STORMWATER

AIM NORMAN

Area & Infrastructure Master Plan

Stormwater Master Plan Update

City of Norman

Norman, Oklahoma

Prepared by: GARVER

In Partnership with: RDG PLANNING • DESIGN

DRAFT

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AIM NORMAN

AREA & INFRASTRUCTURE MASTER PLAN

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Acronyms and Abbreviations

°F	degrees Fahrenheit
µg/l	Micrograms per liter
ac-ft	acre-feet
BLE	base level engineering
BMP	best management practice
BNSF	Burlington Northern and Santa Fe Railroad
CEQ	Council of Environmental Quality
cfs	cubic feet per second
CIP	Capital Improvement Projects
City	City of Norman, Oklahoma
CLOMR	Conditional Letter of Map Revision
CMP	corrugated metal pipe
COMCD	Central Oklahoma Master Conservancy District
CPI	consumer price Index
CRS	community rating system
DO	dissolved oxygen
EDC	engineering design criteria
EPA	U.S. Environmental Protection Agency ERU equivalent runoff/residential unit
ESU	equivalent storm water unit
FC	fecal coliform
FEMA	Federal Emergency Management Agency
FIS	Flood Insurance Study
ft	feet/foot
FY	fiscal year, October 1 through September 30
GIS	Geographic Information System
GO	general obligation
H:V	horizontal to vertical side slope ratio
HEC	U.S. Army Corps of Engineers Hydrologic Engineering Center
HEC-RAS	USACE HEC's River Analysis System
IH	Interstate Highway
LID	Low Impact Development
LIDAR	light detection/distance and ranging
LOMR	Letter of Map Revision

MCM	minimum control measures
MS4	municipal storm water separate storm sewer systems
MSE	mechanically stabilized earth
NAVD	North American Vertical Datum
NGVD	National Geodetic Vertical Datum
NLCD	national land cover dataset
NOI	Notice of Intent
NPDES	National Pollutant Discharge Elimination System
NRCS	Natural Resources Conservation Service
NSQD	National Stormwater Quality Database
O&M	operations and maintenance
OCARTS	Oklahoma City Area Regional Transportation Study
OCC	Oklahoma Conservation Commission
ODEQ	Oklahoma Department of Environmental Quality
OPDES	Oklahoma Pollutant Discharge Elimination System
OWRB	Oklahoma Water Resources Board
PBCR	primary body contact recreation
POA	Property Owner Association
RCB	reinforced box culvert
RFD	Rapid Floodplain Delineation
ROW	right of way
SFHA	special flood hazard areas
SH	State Highway
SPC	stream planning corridor
sq ft	square feet
SSO	sanitary sewer overflow
SSURGO	Soil Survey Geographic Database
State	State of Oklahoma
SWAT	Soil Water Assessment Tool
SWMM	Surface Water Management Model
SWMP	Stormwater Master Plan
SWS	sensitive water supply
SWU	Stormwater Utility
TMDL	Total Maximum Daily Load

TOD	transit oriented development
T-P	total phosphorus
TSS	total suspended solids
USACE	U.S. Army Corps of Engineers
USDA	U.S. Department of Agriculture
USGS	U.S. Geological Survey
WPA	Work Projects Administration
WQPZ	Water Quality Protection Zones
WQS	Water Quality Standards
WQV	Water Quality Volume

Project Identification Numbers

BC Bishop Creek

BHC Brookhaven Creek

CC Clear Creek

CR Canadian River

DBC Dave Blue Creek

IC Imhoff Creek

LR Little River Mainstem

TGLR Little River, Tributary G

WC Little River, Woodcrest Creek

MC Merkle Creek

RC Rock Creek

TMF Ten Mile Flat

2025 Acknowledgements

City of Norman City Leadership

- Mayor - Larry Heikkila

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- Ward 1 - Austin Ball
- Ward 2 - Matthew Peacock
- Ward 3 - Bree Montoya
- Ward 4 - Helen Grant
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Trey Bates	Norman Developers Council
Geoff Canty	ECAB Board Member/Norman Area Land Conservancy Board Member

Norman Stormwater Task Force Members, cont'd

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Russ Dutnell	Geomorphologist/Sole Proprietor – Riverman Engineering
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Richard McKown	Greenbelt Commission/Norman Developers Council Chairman
Richard Ryan	University of Oklahoma
Lyntha Wesner	Greenbelt Commission, Imagine Norman, Parks Advocate

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Curtis McCarty	Planning Commission
Joyce Pitchlynn	Tree Board
Duane Winegardner	Central Oklahoma Master Conservancy District

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Glen Brown	Geologist
Dan Butler	Oklahoma Conservation Commission
Alan Haws	Planning Commission
Tom McCaleb	SMC Consulting Engineers
Sarah Peterson	University of Oklahoma
Richard Ryan	University of Oklahoma
Jean Vieux	Vieux and Associates, Inc.

INTRODUCTION TO AIM NORMAN

In 2023, the City of Norman embarked on an ambitious endeavor: The Norman Area & Infrastructure Master Plan (AIM Norman). Decisions made in Norman today and in the years to come will shape city's growth, development patterns, and the community image for decades. Rapidly changing and evolving technology, extreme weather events, and the University of Oklahoma's growing national audience as a new member of the Southeastern Conference will all impact these decisions.

AIM Norman examines all elements of city development and quality of life to help shape the community's growth through 2045. Together, all seven Master Plans of AIM Norman provide a roadmap that will provide essential guidance to leaders and decision-makers, representing the City and its partners' plan for growth, change, and adaptation.

AIM Norman is:

- A combination of processes and Master Plans.
- A blueprint for a sustainable and resilient future that embraces Norman's unique character.
- A collective vision for Norman that should resonate with every community member.
- All-encompassing and inclusive, supported by every facet of the community, and align with the values and aspirations of Norman residents.

AIM Norman encompasses distinct master planning elements, with the Land Use Plan as the guide for development and land use policy to help inform all Master Plans.

HOUSING

A safe, comfortable, and attainable home for all is critical to Norman's future success. Rising home prices contribute to housing challenges. The recognition of poverty and unhoused populations in Norman is growing, while limited student housing options strain existing neighborhoods. The increasing popularity of the Oklahoma City metro as a place to live creates more demand, coupled with long-time residents wanting to age in the community. The AIM Norman Housing Plan analyzes the housing market and outlines a strategic plan for addressing housing needs.

STORMWATER

Major rain events impact Norman's residents and infrastructure. The City has recently shifted away from the traditional system of hard, channelized drainage paths and concentration of stormwater flows toward more sustainable stormwater policies. However, challenges remain, including flooding, erosion, and pollution of streams flowing into Lake Thunderbird. As growth and development increase impervious surface coverage, the City must accommodate stormwater effectively throughout the community. The AIM Norman 2025 Stormwater Master Plan Update outlines resilient solutions to help Norman's stormwater management systems adapt to both current and future challenges.

TRANSPORTATION

Mobility routes create a more connected community when it feels safe, comfortable, and accessible for all users. As the Norman community grows geographically and in population, so too must the routes and options to get to places. Car-centric communities like Norman are considering a more multi-