept and accelerated erosion occurs when kinetic energy is higher than we accept.

8.1.2 Temporal and Spatial Implications

The dominant process in a stream reach is influenced by its location in the watershed as shown on Figure 8-5.

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[1] For modeling purposes, the continuity relationship expresses the concept that the quantity of water in any one point in a system is the same as the quantity of water at another point or changes only gradually. At each confluence, hydraulic models are partitioned into discrete reaches.
[2] Manning's loss equation is commonly expressed as $Q = 1.49(R^{2/3}S^{1/2})A/n$

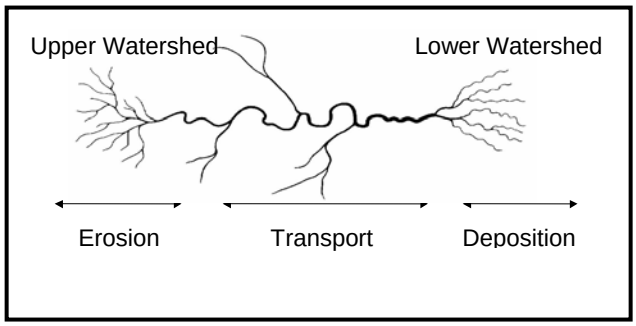

Figure 8-5
Stages of a river system (adapted from Rienick and Singh 1980)

As shown on Figure 8-6, the profile of the channel slope becomes flatter progressing downstream. In the most general sense, incision dominates the steep, upper watershed and plan form adjustments are most common in the relatively flat lower watershed.

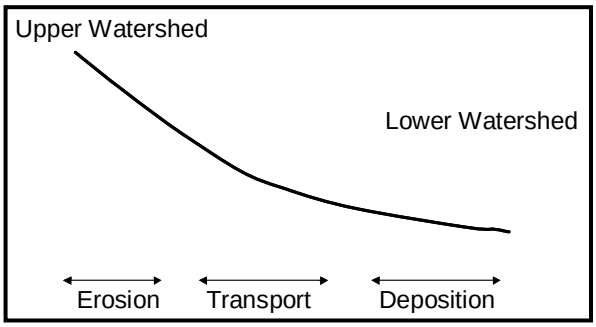

Figure 8-6
General channel profile of a watershed

In disturbed watersheds, this pattern may be reset by infrastructure. For example, a dammed stream can act as the end of a watershed, where sediment and water is deposited in the receiving lake (Figure 8-7). Here the outfall behaves like a spring beginning the next watershed.

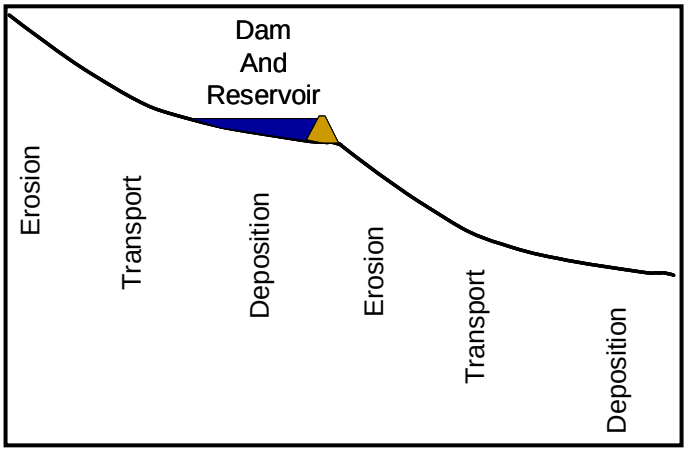

Figure 8-7
Effect of a dam resetting the stream formation sequence

Stream crossings such as bridges and culverts can also reset river formation, as shown on Figure 8-8. In developing areas, the characteristic profile shape of natural watersheds may be repeated after each hard crossing that materially effects transport of water and sediment. These obstructions may geomorphically isolate the reach.

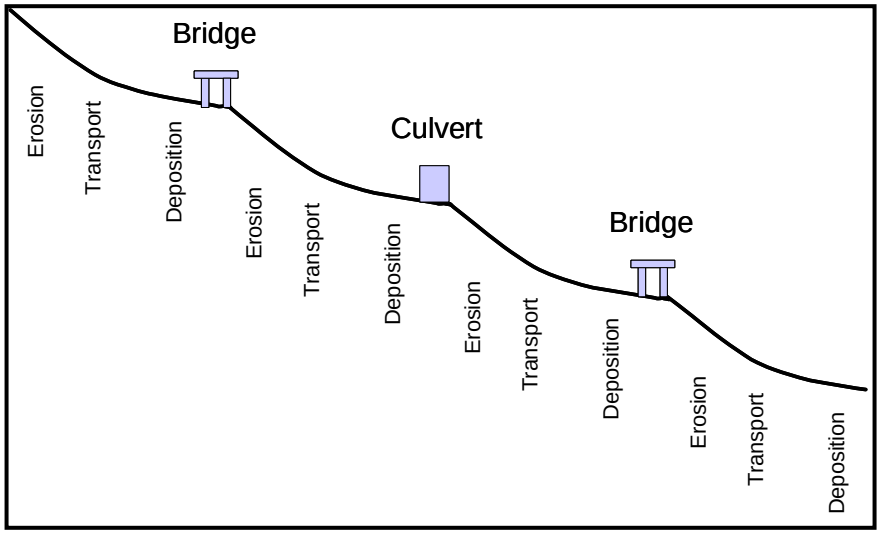

Figure 8-8
Effect of stream crossings resetting the stream formation sequences

8.1.3 Sediment Transport

Natural channels transport both water and sediment through the watershed. Sediment and water movement play parallel roles in flood and erosion control and in the performance of bridges and culverts. For this discussion, sediment includes large woody debris, man-introduced materials, and other debris that comes to rest on the streambed. A stream in dynamic equilibrium maintains the movement of water and sediment without sudden and wholesale areas of erosion and deposition. Flow rate governs both the initiation of sediment movement and its deposition, moving material when the system has sufficient kinetic energy and depositing it when the kinetic energy is depleted. As described earlier, gravity, expressed here as hydraulic slope, is the driving force acting on the system. The movement of water transfers that force to dislodge and keep particles moving. Figure 8-9 is a generic hydrograph and sedigraph relating the rate of flow to time. Note that there is a lag between the flow of water and the movement of sediment ($t_{s\,i}$). The lag represents the flow necessary to exceed the critical shear stress as described in Section 6.5. At the peak water flow there is often a decrease in the transport of sediment as the hydraulic slope decreases. The falling leg of the hygrograph may coincide with the peak of the sedigraph with the particles already mobile and an increase in hydraulic slope.

As the flow recedes and kinetic energy declines, the stream deposits particles of decreasing particle size. This process forms the riffles between pools. In Stevens Creek, this is most apparent where the woody debris jams morphologically behave as riffles.

Issues of sediment transport are particularly relevant to stream managers at infrastructure crossings. Bridge, culvert, and pipeline crossings may interrupt the hydraulic slope with predictable, adverse consequences. A crossing backwatered under high flow conditions decreases the hydraulic slope and may induce deposition that reduces flow capacity. Over-widened or excessively smooth crossings increase hydraulic slope and induce scour. The scour may occur immediately downstream and undermine the structure or may, as the result of an upstream drawdown curve, induce incision. This incision migrates upstream until the stream reaches a stable bed slope.

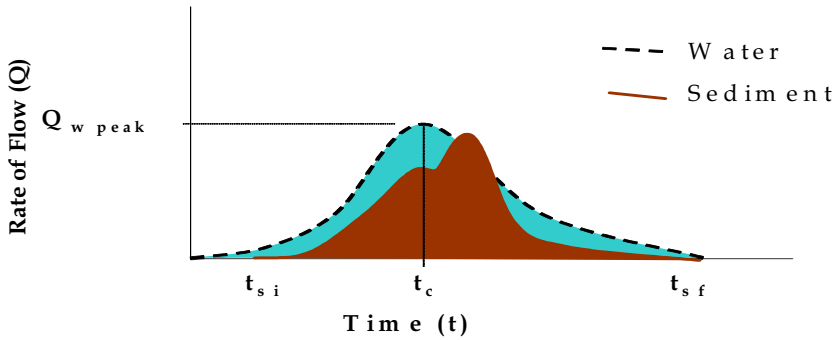

Figure 8-9
Hydrograph and Sedigraph

Management activities that remove or add material to the stream also interrupt equilibrium sediment transport and may have similarly adverse consequences. Snagging, straightening, and widening a channel all disrupt the sediment balance. These and similar activities induce upstream erosion and eventual deposition at the site of disturbance. Undesigned bank armor such as dumped riprap or waste concrete disrupts sediment transport when it migrates into the bed. These large, rough particles induce deposition where they enter the bed but induce scour downstream. Dumping materials on the bed can also reset the pool and riffle sequence if the dumped material becomes the hardest point in the reach.

8.2 Stevens Creek Evaluation

The stream stability analysis included an extensive background and field investigation to document the key geomorphic characteristics of the main channel and tributaries. This included walking 81 miles of stream to assess, record, and photograph the condition of the streambed, streambank, riparian vegetation and to assess the overall stability of the stream. Details of the geomorphic field investigation are presented in Section 2.5.2.

Generally, the field investigation revealed widespread instability. The instability most commonly occurs as incision, a downward cutting of the channel, migrating upstream from the lower main stem and extending through the tributaries. The bed and bank materials are relatively weak and are responsive to increased stress. Streambank failures are common in all parts of the watershed. The bank failures are usually a consequence of the incision. The absence of a vigorous woody corridor protecting the streambanks increases the frequency and severity of bank failures.

8.2.1 Channel Geometry

Stevens Creek was evaluated in plan, cross section, and profile. Detailed information regarding individual reaches is provided in Volume II, Appendix I, Stream Reach Descriptions.

Plan Form

Evaluating the shape of the watershed in plan form provides insight on whether and how parts of the basin differ from one another. For example, subbasins with a greater degree of geologic control, higher density of tributaries, or more severe degrees of channel manipulation may require different management approaches than the remaining subbasins. The drainage basin analysis was conducted in accordance with the method described by Lueder (1959). Consistent with the regional geology, the drainage network analysis indicates relatively high erodibility and low permeability. The angle at which the tributaries intersect each other and intersect the main stem suggests manipulation, most likely channel relocation along farm field lines.

Outside of the highly altered southern third, there are no major differences from one subbasin to the next. The minor differences include a slightly higher tributary density and higher tributary sinuosity east of the main stem relative to the west. The differences are within the range one might expect to be associated with the greater degree of urbanization on the west side and do not imply a need for different management methods based on subbasin location.

Meander geometry evaluation revealed that, at the broadest levels, the basic ratios of radius of curvature to width (Rc/w) and wavelength to width (λ/w) fall within the reported values as indicated on Figures 8-10 and 8-11. In analyzing the data, the ratio of radius of curvature to width is higher than the normal boundary for some of the eastern tributaries in the 5- to 10-foot width class. Similarly, the drainage network density is greater on the eastern tributaries indicating that these soils may be weaker and more erodible, therefore unable to hold a tighter radius as shown on Figure 8-12.

The wavelengths appear slightly longer relative to channel width than is typical, particularly on the lower main stem (Figure 8-13). This may accurately reflect the channel conditions or may be an artifact of using the aerial two-foot contour to determine width.

Eighty-one per cent of the radius of curvature to width ratios falls within published norms (Nanson and Hickin 1983). Areas that are substantially outside the norm were noted on the GIS layer and field evaluation focused on determining why the anomalous data occurs. No specific differences were observed during the field work. Geometry outside the norm does not necessarily imply instability either now or in the future. Especially tight or flat curves may simply indicate a vegetative or geologic control or the presence of a stabilized manmade structure.

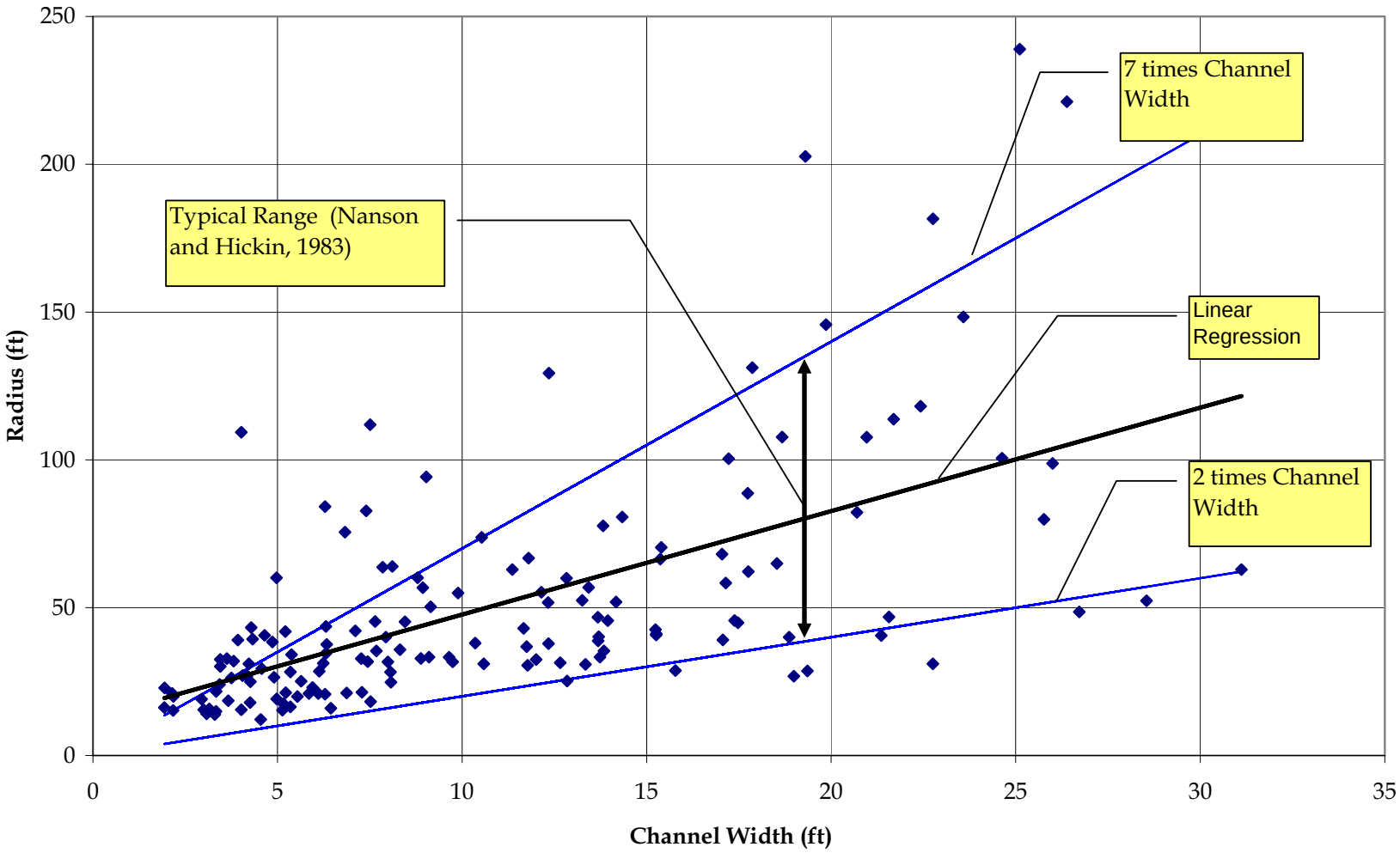

Figure 8-10
Width versus Radius

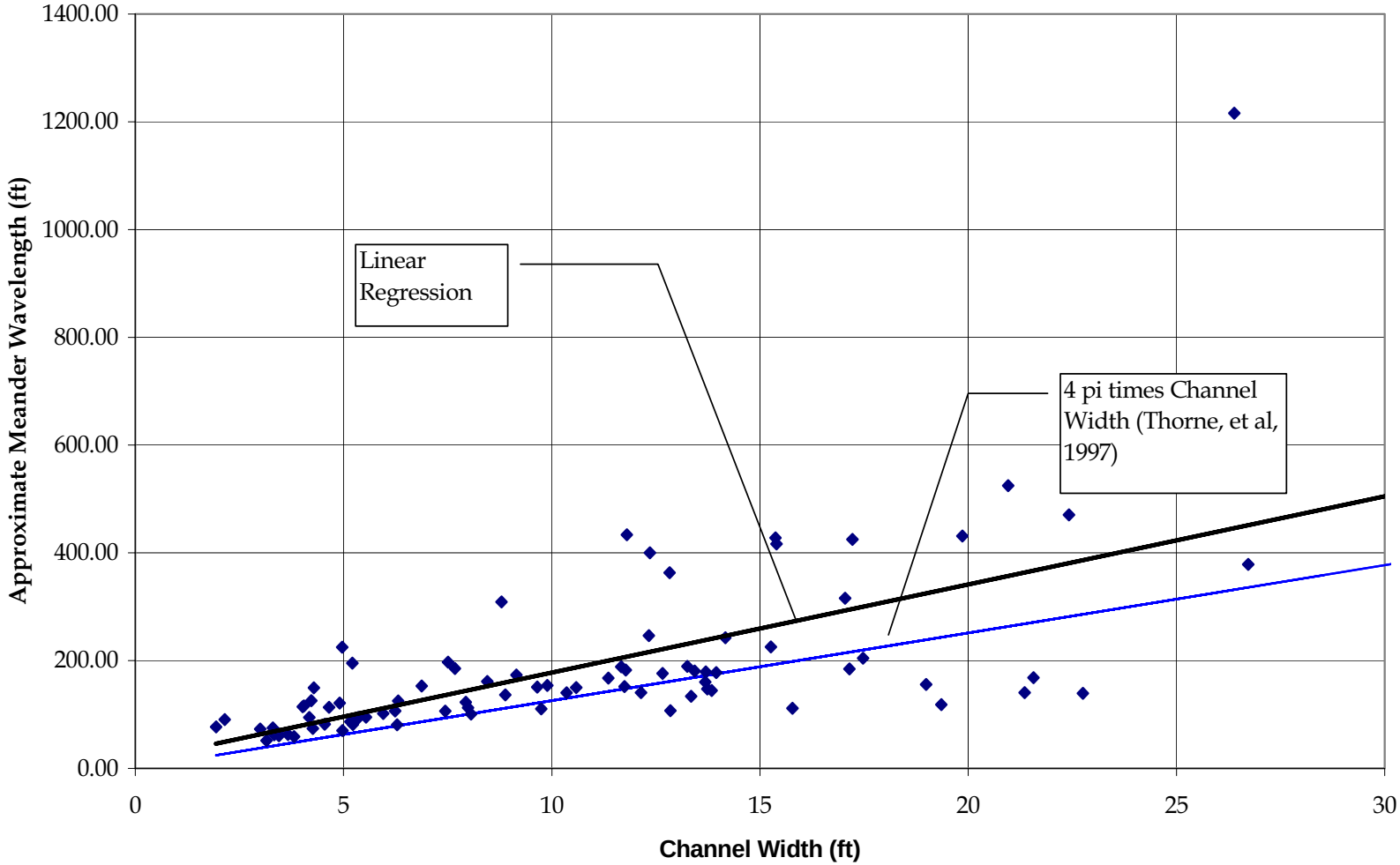

Figure 8-11
Width versus Meander Wavelength

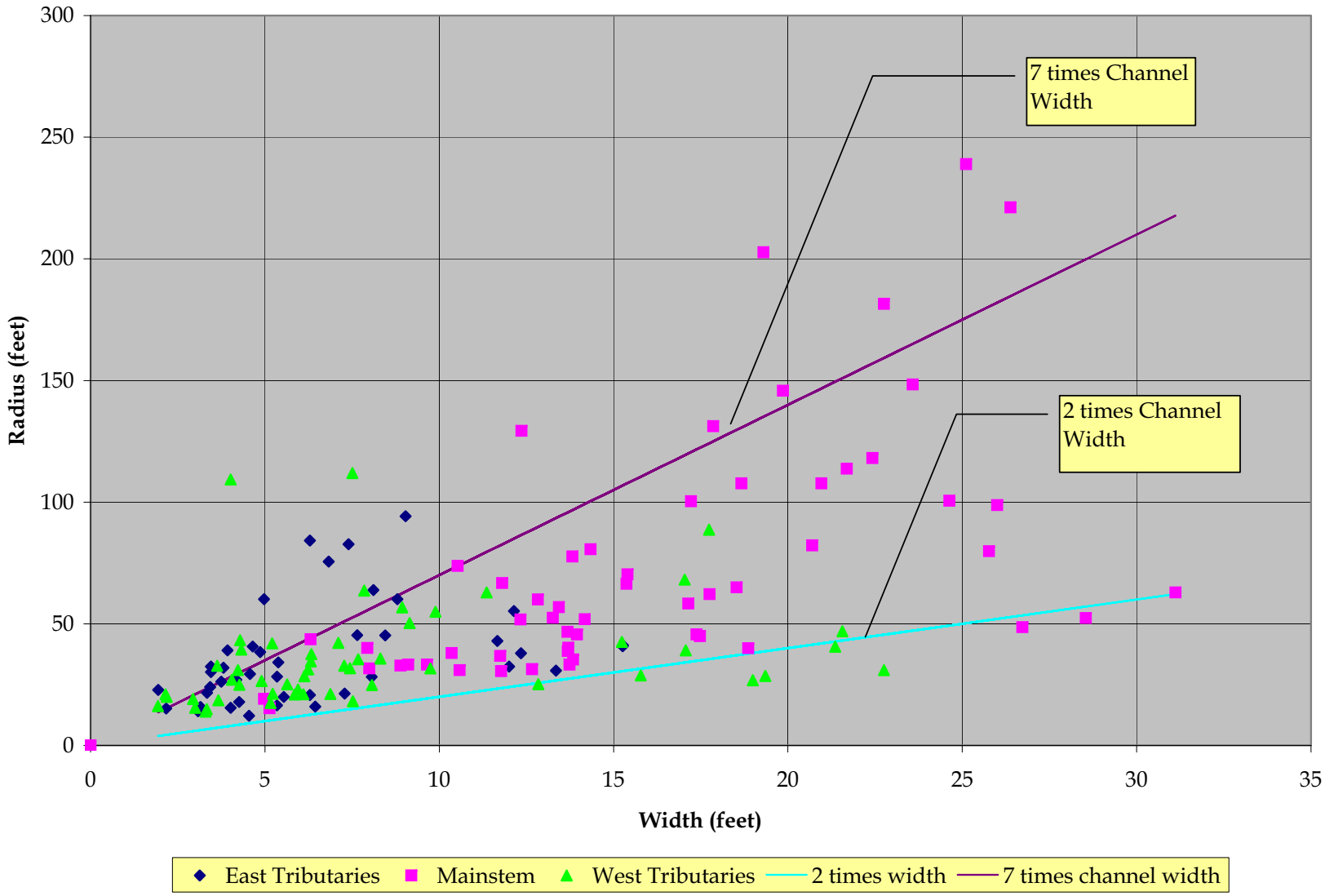

Figure 8-12
Radius versus Width by Location

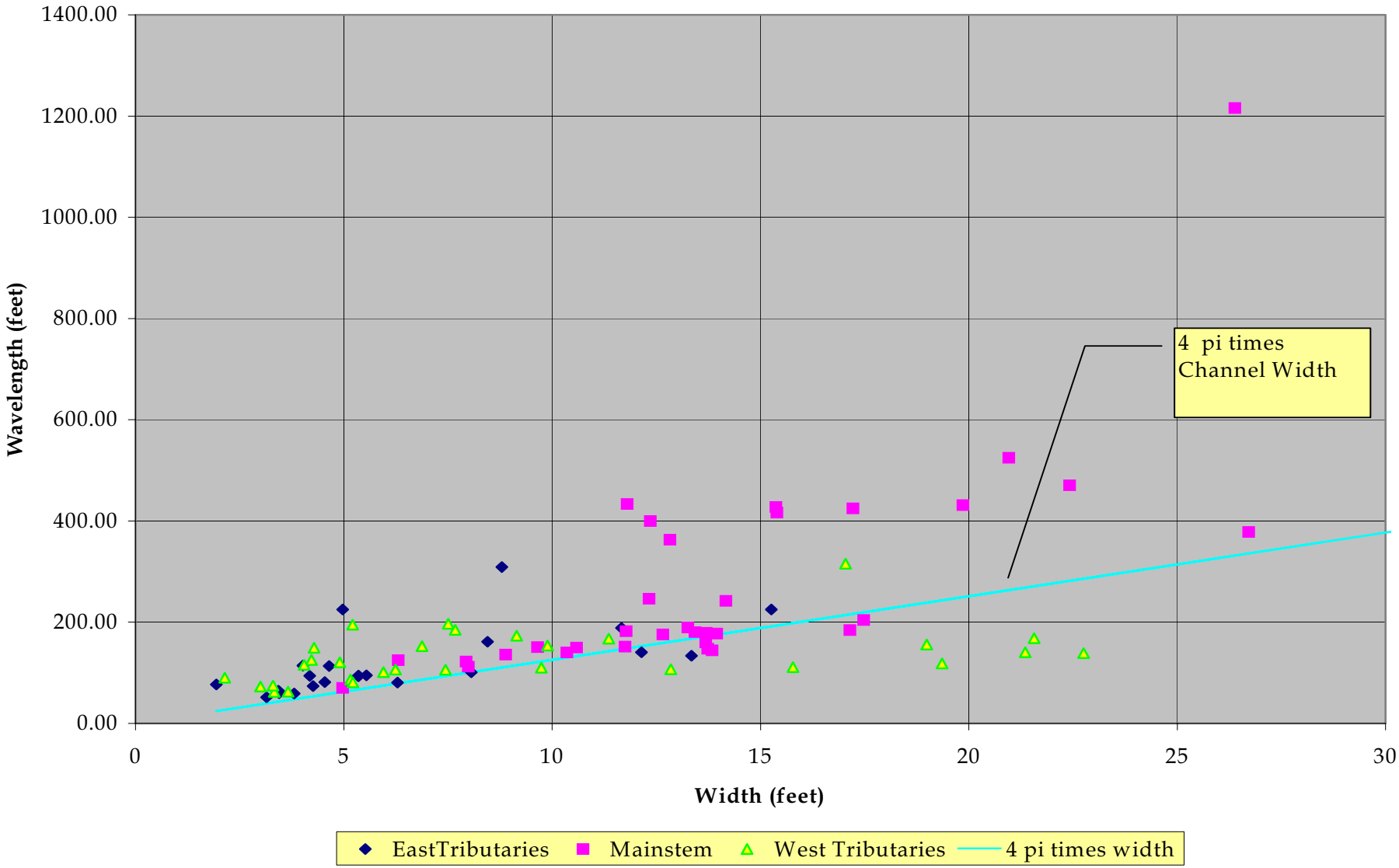

Figure 8-13
Wavelength versus Width by Location

Cross Section

The cross sectional shape of a stream channel indicates the stage of channel evolution. When integrated with plan and profile indicators such as bar building or knickpoints, cross section data are used to determine the dominant channel process. No one data set is adequate to diagnose channel process, the foundation of stream management, but analyzed in the aggregate, it is possible to build a defensible case. Figure 8-14 illustrates the point. Here channel bed profile, the 2-year water surface elevation, and breaks in bank slope are plotted together. The breaks in bank slope used in this analysis are generally at the lowest elevation of an abrupt flattening of the slope. In many stable streams, the lowest break in bank slope occurs at a consistent elevation corresponding to the dominant discharge, roughly the 1.8-year return interval. The field investigation revealed very few bankfull features at any elevation. Those few features identified as potential bankfull floodplains occurred at elevations between 1.5 and 5 feet above channel bed, well below the major breaks in slope now dominating the channel cross section. In Figure 8-14 it is clear that the lowest consistent breaks in bank slope are substantially lower than the 2-year elevation. This finding is consistent with Section 6.5, which demonstrated the increased frequency of dominant discharge.

Figure 8-14 also includes two lines representing the average bed elevation and the average elevation of breaks in bank slope. There are four reaches where the section break occurs below the average for the main stem. The lower three of these are areas of channel widening as determined from analysis of the hydraulic and field data. This follows since for lower flows the water surface level will drop in wider reaches as compared to narrower reaches.

The cross-sectional data is useful in developing Bank Stability Charts for the watershed. The plot of bank angle versus bank height is a Bank Stability Chart. Bank stability is the relationship between bank height, angle, material, and saturation level. A Bank Stability Chart can be a powerful planning tool. Just because a bank is steep and bare of vegetation does not necessarily mean that it is unstable and that a landslide might occur after the next major flow event. Simple measurements of height and angle and observation of groundwater and other conditions can be checked against the chart to assist in determining the probability of a bank failing as a result of a landslide.

The method for creating bank stability charts and their application is explained in Chapters 7 and 8 of *Stream Corridor Restoration, 1998* [3]. The method entails recording the heights, angles, and groundwater conditions of both failed and intact slopes throughout the watershed. A parametric analysis is performed using slope stability software such as ARS Bank Stability Model, Static Version 2.1. (USDA 2002). In the analysis, the limits between stable, meta-stable, and unstable are confirmed by calculation. Meta-stable is the condition of eminent failure where changing any one of the conditions could result in a landslide. For the Stevens Creek analysis, the default values for silt and a simple model of one layer of silt and a planar slope were used. In the parametric analysis the water table was varied to match conditions observed in the field.

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[3] Stream Corridor Restoration, Principles, Processes, and Practices, The Federal Interagency Stream Restoration Working Group, National Technical Information Services (NTIS), November 1998, PB 98-502487, ISBN-0-934213-60-7

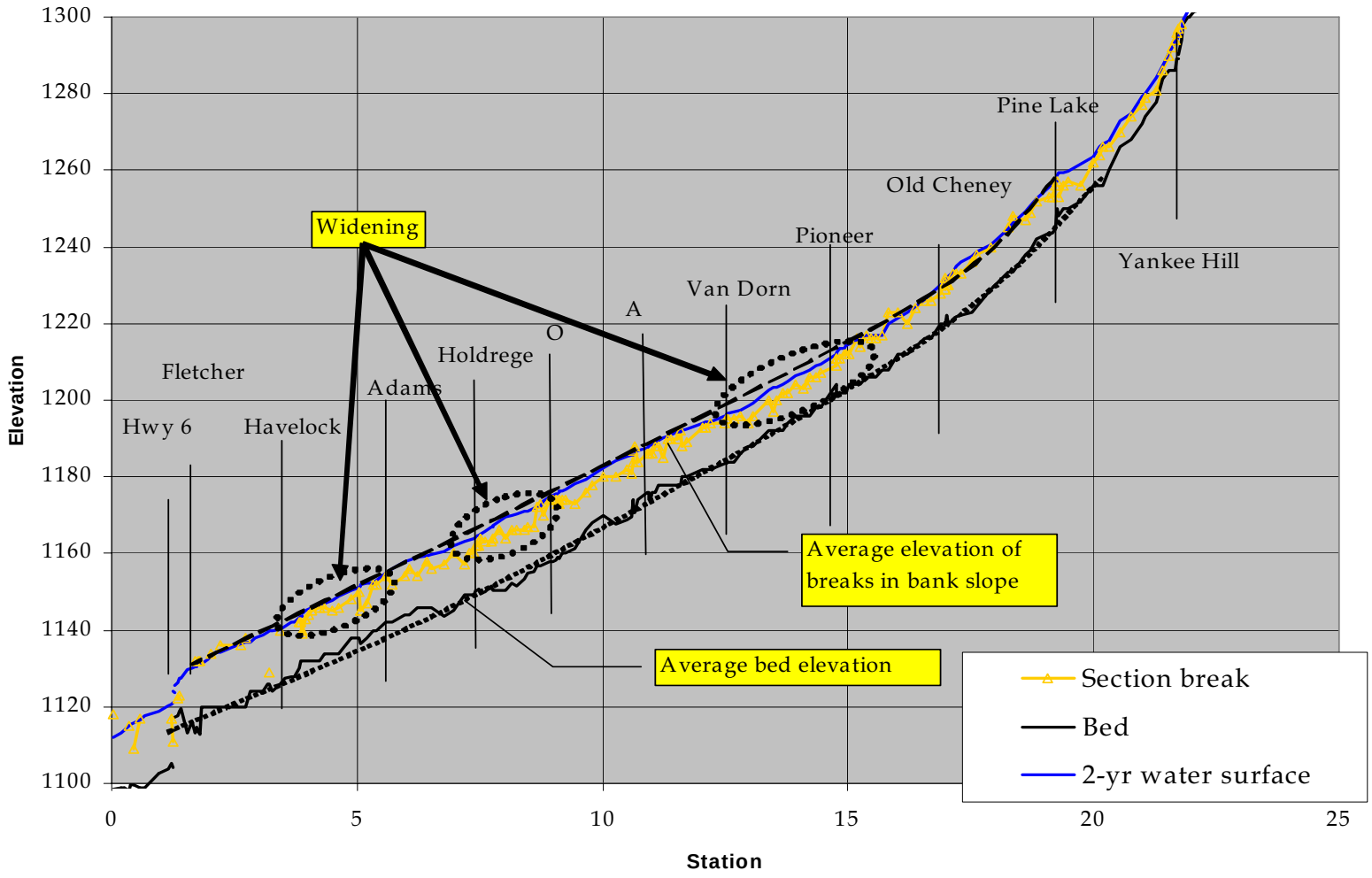


Figure 8-14
Channel Bed Profile

Two separate conditions were modeled, a saturated low steep slope and a partially saturated, high steep slope. The saturated low steep slope is typical of the conditions in the tributaries and upper watershed that has not incised beyond 5 feet. The Bank Stability Chart for the low saturated bank is presented on Figure 8-15. The partially saturated high steep slope is typical of the rapidly incising channel greater than 5 feet high. The relationship between gravity and capillary tension prevents saturation of steep slopes greater than about 5 feet. The Bank Stability Chart for the partially saturated high bank is presented on Figure 8-16.

The reader will note that there are many points above the unstable limit for the partially saturated condition. These include complex cross-sectional geometry, vegetated reinforced slopes, unsaturated conditions, possibly stronger soils, and other conditions beyond the scope of this analysis. It is likely that many of the slopes are meta stable and will fail, particularly under saturated conditions.

Longitudinal Profile

The longitudinal profile of a stream is one of the most useful diagnostic tools for determining the fluvial processes active in a stream system. Figure 8-17 is the longitudinal profile of the main stem from the HEC-RAS analysis. The channel bed is from the 2-foot interval contour and is shown as a black line with black rectangles at data points. The dashed (red) line represents the typical longitudinal profile of a stream, steeper at the headwaters and flattening downstream. Notice that the channel bed measured from the 2-foot contour is below the typical longitudinal profile downstream of Holdrege. This indicates a knickzone between Adams and Holdrege; the channel has incised to Adams and is currently incising towards Holdrege. Collected field data confirms this diagnosis.

The longitudinal profiles of Stevens Creek and its tributaries are typical of a stream that has undergone several waves of manipulation. The combination of road and railway crossing, channelization, and land disturbance has interrupted the fluvial process. Using Figure 8-17 as an example, the channel is interrupted near the crossings as explained in Section 8.1.2 and is shown by the solid (blue) line. Between each interruption, the profile is the shape of a watershed. Interruptions are at Highway 6, MoPac Trail, Holdrege, A, Pioneer, Pine Lake, and the NRD dam. These interruptions can affect sediment transport continuity and therefore fluvial process and will be discussed in Section 8.2.4.

Although there are differences in bed composition, in general, meta-stable reaches have a bed slope of 0.03 per cent. The bed slope for widening reaches varies from 0.03 to 0.13 percent. Incising reaches have higher slopes.

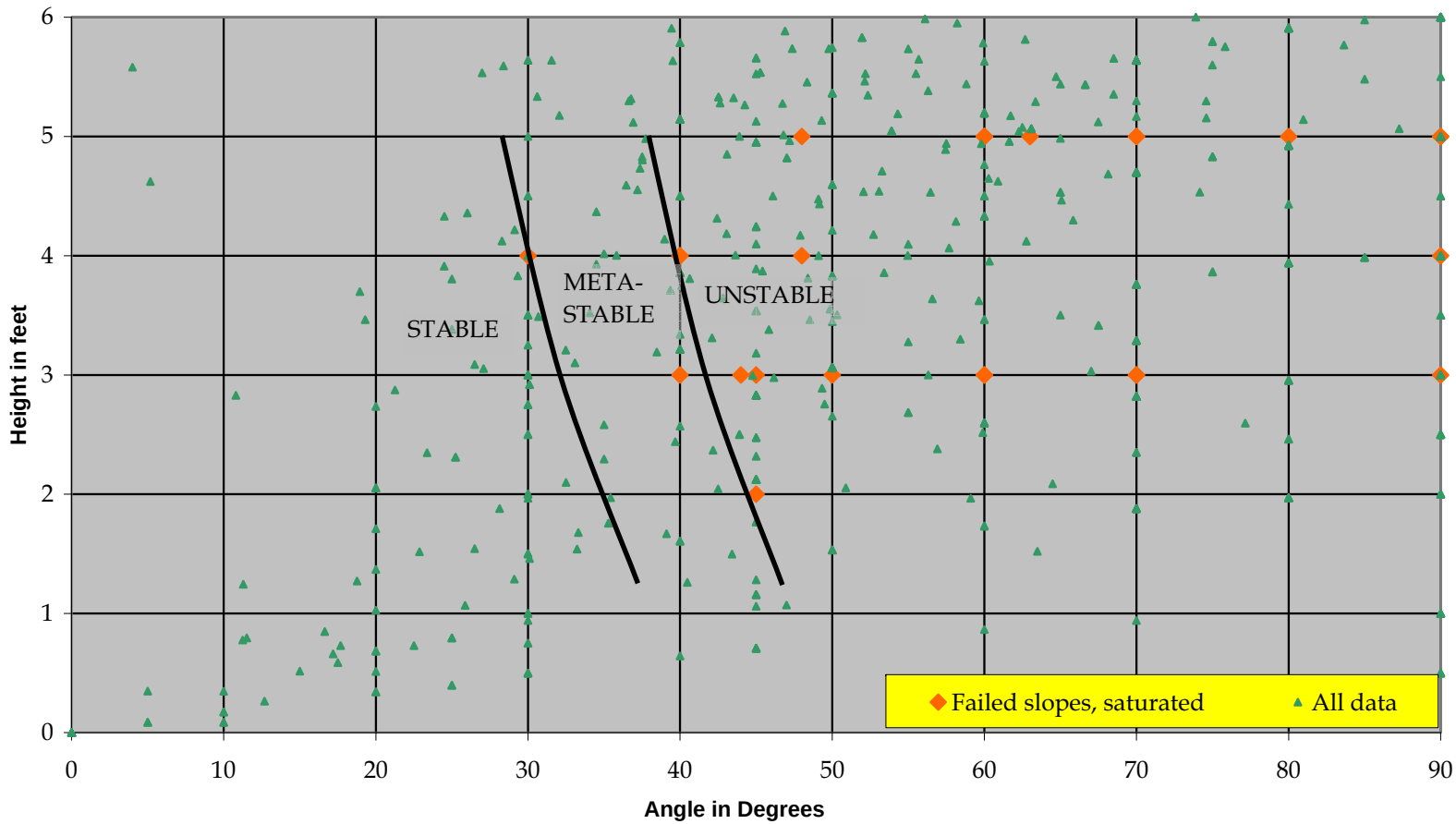


Figure 8-15
Critical Bank Height and Angle for Saturated Condition, Slopes <5 Feet for Tributaries and Upper Watershed

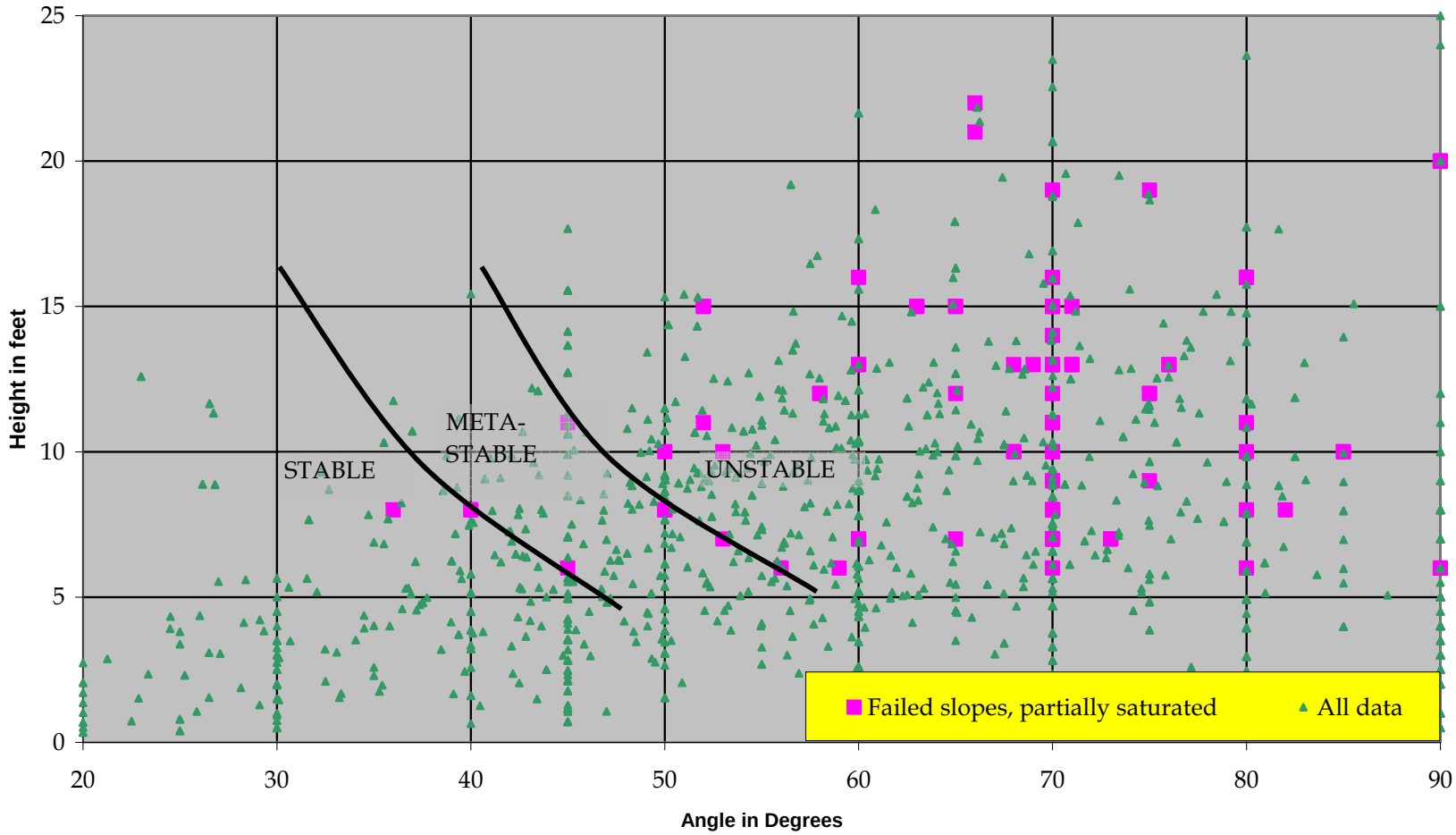


Figure 8-16
Critical Bank Height and Angle for Slopes > 5 Feet High,
Partially Saturated Condition for Rapidly Incised Channel

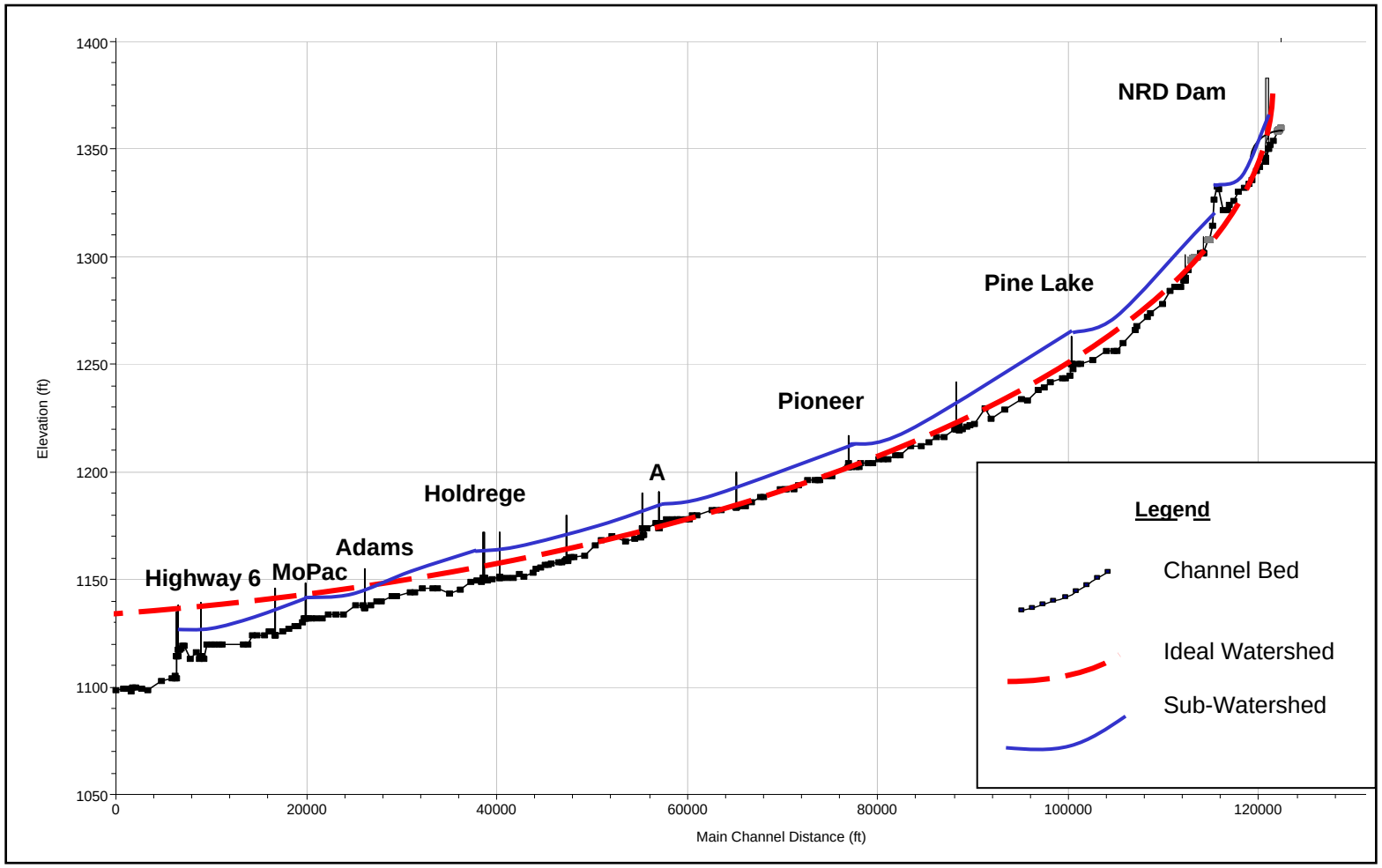


Figure 8-17
Main Stem Longitudinal Profile

The reach average slopes used in the geomorphic analyses were calculated from longitudinal profiles generated from 2-foot contours. The longitudinal profile was also surveyed for specific reaches of Stevens Creek as illustrated on Figure 2-2. Comparison of the two profiles (contour-generated vs. surveyed) validated the accuracy of the reach average slope calculated from contour-generated profiles. The reach average slopes are nearly identical with that of the surveyed profile. Localized changes in slope between contours were recorded during field observations. Rather than survey a longitudinal profile of the entire watershed, the profile information gathered as a GIS layer during the field investigation was used for this analysis. The strong correlation between surveyed profiles, contour data and field data provides confidence in the validity of the findings.

8.2.2 Boundary Material

The bed and bank materials are composed of the native soil, large woody debris, introduce debris and rock, vegetation, and groundwater.

Soil

Soils throughout the basin are clayey silts, silty clays, and clay. In general, the soils are weak and erodible. They become less plastic with depth until the clayey till contact. The banks are moderately well drained; however, saturation increases the mass and weakens the soil. The most common failure modes are circular, wedge, and toppling. If the silt-till interface is exposed, the banks usually fail on this surface. Reaches that have incised deeper than 10 feet with bank angles around 60 degrees are meta-stable. The incision has lowered the groundwater table and drained the near-bank soils. This increase in capillary tension increases the apparent strength of the soils. These banks however, are susceptible to raveling by drying and freeze-thaw cycles and to undercutting by toe erosion. These higher banks are also susceptible to failure as saturation increases. Critical bank height and angle are discussed in Section 8.2.1.2.

As the clay content increases, the fluvial process shifts from incision to widening. This is demonstrated on the main stem between Fletcher and Adams. The main stem has incised down to the till, which is more resistant to incision. That reach of channel is now responding by widening.

Critical shear resistance for the silt is estimated as 0.15 psf. Critical shear strength for the silty clay and clay is estimated as 0.26 psf.

Debris

This discussion of debris includes large woody debris, dumped concrete, rock, and other waste. Other waste includes discarded appliances, hay bales, fence, and similar materials. Dumped debris falls into several categories; waste, bank armoring, or bed armoring. With the exception of infrastructure protection, there is little systematic armoring in this stream. Whether intended to stabilize a failing bank, arrest incision or dispose of waste, the dumped material in the stream is not effective in improving stream stability and in some cases aggravates the instability.

The natural response to incision in this region is the development of woody debris jams. As trees and shrubs fall into the creek, the woody debris is distributed throughout the

system forming a pool and riffle system. The debris jams generate the profile form that manages energy. The jams reinforce the bed and increase the hydraulic roughness dissipating erosive energy. The backwater effect of the jams lowers the hydraulic gradient for low flows. The critical shear resistance for woody debris is estimated at 3 psf.

While debris jams may contribute to local flooding, they also reinforce local stability. Removal of debris jams without reinforcing the bed usually leads to incision, widening, or meandering. The location of debris jams is presented as a GIS layer.

Vegetation

The vigor and integrity of riparian vegetation plays an important role in the physical, chemical and biological health of stream systems. In their landmark report, Riparian Areas: Functions and Strategies for Management (National Research Council 1999), the authors define riparian areas as "transitional between terrestrial and aquatic ecosystems and are distinguished by gradients between biophysical conditions, ecological processes, and biota. They are areas through which surface and subsurface hydrology connect water bodies with their adjacent uplands." Diverse stands of healthy native vegetation process and sequester pollutants, temper the volume and timing of surface runoff, moderate soil moisture, and increase the shear strength of streambanks. By adjusting the rate of evapotranspiration as plant-available moisture varies, trees and shrubs moderate the extremes of soil moisture and help maintain optimum moisture for soil strength.

The riparian corridor of Stevens Creek is in poor condition. While there are some stands of trees remaining, most of the watershed is denuded. When not farmed to the edge, the banks are often lined with a thin band of cottonwood, mulberry, or locust. The sparse trees and shrubs do not provide the benefits expected of a vigorous woody corridor. Both the water quality and physical stability of the system suffer as a result. The absence of an intact corridor increases the sensitivity of the banks to groundwater related failures. In the absence of extensive root reinforcement to mechanically strengthen the soil and evapotranspiration to reduce the saturation near the surface, the banks are excessively vulnerable to failure under mild stresses.

Groundwater

The depth to groundwater is seasonal. The water table varies from 1 to 6 feet below the surface. The water table for the Crete loam along Tributary 5 in the northwest may be 12 feet below the surface. The channeled Nodaway silt loam that comprises much of the channels has a high water table, typically 6 feet below the surface. The effect of groundwater on soil behavior is discussed in Section 8.2.2.1. The near-stream groundwater table appears to be directly related to the depth of incision. As the streams incise, the groundwater table lowers. A binary system has developed with high groundwater in shallow streams and suppressed groundwater levels in steep, deep stream reaches.

8.2.3 Hydraulics

The HEC-RAS analysis provided the shear stresses applied to the bed and channel. This in turn allowed assessment of which reaches of the stream are likely to erode under a specified condition. The results of this analysis were compared with the field assessment of geomorphic stability with generally good agreement. The HEC-RAS was developed

using the 2-foot contour data. The applied shear stresses for the 2-year flows are used in analysis. This is the lower limit that is reasonable to use based on the topographic data and the arrangement of the model. Shear values are calculated at discrete cross sections in the model. Reach-average shears compare well with reach-average fluvial process.

Applied shear strongly influences channel process. Reaches with high shear are generally incising. Reaches with low applied shear are most often in deposition or are meta-stable. For incising reaches total shear and bed shear are the same when the flows are contained in the channel. For other processes the comparison will vary.

Figure 8-18 presents a portion of the watershed near Van Dorn and 134th. The figure identifies knickpoints and the total shear values where the circle size is proportional to the magnitude of the shear stress. Knickpoints provide an indication of ongoing or recent incision. For these tributaries the total shear is high in areas with knickpoints. This indicates ongoing incision. There are also relatively fewer knickpoints along the main stem where the shear values are lower. This portion of the channel has incised but is currently widening. The strong correlation between applied shear and fluvial process is consistent throughout the watershed.

8.2.4 Sediment Transport Competency

Stevens Creek is exporting sediment to Salt Creek. Stevens Creek is competent to transport sediment throughout the watershed. Once dislodged, the soil particles are easily transported only depositing in reaches with low bed slope or debris jams. As demonstrated in Section 6, the frequency of flows capable of transporting fine sediment has increased. This decreases the time for the soil to consolidate and for vegetation to become established. Although a lot of sediment is being delivered to the system, little is stored in bars.

Three reaches along the main stem appear to be in dynamic equilibrium. These reaches are above Highway 6, O Street, and Pioneer. These bridges hold grade and meter the movement of sediment.

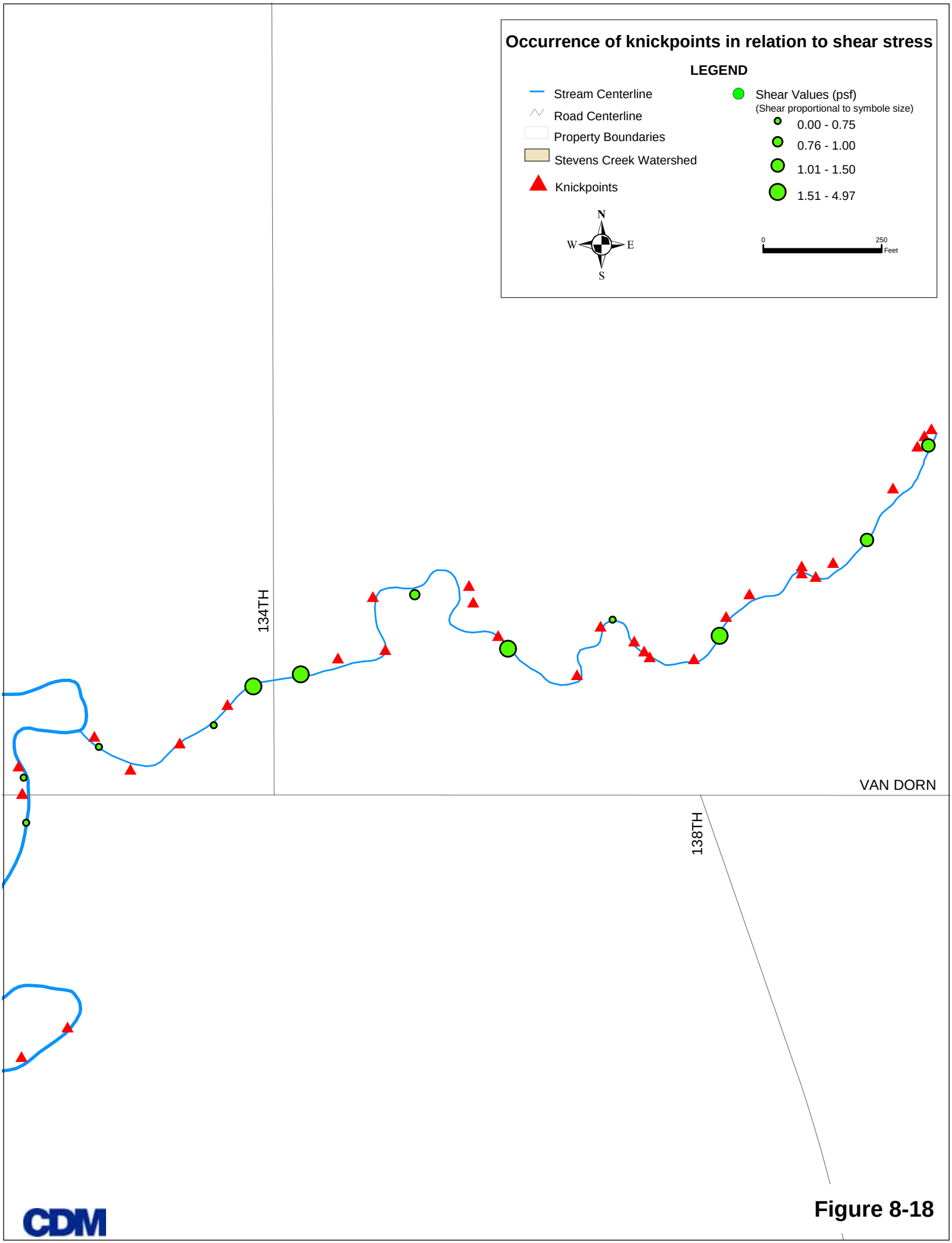
The main channel below Highway 6 meanders in response to the changes in proportions of the rate of water and sediment. Insufficient time has elapsed to determine if bed slope is increasing or decreasing.

Headwater tributaries 5, 105, 40, 460, and 396 are in dynamic equilibrium.

8.3 Physical Stability of the Watershed

8.3.1 Existing Channel Process

The dominant fluvial process in Stevens Creek Watershed is incision. Areas of channel widening interrupt areas of incision. Widening occurs when the bed is more resistant, either from an increase in clay content or the formation of debris jams. Meta-stable zones exist on the main stem upstream of three bridges as explained in Section 8.1.3, Sediment Transport Competency. Two areas of meandering are active, below Highway 6 and below the confluence of Tributary 96 and 196. Current fluvial process for reaches in the



CDM

Figure 8-18

watershed is determined from the geomorphic observations and analysis and from the hydraulic analysis.

Figure 8-19 is a screen capture of some geomorphic data developed in a GIS format and demonstrates how the data is used in analysis. Figure 8-19 is of the confluence of the main stem, Tributary 60 and Tributary 65. These reaches have similar bed and bank material and scour patterns. However, there is an obvious increase in the number and frequency of knickpoints for the incising reach.

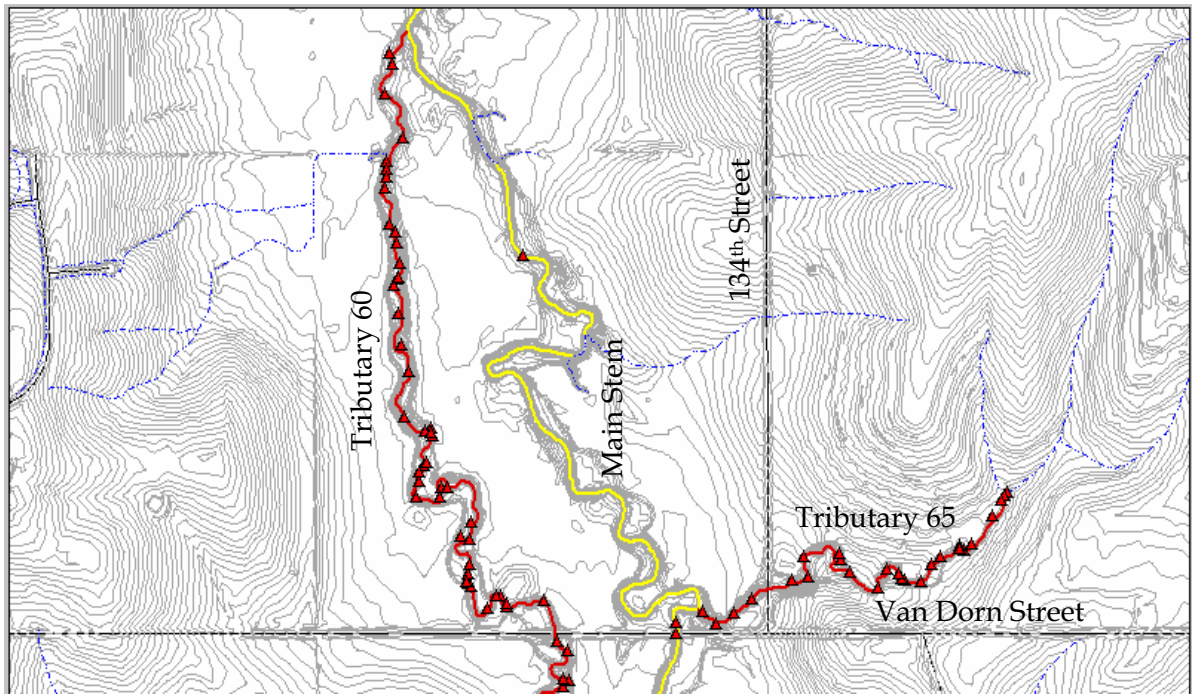


Figure 8-19
Difference in the number and frequency of knickpoints along an incising reach (red) versus a widening reach (yellow)

The results of the process analyses are presented on Figure 8-20. Green reaches are stable, yellow are widening, red are incising, and orange are meandering.

8.3.2 Erosion Hazard

Stevens Creek will continue to degrade until the driving forces are limited and channel interventions are installed. Generally, until then the current fluvial processes will continue. Incision and widening will continue. If streams incise below the critical bank height and angle for soil saturation conditions (see Section 8.2.1.2 for a discussion of critical bank height) mass wasting will occur. The channel will either widen or begin meandering. The fluvial processes are presented on Figure 8-20. Stable reaches in headwaters of western tributaries (Tributaries 5, 105, 10, 30, 25, 460, and 396) are threatened by possible incision moving upstream.

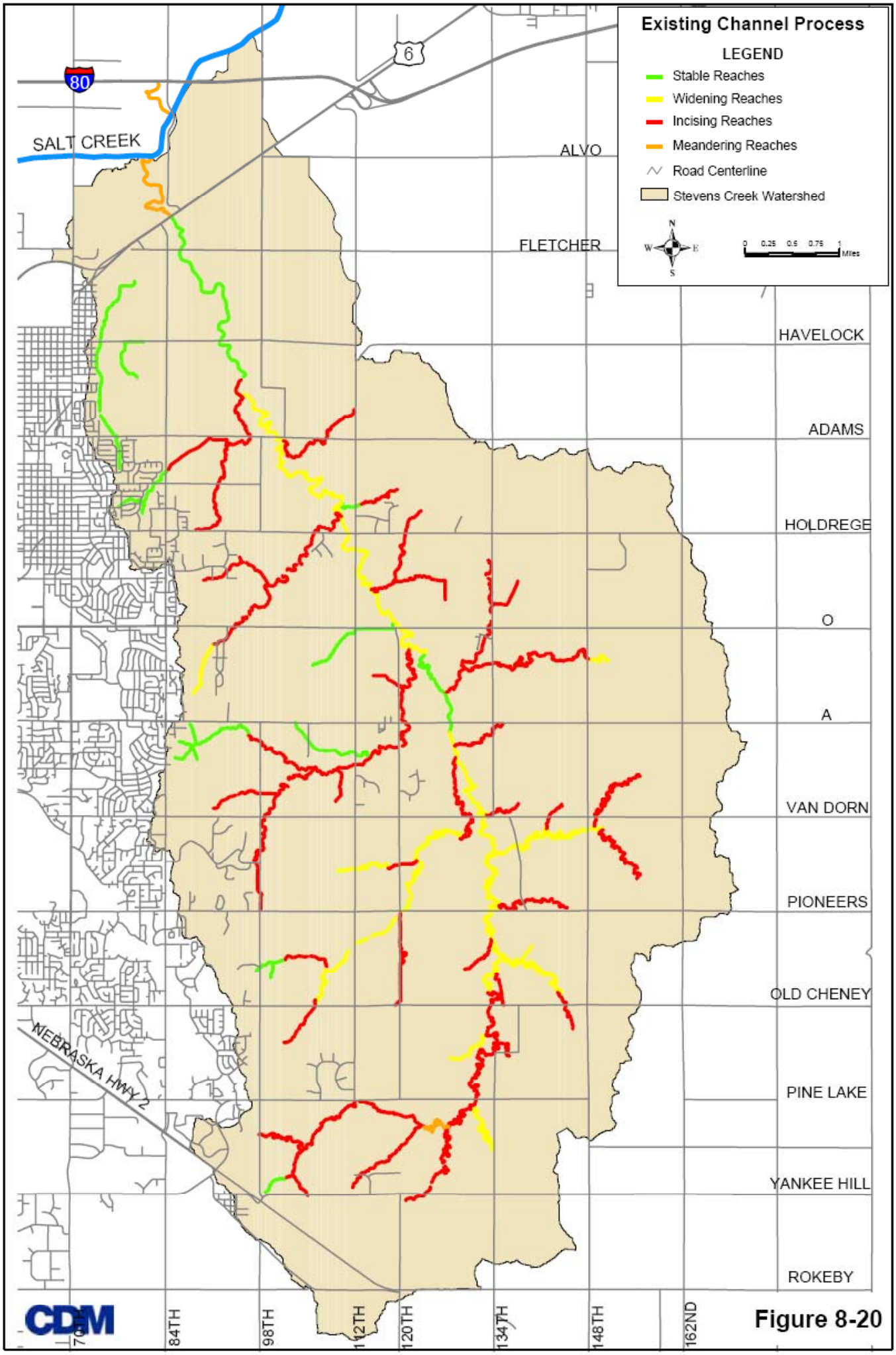

Existing Channel Process
LEGEND
Stable Reaches
Widening Reaches
Incising Reaches
Meandering Reaches
Road Centerline
Stevens Creek Watershed
N
W
E
S
0 0.25 0.5 0.75 1 Miles
80
6
SALT CREEK
ALVO
FLETCHER
HAVELOCK
ADAMS
HOLDREGE
O
A
VAN DORN
PIONEERS
OLD CHENEY
PINE LAKE
YANKEE HILL
ROKEBY
NEBRASKA HWY 2
70TH
84TH
98TH
112TH
120TH
134TH
148TH
162ND
CDM

Figure 8-20

8.4 Methods of Management

8.4.1 Watershed-Scale Stability

Arrest Channel Incision

Arresting channel incision is the single most beneficial action available to stabilize the Stevens Creek Watershed. Incision causes most of the problems throughout the basin including mass wasting, scoured or sedimented crossings, and plan form adjustment. Fortunately, incision responds well to treatment. Stopping the incision "short circuits" the cycle of channel evolution and improves the likelihood that the channel will self-heal. The knickpoints and knickzones are sites where the hydraulic slope is locally high enough to induce upstream-migrating erosion. Grade control structures will lower the slope below the threshold for bed erosion in this stream. Because of the high erodibility of the streambed, it is necessary to dissipate energy gradually over the length of the structure. For this application, Newbury-style grade control structures offer compelling advantages over concrete or sheet pile drop structures. These rock structures, illustrated on Figure 8-21, provide artificial riffles along the streambed. In addition to distributing energy, these rock structures improve water quality by increasing dissolved oxygen and providing refuge for benthic organisms.

Restore Riparian Buffers Throughout the Watershed

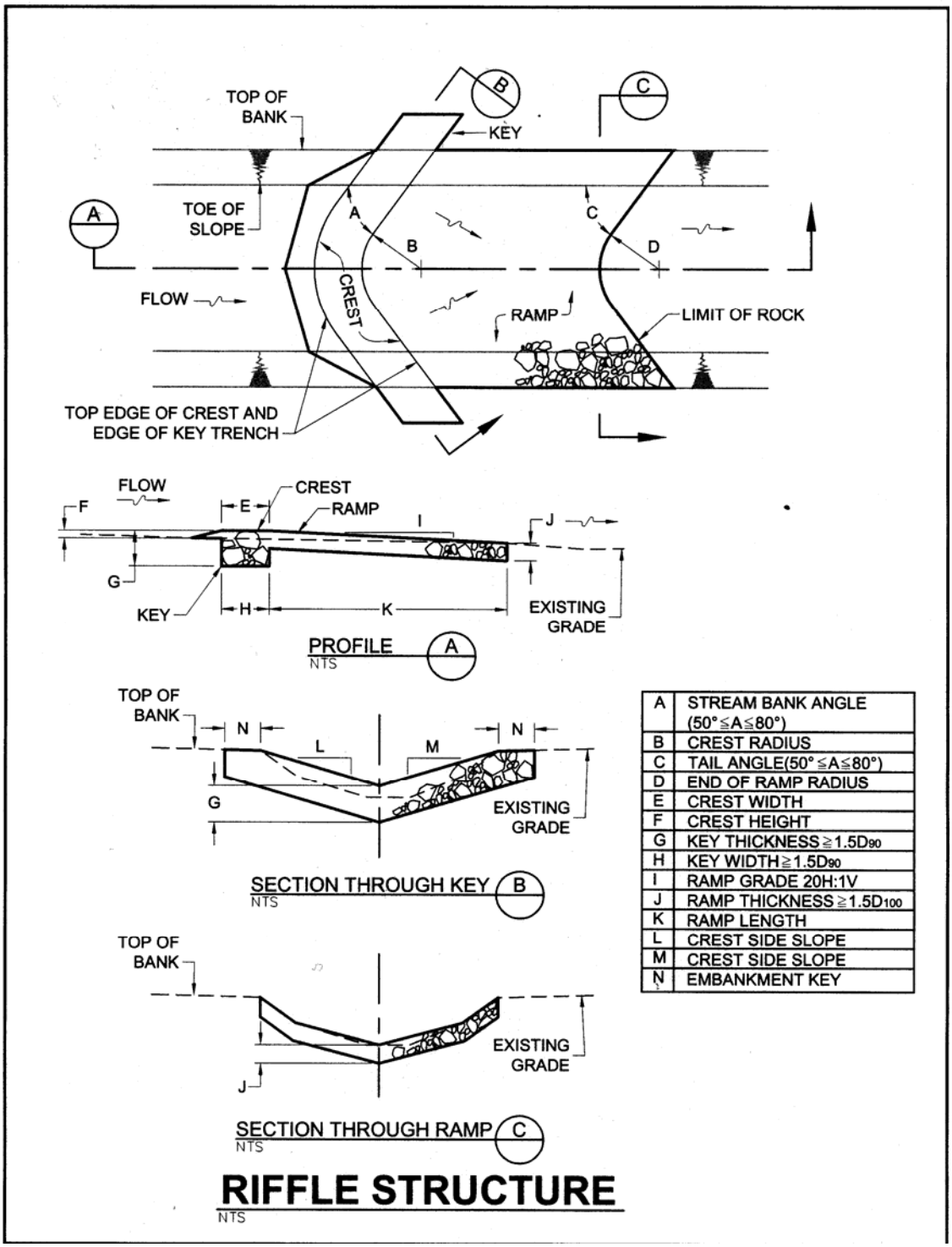
The second major issue influencing systemic stability is the poor condition of the riparian corridor. Without the root reinforcement and hydraulic roughness afforded by streamside vegetation, the banks are vulnerable to even minor insult. The few trees that are left become vulnerable to toppling and eventually become debris jams. A wide band of native trees and shrubs supports stream stability by increasing bank strength and reducing the influence of surface runoff. Streambank vegetation influences sediment dynamics by trapping and storing suspended sediment. Good canopy cover also improves water quality and habitat by shading the stream and providing leaf litter important for benthic species. When coupled with comprehensive grade stabilization and controlled post-development hydrology, a re-established woody corridor is a major step towards improving the condition of the stream now and preventing serious problems in the future.

The corridor should be wide, dense, and extend the entire length of the stream. Headwater reaches are particularly vulnerable to erosion and benefit from a protective corridor as much as lower reaches. Species represented should include canopy and understory trees, shrubs, and where appropriate, native grasses and forbs. Turf grasses have little value and should not be included in riparian buffer areas. Detailed, thoroughly researched guidance on the design and benefits of riparian buffers is available in the recent text released by the National Academy of Science (National Research Council 2002).

The actions described above will make progress towards improving the stream's current condition. Protection against future degradation requires watershed management outside the stream channel. The management guidelines recommended in Section 6.7.4 maintain the hydrologic equilibrium critical to preventing future problems.

8.4.2 Local Stability

Stevens Creek has an abundance of failed streambanks, undermined or filled in culverts and a few areas of meander adjustment. Most of these problems are a consequence of



A	STREAM BANK ANGLE (50°≦A≦80°)
B	CREST RADIUS
C	TAIL ANGLE(50°≦A≦80°)
D	END OF RAMP RADIUS
E	CREST WIDTH
F	CREST HEIGHT
G	KEY THICKNESS ≧ $1.5D_{90}$
H	KEY WIDTH ≧ $1.5D_{90}$
I	RAMP GRADE 20H:1V
J	RAMP THICKNESS ≧ $1.5D_{100}$
K	RAMP LENGTH
L	CREST SIDE SLOPE
M	CREST SIDE SLOPE
N	EMBANKMENT KEY

Figure 8-21
Newbury-Style Grade Control Structures

incision and are best addressed in a context of systemic grade control. Once systemic incision is controlled, the driving force for bank failure will have been removed. However, streambanks with substantial toe scour or those standing near or above critical bank height will continue to fail until a stable cross section is achieved. Attempting to prevent all of these failures and repair all streambanks that are failing now is prohibitively expensive. It is appropriate to treat areas of threatened infrastructure using methods consistent with systemic stabilization.

The organizing principle for local stability is, like systemic stability, energy management. The goal is to manage energy throughout the intervention so that neither scour nor deposition is induced in the adjoining reaches. This implies managing hydraulic roughness, focusing flows and achieving an equilibrium channel shape. Where streambank repair is necessary, it is preferable to reduce the stress acting on the bank while strengthening, rather than hardening, the bank. Lowering the slope of the bank above the effective discharge elevation and increasing the near-bank hydraulic roughness will lower the applied shear stress. Vegetative reinforcement and selective use of armor will provide the necessary strength.

Excessive erosion and the development of scour pools occur at every pond outfall with the exception of the newest pond, which had not yet been stressed. Scour immediately downstream of a pond is exacerbated by the lack of sediment in the discharge water. Similar to streambank repair, it is preferable to reduce the stress acting on the stream. Lowering the slope of the bed with grade controls or a designed stilling basin and increasing the near-bank hydraulic roughness will lower the applied shear stress. Vegetative reinforcement and selective use of armor will provide the necessary strength. The armor should fully encompass the zone of the influence of the structure including the potential hydraulic jump downstream.

8.4.3 Conclusions

The soils in this basin are highly erodible, creating a low threshold for stream disturbance, and even relatively minor physical and hydrologic changes may induce undesired changes in the stream that threaten people or property. The channelization of Salt Creek, historic farming practices, and early suburban developments have induced extensive channel downcutting and widening. There are some stream reaches that are stable and have fairly good habitat. However, this stability is threatened by the advancing knickpoints and bank failures progressing through the system. There is scant evidence that the stream is close to regaining its equilibrium, and the condition is likely to worsen.

The current Stevens Creek Watershed farming techniques such as no-till and contour plowing are major improvements from past practices, and their widespread use improves the sustainability of the watershed. Most of the improvement projects recommended in Section 9 are designed to correct past practices. Comprehensive grade stabilization will remove the driving force for continued bed degradation. Concurrent with this action, the site-specific structural BMPs described in Section 6 are recommended to offset the effects of urbanization on hydrology and stream stability. The third major recommendation is the restoration of the woody riparian buffer along Stevens Creek and its tributaries. Together, these management measures contribute to a more robust, self-managing stream system.

Section 9
Capital Improvement Projects

9.1 Problem Identification

The results of the hydrologic, hydraulic, and geomorphic evaluations discussed in the previous sections of this report formed the foundation for identifying problem areas in the watershed. Problem areas were classified as primary or secondary.

Primary problem areas are those that pose a serious public safety concern or include significant structural damage. In addition, primary problem areas include sites where the problem creates a clear influence elsewhere in the watershed. Secondary problem areas include sites where stream degradation or instability exists, but it is not likely to propagate to other areas in the near watershed. Secondary problem areas also include infrequent flooding of habitable buildings.

Three major categories were used to evaluate potential primary and secondary problem areas, including 1) drainage infrastructure, 2) habitable buildings, and 3) natural streams. For primary problem areas, a recommended improvement was developed and is presented in Section 9.2. The recommended improvements were then grouped and prioritized to form the basis of the capital improvement projects (CIPs), which are described in Section 9.3. Secondary problems are described in Section 9.4.

The following provides the methodology used to identify primary and secondary problems within each of the three major categories.

9.1.1 Drainage Infrastructure

Because of the rural nature of the watershed, a significant number of unimproved roads are located throughout the study area. As development continues in the watershed, it is anticipated that drainage infrastructure (e.g., culverts and bridges), will be replaced or retrofitted at the same time the road is improved. Therefore, for the purposes of this study, the approach was to provide the necessary design data for each modeled drainage structure, to be used during detailed design at the time the roadway is upgraded. The design data for each modeled drainage structure is provided in Appendix J located in Volume II of this report.

Drainage structures in need of immediate structural repair were considered a primary problem. Routine maintenance needs required to maintain the capacity of the drainage system were classified as secondary problems. Applying these criteria resulted in no primary or secondary problem areas under this category.

9.1.2 Habitable Buildings

The hydrologic and hydraulic analysis as described in Sections 3 and 4 of this report include the estimation of the 2-, 5-, 10-, 50-, 100-, and 500-year peak stormwater flow rates and resultant water surface elevations (WSEs). For the purposes of this study, habitable buildings being impacted from the 2- and 5-year design storms were

considered primary problems. Applying these criteria resulted in no primary habitable building problem areas in the watershed.

Habitable buildings being impacted from the 10-, 50-, and 100-year design storms occur much less frequently, and therefore were classified as secondary problems. Secondary problems are associated with deficiencies within the adjacent manmade drainage system, which is the primary cause of the flooding. However, habitable buildings located in the natural 100- and 500-year floodplains were not considered problem areas. Improvements designed to remove habitable buildings from the natural floodplain are cost-prohibitive. A total of five secondary problem areas were identified in the watershed and are described in Section 9.4.

9.1.3 Natural Streams

The geomorphic evaluation discussed in Section 8 was used to identify primary and secondary stream instability problems. Each stream instability problem was assigned a priority based on the descriptions below.

- Priority 1 – Hazard. These stream conditions pose a near-term threat to public safety or significant infrastructure and should be repaired promptly. Sites exhibiting clear evidence that a long delay in treatment will potentially lead to a permanent loss of property or a dramatic increase in the cost of treatment directly associated with the progression of the problem receive a priority of 1.

- Priority 2 – Systemic. These sites, while not posing an immediate public hazard, are fundamentally unstable with clear influence elsewhere in the watershed. The series of knick points mentioned above is an example of this case. While the knick points may pose no immediate threat, if left untreated, the incision migrating throughout the watershed will. As the bed elevation drops, bank heights increase and consequently so does the risk of mass wasting, the generation of massive sediment, and the risk of bridge and culvert sedimentation. Priority 2 projects are not emergencies but should be addressed as soon as funding permits.

- Priority 3 – Supporting. Like the Priority 2 problems, these sites include ongoing channel adjustment conditions. However, either because of location in the watershed or particularly robust channel conditions, propagation of the problem is less likely or is proceeding relatively slowly.

- Priority 4 – Localized. These problems are distinct from the two previous categories in that the cause is local rather than systemic. Examples of this type of problem include overbank drainage, removal of riparian corridor, and debris dumping.

- Priority 5 – Preservation. These are opportunities to protect the higher quality reaches of Stevens Creek. In addition to the aesthetic, water quality, and habitat benefits, protecting the better-functioning reaches provide a reference point for reclaiming the damaged areas. Moreover, the presence of self-managing reaches buffers some of the effects of stream degradation.

- Priority 6 – Enhancements. These are opportunities to prevent future problems, reduce water and sediment conveyance stress on the stream system, or to otherwise improve stream performance. This category includes improvements that increase infiltration, dissipate or direct energy, or re-establish a normal grade for streambanks.

Priorities 1, 2, and 3 are considered primary problems, while priorities 4, 5, and 6 are considered secondary problems. None of the problem areas were given a priority 1 designation, while 18 problem areas were assigned as priority 2 and 8 problem areas were assigned as priority 3, for a total of 26 primary problem areas. A total of 79 secondary problems were identified that received a priority of 4, 5, or 6.

9.1.4 Summary

Figure 9-1 shows the location of the primary and secondary problem areas. Primary problem areas are designated with a "star ★" symbol, while secondary problem areas are designated with a "filled in circle ●" symbol. All 26 primary problems were classified as stream instability problems. The secondary problems include 5 habitable building flooding problems and 79 stream instability problems.

9.2 Recommended Improvements

Conceptual recommended improvements were developed to address each primary problem area. For this study, only stream stability problem areas were identified as primary problems. The types of improvements to address these problems are referred to as stream interventions. A general description of the methodology followed by a detailed description of each stream intervention is provided below. Secondary problem areas are addressed in Section 9.4.

9.2.1 Methodology

The stream interventions recommended in this report generally comply with the principles of river engineering. This approach represents the integrated knowledge of fluvial geomorphology and civil engineering accumulated over the last half century. Much of this work is documented in USACE engineering reports and manuals (1994, 2001). Here project objectives such as flood or erosion protection are achieved by working *with*, rather than against, the forces shaping the stream. Preservation of complex channel form and process including native vegetation are central to this approach.

The recommendations that follow do not constitute a compendium of all problems in the watershed. Stevens Creek is systemically unstable and continuing to degrade watershed-wide. A program to repair all of the problem sites along this stream would easily top $100 million, excluding the cost of property acquisition, utility relocation, or infrastructure replacement. Instead, the recommended improvements are strategic, focusing on interrupting the cycle of degradation and moving the entire system closer to self-sustaining dynamic equilibrium.

Most of the stream interventions address systemic channel incision, the source of much of the erosion and mass wasting observed throughout the Stevens Creek Watershed.

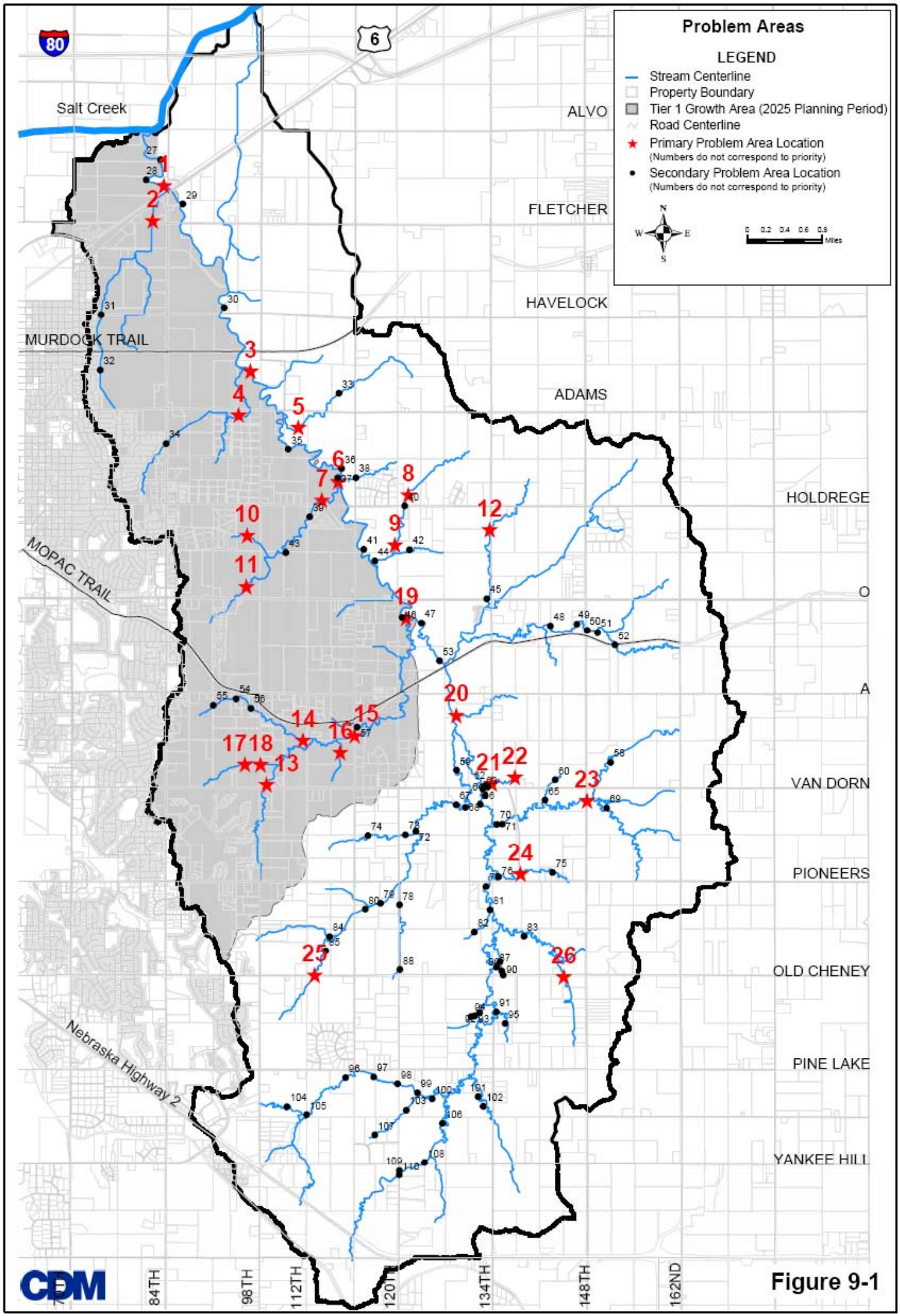

Problem Areas
LEGEND
Stream Centerline
Property Boundary
Tier 1 Growth Area (2025 Planning Period)
Road Centerline
Primary Problem Area Location
(Numbers do not correspond to priority)
Secondary Problem Area Location
(Numbers do not correspond to priority)
N
W
E
S
0 0.2 0.4 0.6 0.8
Miles
80
6
Salt Creek
ALVO
FLETCHER
HAVELOCK
MURDOCK TRAIL
ADAMS
HOLDREGE
MOPAC TRAIL
VAN DORN
PIONEERS
OLD CHENEY
Nebraska Highway 2
PINE LAKE
YANKEE HILL
84TH
98TH
112TH
120TH
134TH
148TH
162ND
CDM

Figure 9-1

Early intervention in this stage of channel evolution minimizes widespread bank failures, mass wasting, and sediment generation. This approach enables construction of stable channel grade and cross section, thereby accelerating channel recovery and re-establishing dynamic equilibrium.

The natural feedback loop to limit incision in this system is the woody debris jam. Although rock grade controls would not normally occur in this watershed, they are easily constructed, flexible, adaptive to minor changes in channel form, flow of water and sediment, and dissipate energy over a long distance. In addition, rock grade controls do not deteriorate over time like large woody debris.

Where incision is not the focus, recommendations generally address either channel widening, the next phase in channel evolution, or localized erosion problems at culverts or outfall structures. Channel widening has occurred along reaches where the channel has already incised to a depth that exceeds critical bank height. Critical bank height is a function of a complex cross section expressed as bank height, angle, material and groundwater level that, when exceeded, results in a geotechnical failure of the slope. Grade controls are sometimes recommended to capture sediment, thereby raising the channel bed and decreasing bank height.

All of the stream intervention recommendations in this report share several common features. All are intended to remedy the cause of instability and not necessarily its most obvious symptom. All recommendations also rely heavily on measures that manage the distribution of energy through the project reach. Focusing flows, dissipating hydraulic energy and developing a gradual transition between native bed or bank and the installed structures are important design features. These are especially important in the erodible soils of Stevens Creek. For these reasons, drop structures, gabions, and other monolithic devices are not recommended.

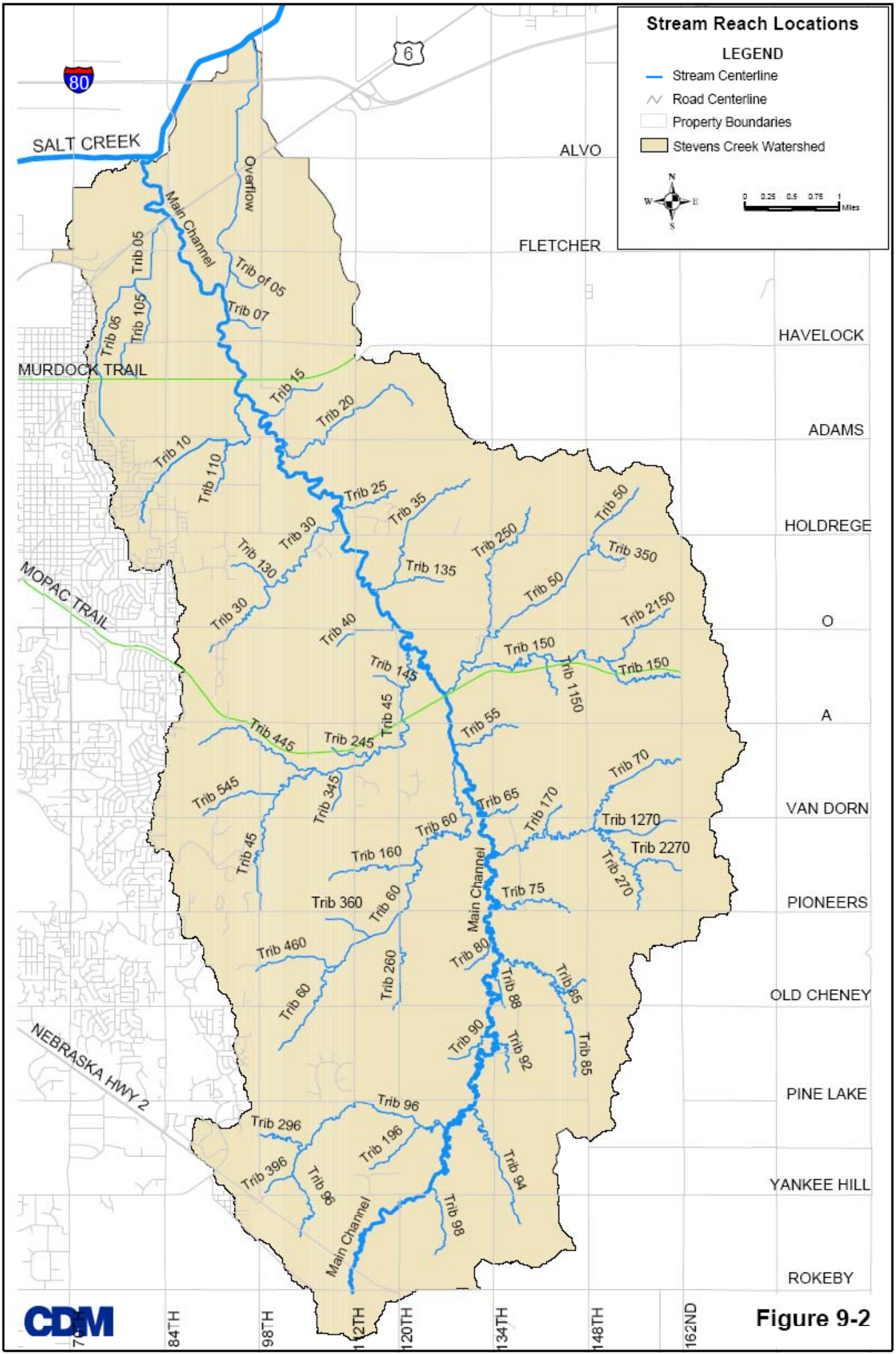
Bank failures are commonplace in this watershed and it is reasonable to question why bank stabilization is so rarely the focus of the recommendations. Stevens Creek is fundamentally unstable. The old truism regarding streambanks is as applicable here as anywhere in this region - *It is impossible to stabilize a streambank on an unstable stream*. Until some measure of equilibrium is regained, extensive bank stabilization efforts are wasteful and probably counterproductive. Critical infrastructure areas, where protection of a bridge or other crossing requires that the stream alignment be fixed, are the exceptions to this rule.

9.2.2 Stream Interventions

One recommendation is applicable throughout this watershed. The restoration and protection of the riparian forest is a vital aspect of sustainable watershed management. This is one of the most cost-effective methods to protect water quality, conserve wildlife habitat, support stream stability, and prevent loss of public and private property. The woody corridor should be wide, dense, and extend the length of the watershed including the headwater tributaries. The corridor should include a diverse selection of native trees, shrubs, and greases. Turf, crops, and pasture grasses do not provide the benefits of native species and should not be used as part of buffers.

While riparian buffers are vitally important, they are most effective when combined with grade stabilization and conservation land use practices throughout the watershed. Conservation farming practices and the improvements to stormwater management described in Section 7 manage hydrology to reduce the flashiness of storm flows. The combination of these three broad measures approximates the behavior of undisturbed systems and will reduce problems in the future.

Stream interventions were formulated for each of the 26 primary problem areas. These 26 interventions are described on the following pages and shown on Figure 9-1. Figure 9-2 shows the referenced stream reach locations.



CDM

Figure 9-2

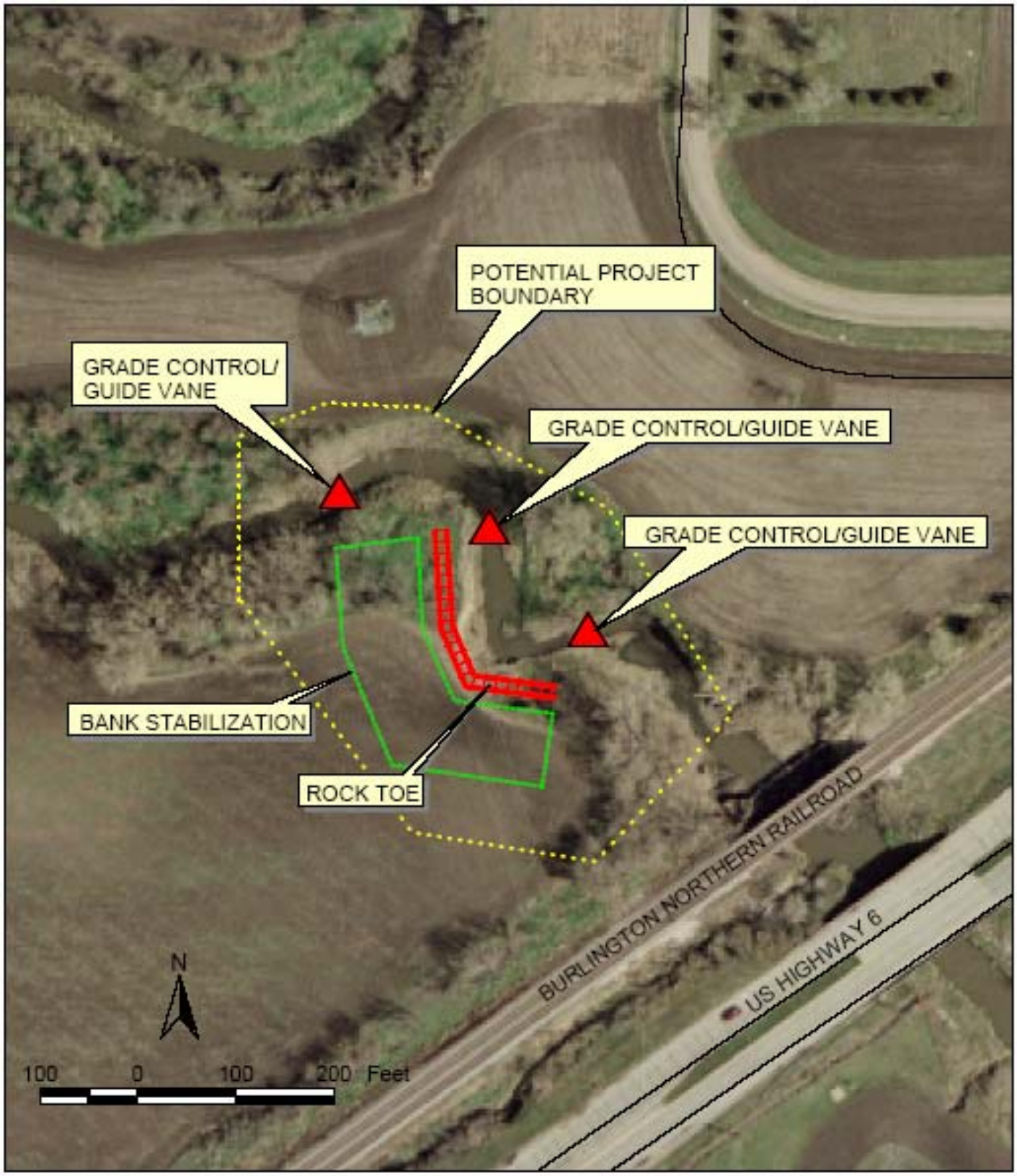
Intervention 1. Lower Main Stem, River Mile 1.222 to 1.167 - Wing dikes and rock toe along eroding streambank

Problem description: Meander adjustment is common along Stevens Creek Lower Main Stem, downstream of Nebraska Highway 6 and the Burlington Northern Railroad crossing. Adjustments in channel plan form have resulted in tall, alternating cutbanks, standing nearly 30 feet tall, between River Mile 1.222 and 1.167. Bank erosion continues to liberate large, toppled chunks of silty clay soils. The addition of such large amounts of sediment is troubling because it further degrades water quality and because the channel bars formed by the sediment aggravates the meander adjustment. This problem is not likely to resolve itself without substantial further damage.

Recommended intervention: The primary function of this intervention is managing and dissipating hydraulic energy immediately downstream of the railroad bridge. Deflecting scouring flows away from the streambanks is an appropriate first step. A series of rock guide vanes or rock grade control structures placed to focus flow in the center of the stream will significantly reduce stress on the streambanks (Figure 9-3). Rock toe armor reinforced with woody vegetation along the left descending bank provides continuity of treatment. Critical design features here are maintenance of sufficient hydraulic roughness to dissipate scouring energy and careful alignment of the rock structures. These are erodible soils and an overly acute angle will induce excessive scour at the apex of the structure while an overly flat angle will induce scour at the root of the structure.

While reducing the stress on the streambank alleviates much of the driving force for bank failure, further treatment has merit. Flattening the slope of the left descending bank reduces the likelihood of bank failures whether geotechnical or fluvial in origin. Re-establishment of native vegetation provides additional stabilization.

Estimated Construction Cost: $434,000



INTUITION & LOGIC

Stevens Creek Intervention #1
Lower Main Stem – River Mile 1.222 to 1.167

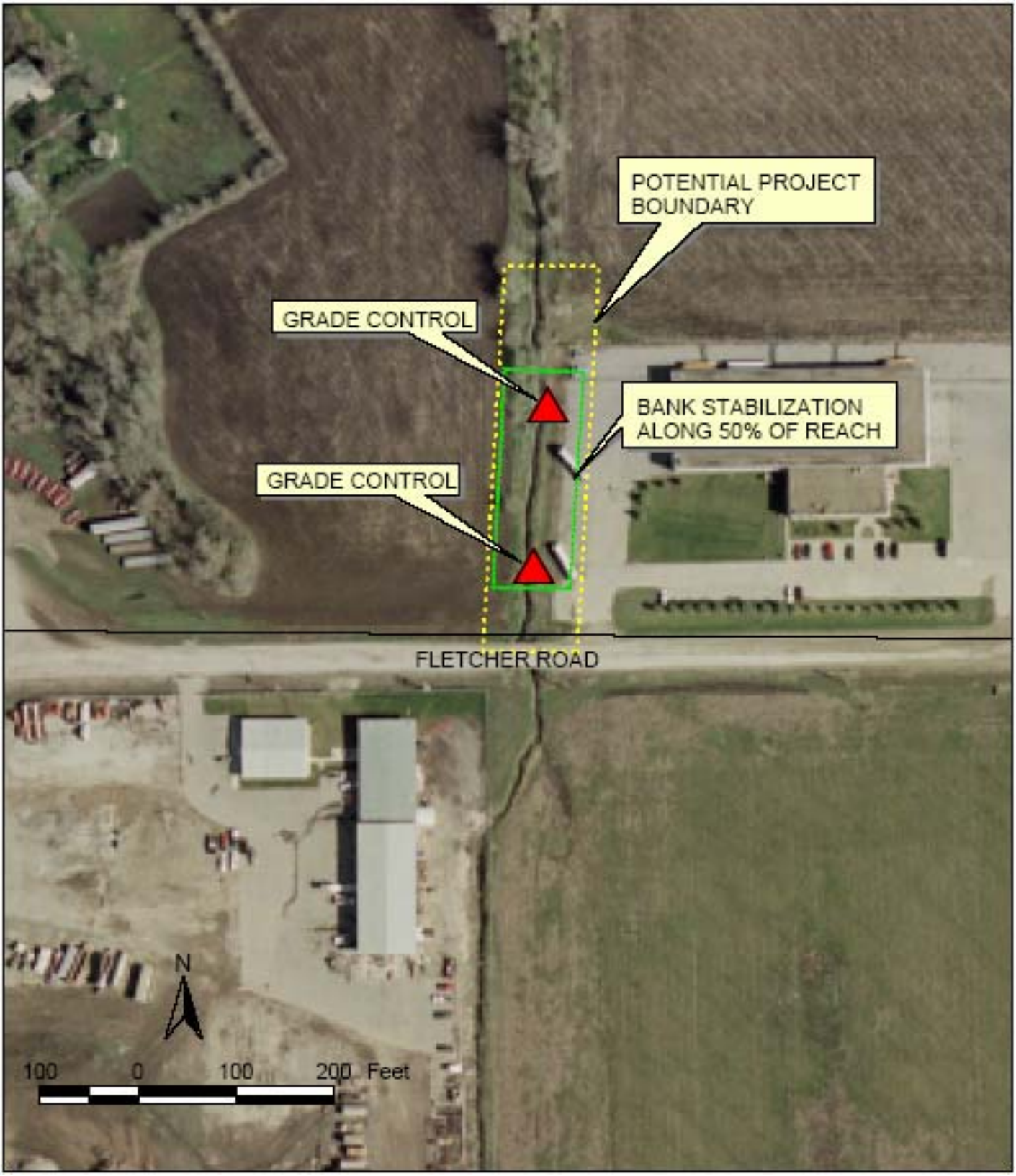
Figure 9-3

Intervention 2. Tributary 5, River Mile 1.708 to 1.689 – Grade control incising channel

Problem description: Channel incision and removal of woody vegetation along Tributary 5 has resulted in bank erosion downstream of the Fletcher Road Bridge. The two factors have reinforced each other; incision has increased the height and steepness of the banks, while the loss of trees and shrubs has reduced the shear strength of the soil. Left untended, this site will most likely continue to degrade until a stable channel slope is achieved. This process increases the likelihood of future bank failures.

Recommended intervention: A series of rock grade control structures immediately downstream of Fletcher Road will stop the incision (Figure 9-4). As with all in-stream structures, providing sufficient hydraulic roughness is an important design feature as is the shape of the upstream-facing arch and the depth of the key trenches. This recommendation does not include large-scale bank revegetation. However, where grade control installation has caused site disturbance, the streambanks should be restored by flattening the slopes and installing both degradable erosion control fabric and native vegetation.

Estimated Construction Cost: $98,000



Stevens Creek Intervention #2
Tributary 5 – River Mile 1.708 to 1.689

Figure 9-4

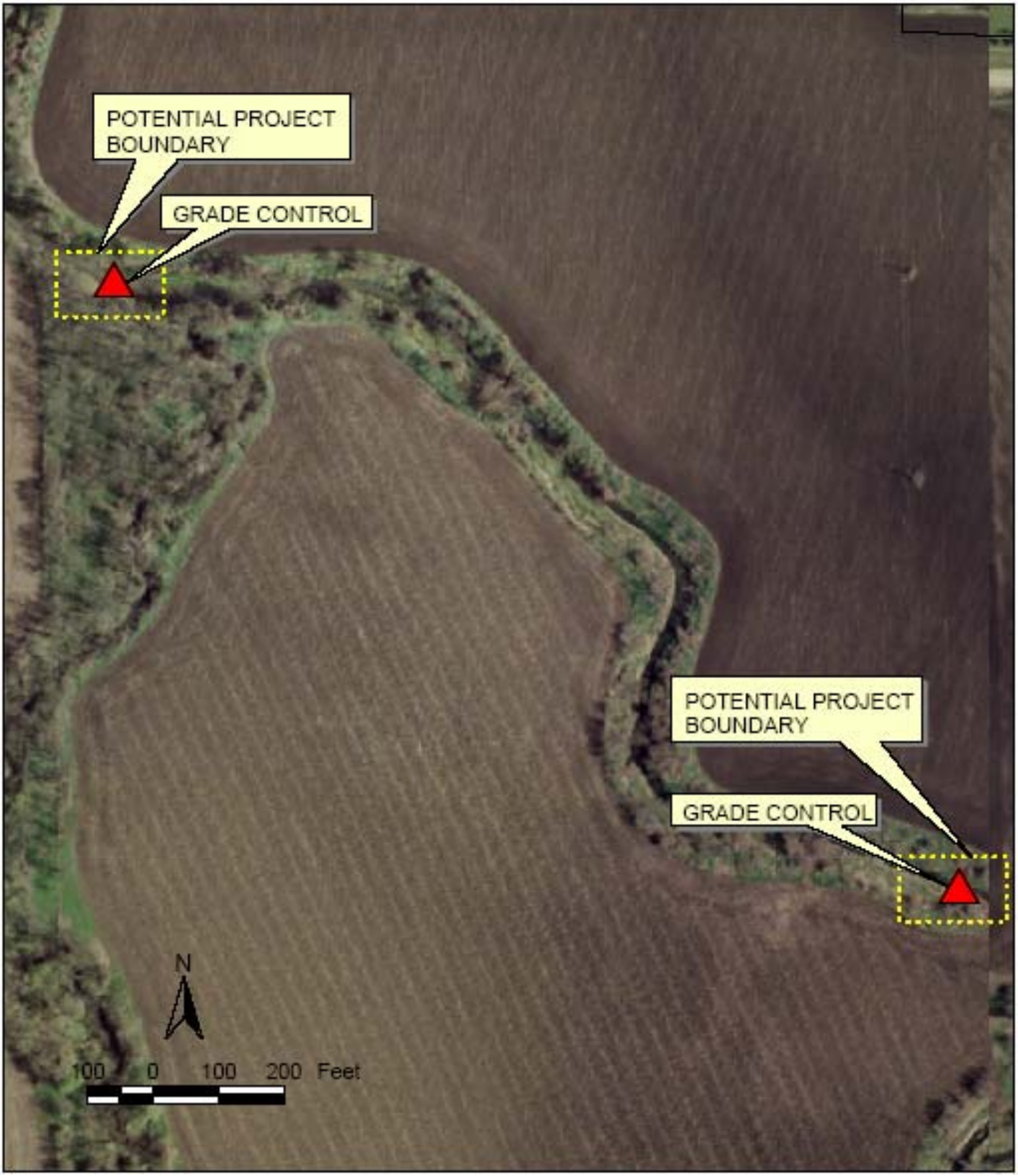
Intervention 3. Lower Main Stem, River Mile 4.545 to 3.839 - Grade control existing knickpoints

Problem description: An advancing headcut along Steven Creek Lower Main Stem has resulted in incision-induced bank failures and generation of toppled trees and woody debris.

No infrastructure or buildings are immediately threatened. However, headcuts in the lower part of any watershed are problematic because of their potential to migrate upstream. This migration eventually moves through all of the tributaries and up to the headwaters. This occurs because all tributaries must match grade with their receiving streams so a drop in grade at any point on the main stem has implications for all channels above it. Therefore the potential for serious future damage warrants immediate treatment. Construction of Intervention 3 should be coordinated with the construction of 98th Street, which is currently planned for this area.

Recommended intervention: Arresting the incision moving up the main stem requires a series of grade controls (Figure 9-5). Because of the relatively flat grade and erodible soils, Newbury-style grade controls are appropriate. Multiple grade controls at each knick point are preferable. Distributing the grade change over two or more structures lowers the stress on each and lowers the risk of a catastrophic failure. The structures should be rock, hydraulically rough and shaped in plan, section and profile to focus and dissipate hydraulic energy. Planting shrub species on the downstream edges of the structures will further dissipate energy and discourage raveling at the soil-rock interface.

Estimated Construction Cost: $229,000



INTUITION & LOGIC

Stevens Creek Intervention #3
Lower Main Stem – River Mile 4.545 to 3.839

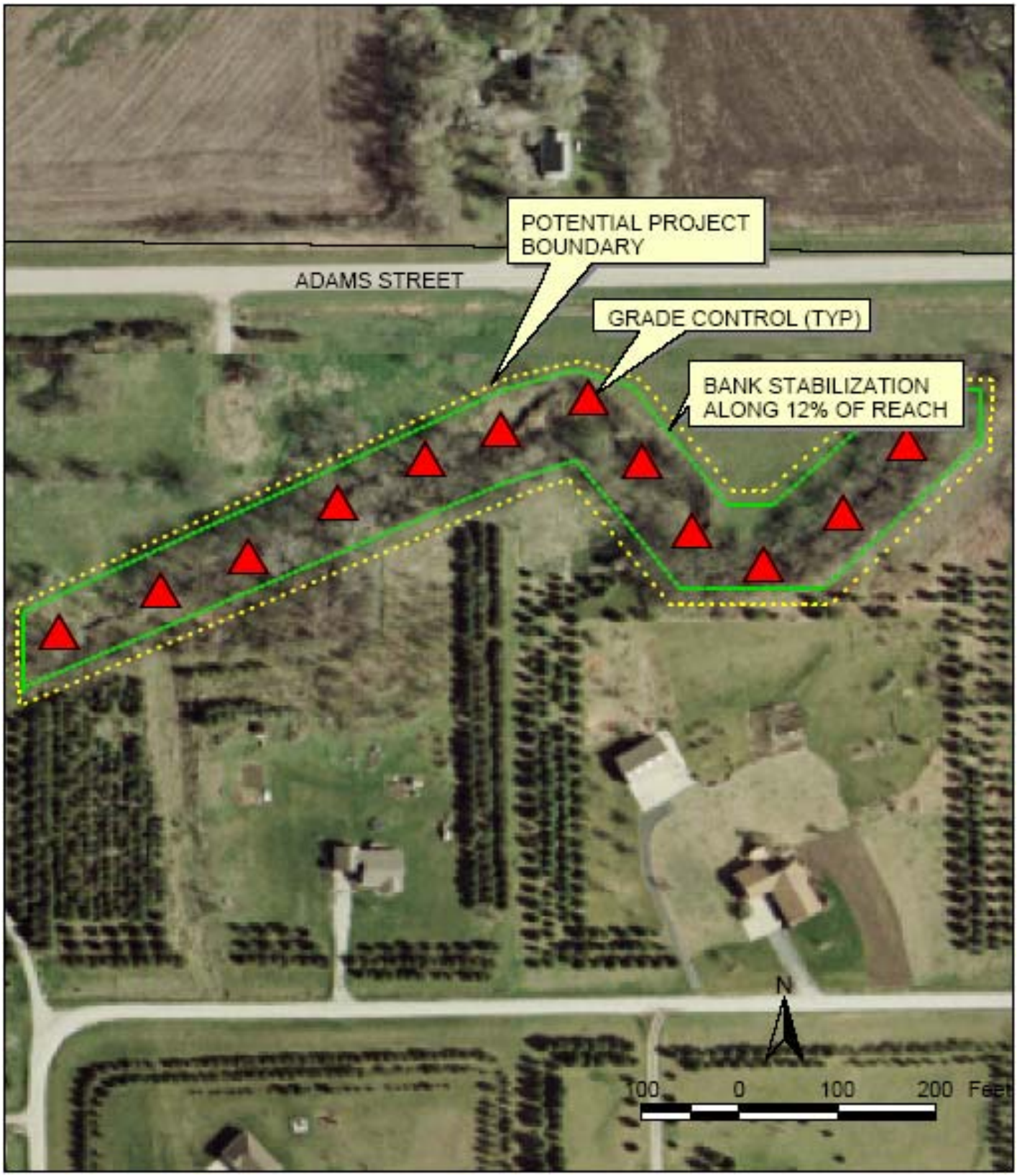
Figure 9-5

Intervention 4. Tributary 10, River Mile 5.043 to 4.191 - Grade control incising channel

Problem description: Channel incision along Tributary 10 has resulted in widespread bank scouring and erosion. The channel bed elevation has dropped approximately four feet based on the height of the exposed tree roots. The streambanks are approaching critical bank height. Further progress of the incision will likely lead to bank failures throughout this reach. In addition to liberating considerable sediment and degrading water quality, extensive bank failures will topple the trees lining the bank generating a series of woody debris jams. This last action is a natural response to incision and would eventually arrest it. However, the debris jams may also contribute to flooding and are not necessarily persistent structures.

Recommended intervention: Incision in erodible-soil streams is best managed with a series of Newbury-style grade controls (Figure 9-6). In Newbury series, grade changes in the reach can be distributed over the rock structures in small steps, sparing the softer bed and banks from scouring flows. The hydraulic roughness and shape of the structures dissipates stream energy. Although the streambanks are high and bank failures possible, the priority is to remove the driving force for continued downcutting. Here the recommended bank restoration is generally limited to areas disturbed during grade control construction.

Estimated Construction Cost: $805,000



INTUITION & LOGIC

Stevens Creek Intervention #4
Tributary 10 – River Mile 5.043 to 4.191

Figure 9-6

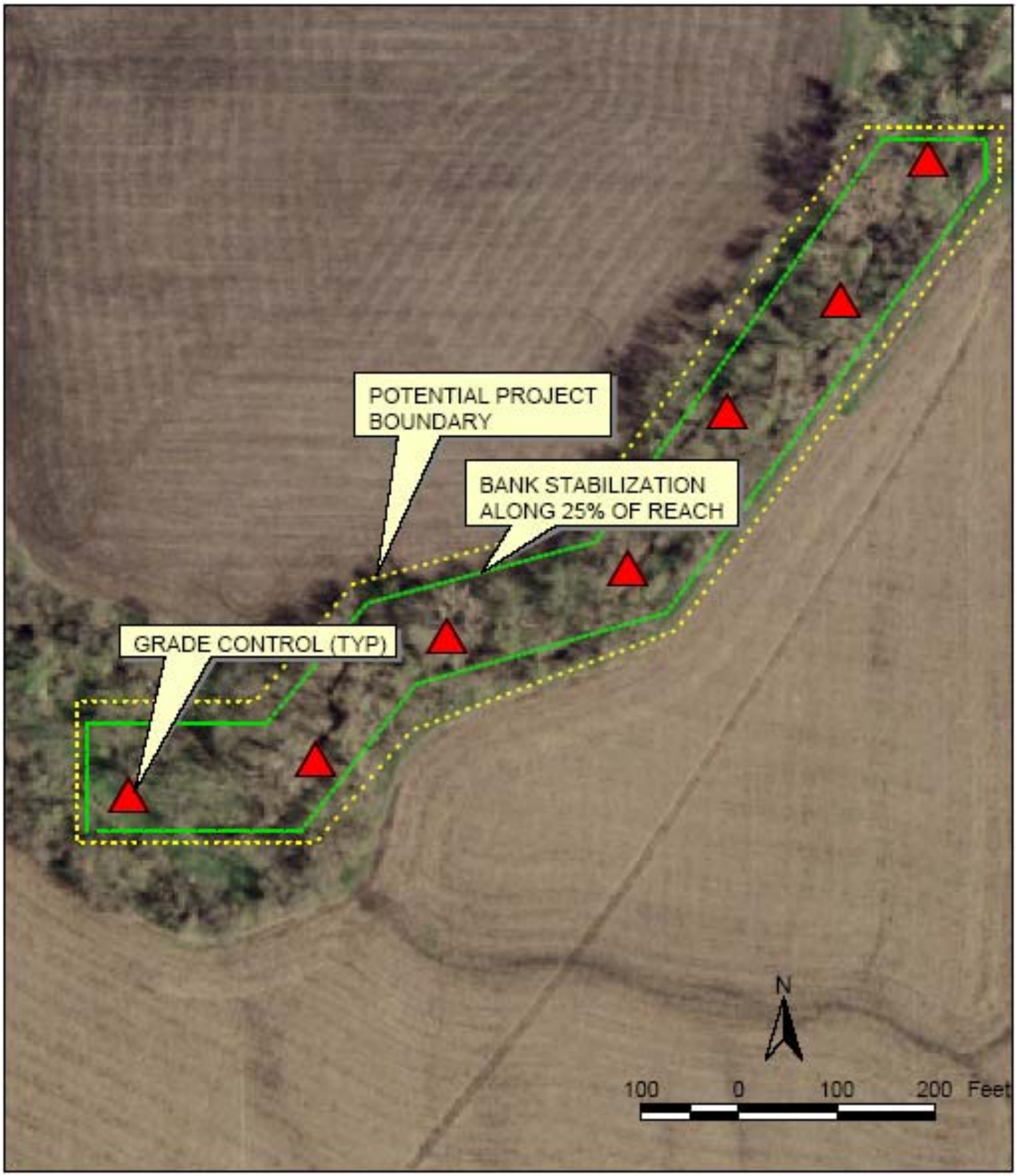
Intervention 5. Tributary 20, River Mile 5.627 to 5.399 - Grade control incising channel

Problem description: Channel incision upstream from the confluence with Stevens Creek Main Stem has resulted in widespread bank erosion. This reach illustrates the far-reaching effects of main channel incision. Here, a previous wave of incision moved up the main channel lowering its grade. In turn, the local change in slope at the mouth of Tributary 20 induced its own incision migrating up this channel and its sub-tributaries. The reach is characterized by steep, undercut banks with extensive undermining of stabilizing tree roots. Once the roots are undermined to this degree, their ability to reinforce the bank is severely compromised. Left untreated, the reach will continue to generate sediment. The excess sediment is detrimental to water quality and when deposited in the main stem in the form of channel bars may contribute to instability there as well.

Recommended intervention: A series of Newbury-style grade controls is an effective treatment for incision. Distributing the grade change over two or more structures lowers the stress on each and lowers the risk of a catastrophic failure (Figure 9-7). The structures should be rock, hydraulically rough and shaped in plan, section and profile to focus and dissipate hydraulic energy. Planting shrub species on the downstream edges of the structures will further dissipate energy and discourage raveling at the soil-rock interface.

Although bank failures may occur on this reach, the treatment priority is arresting incision thereby removing the driving force for bank erosion. Because there are some riparian trees along this reach, the bank stabilization is generally limited to restoring areas disturbed by grade control installation.

Estimated Construction Cost: $311,000



INTUITION & LOGIC

Stevens Creek Intervention #5
Tributary 20 – River Mile 5.627 to 5.399

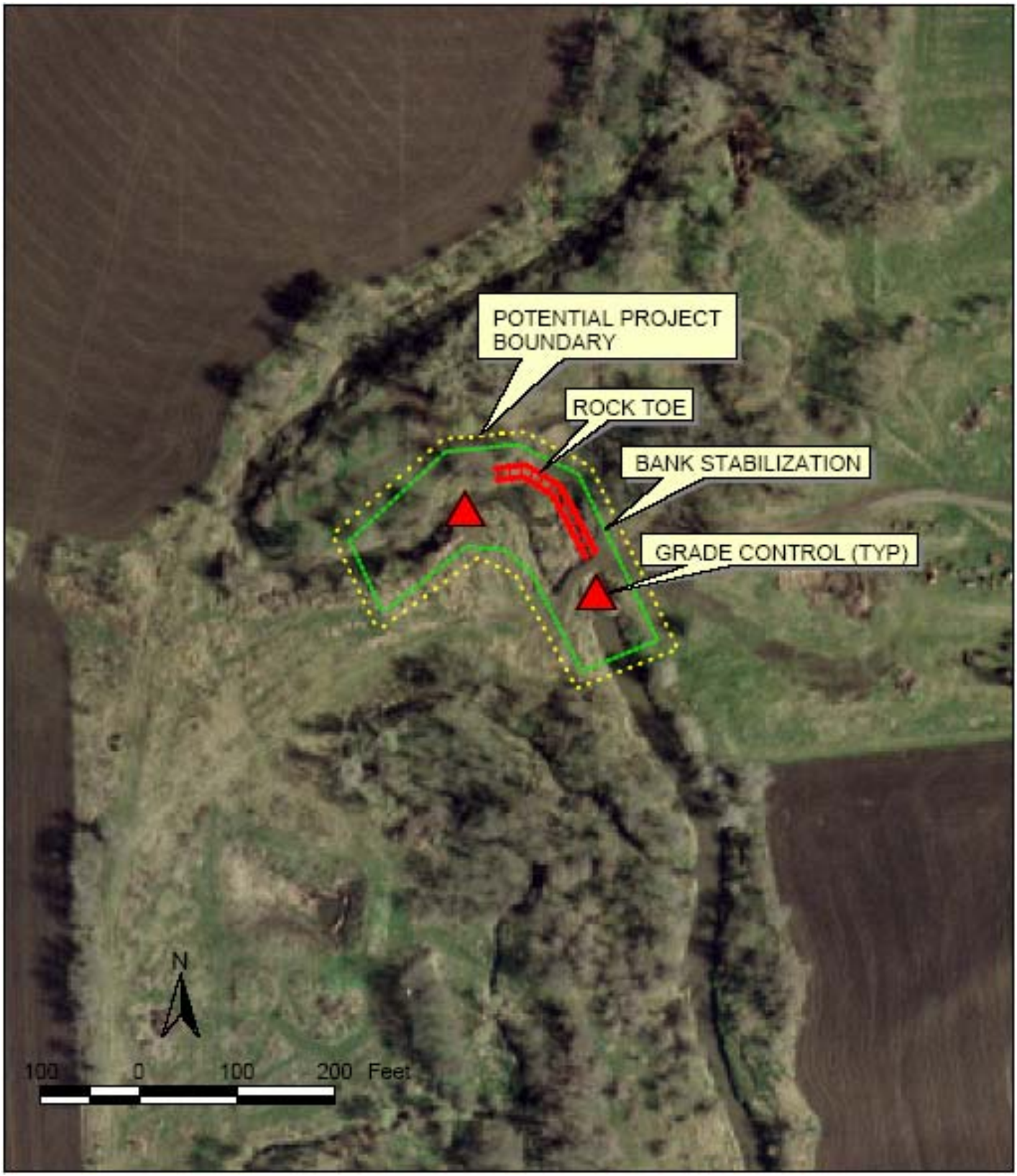
Figure 9-7

Intervention 6. Lower Main Stem, River Mile 7.172 to 7.134 - Restore stable channel geometry and grade control headcut

Problem description: The combined influence of in-stream excavation, failed cattle crossings, and concrete rubble dumping has induced the propagation of a headcut and localized channel widening along 200 feet of Stevens Creek Lower Main Stem. Along the failed crossing, the stream is drastically over-widened. Random actions including rubble dumping often worsen the problem they may have been intended to solve. The channel is severely degraded and aggravating the systemic channel adjustments downstream.

Recommended intervention: This project lies in a sharp meander bend with high stress downstream of the apex of the bend. In addition to a series of designed rock grade control structures, treatment includes rock toe armor along the outside bend and reshaping the channel to restore a more stable geometry (Figure 9-8). The radius of curvature should be slightly flattened. Concrete rubble with no exposed rebar may be broken up and used in the grade controls. In this badly damaged reach, it is also necessary to stabilize the streambank. This task requires reshaping the slopes, installing erosion control blanket and establishing a vigorous stand of woody vegetation.

Estimated Construction Cost: $379,000



INTUITION & LOGIC

Stevens Creek Intervention #6
Lower Main Stem – River Mile 7.172 to 7.134

Figure 9-8

Intervention 7. Tributary 30, River Mile 7.821 to 7.684 - Grade control incising channel

Problem description: Channel incision in the lower reach of Tributary 30 has resulted in widespread bank scouring and erosion upstream from the confluence with Stevens Creek Main Stem. Continued incision in this tributary threatens upstream reaches with further degradation of the channel bed. Bank failures will likely ensue when critical bank height is exceeded. The liberation and transport of the sediment generated by in-channel erosion is detrimental to both the water quality and the physical stability of the main stem. The removal of the woody riparian corridor from part of this reach further weakens the banks.

Recommended intervention: Rock grade control structures are an appropriate treatment for reducing the channel bed slope arresting channel incision. As is the case with the entire watershed, the structures should be of the Newbury style with gradual tail ramps and upstream-facing, arched head ramps. Minor bank stabilization is appropriate along the denuded area and to restore areas disturbed by grade control construction (Figure 9-9).

Estimated Construction Cost: $63,000

INTUITION & LOGIC

Stevens Creek Intervention #7
Tributary 30 – River Mile 7.821 to 7.684

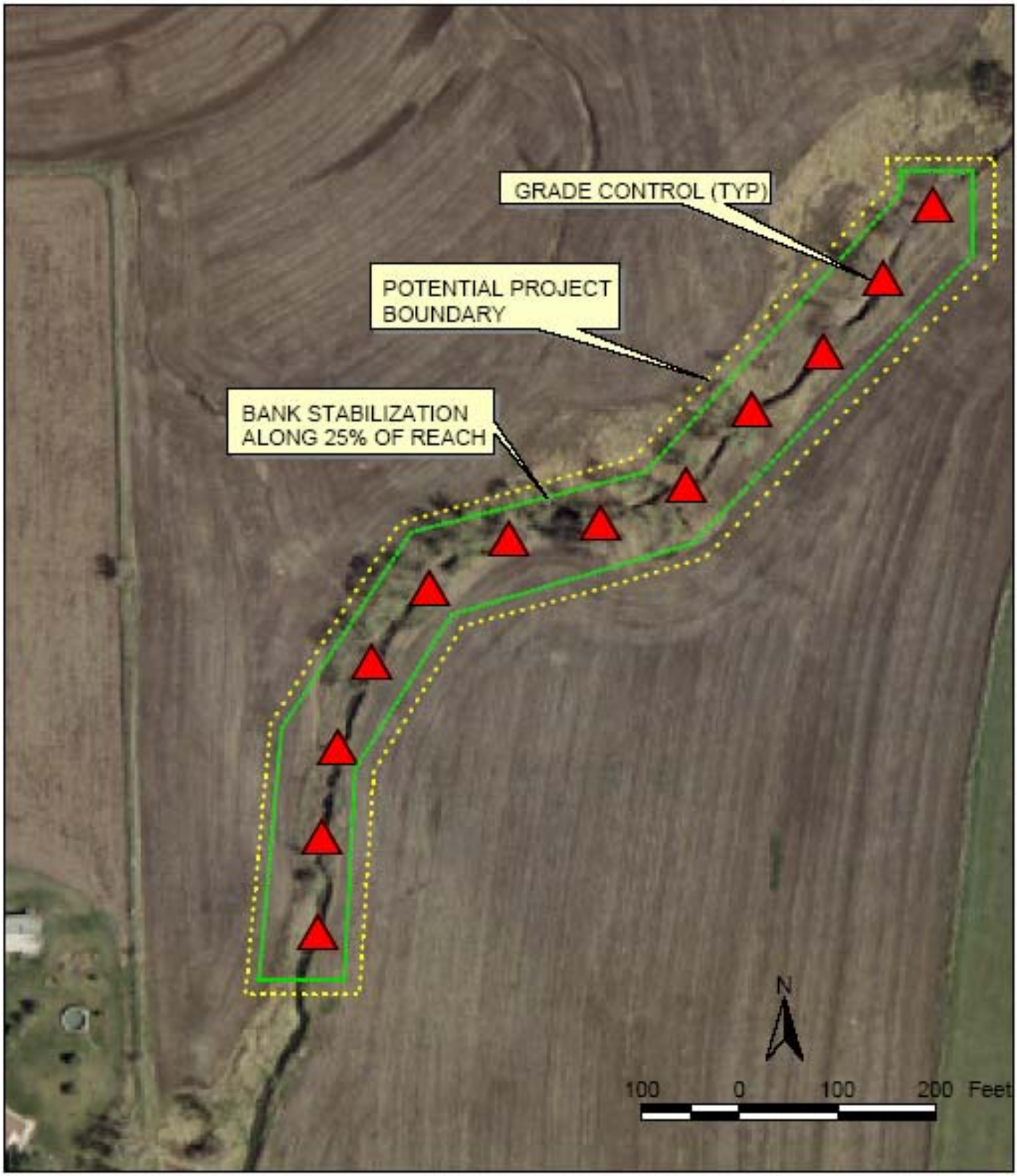
Figure 9-9

Intervention 8. Tributary 35, River Mile 9.878 to 9.575 - Grade control incising channel

Problem description: Channel incision along Tributary 35 has resulted in steep eroding banks and wedge failures. The reach appears to have been previously straightened, a possible contributor to the incision. Nine knickpoints occur along this project reach, each approximately 0.5 to 1 foot vertical drop through consolidated clay or silty clay. There is little in the way of woody riparian corridor and consequently little root reinforcement for the streambanks. No infrastructure or buildings lie along this reach. The threat to the basin lies in the continued generation of sediment damaging both water quality and physical stability of the receiving waters.

Recommended intervention: This is a straightforward application of grade stabilization. A drop of approximately one foot across each grade control is appropriate here. Small, Newbury-style rock structures should be designed to establish a stable slope for a channel bed of this strength. Vegetating the downstream edges of the rock structures is useful for additional energy dissipation and for managing the transition between structure and native channel material. Bank stabilization here is generally limited to restoring areas damaged by grade control installation (Figure 9-10).

Estimated Construction Cost: $309,000



INTUITION & LOGIC

Stevens Creek Intervention #8
Tributary 35 – River Mile 9.878 to 9.575

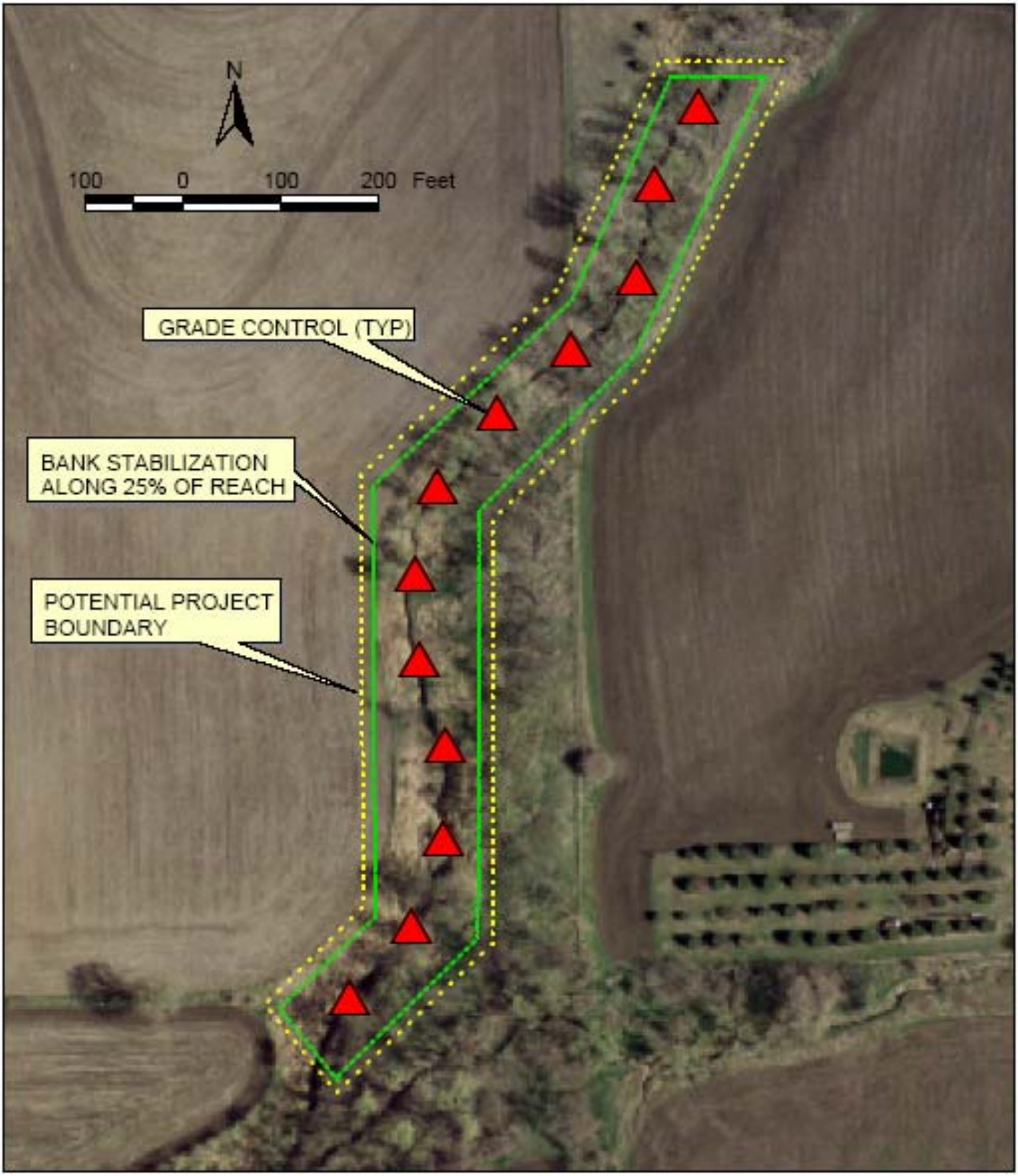
Figure 9-10

Intervention 9. Tributary 35, River Mile 9.239 to 8.844 - Grade control existing knickpoints

Problem description: The upstream advance of several knickpoints has precipitated steep eroding banks and frequent bank failures. Several knickpoints mark dramatic changes in channel bed elevation of more than one foot, including the 3-foot knickpoint immediately downstream of Tributary 35, River Mile 9.234 and an unarmored knickpoint in the clay bed at Tributary 35, River Mile 9.160. Wedge failures are common in this reach. The incision is progressing upstream unimpeded and unless arrested, will continue to liberate sediment damaging to water quality and downstream stability.

Recommended intervention: A series of rock grade control structures is an appropriate treatment here (Figure 9-11). The series, taken as a group, should re-establish a stable grade for the channel bed so that the upstream progress of incision is stopped. The drops at major knickpoints should be distributed over multiple rock structures. A drop of approximately one foot over each grade control should be sufficient. Although the banks are in generally poor condition, once incision is stopped, they may begin to self-heal. Most of the bank restoration effort is directed to repairing areas damaged by grade control construction.

Estimated Construction Cost: $356,000



INTUITION & LOGIC

Stevens Creek Intervention #9
Tributary 35 – River Mile 9.239 to 8.844

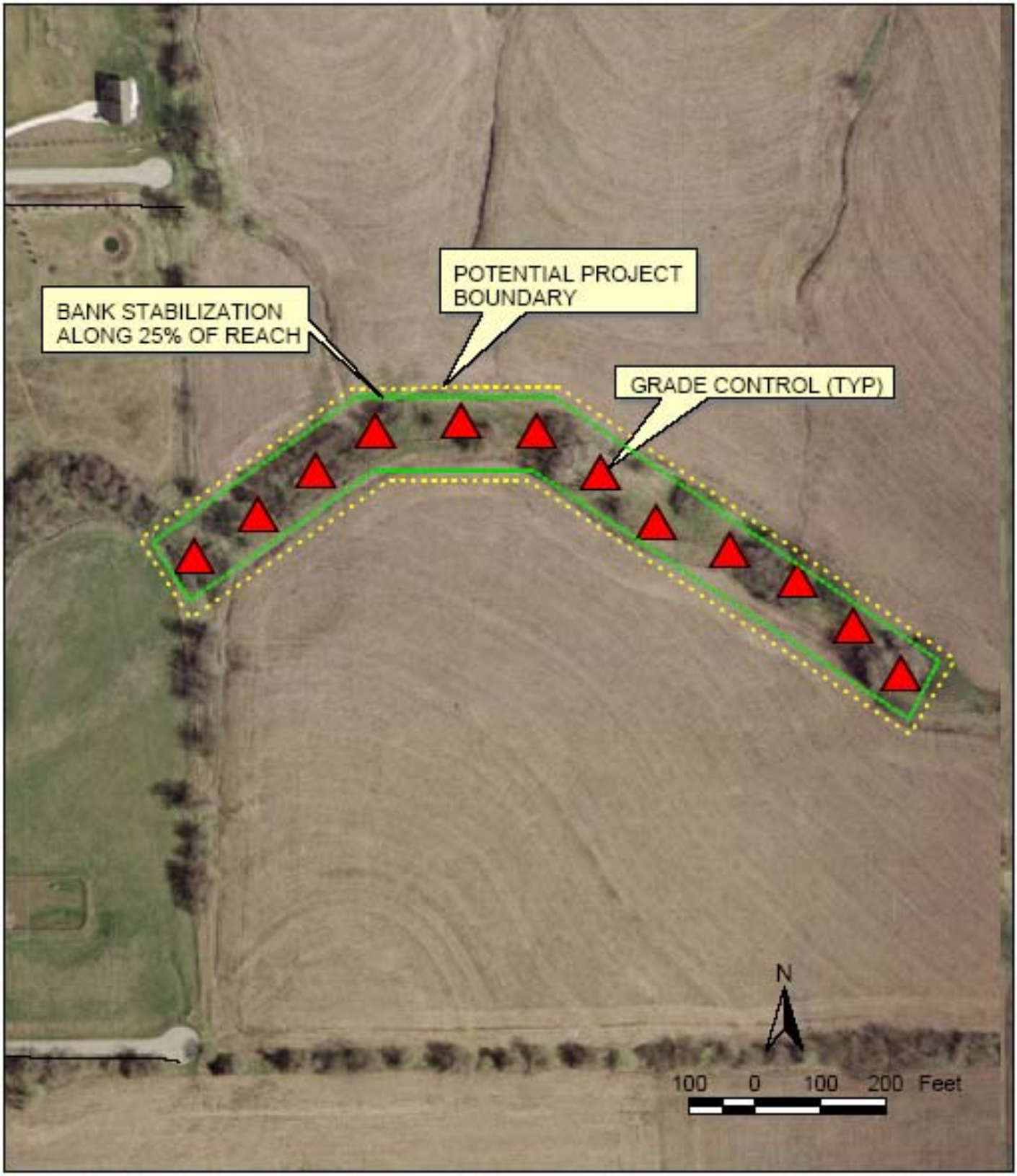
Figure 9-11

Intervention 10. Tributary 130, River Mile 7.754 to 7.489 - Grade control incising channel

Problem description: Tributary 130 is a narrow, entrenched channel with persistent incision-induced bank erosion along the upper 1,500 feet of channel. Bank failures are common throughout the reach. Occasionally the bank failures have doubled the top-of-bank width. The tributary continues to incise and has no existing structure in this reach that is likely to arrest the downcutting in the near future. In this lower reach of the tributary, the canopy cover is poor and there is little root reinforcement of the streambanks. The eroded banks contribute excessive sediment downstream where it impairs water quality. In addition the liberated sediment may contribute to physical instability in the receiving waters.

Recommended intervention: Grade stabilization is the appropriate remedy for both the incision and the bank erosion (Figure 9-12). By re-establishing a stable channel grade, the driving force for continued bank failure is removed and some degree of self-healing can begin. As is the case throughout the basin, relatively flat, Newbury-style rock structures effectively manage the grade change through the reach without inducing excessive scour downstream of the structure. A drop of one foot or less across each rock structure and construction of a gently sloped tail ramp should be sufficient. Vegetating the edges of the structures provides additional scour protection and manages the transition between native channel material and installed structure.

Estimated Construction Cost: $217,000



INTUITION & LOGIC

Stevens Creek Intervention #10
Tributary 130 – River Mile 7.754 to 7.489

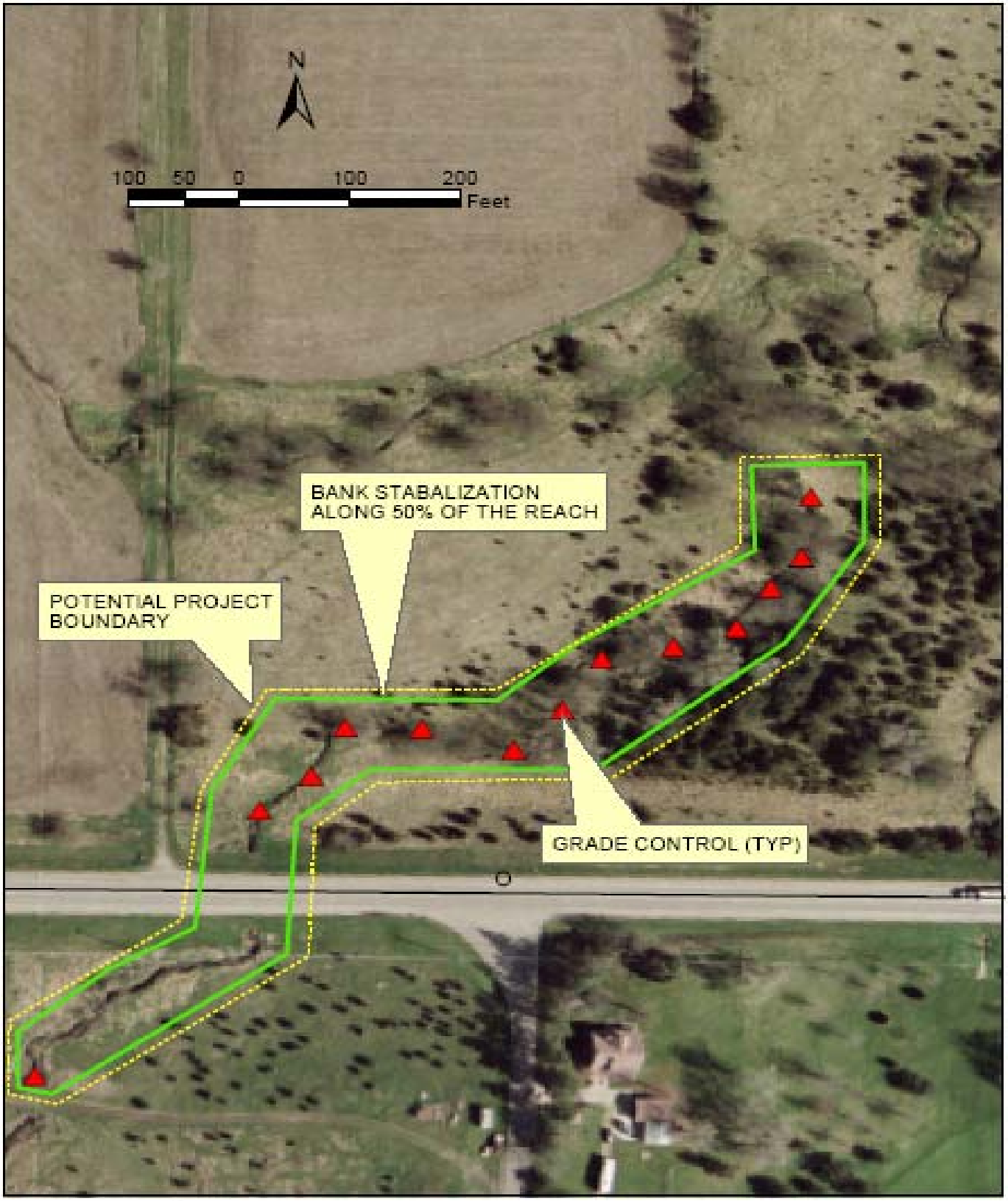
Figure 9-12

Intervention 11. Tributary 30, River Mile 9.972 to 9.364 - Grade control incising channel and armor plunge pool at culvert outfall

Problem description: This tributary has degraded throughout its length. Since the installation of the culvert illustrated at left (a private drive upstream of O Street), the channel has incised approximately 4.5 feet. The culvert provides no energy dissipation and the resulting scour of both bed and bank may eventually threaten the integrity of the crossing. North of the crossing, the woody riparian corridor is sparse and provides little bank protection.

Recommended intervention: Arresting the incision in this reach requires a series of rock grade controls (Figure 9-13). Newbury-style grade structures with gradually sloping tail ramps are appropriate here. Vegetating the downstream edges of the rock structures provides additional energy dissipation and protection for the interface between rock and native bank. The downstream side of the culvert requires construction of a riprap lined scour pool to dissipate energy properly. The scour pool should be sized so that the applied shear stress at the downstream edge does not exceed the critical shear strength of the bed. The poor condition of the woody corridor and the extensive grade control required here also necessitates restoration of approximately 50% of the streambank. Most of this effort is concentrated at areas disturbed by grade control construction but also includes establishment of trees and shrubs along the denuded bank.

Estimated Construction Cost: $703,000



INTUITION & LOGIC

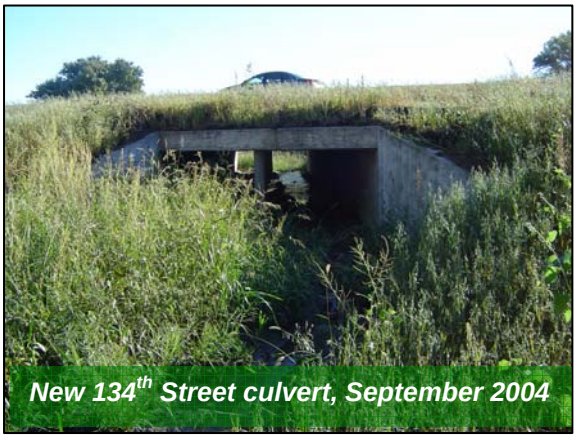
Stevens Creek Intervention #11
Tributary 30 – River Mile 9.972 to 9.364

Figure 9-13

Intervention 12. Tributary 250, River Mile 12.692 to 11.740 - Grade control channel

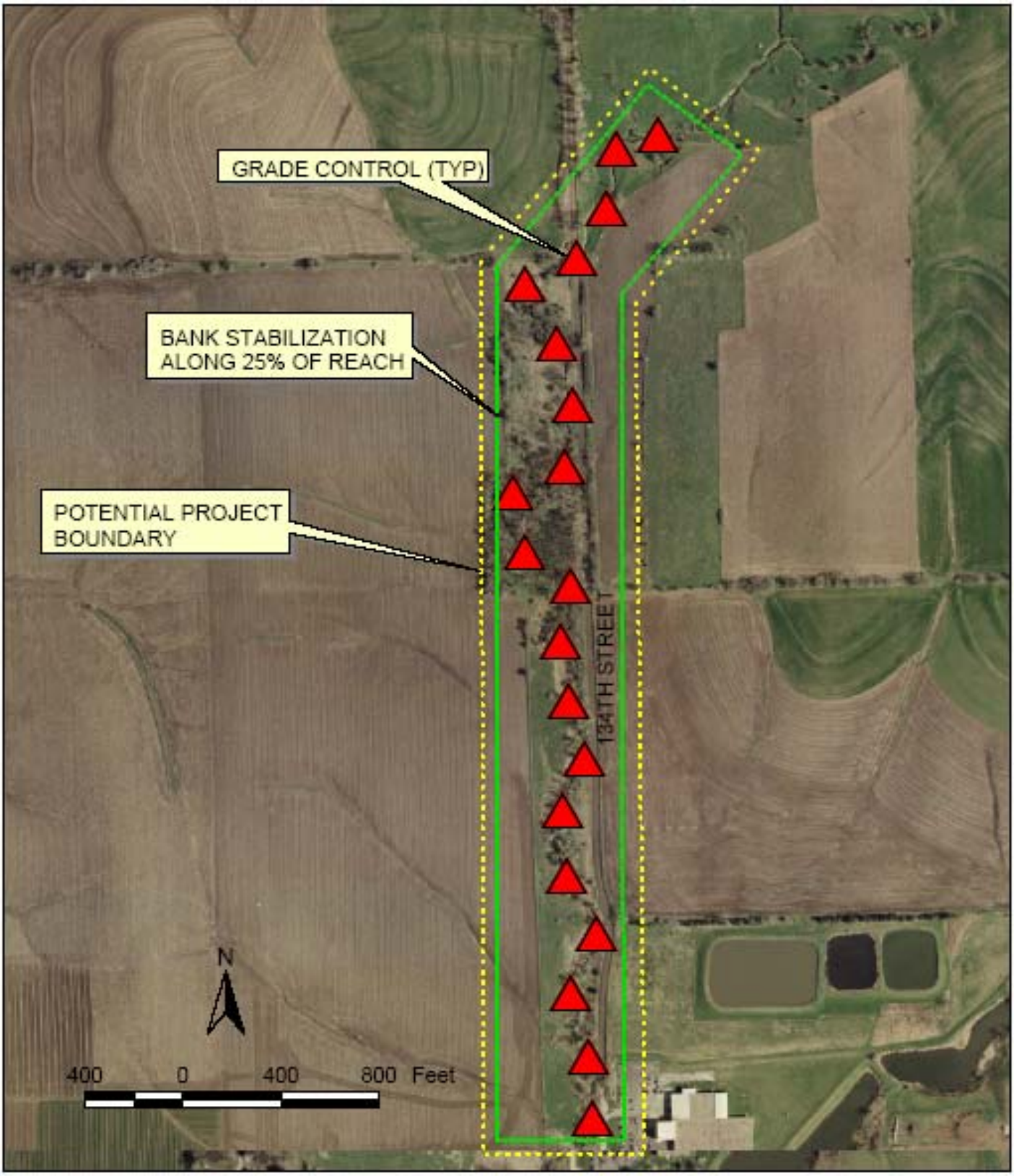
134 Street culvert, March 2004

Problem description: During the field reconnaissance of Tributary 250 in March 2004, the culvert under 134th Street had an invert 3 feet above pool elevation and both banks were severely eroded. The culvert has since been replaced with a double box culvert at channel grade, and local bank scouring in the vicinity of 134th Street has been repaired (see picture below). However, bank erosion extends downstream as a result of continued channel incision. The reach confined by the farm fields and 134th Street is distinctly less sinuous than the adjacent streams. The additional increase in channel slope caused by a presumed straightening has increased the driving force for incision. Knickpoints are common throughout the reach occurring roughly 500 feet apart. In addition to bank failures and threats to infrastructure, this tributary supplies excess sediment to the receiving waters degrading water quality and potentially decreasing physical instability. If left untreated, channel incision will progress upstream, posing a threat to the new culvert at 134th Street.


New 134th Street culvert, September 2004

Recommended intervention: Downstream of the culvert, a series of rock grade control structures will control channel grade and dissipate scouring energy. In addition, three grade controls upstream of 134th Street will mitigate a draw-down effect, resulting from the lower elevation of the new culvert, which could exacerbate existing erosion problems upstream. In this basin, relatively flat Newbury-style structures are appropriate. The grade change across each structure should be no more than 1 foot.

Estimated Construction Cost: $906,000



INTUITION & LOGIC

Stevens Creek Intervention #12
Tributary 250 – River Mile 12.692 to 11.740

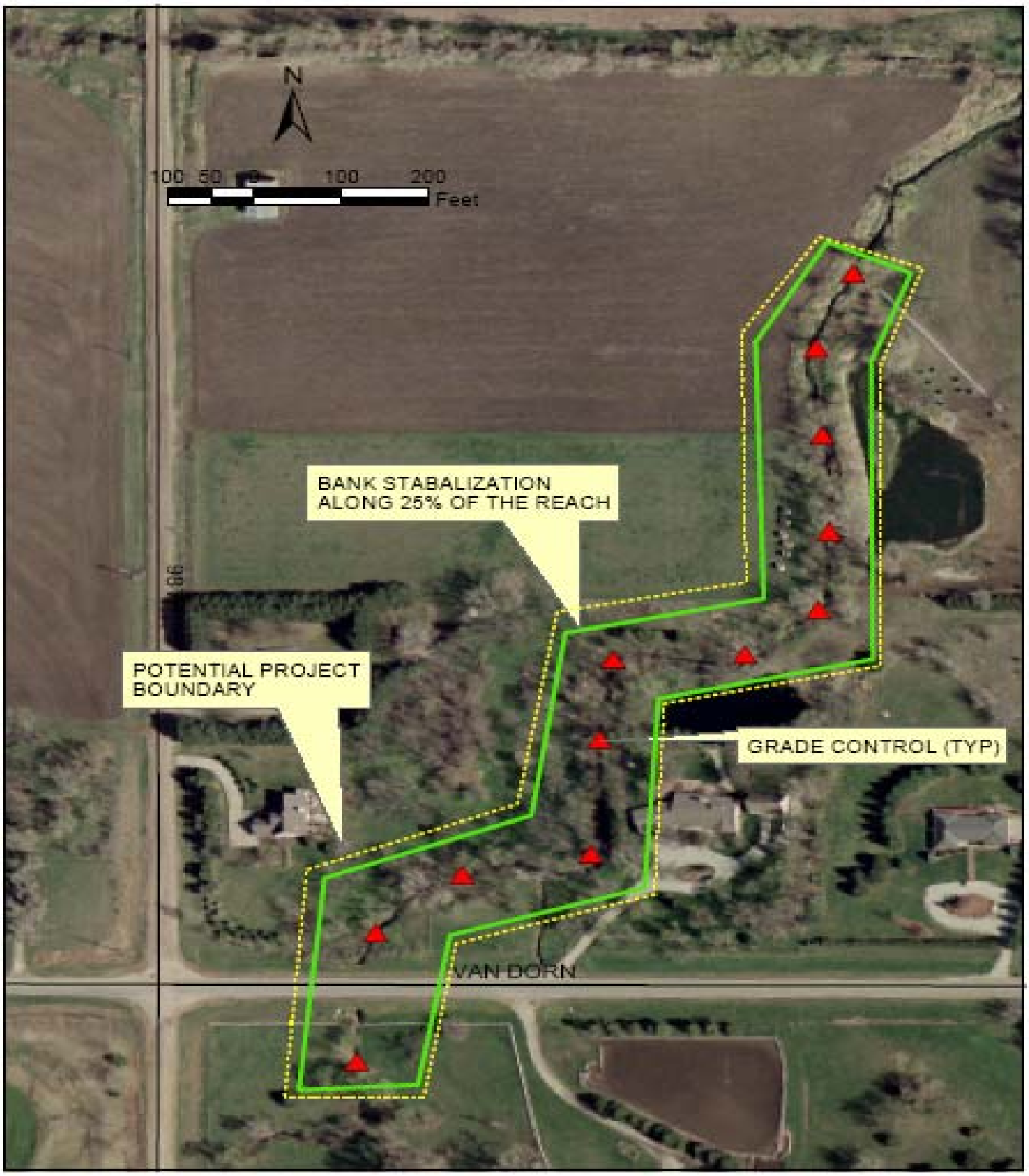
Figure 9-14

Intervention 13. Tributary 45, River Mile 13.762 to 13.468 - Grade control incising channel

Problem description: Extensive bank scouring and erosion caused by channel incision dominate this reach of Tributary 45. The knickpoints are relatively close together (five occur between 98th Street and Van Dorn) and are typically reinforced by woody debris jams. Natural streams in this region often self-manage incision by constructing grade controls from large woody debris. In undisturbed conditions, this may be sufficient to stabilize grade and re-acquire dynamic equilibrium. In this developing watershed, however, the risks associated with relying exclusively on debris jams for incision control outweigh the benefits. In addition to raising flood levels, the debris jams may fail under intense flows potentially blocking bridges or culverts.

Recommended intervention: A series of rock structures provides more persistent grade stabilization than debris jams. The structures should be hydraulically rough, shaped in plan, profile and section to direct flows to the center of the channel and relatively flat. Producing a stable, non-eroding channel grade removes most of the driving force for bank failures. For this reason, extensive bank stabilization is not warranted and most of the bank effort is focused on repairing the areas disturbed by grade control installation (Figure 9-15).

Estimated Construction Cost: $299,000



INTUITION & LOGIC

Stevens Creek Intervention #13
Tributary 45 – River Mile 13.762 to 13.468

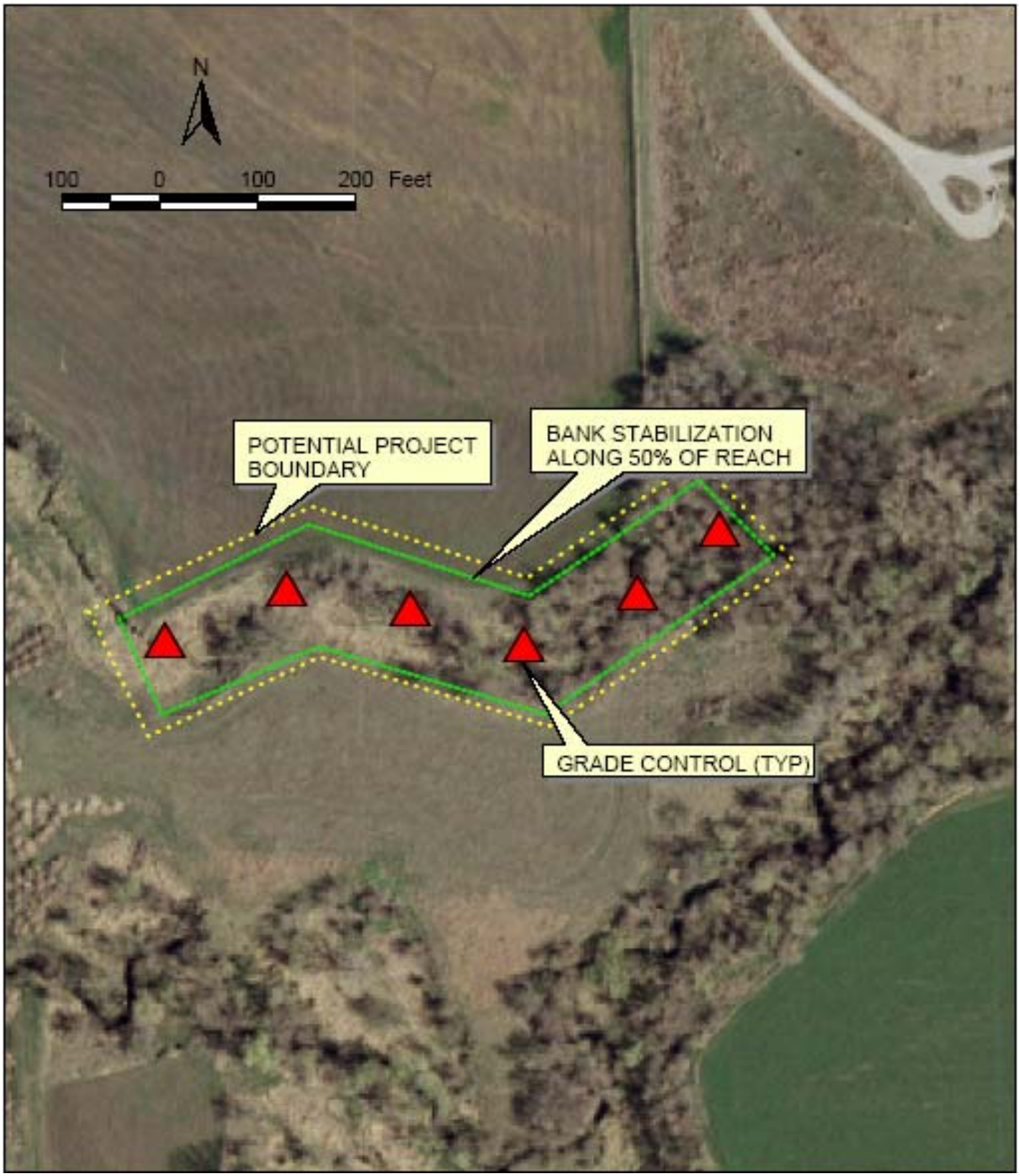
Figure 9-15

Intervention 14. Tributary 445, River Mile 12.802 to 12.656 - Grade control existing knickpoints

Problem description: Tributary 445 is an incising stream, with several knickpoints occurring between the confluence with Tributary 45 and the headwaters reach of the tributary. Although previous incision and occasional bank scour is apparent in the tributary, this stream also exhibits signs of recovery. Parts of the reach are now metastable and barring additional insult, should self-manage. However, the receiving waters, Tributary 45 is continuing to incise and a knickpoint in Tributary 445 indicates that this grade change is propagating up the sub-tributary. Unless arrested, another wave of incision will move through this sub-basin.

Recommended intervention: The active knickpoints should be arrested. A series of rock grade controls is an appropriate treatment (Figure 9-16). In the relatively erodible soils of the Stevens Creek Watershed, Newbury-style structures effectively manage grade changes without inducing scour. The change in grade should be distributed over a series of structures with no one grade control dropping more than approximately one foot. The structures should be hydraulically rough and should be shaped in plan, section and profile to focus the flow towards the center of the channel. The focus of the bank stabilization is repair of areas disturbed by grade control construction.

Estimated Construction Cost: $307,000



INTUITION & LOGIC

Stevens Creek Intervention #14
Tributary 445 – River Mile 12.802 to 12.656

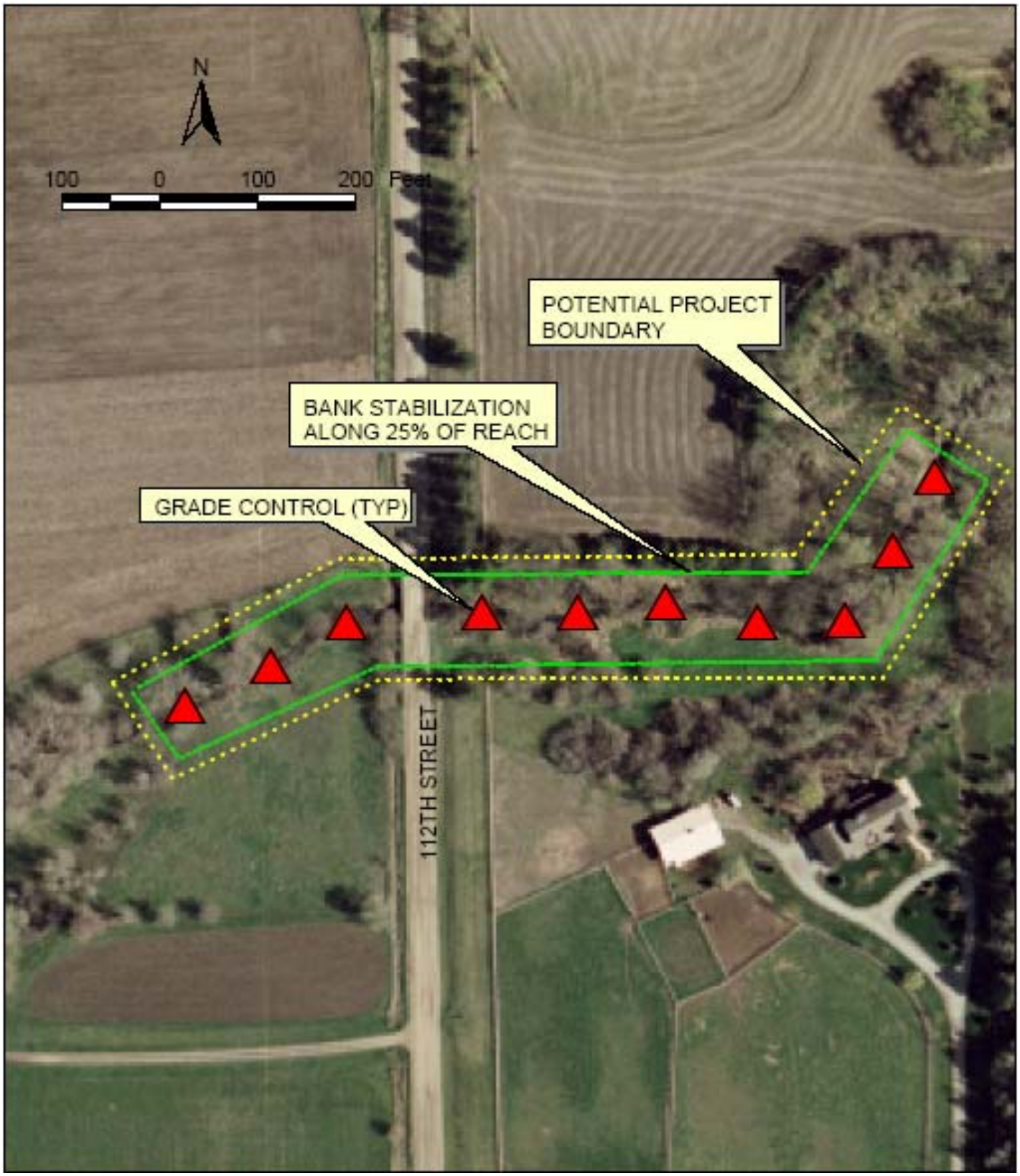
Figure 9-16

Intervention 15. Tributary 45, River Mile 12.114 to 11.641 - Grade control incising channel

Problem description: Channel incision has resulted in widespread bank scouring and erosion between Tributary 45, River Mile 2.727 and 2.254. Circular and wedge failures continue to introduce large volumes of sediment and woody debris into the channel. Several woody debris jams appear to have slowed the advance of incision. However, the effects of incision do not subside upstream, and continued damage to surrounding farm fields and riparian corridor is likely without intervention.

Recommended intervention: Constructing a series of rock grade controls is necessary to halt channel incision and prevent systemic bank erosion. As is the case throughout the watershed, relatively flat, Newbury-style rock structures effectively manage the grade change through the reach without inducing excessive scour downstream of the structure. A drop of one foot or less across each rock structure and construction of a gently sloped tail ramp should be sufficient. Vegetating the edges of the structures provides additional scour protection and manages the transition between native channel material and installed structure (Figure 9-17).

Estimated Construction Cost: $435,000



INTUITION & LOGIC

Stevens Creek Intervention #15
Tributary 45 – River Mile 12.114 to 11.641

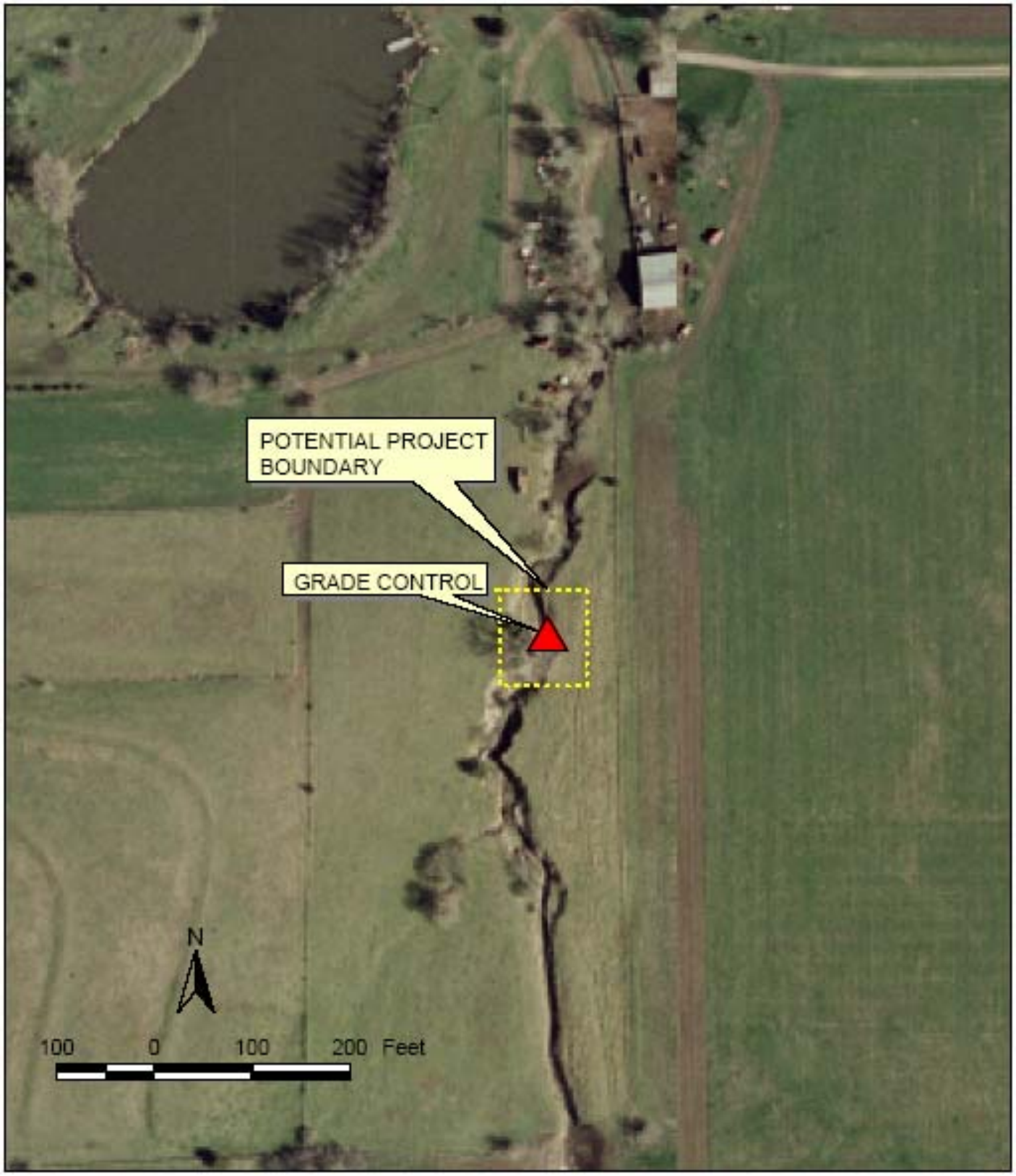
Figure 9-17

Intervention 16. Tributary 345, River Mile 12.406 to 12.403 - Grade control existing knickpoint

Problem description: A 3.5-foot headcut occurs in silty clay bed material along Tributary 345, near River Mile 12.406. The advancing headcut has precipitated widespread bank erosion downstream. Upstream of the headcut, past channel incision has resulted in a deep, "V"-shaped channel with banks very near critical bank height. Should the headcut continue to advance unimpeded, this would likely aggravate existing erosion problems upstream as banks exceeded critical bank height.

Recommended intervention: A rock grade control is recommended to halt the advancing headcut and maintain a stable channel grade upstream. A single, strategically placed grade control will alleviate the driving force for bank failure and avert an otherwise costly stream restoration effort in the future, as banks fail catastrophically once they have exceeded critical bank height (Figure 9-18).

Estimated Construction Cost: $35,000



INTUITION & LOGIC

Stevens Creek Intervention #16
Tributary 345 – River Mile 12.406 to 12.403

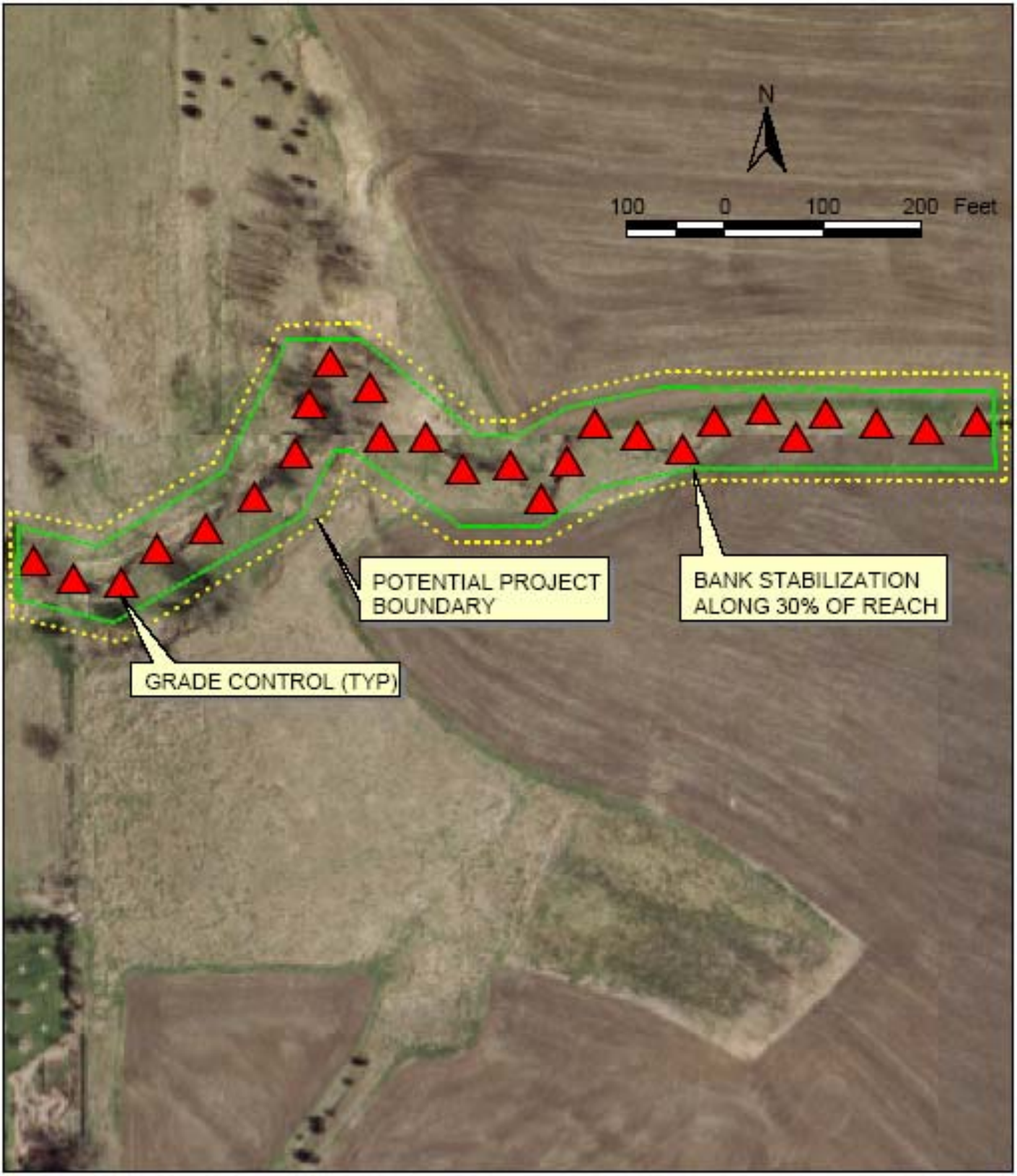
Figure 9-18

Intervention 17. Tributary 545, River Mile 13.579 - Grade control incising channel and restore streambanks

Problem description: Channel incision and subsequent widening along Tributary 545 has initiated severe bank erosion and mass wasting as banks exceeded critical bank height. While channel incision has been slowed by several large woody debris jams acting as *de facto* grade controls, widening occurring between knickpoints continues to liberate sediment from the streambanks and undermine trees, compromising channel stability and impairing water quality.

Recommended intervention: Constructing a series of rock grade controls is necessary to replace existing woody debris jams and stop systemic bank erosion (Figure 9-19). By re-establishing a stable channel grade, the driving force for continued bank failure is removed and some degree of self-healing can begin. As is the case throughout the watershed, relatively flat, Newbury-style rock structures effectively manage the grade change through the reach without inducing excessive scour downstream of the structure. Approximately 26 grade controls, each accommodating a 1-foot drop in channel bed elevation, are recommended to achieve a stable channel grade along the 3,000-foot reach. Vegetating the edges of the structures provides additional scour protection and manages the transition between native channel material and installed structure. Where the effects of mass wasting and erosion are particularly severe, regrading and vegetating the banks will be necessary to provide a stable bank shape and hydraulic roughness.

Estimated Construction Cost: $659,000

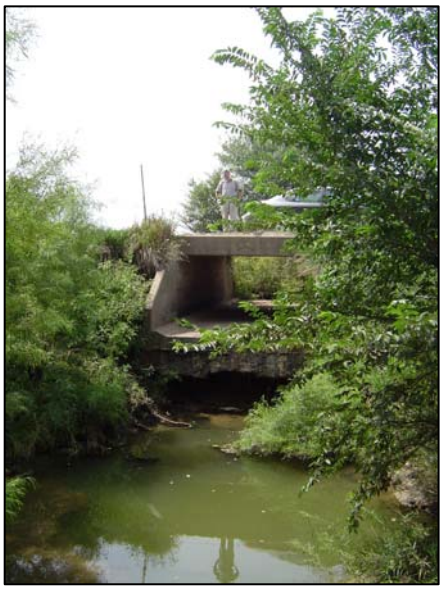


INTUITION & LOGIC

Stevens Creek Intervention #17
Tributary 545 – River Mile 13.579

Figure 9-19

Intervention 18. Tributary 545, River Mile 13.579 - Armored plunge pool downstream of 98th Street culvert



Problem description: Bed scouring downstream of 98th Street has produced a 2-foot drop at the culvert outfall. Due to a lack of bed armoring, localized scouring continues to undermine the lip of the concrete box, threatening the structural integrity of the culvert.

Recommended intervention: Due to the severity of localized erosion downstream of 98th Street, a riprap-armored plunge pool at the culvert outfall is necessary to dissipate energy and prevent continued bed scouring (Figure 9-20). The armored plunge pool should be sized so that the applied shear stress at the downstream edge does not exceed the critical shear strength of the bed. Both banks are already well-vegetated and show no signs of fresh erosion. Therefore, additional bank stabilization is not needed.

Estimated Construction Cost: $137,000

INTUITION & LOGIC

Stevens Creek Intervention #18
Tributary 545 – River Mile 13.579

Figure 9-20

Intervention 19. Tributary 45, River Mile 0.042 to 0.008 - Grade control confluence

Problem description: A headcut occurs along Tributary 45, no more than 40 feet upstream from the confluence with Stevens Creek Lower Main Stem. Channel incision along Tributary 45 has resulted in widespread bank erosion and failures, and the upstream advance of yet another headcut would aggravate existing erosion problems along this tributary.

Recommended intervention: The active knickpoint upstream of the confluence should be arrested. A Newbury-style grade control structure will effectively manage grade changes in the lower reach of Tributary 45 without aggravating existing bank scour. The change in grade can be accommodated in a single structure with a grade change of approximately 1 foot (Figure 9-21). The structures should be hydraulically rough and should be shaped in plan, section and profile to focus the flow towards the center of the channel. The focus of the bank stabilization is repair of areas disturbed by grade control construction.

Estimated Construction Cost: $44,000

INTUITION & LOGIC

Stevens Creek Intervention #19
Tributary 45 – River Mile 9.429 to 9.395

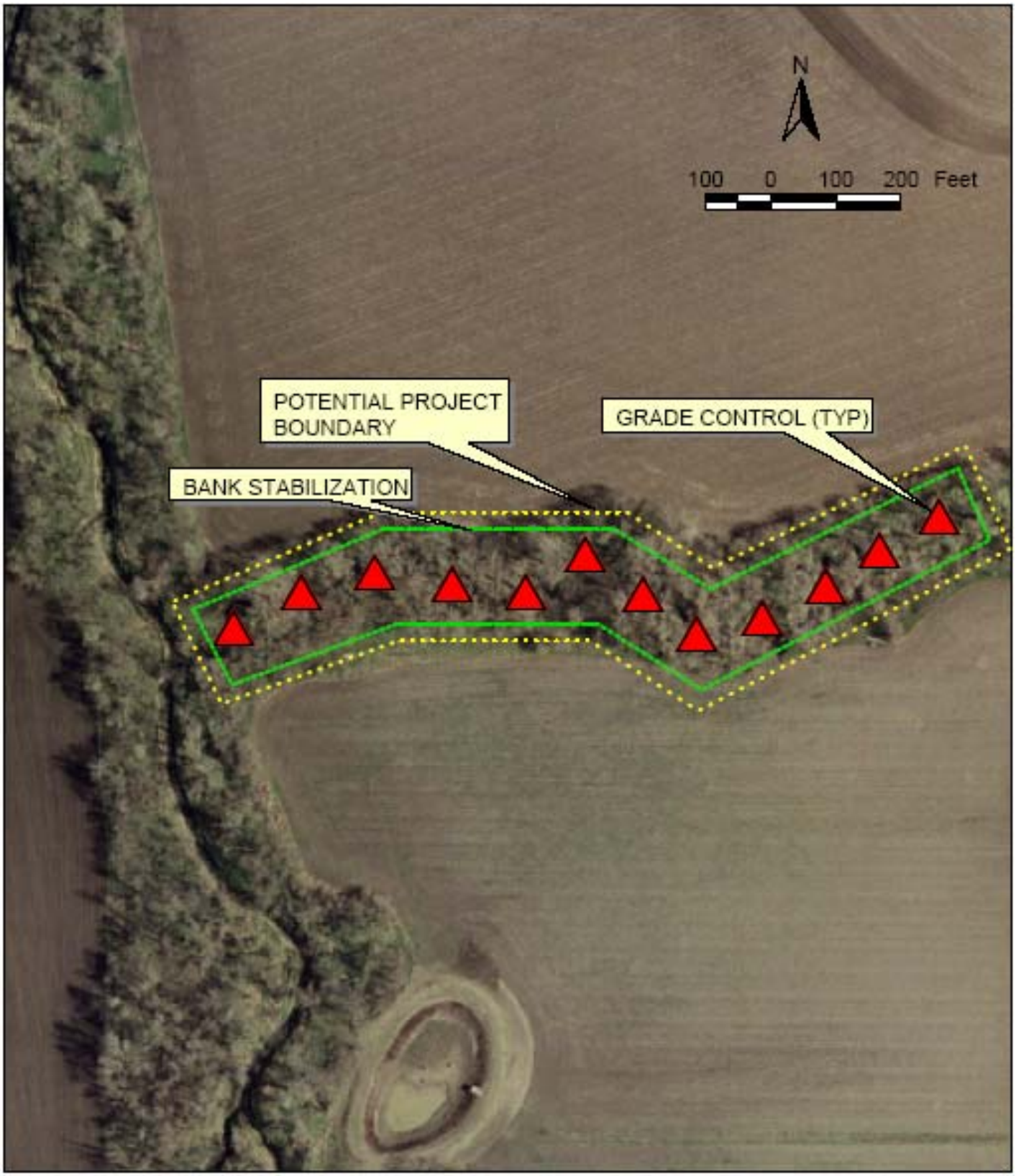
Figure 9-21

Intervention 20. Tributary 55, River Mile 11.472 to 11.245 - Grade control incising channel

Problem description: Tributary 55 is a deeply incised channel with several severe knickpoints occurring along the lower 1,400 feet of channel. The largest and most dramatic example is a 4-foot headcut in consolidated clay or till bed material near River Mile 11.472. In contrast to other incising reaches encountered in the Stevens Creek Watershed, woody debris and toppled trees have failed to slow incision along Tributary 55. It appears that incision will continue unimpeded, resulting in substantial damage to the stream, without additional interventions.

Recommended intervention: Arresting the incision in this reach requires a series of Newbury-style rock grade controls. Vegetating the downstream edges of the rock structures provides additional energy dissipation and protection for the interface between rock and native bank (Figure 9-22). The poor condition of the woody corridor and the extensive grade control required along this reach also necessitates restoration of 100% of the streambank. This effort includes both areas disturbed by grade control construction as well as the establishment of trees and shrubs along the entire intervention reach.

Estimated Construction Cost: $460,000



INTUITION & LOGIC

Stevens Creek Intervention #20
Tributary 55 – River Mile 11.472 to 11.245

Figure 9-22

Intervention 21. Tributary 65, River Mile 12.547 to 12.536 - Armored plunge pool downstream of 134th Street culvert

Problem description: The 134th Street culvert has an exceptionally steep grade and, as a result, the bed and banks at the culvert outfall are severely scoured. In addition, incision up to the culvert outfall has aggravated bank erosion immediately downstream.

Recommended intervention: Constructing an armored plunge pool at the culvert outfall will dissipate hydraulic energy and prevent continued bank erosion at the culvert outfall (Figure 9-23). The armored plunge pool should be sized to release flows at shear stresses below the critical shear strength of the native channel material. A critical design feature of the armored plunge pool is the addition of a grade control outfall, keyed-in deep into the channel bed to prevent channel incision from potentially undermining the structure. The grade control outfall will also focus flow toward the center of the channel, thereby reducing stress along both banks.

Estimated Construction Cost: $137,000

INTUITION & LOGIC

Stevens Creek Intervention #21
Tributary 65 – River Mile 12.547 to 12.536

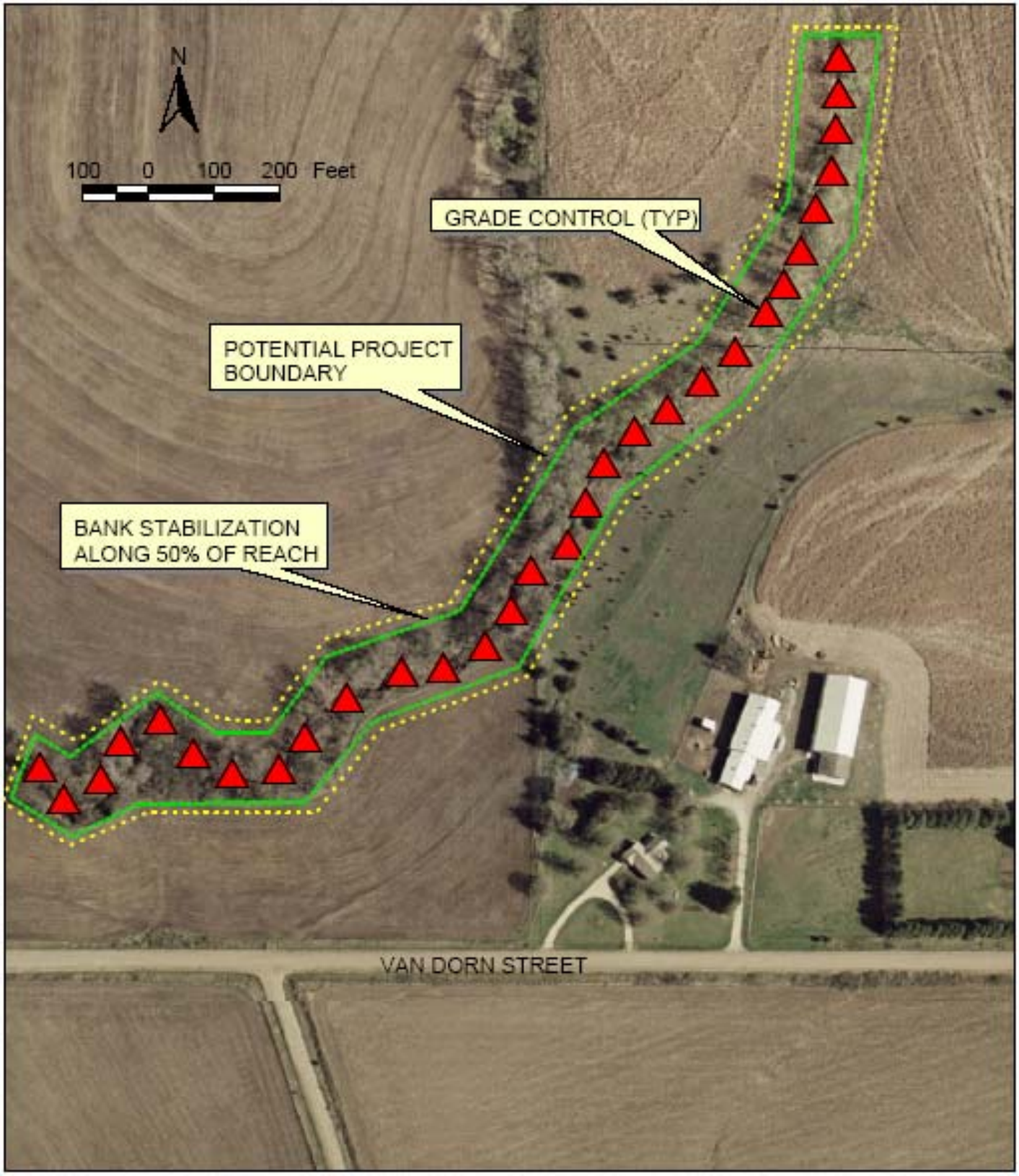
Figure 9-23

Intervention 22. Tributary 65, River Mile 12.945 to 12.547 – Grade control existing knickpoint

Problem description: The extent of channel incision along Tributary 65 is marked by a 5-foot headcut near Tributary 65, River Mile 12.949. The upstream advance of the headcut appears to have been temporarily slowed by dumped concrete slabs and debris acting as a *de facto* grade control. Continued incision along this reach will eventually undermine the concrete slabs and debris that are currently supporting a stable channel grade upstream, liberating additional sediment, and posing a threat to channel stability and water quality.

Recommended intervention: The existing concrete rubble and debris should be removed and replaced with a series of grade controls extending downstream to Tributary 65, River Mile 12.911 (Figure 9-24). Small, Newbury-style rock structures should be designed to establish a stable slope. The drops at major knickpoints should be distributed over multiple rock structures. Although the banks along Tributary 65 are in poor condition, once incision is stopped, they may begin to self-heal.

Estimated Construction Cost: $332,000



INTUITION & LOGIC

Stevens Creek Intervention #22
Tributary 65 – River Mile 12.949 to 12.911

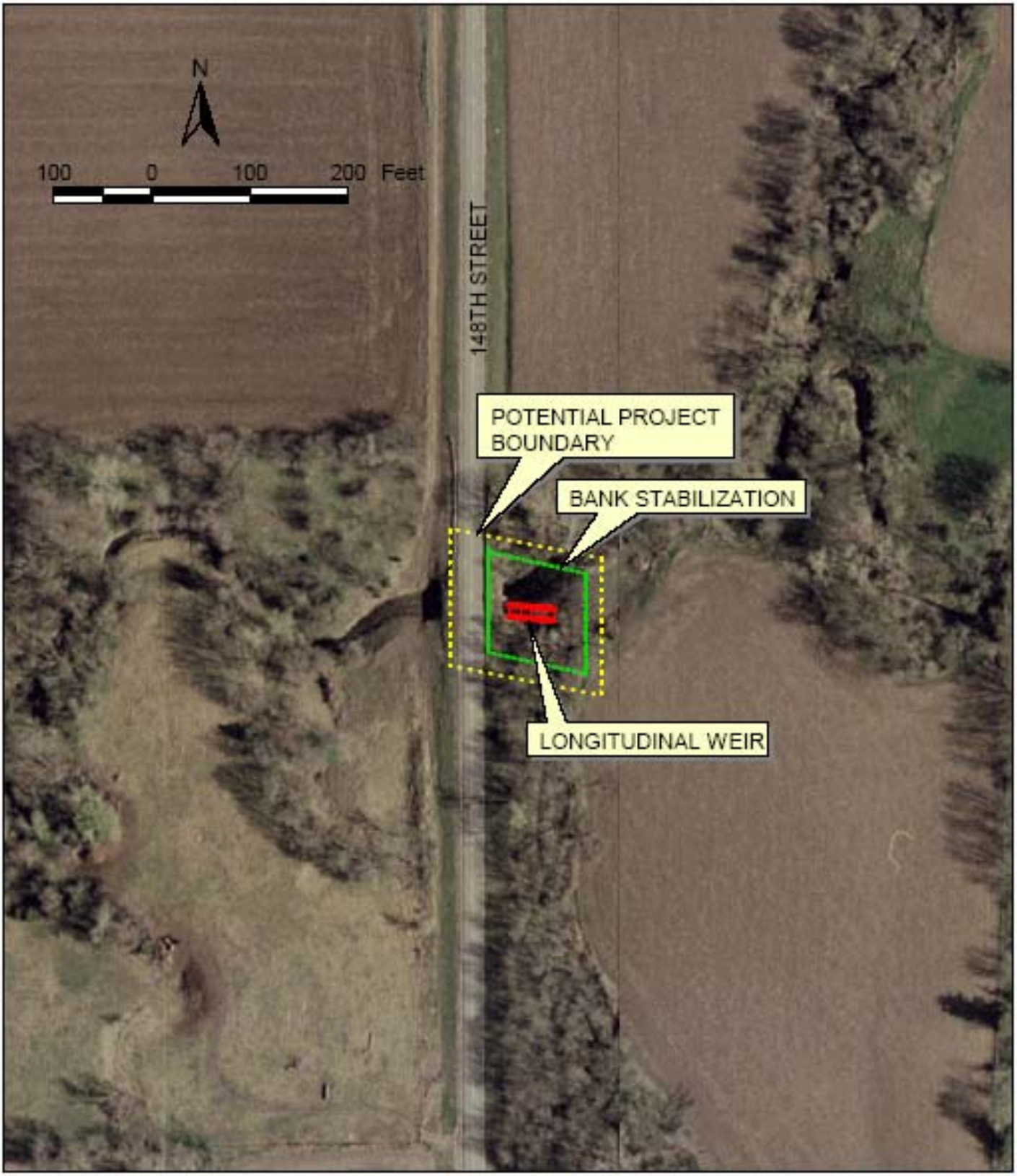
Figure 9-24

Intervention 23. Tributary 70, River Mile 15.283 – Longitudinal weir upstream of culvert

Problem description: Deposition and accumulation of large woody debris in the right descending box of the 148th Street culvert has reduced hydraulic capacity and poses an increased flood risk. While simply removing the deposition and debris may temporarily increase capacity through the culvert, it would also induce upstream erosion as the stream re-establishes a stable hydraulic grade, and eventually replace the removed material with freshly eroded sediment and debris.

Recommended intervention: The long-term solution is to remove the accumulated debris upstream of the culvert and to replace it with a longitudinal weir (Figure 9-25). The weir would be designed to direct low flow through a single box, maintaining sediment transport continuity during stream-forming flow, but allowing for additional flow capacity through the second box during higher flood flows.

Estimated Construction Cost: $71,000



INTUITION & LOGIC

Stevens Creek Intervention #23
Tributary 70 – River Mile 15.283

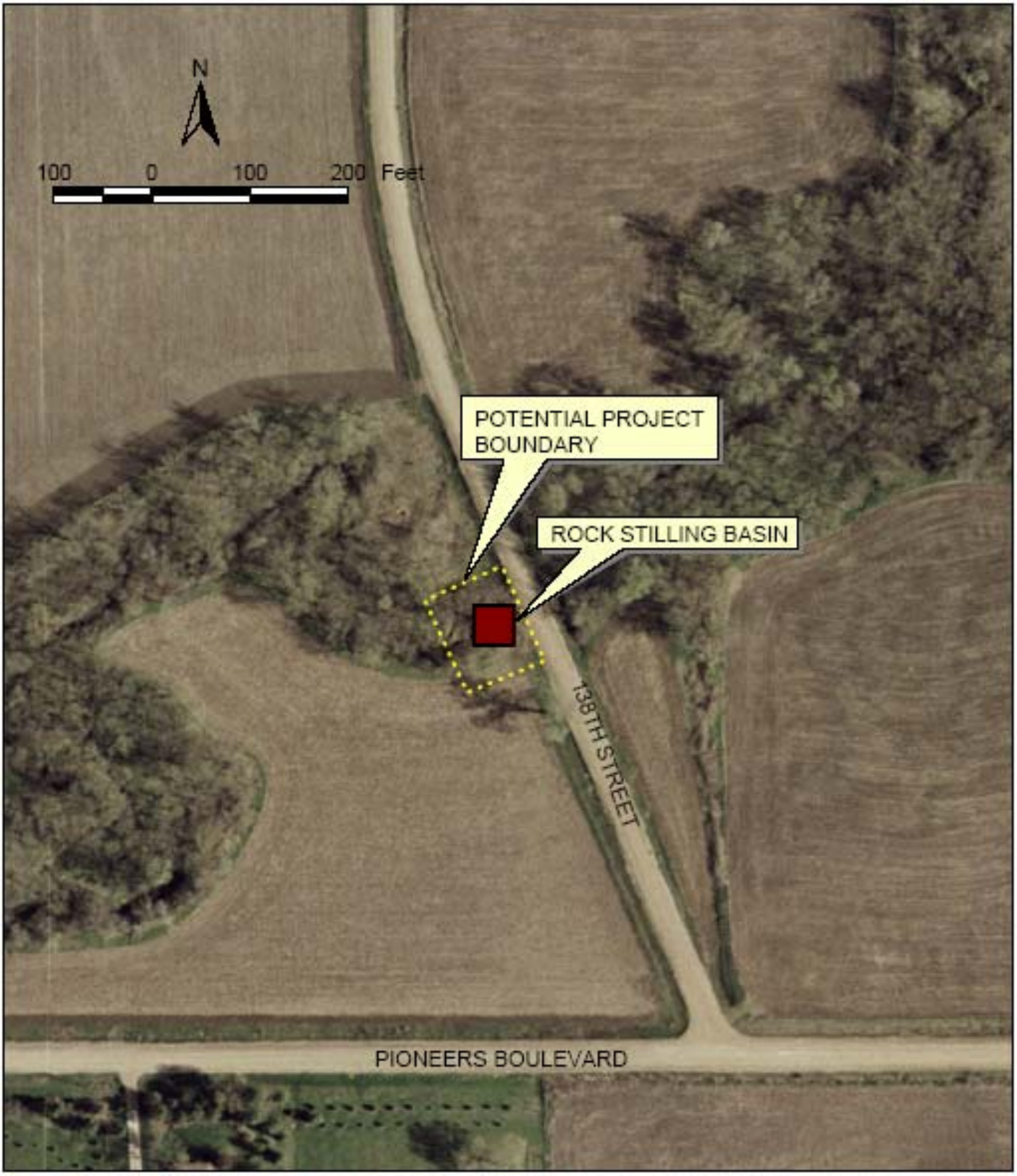
Figure 9-25

Intervention 24. Tributary 75, River Mile 15.056 – Stilling basin with grade control outfall

Problem description: Past incision has scoured the channel bed along Tributary 75, leaving the 138th Street culvert outfall perched 4.5 feet above the channel bed. In addition, a series of knickpoints downstream of the culvert, near the confluence with Stevens Creek Upper Main Stem, indicates more recent channel incision advancing upstream, posing an added threat to the already undermined culvert.

Recommended intervention: Constructing an armored stilling basin at the culvert outfall will dissipate hydraulic energy and protect the bed and banks from the effects of localized scour (Figure 9-26). The stilling basin should be sized so that the applied shear stress at the downstream edge does not exceed the critical shear strength of the bed. Similar to previously described outfall protection, a key design element of the stilling basin is the addition of a grade control outfall. The grade control outfall must be keyed-in deep into the channel bed to prevent channel incision from undermining the structure.

Estimated Construction Cost: $137,000



INTUITION & LOGIC

Stevens Creek Intervention #24
Tributary 75 – River Mile 15.056

Figure 9-26

Intervention 25. Tributary 60, River Mile 11.320 to 11.314 – Stilling basin with grade control outfall

Problem description: Tributary 60 is currently widening subsequent to channel incision. The extent of past incision is indicated by the 4-foot culvert invert at Old Cheney Road. Localized scouring at the culvert outfall and a lack of hydraulic roughness along both banks has left both the bed and banks severely eroded.

Recommended intervention: Constructing an armored stilling basin at the culvert outfall will dissipate hydraulic energy and reduce the driving force for localized widening downstream of the culvert (Figure 9-27). The stilling basin should be sized so that the applied shear stress at the downstream edge does not exceed the critical shear strength of the bed. Vegetating the riprap along the banks and at the downstream end of the proposed stilling basin will provide additional hydraulic roughness and reduce shear stress along the banks and at the downstream end of the basin.

Estimated Construction Cost: $90,000

INTUITION & LOGIC

Stevens Creek Intervention #25
Tributary 60 – River Mile 11.320 to 11.314

Figure 9-27

Intervention 26. Tributary 85, River Mile 17.810 to 17.582 – Grade control incising reach and protect culvert outfall

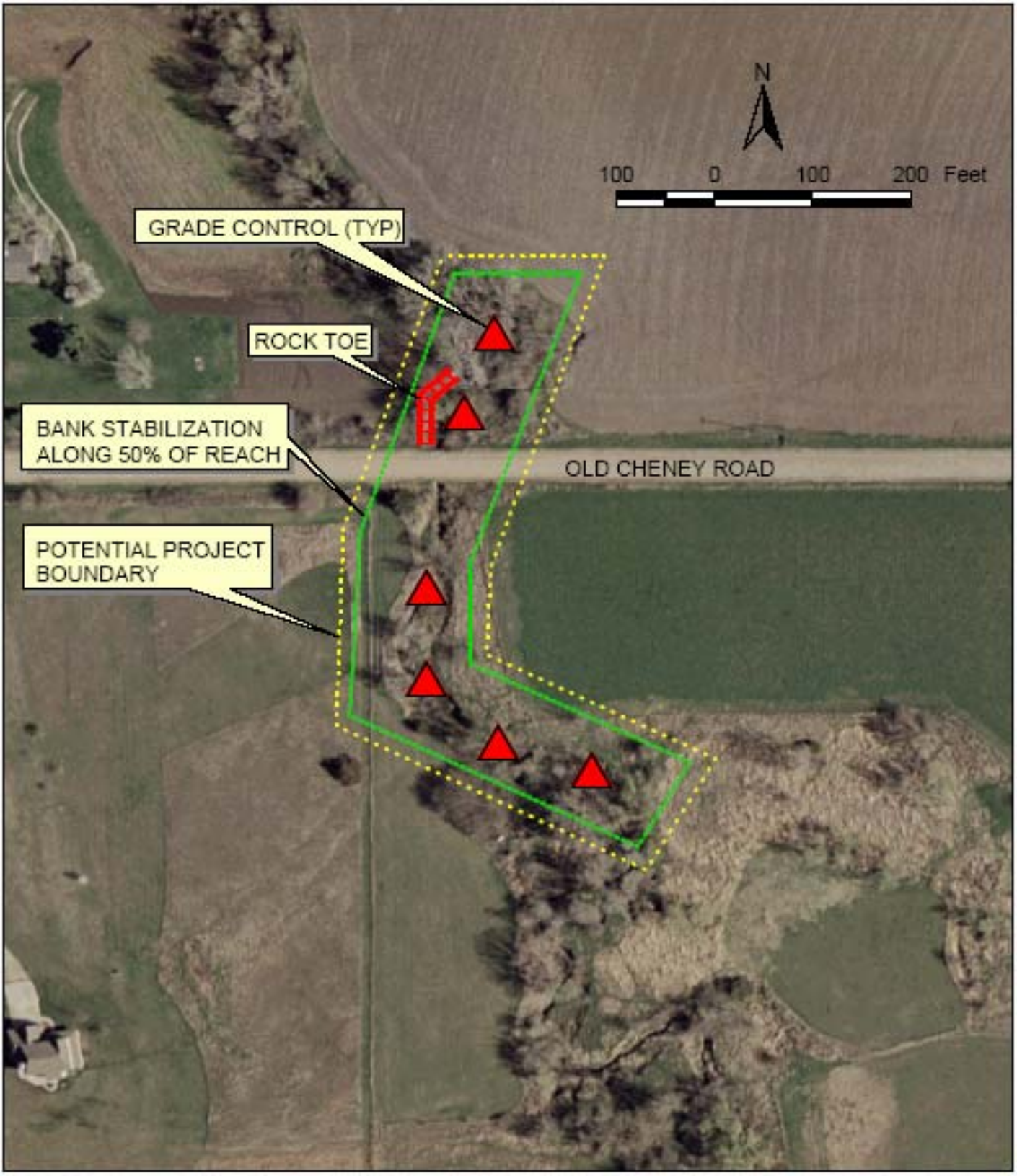
Problem description: Channel incision upstream of Old Cheney Road has resulted in extensive bank failures between Tributary 85, River Mile 17.810 and 17.852. Bank erosion is particularly severe immediately upstream from the Old Cheney culvert, where wedge failures continue to erode the bank no more than 8 feet from a fence along the top of the right descending bank.

Downstream of Old Cheney culvert both banks are eroded as a result of localized scouring and a lack of hydraulic roughness at the culvert outfall.

Recommended intervention: Arresting channel incision upstream of Old Cheney requires a series of rock grade controls (Figure 9-28). Newbury-style grade structures with gradually sloping tail ramps are appropriate here. Vegetating the downstream edges of the rock structures provides additional energy dissipation and protection for the interface between rock and native bank. Additional bank stabilization includes streambanks immediately upstream of Old Cheney. Rock toe armor along the right descending bank will deflect flow away from the bank and reduce stress at the bank toe.

Downstream of the Old Cheney culvert requires construction of a riprap-lined scour pool and grade controls to dissipate energy properly. The scour pool should be sized so that the applied shear stress at the downstream edge does not exceed the critical shear strength of the bed.

Estimated Construction Cost: $203,000



INTUITION & LOGIC

Stevens Creek Intervention #26
Tributary 85 – River Mile 17.810 to 17.582

Figure 9-28

9.3 Capital Improvement Projects

A priority scheme was used to develop a CIP list to address the 26 primary problem areas. After the interventions are rated by priority, each intervention is ranked as low, medium and high based on its location in the watershed and its potential to affect other reaches. Interventions are ranked high if they are in the bottom of the watershed or possess other characteristics that potentially affect larger amounts of stream than other interventions of the same priority. For example, an intervention may be ranked high because it is a single headcut with the potential to propagate up an entire reach.

Interventions are ranked low if they have the potential to effect less amounts of stream or propagation of the problem is limited by physical characteristics such as culverts or large amounts of woody debris. For example, an intervention may be ranked low because it is a single headcut in the headwaters of the sub-basin, has a small cross section and high debris jam potential.

Those interventions that are located in the mid portion of the watershed or subarea and possess no distinguishing characteristics that would qualify as a high or low rating, are rated medium. A construction sequence was developed based on the priority and ranking assigned to each intervention. The 18 priority 2 projects should be constructed before the 8 priority 3 projects.

Ten of the 18 priority 2 interventions are ranked high; therefore, these 10 projects are proposed for construction first. Four of the priority 2 interventions are ranked medium and these projects are proposed for construction second. Four priority 2 interventions are ranked low. These interventions are proposed for construction third. And finally, the priority 3 interventions all have a ranking of 4 and are proposed for construction last.

The next step was to define CIPs by grouping stream interventions by location and construction cost. Combining multiple stream interventions to form a CIP reduces overall project design costs for construction documents and engineering services. The target project cost for each CIP is $1,000,000.

Stream interventions 2 and 18 were each paired with another intervention of a higher construction sequence. These groupings are reasonable because the interventions are located close to those with which they were paired. The final groupings resulted in 11 CIPs as shown in Table 9-1 and illustrated on Figure 9-29. Surveying, engineering and construction management costs were estimated for each CIP as shown in Table 9-2. The total estimated cost for the 11 CIPs was $10.3 Million.

Detailed cost information is presented in Appendix K, located in Volume II of this report. Appendix K summarizes typical costs. All costs are in 2004 dollars and do not include land acquisition, hazardous waste remediation, utility relocation, or rehabilitation.

Table 9-1
Capital Improvement Project List

Capital Improvement Project	*Intervention Number*	*Tributary*	*Priority*	*Ranking*	*Construction Sequence*
1	**3**	ML	2	1-high	1
	4	10	2	1	1
2	**5**	20	2	1	1
	7	30	2	1	1
	9	35	2	1	1
	8	35	2	1	1
3	**19**	45	2	1	1
	15	45	2	1	1
	16	345	2	1	1
	20	55	2	1	1
4	**14**	445	2	2-medium	2
	13	45	2	2	2
5	**22**	65	2	2	2
	26	85	2	2	2
6	**11**	30	2	3-low	3
7	**12**	250	2	3	3
8	**17**	545	2	3	3
	18	545	3	4	4
9	**1**	ML	2	3	3
	2	5	3	4	4
10	**6**	ML	3	4	4
	10	130	3	4	4
11	**21**	65	3	4	4
	23	70	3	4	4
	24	75	3	4	4
	25	60	3	4	4

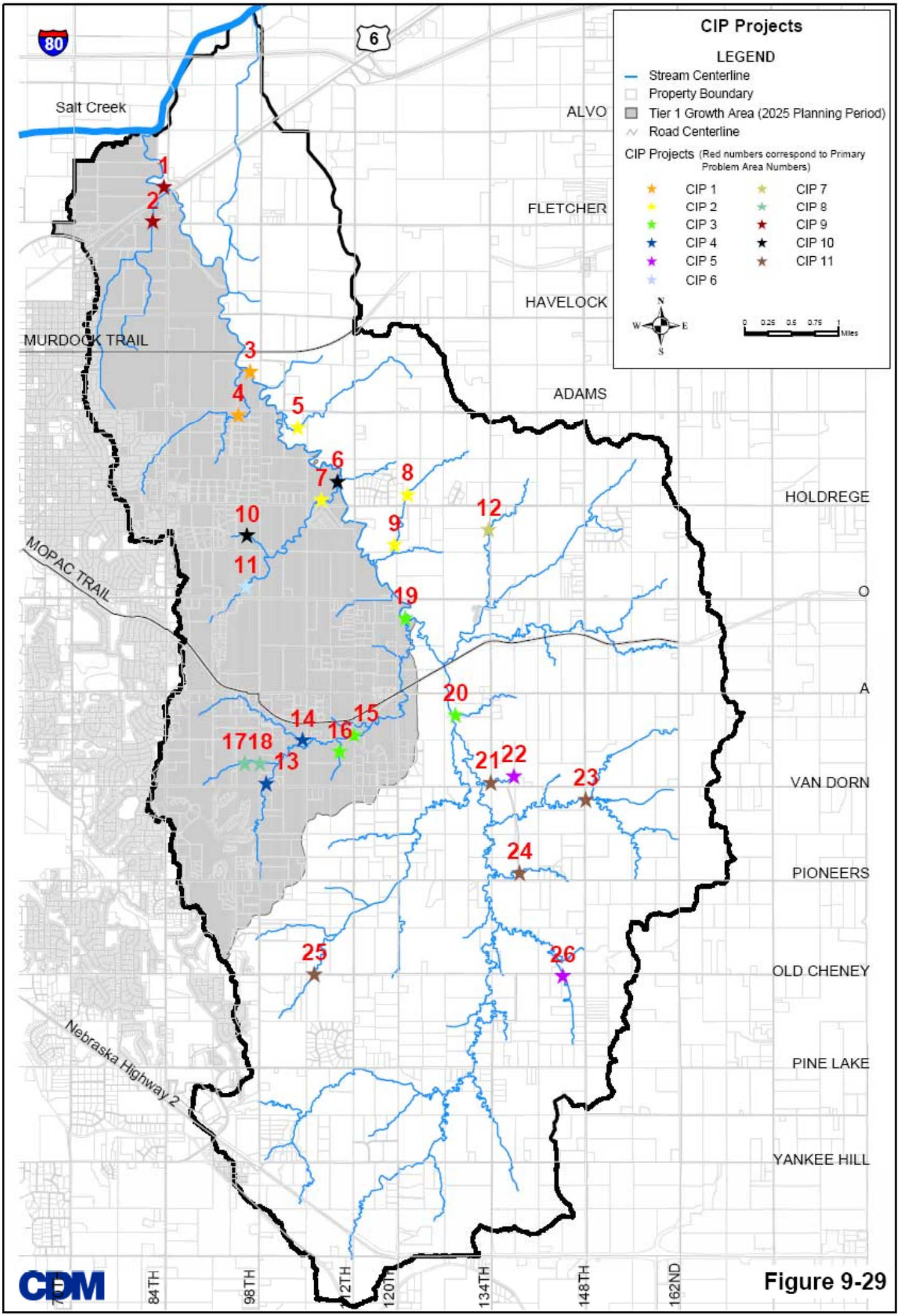

CIP Projects
LEGEND
Stream Centerline
Property Boundary
Tier 1 Growth Area (2025 Planning Period)
Road Centerline
CIP Projects (Red numbers correspond to Primary Problem Area Numbers)
CIP 1
CIP 2
CIP 3
CIP 4
CIP 5
CIP 6
CIP 7
CIP 8
CIP 9
CIP 10
CIP 11
N
W
E
S
0 0.25 0.5 0.75 1 Miles
80
6
Salt Creek
ALVO
FLETCHER
HAVELOCK
MURDOCK TRAIL
ADAMS
HOLDREGE
MOPAC TRAIL
O
A
VAN DORN
PIONEERS
OLD CHENEY
PINE LAKE
YANKEE HILL
Nebraska Highway 2
84TH
98TH
112TH
120TH
134TH
148TH
162ND
1
2
3
4
5
6
7
8
9
10
11
12
13
14
15
16
17
18
19
20
21
22
23
24
25
26
CDM

Figure 9-29

Table 9-2
Capital Improvement Project Cost Estimate

CIP 1	
Construction:	
Intervention 3:	$229,000
Intervention 4:	$805,000
Surveying:	$57,000
Engineering:	$117,000
Construction Management:	$48,000
TOTAL	**$1,256,000**
CIP 3	
Construction:	
Intervention 15:	$435,000
Intervention 16:	$35,000
Intervention 19:	$44,000
Intervention 20:	$460,000
Surveying:	$52,000
Engineering:	$115,000
Construction Management:	$60,000
TOTAL	**$1,201,000**
CIP 5	
Construction:	
Intervention 22:	$332,000
Intervention 26:	$203,000
Surveying:	$37,000
Engineering:	$105,000
Construction Management:	$48,000
TOTAL	**$725,000**
CIP 7	
Construction:	
Intervention 12:	$906,000
Surveying:	$57,000
Engineering:	$107,000
Construction Management:	$48,000
TOTAL	**$1,118,000**
CIP 9	
Construction:	
Intervention 1:	$434,000
Intervention 2:	$98,000
Surveying:	$9,000
Engineering:	$80,000
Construction Management:	$36,000
TOTAL	**$657,000**
CIP 11	
Construction:	
Intervention 21:	$137,000
Intervention 23:	$71,000
Intervention 24:	$137,000
Intervention 25:	$90,000
Surveying:	$26,000
Engineering:	$97,000
Construction Management:	$36,000
TOTAL	**$594,000**

CIP 2	
Construction:	$311,000
Intervention 5:	$63,000
Intervention 7:	$309,000
Intervention 8:	$356,000
Surveying:	$64,000
Engineering:	$139,000
Construction Management:	$94,000
TOTAL	**$1,336,000**
CIP 4	
Construction:	
Intervention 13:	$299,000
Intervention 14:	$307,000
Surveying:	$28,000
Engineering:	$94,000
Construction Management:	$48,000
TOTAL	**$776,000**
CIP 6	
Construction:	
Intervention 11:	$703,000
Surveying:	$36,000
Engineering:	$88,000
Construction Management:	$36,000
TOTAL	**$863,000**
CIP 8	
Construction:	
Intervention 17:	$659,000
Intervention 18:	$137,000
Surveying:	$49,000
Engineering:	$113,000
Construction Management:	$48,000
TOTAL	**$1,006,000**
CIP 10	
Construction:	
Intervention 6:	$379,000
Intervention 10:	$217,000
Surveying:	
Engineering:	$86,000
Construction Management:	$48,000
TOTAL	**$748,000**
Total for All CIPs	**$10.3 M**

9.4 Other Areas of Concern

The secondary problem area locations are illustrated on Figure 9-1 and summarized below. These problem areas are not as serious as the primary problems, but should be addressed in conjunction with other infrastructure projects occurring in the watershed. For example, many of the secondary problems could be addressed at the same time roadways are improved and water and wastewater pipelines are installed, if they are located in the same general vicinity. In addition, many of these secondary problems could be combined with routine maintenance activities.

Location 27. Lower Main Stem, River Mile 0.580 to 0.557 - Wing dikes and rock toe along eroding streambank

Problem description: Meander adjustment along Stevens Creek Lower Main Stem has resulted in tall, alternating cutbanks and severe bank erosion.

Recommended intervention: Protect the banks from erosion by deflecting flow with rock wing dikes and rock toe armor.

Location 28. Lower Main Stem, River Mile 0.955 to 0.922 - Wing dikes and rock toe along eroding streambank

Problem description: Meander adjustment along Stevens Creek Lower Main Stem has resulted in tall, alternating cutbanks and severe bank erosion.

Recommended intervention: Protect the banks from erosion by deflecting flow with rock wing dikes and rock toe armor.

Location 29. Lower Main Stem, River Mile 1.500 to 1.447 – Remove dumped rubble and restore eroding streambank

Problem description: Concrete and asphalt rubble has been dumped along the right descending bank, aggravating localized bank erosion.

Recommended intervention: Remove the rubble and restore the degraded bank by regrading, fabric, and planting.

Location 30. Lower Main Stem, River Mile 3.231 to 3.152 – Composite revetment bank protection to restore eroded streambank

Problem description: Channel widening along Stevens Creek Main Stem has prompted severe bank erosion along the right descending bank downstream of Havelock Avenue, threatening a fenceline and farm building at the top of the bank. A lack of woody vegetation and a narrow riparian corridor has allowed erosion to proceed unimpeded.

Recommended intervention: Construct composite revetment bank protection along approximately 400 feet of streambank to halt bank erosion, restore a stable slope, and protect the property along the top of the bank.

Location 31. Tributary 5, River Mile 3.074 – Flood mitigation at Havelock Street

Problem description: Three habitable buildings are affected by the existing 100-year floodplain, per the model near the intersection at Havelock Street and 73rd Street. This may be due to insufficient conveyance capacity of the channel and drainage structure under Havelock Street. The culvert is causing backwater, which affects the houses approximately 500 feet upstream.

Recommended improvement: Resizing and replacing the culvert with a two-stage, conservation culvert may decrease the water surface elevation and mitigate the effects of the floodplain 500 feet upstream from Havelock. However, one of the houses, located east of 73rd Street on Morril Street, appears to be within the natural floodplain. Potential solutions, in conjunction with culvert resizing, could include adding a berm or channel modification to address flooding at this property.

Location 32. Tributary 5, River Mile 3.695 – Flood mitigation near Fremont Street

Problem description: Two habitable buildings are affected by the existing 100-year floodplain, per the model near Fremont Street, east of 70th Street. This may be due to insufficient conveyance capacity of the drainage structure under Havelock Street and the grading of a sidewalk that passes over the tributary near the effected houses. The culvert is causing backwater, which affects the houses approximately 250 feet upstream. In addition, three habitable buildings are affected by the existing 100-year floodplain. While structural improvements may lower the water surface elevation at the culvert, effects will still exist immediately upstream of the culvert after improvements. The houses appear to be within the natural floodplain.

Recommended improvement: Possible solutions include structure improvements, berm installation, or channel modifications.

Location 33. Tributary 20, River Mile 6.511 to 6.006 – Grade control incising channel

Problem description: Channel incision along Tributary 20 has resulted in extensive bank scouring and erosion.

Recommended intervention: Install a series of rock grade controls to reduce channel bed slope and halt channel incision.

Location 34. Tributary 10, River Mile 5.903 – Flood mitigation at 98th Street

Problem description: Three habitable buildings are affected by the existing 100-year floodplain, per the model near 84th Street, south of Adams Street. This may be due to insufficient conveyance capacity of the drainage structure under 98th Street. The culvert is causing backwater, which affects the houses west of the tributary.

Recommended improvement: Possible solutions include structure improvements, berm installation, channel modifications, and detention upstream of the flood location.

Location 35. Lower Main Stem, River Mile 5.913 to 5.663 – Grade control existing knickpoints

Problem description: Channel incision along the Lower Main Stem of Stevens Creek has resulted in systemic bank erosion and the generation of sediment and woody debris.

Recommended intervention: Grade control existing knickpoints to reduce channel bed slope and halt channel incision.

Location 36. Lower Main Stem, River Mile 6.909 to 6.890 – Remove dumped rubble and restore eroding streambank

Problem description: Concrete and asphalt rubble has been dumped along the right descending bank, aggravating localized bank erosion.

Recommended intervention: Remove the rubble and restore the degraded bank with composite revetment bank protection.

Location 37. Lower Main Stem, River Mile 7.055 to 6.924 – Grade control incising channel

Problem description: Channel incision along the Lower Main Stem has resulted in systemic bank erosion.

Recommended intervention: Install a series of rock grade controls to reduce channel bed slope and halt channel incision.

Location 38. Tributary 25, River Mile 7.197 to 7.183 – Turning vane upstream of culvert to direct flow

Problem description: The culvert under 112th Street is being flanked by localized bank erosion along the left descending bank.

Recommended intervention: Construct a rock turning vane to direct flow through the box culvert and maintain sediment transport continuity. Additional rock toe protection along the left descending bank is necessary to reduce localized erosion and protect the turning vane.

Location 39. Tributary 30, River Mile 7.987 to 7.959 – Grade control existing knickpoints

Problem description: Channel incision along Tributary 30 has resulted in systemic bank erosion.

Recommended intervention: Grade control existing knickpoints to reduce channel bed slope and halt channel incision.

Location 40. Tributary 35, River Mile 9.493 – Flood mitigation at Holdrege Street

Problem description: One habitable building is affected by the existing 100-year floodplain, per the model near Holdrege Street, east of 112th Street. This may be due to insufficient conveyance capacity of the drainage structure under Holdrege Street. The culvert is causing backwater, which affects the house west of the tributary.

Recommended improvement: Possible solutions include structure improvements, berm installation, and channel modifications.

Location 41. Lower Main Stem, River Mile 8.979 to 8.127 – Grade control existing knickpoints

Problem description: Channel incision along the Lower Main Stem has resulted in systemic bank erosion.

Recommended intervention: Grade control existing knickpoints to reduce channel bed slope and halt channel incision.

Location 42. Tributary 135, River Mile 9.106 to 8.917 – Grade control incising channel

Problem description: Channel incision along Tributary 135 has resulted in severe bank erosion and frequent wedge failures.

Recommended intervention: Install a series of rock grade controls to raise the channel bed and prevent continued mass wasting.

Location 43. Tributary 30, River Mile 8.779 to 8.756 – Grade control existing knickzone

Problem description: The upstream advance of a single knickzone along Tributary 30 has precipitated systemic bank erosion.

Recommended intervention: Grade control the existing knickzone to halt channel incision and maintain a stable channel grade.

Location 44. Tributary 35, River Mile 8.550 to 8.533 – Composite revetment bank protection to restore eroded streambank

Problem description: A tall, near vertical cutbank has resulted from high shear stress on the outside of a meander and the removal of trees and woody vegetation along the right descending bank, thereby reducing shear resistance.

Recommended intervention: Construct composite revetment bank protection along 100 feet of streambank to halt bank erosion and restore a stable channel cross section.

Location 45. Tributary 250, River Mile 11.741 to 11.707 – Longitudinal weirs upstream of culvert to direct flow

Problem description: A poorly aligned culvert under O Street has induced erosion upstream and downstream of the culvert.

Recommended intervention: Construct longitudinal weirs and rock toe protection to direct flow away from eroding streambanks and center the flow through the culvert.

Location 46. Lower Main Stem, River Mile 9.492 to 9.426 – Composite revetment bank protection to restore eroded streambank

Problem description: Channel widening has resulted in recurrent wedge failures along the Lower Main Stem.

Recommended intervention: Restore and protect eroding streambanks with composite revetment bank protection along roughly 350 feet of channel.

Location 47. Upper Main Stem, River Mile 9.845 to 9.780 – Grade control incising channel

Problem description: Channel incision has resulted in severe bank erosion and frequent bank failures.

Recommended intervention: Install a series of rock grade controls to reduce channel bed slope and halt channel incision.

Location 48. Tributary 150, River Mile 12.735 to 12.701 – Replace existing culvert

Problem description: A driveway culvert on Tributary 150 is misaligned and the wooden headwalls upstream of the culvert are in general disrepair, failing in toward the channel.

Recommended intervention: Replace the existing culvert with a two-stage conservation culvert, or a bridge with a rock or concrete headwall.

Location 49. Tributary 150, River Mile 13.242 to 12.962 – Grade control incising channel

Problem description: Channel incision and subsequent widening along Tributary 150 has resulted in widespread bank erosion.

Recommended intervention: Install a series of rock grade controls to reduce channel incision, and restore a stable channel shape downstream with rock toe protection and regrading, fabric, and planting eroded streambanks.

Location 50. Tributary 150, River Mile 13.418 to 13.388 – Replace existing culvert

Problem description: The culvert under 148th Street appears to be undersized and inducing sediment deposition upstream.

Recommended intervention: Replace the existing culvert with a two-stage conservation culvert.

Location 51. Tributary 150, River Mile 13.918 to 13.415 –Restore riparian corridor

Problem description: A lack of riparian trees and woody vegetation combined with cattle access to the tributary has resulted in severe, localized bank erosion or poaching between the MOPAC trail and 148th Street.

Recommended intervention: Limit cattle access to the tributary and restore the riparian corridor with a mix of native trees and woody vegetation to mechanically stabilize eroding banks and increase shear resistance.

Location 52. Tributary 150, River Mile 13.949 – Longitudinal weirs upstream of culvert to direct flow

Problem description: A poorly aligned approach to the culvert under the MOPAC trail has resulted in bank scouring upstream of the culvert.

Recommended intervention: Construct a longitudinal weir upstream to direct flow away from the banks and through the culvert.

Location 53. Upper Main Stem, River Mile 10.976 to 10.218 – Grade control incising channel

Problem description: Channel incision along the Upper Main Stem has resulted in persistent toe scour and a frequent occurrence of debris jams.

Recommended intervention: Install a series of rock grade controls to reduce channel bed slope and halt channel incision.

Location 54. Tributary 445, River Mile 13.847 – Flood mitigation near A Street and 94th Street

Problem description: One habitable building is affected by the existing 100-year floodplain, per the model near A Street, east of 94th Street. This may be due to insufficient conveyance capacity of the drainage structure under a private drive. The culvert is causing backwater, which impacts the house south of the tributary.

Recommended improvement: Possible solutions include structure improvements, berm installation, and channel modifications.

Location 55. Tributary 445, River Mile 14.129 to 14.112 – New pond outfall with stilling basin

Problem description: An old concrete pond outfall is in deteriorating condition, with dumped rubble at angle of repose.

Recommended intervention: Repair or replace the pond outfall and add a riprap-armored stilling basin downstream.

Location 56. Tributary 445, River Mile 13.565 – Grade control existing knickpoint downstream of pond outfall

Problem description: Haphazardly placed riprap appears to have been undermined by an advancing headcut, threatening a detention pond outfall upstream.

Recommended intervention: Install a grade control at the existing knickpoint to maintain a stable channel grade downstream of the pond outfall.

Location 57. Tributary 245, River Mile 12.049 to 11.964 – Restore riparian corridor

Problem description: Systematic clearing of trees and woody vegetation from the riparian corridor has prompted overbank erosion and gullying of bare soil banks along Tributary 245.

Recommended intervention: Grade, fabric, and plant the banks to restore the riparian corridor and prevent continued overbank erosion.

Location 58. Tributary 70, River Mile 16.213 to 15.497 – Grade control incising channel

Problem description: Incision-induced bank erosion occurs from Van Dorn Street to a cattle crossing at Tributary 70, River Mile 16.213.

Recommended intervention: Install a series of rock grade controls to reduce channel bed slope and halt channel incision.

Location 59. Tributary 60, River Mile 6.964 to 6.149 – Grade control incising channel

Problem description: Channel incision has resulted in systemic bank erosion from the confluence with an unnamed tributary to Van Dorn Street.

Recommended intervention: install a series of rock grade controls to reduce channel bed slope and halt channel incision.

Location 60. Tributary 170, River Mile 14.611 to 14.592 – Grade control existing knickpoint

Problem description: Bank failures along Tributary 170 occur in the vicinity of an existing debris jam-reinforced knickpoint.

Recommended intervention: Replace the existing debris jam with an engineered rock grade control to halt channel incision, and restore failed streambanks to a stable slope and shape.

Location 61. Tributary 65, River Mile 12.458 to 12.453 – Grade control existing knickpoint

Problem description: An advancing headcut upstream from the confluence with Stevens Creek Upper Main Stem has resulted in systemic bank erosion along Tributary 65.

Recommended intervention: Install a grade control at the existing knickpoint to maintain a stable channel grade upstream from the confluence with Stevens Creek Upper Main Stem.

Location 62. Tributary 65, River Mile 12.491 to 12.466 – Composite revetment bank protection to restore eroded streambank

Problem description: An existing cutbank appears to be advancing in the direction of Van Dorn Street.

Recommended intervention: Construct composite revetment bank protection along approximately 150 feet of streambank to halt advancing erosion.

Location 63. Upper Main Stem, River Mile 12.517 to 12.495 – Grade control existing knickpoint

Problem description: Channel incision along the Upper Main Stem has generated large volumes of sediment and woody debris. Woody debris and toppled trees have accumulated upstream of the Van Dorn bridge, reinforcing an existing knickpoint.

Recommended intervention: Remove the debris jam and replace it with an engineered rock grade control to maintain a stable channel grade.

Location 64. Upper Main Stem, River Mile 12.654 to 12.631 – Composite revetment bank protection to restore eroded streambank

Problem description: Severe bank erosion along the right descending bank has resulted in a near-vertical cutbank and gullying through the farm field at the top of the bank.

Recommended intervention: Restore and protect the eroding streambank with composite revetment bank protection along approximately 120 feet of channel.

Location 65. Tributary 70, River Mile 14.350 to 14.312 –Restore riparian corridor

Problem description: A lack of riparian trees and woody vegetation combined with cattle access to Tributary 70 has resulted in severe bank poaching.

Recommended intervention: Limit cattle access to the tributary and restore the riparian corridor with a mix of native trees and woody vegetation.

Location 66. Upper Main Stem, River Mile 12.864 to 12.769 – Grade control incising channel

Problem description: Channel incision has resulted in systemic bank erosion along the Upper Main Stem.

Recommended intervention: Install a series of rock grade controls to reduce channel bed slope and halt channel incision.

Location 67. Tributary 60, River Mile 9.151 to 7.323 – Regrade, fabric, and plant banks with rock toe armor

Problem description: Channel widening along Tributary 60 has resulted in severe channel degradation and widespread mass wasting between Pioneers Street and a 48-inch CMP culvert under a private drive.

Recommended intervention: Repair eroded streambanks and restore a stable channel cross section shape by regrading, fabric and planting with rock toe armor.

Location 68. Tributary 60, River Mile 7.323 – Grade control existing knickpoint

Problem description: Channel incision along Tributary 60 has been temporarily halted by a large woody debris jam immediately upstream from a 48-inch CMP culvert under a private drive.

Recommended intervention: Remove the debris jam and replace it with an engineered rock grade control to maintain a stable channel grade.

Location 69. Tributary 270, River Mile 16.556 to 15.372 – Grade control incising channel

Problem description: Channel incision along Tributary 270 has resulted in widespread bank erosion and mass wasting.

Recommended intervention: Install a series of rock grade controls to reduce channel bed slope and halt channel incision.

Location 70. Upper Main Stem, River Mile 13.250 to 13.182 – Grade control existing knickpoints

Problem description: The upstream advance of several knickpoints has precipitated bank erosion and frequent bank failures.

Recommended intervention: Grade control each of the existing knickpoints to halt channel incision.

Location 71. Tributary 70, River Mile 13.367 to 13.196 – Grade control incising channel

Problem description: Channel incision along Tributary 70 has resulted in systemic bank erosion.

Recommended intervention: Install a series of rock grade controls to reduce channel bed slope and halt channel incision.

Location 72. Tributary 160, River Mile 14.086 to 14.083 – Grade control existing knickpoint

Problem description: Channel incision along Tributary 160 has been temporarily halted by a large woody debris jam acting as a *de facto* grade control.

Recommended intervention: Remove the debris jam and replace it with an engineered rock grade control to maintain a stable channel grade.

Location 73. Tributary 160, River Mile 14.287 to 14.153 – Grade control incising channel and restore corridor

Problem description: Channel incision along Tributary 160 has resulted in severe erosion and mass wasting. Removal of trees and woody vegetation along the streambanks has accelerated systemic erosion.

Recommended intervention: Install a series of rock grade controls to reduce channel bed slope and halt channel incision. In addition, grade, fabric, and plant the banks to restore the riparian corridor and increase shear resistance.

Location 74. Tributary 160, River Mile 15.026 to 14.391 – Grade control existing knickpoint and restore corridor

Problem description: The upstream advance of a knickpoint has precipitated bank erosion and frequent bank failures. Cattle access to the tributary has accelerated bank erosion, resulting in reaches of severe, localized bank erosion or poaching.

Recommended intervention: Grade control the existing knickpoint to halt channel incision and limit cattle access to the tributary.

Location 75. Tributary 75, River Mile 15.772 to 15.450 – Grade control incising channel

Problem description: Channel incision along Tributary 75 has resulted in systemic bank erosion.

Recommended intervention: Install a series of rock grade controls to reduce channel bed slope and halt channel incision.

Location 76. Tributary 75, River Mile 14.602 to 14.586 – Grade control existing knickpoint

Problem description: Channel incision along Tributary 75 has been temporarily halted by a debris jam of dumped hay bales and woody debris acting as a *de facto* grade control.

Recommended intervention: Remove the debris jam and replace it with an engineered rock grade control to maintain a stable channel grade.

Location 77. Upper Main Stem, River Mile 14.843 to 14.834 – Grade control existing knickpoint

Problem description: A woody debris jam acting as a *de facto* grade control has temporarily halted the advance of an existing knickpoint on the Upper Main Stem.

Recommended intervention: Remove the debris jam and replace it with an engineered rock grade control to maintain a stable channel grade.

Location 78. Tributary 260, River Mile 15.474 to 15.015 – Grade control incising channel

Problem description: Channel incision along Tributary 260 has resulted in severe bank erosion in the near 120th Street.

Recommended intervention: Install a series of rock grade controls to reduce channel bed slope and halt channel incision.

Location 79. Tributary 60, River Mile 10.234 to 9.642 –Restore riparian corridor

Problem description: A lack of riparian trees and woody vegetation along Tributary 60 has resulted in overbank erosion and mass wasting between 112th and 120th Streets.

Recommended intervention: Grade, fabric, and plant the banks to restore the riparian corridor and prevent continued erosion.

Location 80. Tributary 60, River Mile 9.928 – Grade control existing knickpoint

Problem description: Channel incision along Tributary 60 is eroding both banks and undermining a concrete low-water crossing.

Recommended intervention: Reinforce the low-water crossing with an engineered rock grade control immediately downstream to halt channel incision and protect the existing structure.

Location 81. Tributary 80, River Mile 15.321 to 15.317 - Armor plunge pool at pond outfall

Problem description: A 36-inch CMP pond outfall is focusing flow against the right descending bank, resulting in bed and bank scouring.

Recommended intervention: Construct a riprap armored plunge pool to dissipate the scouring energy at the pond outfall.

Location 82. Tributary 80, River Mile 15.757 to 15.647 – Grade control incising channel

Problem description: Channel incision along Tributary 80 has resulted in severe bank erosion and mass wasting.

Recommended intervention: Install a series of rock grade controls to reduce channel bed slope and halt channel incision.

Location 83. Tributary 85, River Mile 16.490 to 16.158 – Grade control existing knickpoints

Problem description: The upstream advance of several knickpoints has precipitated bank erosion and frequent bank failures.

Recommended intervention: Grade control each of the existing knickpoints to halt channel incision.

Location 84. Tributary 460, River Mile 16.041 to 16.003 – Grade control existing knickpoint

Problem description: The upstream advance of a 2-foot knickpoint has precipitated systemic bank erosion and threatens channel stability upstream.

Recommended intervention: Grade control the existing knickpoint to halt channel incision and maintain a stable channel grade upstream.

Location 85. Tributary 60, River Mile 11.314 to 10.734 – Composite revetment bank protection and guide vanes

Problem description: Channel widening along Tributary 60 has resulted in severe channel degradation and widespread mass wasting.

Recommended intervention: Repair eroded streambanks and protect them from continued erosion with composite revetment bank protection along approximately 3,000 feet of channel. In addition, construct a series of rock guide vanes to deflect flow away from the banks and toward the center of the channel.

Location 86. Tributary 88, River Mile 16.430 to 16.203 – Grade control incising channel

Problem description: Tributary 88 is an entrenched channel with frequent, incision-induced bank failures.

Recommended intervention: Install a series of rock grade controls to halt channel incision, raise the channel bed, and establish a stable bed slope.

Location 87. Upper Main Stem, River Mile 16.752 to 16.695 – Grade control existing knickpoint

Problem description: Channel incision along the Upper Main Stem has generated large volumes of sediment and woody debris. Woody debris has formed a large debris jam, reinforcing an existing knickpoint.

Recommended intervention: Remove the debris jam and replace it with an engineered rock grade control to maintain a stable channel grade.

Location 88. Tributary 260, River Mile 16.091 to 16.082 - Armor right descending bank at culvert outfall

Problem description: Twin 48-inch CMP outfalls downstream of the 120th Street culvert are directing flow against the right descending bank, resulting in bank scouring.

Recommended intervention: Add vegetated rock toe armor along approximately 50 feet of the right descending bank to dissipate scouring energy at the culvert outfall.

Location 89. Tributary 88, River Mile 16.458 to 16.430 – Grade control existing knickpoints and regrade, fabric, and plant banks with rock toe armor

Problem description: Channel incision along Tributary 88 has resulted in severe bank erosion. However, the advance of incision has been slowed by a series of woody debris jams acting as a *de facto* grade controls.

Recommended intervention: Remove the debris jams and replace them with engineered rock grade controls to maintain a stable channel grade. In addition, repair eroded streambanks and restore a stable channel cross section shape by regrading, fabric and planting with rock toe armor.

Location 90. Tributary 88, River Mile unknown - Stilling basin with grade control outfall

Problem description: Channel incision along Tributary 88 has scoured the channel bed, leaving the 138th Street culvert outfall perched 1 foot above channel bed.

Recommended intervention: Construct a stilling basin downstream of the culvert with a grade control outfall to dissipate the scouring energy from the culvert and to halt channel incision.

Location 91. Tributary 92, River Mile 17.677 to 17.658 – Grade control incising channel

Problem description: Channel incision along Tributary 92 has resulted in severe bank erosion and mass wasting.

Recommended intervention: Install a series of rock grade controls to reduce channel bed slope and halt channel incision.

Location 92. Tributary 90, River Mile 17.551 to 17.547 – Grade control existing knickpoint

Problem description: Channel incision along Tributary 90 has been slowed by a large woody debris jam at an existing 3-foot tall knickpoint.

Recommended intervention: Remove the debris jam and replace it with a series of rock grade controls or a single drop structure to prevent the advance of the knickpoint and to maintain a stable channel grade.

Location 93. Tributary 90, River Mile 17.670 to 17.615 – Composite revetment bank protection to restore eroded streambank

Problem description: Severe bank scouring and wedge failures have resulted from high shear stress on the outside of a meander and the removal of trees and woody vegetation along the left descending bank.

Recommended intervention: Construct composite revetment bank protection along approximately 300 feet of streambank to halt bank erosion and restore a stable channel cross section.

Location 94. Tributary 90, River Mile 17.727 to 17.670 – Grade control incising channel

Problem description: Channel incision along Tributary 90 has resulted in systemic bank erosion.

Recommended intervention: Install a series of rock grade controls to reduce channel bed slope and halt channel incision.

Location 95. Tributary 92, River Mile 17.962 to 17.941 - Armor plunge pool at culvert outfall

Problem description: An unarmored 60-inch CMP outfall at the Pleasant Hill culvert has resulted in bed and bank scouring.

Recommended intervention: Construct a riprap armored plunge pool to dissipate the scouring energy at the culvert outfall.

Location 96. Tributary 96, River Mile 21.894 to 21.889 - Armor plunge pool at pond outfall

Problem description: A 36-inch CMP pond outfall is focusing flow against the left descending bank, resulting in bed and bank scouring.

Recommended Location: Construct a riprap armored plunge pool to dissipate the scouring energy at the pond outfall.

Intervention 97. Tributary 96, River Mile 21.542, 21.459, 21.379, & 21.294 – Grade control existing knickpoints

Problem description: A series of beaver dams are reinforcing several 1 to 3-foot knickpoints along Tributary 96.

Recommended intervention: Replace or reinforce each of the beaver dams with an engineered rock grade control to maintain a stable channel grade.

Location 98. Tributary 96, River Mile 21.150 to 21.131 – Grade control existing knickpoint

Problem description: Channel incision along Tributary 96 has undermined a *de facto* grade control of dumped concrete and asphalt rubble.

Recommended intervention: Replace the concrete and asphalt with an engineered rock grade control to halt channel incision.

Location 99. Tributary 96, River Mile 20.964 to 20.839 – Grade control incising channel and replace low –water crossing

Problem description: Channel incision along Tributary 96 has resulted in systemic bank erosion between the confluence with Tributary 196 and a low-water crossing at River Mile 20.964.

Recommended intervention: Install a series of rock grade controls to reduce channel bed slope and halt channel incision. In addition, replace the existing low-water crossing with a bridge or appropriately sized CMP culvert.

Location 100. Tributary 96, River Mile 20.801 to 20.139 – Conservation easement along meandering reach

Problem description: Meander adjustment along the lower reach of Tributary 96 has resulted in alternating cutbanks and mass wasting.

Recommended intervention: Because the existing corridor is wide enough to accommodate meander adjustment, provide a conservation easement along the top of both banks to allow for continued planform adjustment until equilibrium is achieved.

Location 101. Tributary 94, River Mile 20.092 to 19.524 – Regrade, fabric, and plant banks with rock toe armor

Problem description: Channel widening along Tributary 94 has resulted in severe bank erosion and widespread mass wasting occurring on the outside of meanders.

Recommended intervention: Repair eroded streambanks and restore a stable channel cross section shape by regrading, fabric and planting with rock toe armor.

Location 102. Tributary 94, River Mile 20.149 to 20.092 – Grade control existing knickpoints

Problem description: The upstream advance of several knickpoints has precipitated bank erosion, frequent bank failures, and channel widening further downstream.

Recommended intervention: Grade control each of the existing knickpoints to halt channel incision.

Location 103. Tributary 196, River Mile 21.358 to 20.843 – Grade control incising channel

Problem description: Channel incision along Tributary 196 has resulted in systemic bank erosion and mass wasting downstream of a pond outfall.

Recommended intervention: Install a series of rock grade controls to reduce channel bed slope and halt channel incision.

Location 104. Tributary 296, River Mile 23.591 to 22.891 – Grade control incising channel and restore corridor

Problem description: Channel incision along Tributary 296 has resulted in severe erosion and mass wasting. Cattle access to the tributary and the removal of trees and woody vegetation along the streambanks has accelerated erosion.

Recommended intervention: Install a series of rock grade controls to reduce channel bed slope and halt channel incision. In addition, grade, fabric, and plant the banks to restore the riparian corridor and increase shear resistance.

Location 105. Tributary 96, River Mile 22.904 to 22.438 - Grade control incising reach and protect culvert outfall

Problem description: Channel incision downstream of a pond outfall has resulted in extensive bank failures. Downstream of the culvert the channel is scoured along both banks.

Recommended intervention: Arrest channel incision downstream of the pond outfall with a series of grade controls and armor the pond outfall with a rock armored plunge pool or stilling basin.

Location 106. Tributary Upper Main Stem, River Mile 21.576 to 20.564– Grade control incising channel and restore corridor

Problem description: Channel incision along the Upper Main Stem has resulted in severe erosion and mass wasting.

Recommended intervention: Install a series of rock grade controls to reduce channel bed slope and halt channel incision. In addition, grade, fabric, and plant the banks to restore a stable channel cross section and increase shear resistance.

Location 107. Tributary 196, River Mile 21.597 to 21.593 - Armor plunge pool and right descending bank at culvert outfall

Problem description: Triple 36-inch CMP outfalls downstream of a private drive off of Middlefork Road are directing flow against the right descending bank, resulting in bank scouring.

Recommended intervention: Construct a riprap armored plunge pool and add rock toe armor along approximately 20 feet of the right descending bank to dissipate the scouring energy at the culvert outfall.

Location 108. Upper Main Stem, River Mile 21.898 to 21.627 – Grade control incising channel

Problem description: Channel incision along the Upper Main Stem has resulted in systemic bank erosion and mass wasting.

Recommended intervention: Install a series of rock grade controls to reduce channel bed slope and halt channel incision.

Location 109. Upper Main Stem, River Mile 22.046 to 22.036 - Armor left descending bank near confluence

Problem description: Bank scouring continues to erode the left descending bank near the confluence with a gully.

Recommended intervention: Add a rock turning vane and vegetated rock toe armor along approximately 50 feet of the left descending bank to deflect flow away from the bank and toward the center of the channel.

Location 110. Upper Main Stem, River Mile 22.089 to 22.072 - Armor right descending bank at culvert outfall

Problem description: Bank scouring continues to erode the right descending bank downstream of the 120th Street culvert outfall.

Recommended intervention: Add a rock turning vane and vegetated rock toe armor along approximately 100 feet of the right descending bank to deflect flow away from the bank and toward the center of the channel.

Section 10
Implementation

10.1 Setting Priorities

A variety of methods are used to set priorities when deciding how to move forward with implementing long-term CIP programs and an integrated approach to watershed planning. Ranking systems are a common method used by numerous communities across the country. The ranking system can be designed to address each city department (i.e., wastewater, roads, stormwater) or general enough to apply to all departments. For stormwater programs specifically, priority ranking systems can be designed for each specific drainage basin, development stage (new development versus existing urban areas), or be comprehensive to address all situations.

As described in Section 9, the priority system used for this study was designed to address a rural watershed with planned future urban growth. However, as the City/County/NRD begin to implement the Stevens Creek CIP program, the priority of these projects will need to be weighted against other stormwater projects within the urbanized portion of the City and other urbanizing watersheds.

10.1.1 Evaluation Criteria

Following is a list of commonly used evaluation criteria when setting prioritizes for stormwater-related capital improvement projects. These criteria cover the broad range of potential screening criteria used in both rural and urban settings. The evaluation criteria are used to quantify the severity of the problem and the corresponding benefits the project would provide to the public.

- Street Flooding - This condition applies to floodwaters overtopping streets in such a manner that it slows vehicles or forces motorists to select an alternate route.
- Habitable Structure Flooding - This condition applies to the entry of floodwaters into habitable buildings.
- Stream Instability - This condition applies to streamflow or overland flow that is causing excessive scour of channels that can pose hazards to people, property, and infrastructure. Refer to Section 9.1.3 for additional detail regarding the types of stream instability categories.
- Water Quality - This condition applies to a degradation of water quality primarily caused by a release of sediment due to stream instability.
- Infrastructure Condition - This condition applies to existing drainage facilities such as culverts, curb inlets, culverts, bridges, and improved channels that need repaired or replaced.
- Poor Drainage - This condition applies to standing water in streets and on public and private property for extended periods.
- Public Benefit - This category is used to account for the number of properties that benefit from the project improvements.

- Ease of Implementation - This category is used to account for implementation issues including acquiring the necessary permits, disturbance of protected species, mitigation requirements, and project accessibility.

- Land Availability - This category is used to access the potential hardship of acquiring the necessary land and/or easements to construct the project.

- Public Acceptance - This category is used to account for stakeholder buy-in of the project.

10.1.2 Other Considerations

In addition to the evaluation criteria, the following issues are typically addressed to account for frequency, risk, economic impact, and land use type associated with the problem and the proposed improvement project.

- Frequency - This category takes into consideration the frequency the problem is occurring. For example, if flooding of a habitable building occurs every rainy season versus once every 5 years, the proposed improvement project to correct this problem will be given a higher priority.

- Degree of Risk - This category accounts for the degree of risk to persons or property associated with the problem continuing to occur. For example, a bridge that historically floods every year and could potentially cause the loss of life would receive a higher priority than a project that involves an icy sidewalk caused by isolated ponding that could result in a broken limb.

- Economic Impacts - This category accounts for the benefits of alleviating flooding to major commercial and/or industrial areas that would significantly impact the economy of the community if this business was halted or repairs were needed as a result of flooding.

- New Development versus Retrofit - This category evaluates the benefits of completing retrofit projects that solve flooding and erosion problems caused by a lack of sound land use planning, versus investing in undeveloped areas to avoid expensive problems in the future.

Once the evaluation criteria are selected, the next step in the process is to assign rating points and adjustment factors that reflect the community's goals and priorities. The estimated cost of the project is then used in conjunction with the point rating system to provide a cost-benefit ratio for each project. As a starting point for understanding which issues are the most important to the citizens of Lincoln, the Stevens Creek Citizen Advisory Committee listed the following categories (listed in order of importance) when asked to rank the screening criteria listed above.

- Degree of Risk
- Frequency
- Infrastructure Condition
- Stream Instability
- Public Benefit

10.2 Implementation Issues

While the Stevens Creek Watershed is predominately undeveloped, this area will be experiencing rapid growth in the coming years. Therefore, time is of the essence with respect to establishing the foundation for implementing the recommendations outlined in Sections 6 and 7. Specifically, the following list of items needs to be accomplished following the adoption of the study.

10.2.1 Maintenance/Funding

- Maintenance Agreements - The drainage standards should be revised to establish uniform criteria for the development of a maintenance plan to be submitted with the preliminary plat and referenced in the subdivision agreement. A good maintenance plan will not only provide a guide for future owners but will help ensure that maintenance responsibilities are clear when ownership is transferred from the developer. The facility owner should be required to perform inspections at a specified frequency and submit inspection forms to the regulatory agency. Penalties for breach of agreement should be clearly stated. The City/NRD should obtain legally binding agreements with property owners stating that the stormwater facilities for the site will not be altered and will be maintained as needed to achieve their original design intent.

- Cost-Share Program - A cost-share program needs to be implemented to address both construction and maintenance of site-specific structural BMPs. A public-private cost-share concept was developed where the City and NRD share in the cost of constructing the BMP portion of the facility, jointly providing funding for $100 of the $210 cost estimated per acre of drainage area. City/NRD funding is anticipated to be provided on a first-come, first-serve basis and be contingent upon City/NRD approval of the proposed cost-share program. In addition, the cost-share program would be subject to yearly budget approvals, voter approval of general obligation bonds, and NRD board approval.

10.2.2 Policy and Ordinances

- Drainage Criteria Manual Revisions - The City's manual will need to be updated to reflect the recommendations outlined in Section 7. These revisions include redefining the WQCV and adding design criteria for extended wet and dry detention basins to include outlet structure details and necessary maintenance activities.

- Ordinances - The implementation of site-specific structural BMPs and required maintenance activities may require modifications to City ordinances.

10.2.3 Education Program

- Water Quality Education - A proactive education program focusing on water quality issues should be developed to educate homeowners associations and private facility owners. The program may include a water quality seminar to address the primary sources of stormwater pollution, the methods for pollution reduction and removal, including both nonstructural and structural BMPs, and the proposed new maintenance requirements.

- Demonstration Project - Designing, constructing, and maintaining a demonstration project that incorporates water quality and flood control features will provide the City/NRD valuable knowledge that can be passed along to the developer and engineering community. The demonstration project could also be used as an education tool for the general public.

- Structural BMP Design Workshop - A structural BMP design workshop should be held to educate engineers and developers on designing and constructing structural BMPs. Providing this education will ensure proper BMP design, which will streamline the plan review process. The workshop would primarily focus on design guidance for extended wet and dry detention basins.

- Natural Stream Design Workshop - A natural stream design workshop should be held for engineers and developers focused on using bioengineering and geomorphic techniques for stream stabilization. The workshop would include proper design techniques for grade control structures and streambank stabilization materials.

10.2.4 Coordination Efforts

- Agency Coordination - A cooperative agreement between the City, NRD, and Lancaster County needs to be established to guide the implementation of the Master Plan. For example, as roadways are upgraded, the design data developed for stream crossings should be used during the design. In addition, the design, construction, and maintenance of structural BMPs need to be closely monitored and enforced by all agencies to make sure these facilities are properly managed. Lastly, many of the secondary problems can be addressed as part of ongoing County maintenance activities and/or combined with other City department or NRD projects.

Items that should be addressed initially include the Drainage Criteria Manual revisions, ordinance modifications, and establishing the maintenance agreements and cost-share program. Once these items are accomplished, the City should move forward with establishing the priority ranking system and conducting the education program.

10.3 Opportunity Areas

Figure 10-1 is a Watershed Planning Map that overlays a wide variety of natural and built elements to support an integrated approach to watershed planning in Stevens Creek. Opportunity Areas are very general planning locations within the watershed that highlight where natural elements and/or existing or future infrastructure come together. There are areas with the potential for multiple benefits and opportunities to protect or enhance features like floodplains, natural resources, historical and cultural features, and open space.

Four Opportunity Areas are highlighted on Figure 10-1 along the Salt Valley Heritage Greenway, which follows the main channel of Stevens Creek. These highlighted areas generally recognize where natural features like the floodplain and drainage corridors overlap or are in the vicinity of other elements such as the East Beltway corridor, existing or future trails, NRD conservation easements, open space, and stormwater or floodplain benefits.

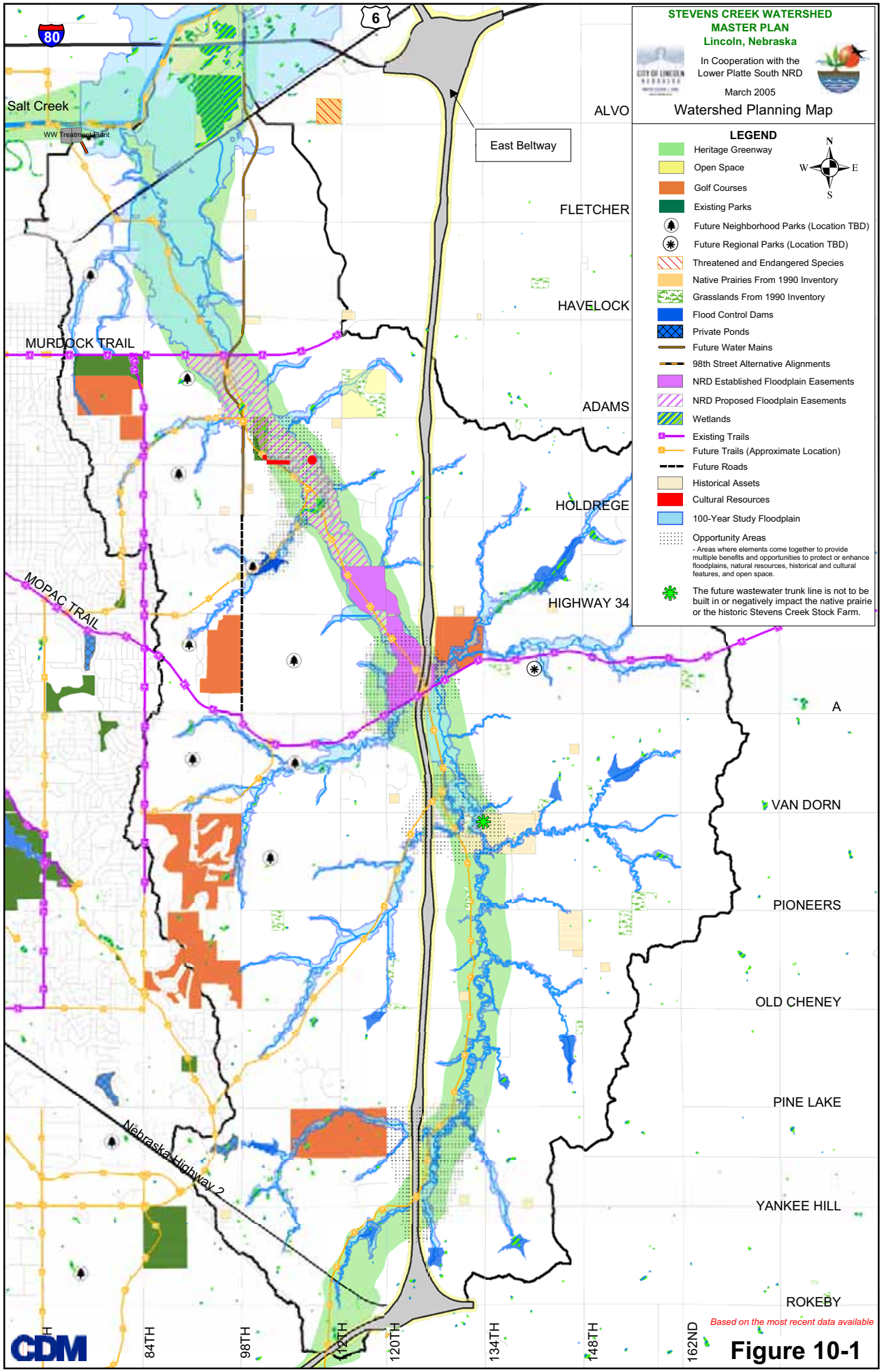

STEVENS CREEK WATERSHED
MASTER PLAN
Lincoln, Nebraska
In Cooperation with the
Lower Platte South NRD
March 2005
Watershed Planning Map
LEGEND
Heritage Greenway
Open Space
Golf Courses
Existing Parks
Future Neighborhood Parks (Location TBD)
Future Regional Parks (Location TBD)
Threatened and Endangered Species
Native Prairies From 1990 Inventory
Grasslands From 1990 Inventory
Flood Control Dams
Private Ponds
Future Water Mains
98th Street Alternative Alignments
NRD Established Floodplain Easements
NRD Proposed Floodplain Easements
Wetlands
Existing Trails
Future Trails (Approximate Location)
Future Roads
Historical Assets
Cultural Resources
100-Year Study Floodplain
Opportunity Areas
- Areas where elements come together to provide multiple benefits and opportunities to protect or enhance floodplains, natural resources, historical and cultural features, and open space.
The future wastewater trunk line is not to be built in or negatively impact the native prairie or the historic Stevens Creek Stock Farm.
N
W
E
S
80
6
Salt Creek
WW Treatment Plant
East Beltway
ALVO
FLETCHER
HAVELOCK
ADAMS
HOLDREGE
HIGHWAY 34
MURDOCK TRAIL
MOPAC TRAIL
Nebraska Highway 2
VAN DORN
PIONEERS
OLD CHENEY
PINE LAKE
YANKEE HILL
ROKEBY
84TH
98TH
120TH
134TH
148TH
162ND
CDM
Based on the most recent data available

Figure 10-1

Each opportunity area is described below:

- Area 1 - This area is located between Adams and Holdrege and contains cultural resources and existing parks. In addition, this area is within the future NRD floodplain easement.
- Area 2 - This area is located between Highway 34 and A Street. Multiple planning and infrastructure components converge at this location including exiting golf courses, the MoPac trail, future trail alignments, the NRD floodplain easement, and the East Beltway alignment.
- Area 3 - This area is located in the vicinity of 134th and Van Dorn and contains historical landmarks and future trail alignments.
- Area 4 - This area is located between Pine Lake and Yankee Hill Road and contains future trails and is adjacent to the East Beltway alignment.

As future planning continues for Stevens Creek, these areas should be referenced as a guide by City and County departments and NRD, particularly with regard to opportunities to integrate parks, open space, and stormwater or floodplain benefits.

Section 11
Digital Deliverables

11.1 Electronic Files

The electronic files associated with the study have been organized according to the following compact discs (CDs). Each CD is located in Appendix A located in Volume II of the report.

- CD 1 - Drainage Structure Data and Photographs, Thalweg Survey, As-Built Data, and Stage/Storage Routing Information
- CD 2 - Photographs - Public Participation
- CD 3 - Photographs - Stream Reaches
- CD 4 - HEC-HMS/HEC-RAS Computer Models
- CD 5 - Study Report (Volume I) and Appendix Information (Volume II)
- CD 6 - GIS Shape Files as described in Section 11.2
- CD 7 - Floodplain Mapping PDF Plots (Index, Tiles 1-7)
- CD 8 - Floodplain Mapping PDF Plots (Index, Tiles 8-15)

11.2 GIS Shapefiles

The following provides a description of GIS data sets used during the study. The list is organized according to the folder structure within CD 6. Each folder on the CD contains an ArcGIS ArcMap version 8.3 document that references the data sets.

- Bioassessment - This data set includes the location of the bioassessment sampling points. The information was obtained by the project team during the water quality analysis.

- Bridges_Culverts - This data set includes identification number, type, size, length, flow capacity, top of road profile, general conditions, and invert elevation. The structure information was obtained by the project team from detailed surveys or from as-built data during the hydraulic analysis. Hydraulic analysis specific to the drainage structures is located within Appendix J, Drainage Structure Performance Tables.

- Detention_Ponds - This data set includes existing and future detention ponds that were included in the hydrologic evaluation. The hydrologic information includes the stage, storage, and discharge tables. The existing detention pond as-built information was used in the hydraulic analysis. The information was obtained from LPSNRD, the City of Lincoln, and Lancaster County.

- Floodplain_and_CrossSections - This data set includes the floodplain boundaries of the 100- and 500-year design storms as well as the channel cross sections for the 10-, 50-, 100-, and 500-year design storms, based on existing land use conditions. This information was obtained by the project team during the floodplain mapping effort.

- Floodway - This data set includes the floodway boundary based on a maximum 1-foot rise in the study 100-year floodplain. This information was obtained by the project team during the floodplain mapping effort.

- Geomorphology_Information - These data sets summarize field information gathered by the project team during field visits to analyze the geomorphic processes within the stream reaches. Data sets include channel bar type and condition, bed and bank material, type and bed consolidation, channel profile and cross section information, erosion and mass wasting, vegetative bank protection and condition of riparian corridor, outfalls, infrastructure crossings, location of stream reach photographs, HEC-RAS shear values throughout the watershed, location of knickpoints, debris jams, and fluvial process layers depicting meander adjustment, incising, widening, and stable channel.

- Impacted_Buildings - This data set includes the location of habitable buildings located within the study 100-year floodplain. The information was obtained by the project team.

- Known_Problem_Areas - These data sets identify the location of CIPs and other areas of concern that address issues due to bank erosion, incision, inadequate drainage structures, or structures in need of repair. The information was obtained by the project team during the CIP analysis.

- Land_Use - This data set includes digital land use data broken out into multiple categories for existing and future conditions. The future land use plan for the watershed is based on a 2025 planning horizon. The information was supplied by the City of Lincoln.

- Livestock_Commercial_Industrial_GolfCourses - These data sets include any land uses having implications for water quality and quantity. The information was obtained from the City of Lincoln.

- Soil_Data - This data set includes the Soil Survey Geographic (SSURGO) database data obtained from the Natural Resources Conservation Service (NRCS) for the Stevens Creek Watershed as well as Hydrologic Soil Groups (HSGs) by soil types determined from the NRCS Lancaster County Soil Survey.

- Stream_Reaches - This data set includes the numbering system for each major stream segment, upstream and downstream flow line elevation, reach length, and grade. The digitized stream reaches were obtained from the City of Lincoln. All attributes associated with the stream reaches were identified by the project team during the hydraulic analysis. General information including channel condition, type, and geometry were obtained during the geomorphic analysis and included in Appendix I, Reach Descriptions.

- Time_of_Concentration - This data set includes flow paths and associated variables used to calculate time of concentration values for each watershed subbasin. The information was developed by the project team during the hydrologic analysis.

- Watershed_Planning_Map - Multiple data sets including the potential East Beltway and buffer locations, potential future wastewater trunk sewer, grasslands, heritage greenway, LPSNRD established and proposed easements, native prairies, potential new road between Holdrege to A Street, open space, opportunity areas, existing and future neighborhood parks, private golf courses, existing and future trails, threatened and endangered species, wetlands, cultural and historic locations, and wastewater treatment plants.

- Watershed_Subbasins - This data set includes the identification number, drainage area size, composite curve number, and time of concentration calculations. The information was obtained by the project team during the hydrologic analysis.

Section 12
Glossary of Terms and References

12.1 Glossary of Terms

The following terms and acronyms are used throughout the report.

- 2-year design storm - A rainfall event with a probability of occurrence of 50 percent in any given year.
- 5-year design storm - A rainfall event with a probability of occurrence of 20 percent in any given year.
- 10-year design storm - A rainfall event with a probability of occurrence of 10 percent in any given year.
- 50-year design storm - A rainfall event with a probability of occurrence of 2 percent in any given year.
- 100-year design storm - A rainfall event with a probability of occurrence of 1 percent in any given year.
- 500-year design storm - A rainfall event with a probability of occurrence of 0.2 percent in any given year.
- Bank angle - The angle measured from the horizontal between the base of the slope and the top of bank. For complex cross sections, it is the series of angles measured from the horizontal at each change in slope.
- Bankfull elevation - In classical terms, the elevation in the channel where water surface reaches the top of the streambanks, also referred to as "top-of-bank" elevation. When the water surface rises above the bankfull elevation, it crests the banks and spills over onto the bankfull floodplain. In urban streams, the bankfull elevation generally coincides with the dominant discharge elevation. This elevation corresponds to the stream forming flow, which creates bankfull floodplains.
- Bankfull floodplain - The bankfull floodplain is a low, vegetated terrace, formed by, and an indicator of, the bankfull discharge. In incised streams, bankfull floodplains form as internal shelves within the main channel. While not an absolute diagnostic, functioning bankfull floodplains indicate stable reaches. Bankfull floodplains fulfill the important function of reducing stress on the streambanks. When the flow crests the internal floodplain, the velocity and thereby the shear stress is reduced as the flow spreads across the internal shelf.
- Base flow - In a perennial stream, the low flow discharge attributable to groundwater flow.
- BFE - Base flood elevation.

- Bioengineering (also called biostabilization) - A scientific and ancient method of restoring the landscape of ecosystems using the physical properties of plants, such as their sheer resistance, tensile strength, and flexibility, to rebuild the terrestrial or aquatic foundation in a manner that is both physically and ecologically stable (see streambank stabilization, synonymous with bioengineering).

- BMP - Best management practice, a structural or nonstructural device designed to temporarily store and treat urban stormwater runoff in order to mitigate flooding, reduce pollution, and provide other amenities.

- cfs - Cubic feet per second, a unit of measurement for labeling flow of water.

- Channel bar - A streambed deposit of silt, clay, sand, or gravel, often exposed during low-water periods. An alluvial deposit composed of silt, clay, sand, gravel, or other material that obstructs flow and induces deposition or transport.

- Channel evolution - The progression of channel form (usually expressed as cross section) over time as a response to a disturbance. The model describes the progression of channel shapes as the stream accommodates the disturbance and eventually reacquires equilibrium. The stages of channel evolution in the most commonly used model are equilibrium, channel disturbance, incision, widening, deposition, and recovery.

- CMP - Corrugated metal pipe.

- Composite revetment - A bank strengthening method in which rock, geogrid, and plants form a composite material and increase resistance to scour and near-surface mass wasting. The revetment is built in layers comprised of durable rock interlaid with woody bare root plants. The thickness of the rock is controlled by geogrid layers wrapping the rock on three sides. The channel-facing side remains open. On steep slopes, a structural geogrid may also be used to increase slope stability.

- Contours - Lines of equal elevation that represent the land surface.

- Conveyance system - Natural channels and manmade structures that convey stormwater downstream.

- Cross section - A one-dimensional line that is drawn perpendicular to the contours to represent the open channel flow conveyance at that location.

- Detention basin - A stormwater facility that collects and temporarily stores runoff to reduce peak flow rates and alleviate downstream flooding and erosion problems.

- DFIRM - Digital Flood Insurance Rate Map

- Dominant discharge - The dominant stream-forming flow or recurring flow responsible for the majority of work and channel maintenance in a stream. It is the flow that over time has the greatest influence on stream form. The recurrence interval for the dominant discharge of most streams is roughly 1.5 years, as determined by flood frequency analysis. In urban areas with highly altered hydrology, this return interval may be much

more frequent. The dominant discharge is sometimes referred to as the bankfull or stream-forming discharge.

- Extended dry detention basin: An extended dry detention basin provides flood control and water quality treatment and is a dry storage facility. The term "extended" means the entire WQCV is treated by slowly releasing the runoff over a specified period of time until the facility completely drains. The primary pollutant removal mechanism is sedimentation, which is achieved through an appropriate detention time.

- Extended wet detention basin: An extended wet detention basin provides flood control and water quality treatment and contains a permanent pool. The term "extended" means the entire WQCV is treated above the permanent pool by slowly releasing it over a specified period of time. The permanent pool provides a medium for the settling of solids between storms and, with longer retention times and aquatic vegetation, nutrients and dissolved pollutants can be removed. Section 8.3.4.2 of the Drainage Criteria Manual refers to these basins as "Retention (Wet) Ponds."

- FEMA - Federal Emergency Management Agency.

- FIRM - Flood Insurance Rate Map

- FIS - Flood Insurance Study.

- Flood bench - A technique used in stormwater control, when horizontal space is available, that removes earth from one or both streambanks such that the result is a visible bench when the stream is viewed in cross section, and done to reduce water velocity, shear stresses, and water surface elevation.

- Floodplain - The area of land that is inundated with water during a given storm event.

- Fluvial geomorphology - The scientific discipline concerned with the study of how moving water shapes landforms.

- Freeboard - Defined as the distance between the maximum water surface elevation anticipated in design and the top of retaining banks or structures, and provided to prevent overtopping due to unforeseen conditions.

- ft/sec - Feet per second, a unit of measurement for labeling velocity of water.

- ft^2 – Square foot or square feet, a unit of measurement for labeling area.

- Geomorphology - The study of surface land forms and the processes that develop those forms. Geomorphic processes are the primary mechanisms that produce these land forms, including drainage patterns, streams, floodplains, and other watershed features (see also fluvial geomorphology).

- GIS - Geographical information system.

- GPS - Global positioning system.

- Gully - A channel or miniature valley cut by concentrated runoff through which water commonly flows only during and immediately after heavy rains and is sufficiently deep that it would not be obliterated by normal tillage operations.
- HEC - Hydrologic Engineering Center of the U. S. Army Corps of Engineers.
- HEC-HMS - A computer model developed by the U. S. Army Corps of Engineers to simulate the hydrologic conditions of a drainage area.
- HEC-RAS - A computer model developed by the U. S. Army Corps of Engineers to simulate the hydraulic conditions of a conveyance system through a drainage area.
- Hydraulic analysis - The study of stormwater flow through the conveyance system that includes underground pipelines, culverts, improved open channels, and natural creeks.
- Hydraulic Profile - A plot of the water surface elevation along the flow line of a stream or pipe.
- Hydrograph - A plot of surface runoff or excess precipitation versus time.
- Hydrology analysis - The study of the occurrence, distribution, movement, and properties of waters of the earth and their environmental relations.
- Hyetograph - A plot of rainfall depth or intensity versus time.
- Illicit connections - The illegal and/or unauthorized connections that result in untreated wastewater discharges into storm drainage systems and receiving waters.
- Illicit discharge - Any discharge to a municipal separate storm sewer system that is not composed entirely of stormwater, except for discharges allowed under an NPDES permit or waters used for certain emergency situations.
- Imbrication - Imbrication refers to the pattern of bed load deposition. Larger particles such as cobbles, concrete slabs, or shale plates deposit on the streambed in a “fish scale” pattern. The stream power necessary to move these larger particles generally results from mid-intensity storms (10- to 25-year events). Imbrication armors streambeds from the major storms and is one indicator of competent bedload transport.
- Impervious - The characteristic of a material that prevents the infiltration or passage of liquid through it. This may apply to roads, streets, parking lots, rooftops, and sidewalks.
- Incision - Vertical channel adjustment, or channel downcutting, generally in response to an alteration upstream or downstream of the incising reach. Incision occurs when sediment or transport material is more easily removed from the channel bed than it is from the streambanks. Bed material is liberated to “heal” a temporary disturbance in sediment transport equilibrium or channel shape.

- Knickpoint - An abrupt discontinuity in bed slope indicating the upward limit of channel incision. A knickpoint usually occurs at a resistant hard point in the channel bed, such as a geologic control, debris jams, de facto grade control, or manmade structure.

- Knickzone - Typically observed in loess or alluvial streams, a knickzone is an area of slope discontinuity similar to a knickpoint, but less pronounced and occurring over a greater length of channel. In bedrock streams, knickzones occur as a series of smaller knickpoints.

- Left (and right) descending bank - Refers to the either side of the channel in relation to the downstream flow of water. For example, left descending bank refers to the left-hand side of an in-channel observer facing downstream. This designation is the convention in river science and engineering.

- Length-to-width ratio - Increasing the length-to-width ratio of the facility increases the water quality treatment potential by providing additional detention time for settling, infiltration, and possibly biological uptake. As a result, a 3:1 length-to-width ratio or greater is generally recommended. Basins should be wedge-shaped, narrowest at the inlet and widest at the outlet. Greater flow lengths can be accommodated by relocating the basin inlet or outlet where possible, or by installing berms or baffles within the basin to the full depth of the WQCV to avoid short circuiting and increase travel time to the outlet.

- lf – Linear foot or linear feet, a unit of measurement for labeling length.

- Littoral zone - An aquatic and safety bench around the perimeter of the basin is called the littoral zone.

- Longitudinal profile - A profile survey down the thalweg of a stream. A thalweg profile is not a channel centerline profile and the two are not interchangeable. Longitudinal profiles are used both for diagnosis of dominant process and for design guidance. Longitudinal profiles are particularly helpful in identifying knickpoints and knickzones and for evaluating pool riffle sequences.

- Manning's formula - A formula used to predict the velocity of water flow in an open channel or pipeline: $V = 1.486/n^* R^{2/3} {}^*S^{1/2}$, where V is the mean velocity of flow in feet per second; R is the hydraulic radius; S is the slope of the channel, in feet per foot; and n is the roughness coefficient of the channel lining.

- Mass wasting - Landslide, a mass downward movement of material caused by gravity in contrast to surficial erosion, which is the movement of individual soil particles.

- Meander advance - The natural process by which the meander waveform migrates downstream. The movement is a consequence of the secondary flows occurring perpendicular to the primary downstream flow. These secondary flows alternately scour and deposit channel materials. The greatest stress and the greatest scour occur just downstream of the apex of a curve on the outside of the bend. Similarly, the peak deposition occurs just downstream of the apex on the inside of a bend. Over time, this pattern moves the waveform downstream.

- Meander amplitude - The linear distance between the apex of one meander and the apex of the next meander.

- Meander wavelength - The length of one complete waveform. Wavelength can be measured as the linear distance between two analogous points on a waveform.

- Micropool - The micropool is an optional feature for extended dry detention basins; a relatively shallow impoundment intended to concentrate sediment and reduce the potential for resuspension during runoff events. Vegetation in the micropool can help stabilize the trapped sediment. A micropool also helps prevent clogging of the outlet.

- Normal depth - Depth of flow in an open conduit during uniform flow for the given conditions (see Manning's equation).

- NPDES - The National Pollutant Discharge Elimination System, established by Section 402 of the Clean Water Act, is a federally mandated system used for regulating point source and stormwater discharges.

- Open channels - Also known as swales, grass channels, streams, and biofilters. These systems are used for the conveyance, retention, infiltration, and filtration of stormwater runoff.

- Outfall - The point where water flows from a conduit, stream, or drain.

- Perennial stream - A stream channel that has running water throughout the year.

- Permanent pool - The permanent pool provides a holding volume between runoff events for continued settling of particulate contaminants and nutrient uptake by aquatic plants. As discussed in Section 6.11.2 of the City's Drainage Criteria Manual, water budget calculations are required for all permanent pool stormwater facilities to demonstrate that a permanent pool will be achieved given the average annual site hydrologic conditions. If the permanent pool cannot be maintained under normal conditions, infiltration losses in the permanent pool can be minimized using various methods, including compaction, incorporating clay into the base materials, and installing an impermeable liner.

- Permanent pool volume - There are a variety of methods for determining the design volume of the permanent pool. Sizing criteria have been developed based on solids settling and nutrient removal mechanisms. Due to limited empirical evidence to support these designs, a simplified method of one to two times the WQCV is suggested (Table 7-1). The permanent pool depth should be between 5 to 10 feet, which is consistent with City's Drainage Criteria Manual guidance.

- Plan form analysis - Evaluation of the horizontal geometry of the shape and size of the channels. Plan form analysis provides insight on whether and how parts of the basin differ from one another and if the geometric relationships of meanders are within the expected norms.

- Pollution prevention plan - A requirement for some land uses or activities (e.g., industrial sites) that outlines techniques to prevent pollutants from being washed off in stormwater runoff (e.g., spill response, material handling, employee training, etc.)

- Pool-riffle sequences - In a streambed, the combination of topographical lows (pools) produced by scour and the topographical high areas (riffles) created by the accumulation of relatively coarse-grained sediment. A sequence is defined as the beginning point of one riffle to the beginning of the next.

- RCB - Reinforced concrete box.

- RCP - Reinforced concrete pipe.

- Rill - Defined as of lesser depth than a gully and would be smoothed by ordinary farm tillage (see gully).

- Riparian - Woody vegetation that is characteristic of an area bordering a stream or river.

- Riprap - A loose assemblage of broken stones built along streams or beaches for erosion protection.

- Runoff - The portion of precipitation that is discharged from a drainage area.

- Sediment forebay - A sediment forebay is a pretreatment feature that can increase the pollutant removal efficiency of the facility by trapping sediment and trash at all basin inlets. Generally it is recommended that the forebay represent at least 10 percent of the WQCV to be effective. The forebay can also facilitate maintenance by concentrating sediment in an accessible location. The forebay consists of a separate cell, formed by an acceptable barrier such as a vegetated earthen weir.

- Sediment transport - The movement of dislodged particles through a stream system. It is one of the driving forces (along with flow) of channel adjustment.

- Sediment transport competence - The condition in which the stream maintains sufficient stream power to transport the sediment supplied to it continuously through the system.

- Sedimentation - Soil particles suspended in stormwater that can settle in streambeds and disrupt the natural flow of the stream.

- Scour line elevation - The distance above a known datum (top of ground) to a persistent near-horizontal erosion feature at the peak depth of any given flow.

- Side slopes - The slope of the sides of a channel, dam or embankment, where customary naming is the horizontal distance first, as 1.5 to 1, or frequently, 1½:1, meaning a horizontal distance of 1.5 feet to 1 foot vertical.

- Sinuosity - The ratio of channel length to valley length. For example, a river 2,000 feet long, winding through a river valley that is 1,000 feet long has a sinuosity of 2.

- Slope - Defined by change in vertical elevation divided by horizontal distance and typically expressed as a percentage.
- Stabilization - Providing adequate measures, vegetative and/or structural that will prevent erosion from occurring.
- Streambank stabilization - The use of the structural properties of live plants to rebuild washed out streambanks and flood terraces, including live slope fascines, hedge brush layers, and live willow brush mattresses.
- Structural BMPs - Constructed facilities designed to remove pollutants and slow down the runoff from smaller rainstorms to preserve water quality and provide long-term stream stability. These facilities can be installed as development progresses (site-specific) or to address multiple developments (regional).
- Subarea - A portion of a watershed that drains and concentrates at point, typically at a catch basin, within a system of drainage pipes, or along a stream.
- Surcharge - A condition of a stormwater system, where the water surface exceeds the freeboard and overflows.
- Swale - An open drainage channel or depression explicitly designed to detain and promote the filtration of stormwater runoff.
- Tail water - Water, in a river or channel, immediately downstream from a structure.
- Thalweg - The deepest part of a channel cross section. The dominant thread of stream flow creates the thalweg.
- Time of concentration - Time required for water to flow from the most remote point of a watershed, in a hydraulic sense, to a point of concentration described within a subarea.
- Toe (of slope) - Where the slope stops or levels out. Bottom of the slope.
- TR-55 - Technical Release 55, a report compiled by the Natural Resources Conservation Service that presents procedures for stormwater calculations.
- Watershed - A region of land that drains to a river, creek, or body of water.
- Wing wall - Side wall extensions of a structure, typically at the head or tail end of a system of stormwater pipes or a culvert, which is used to prevent sloughing of banks or channels and to direct runoff.
- WQCV - Water quality control volume.
- WSE - Water surface elevation.

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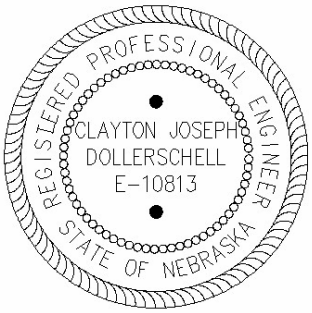
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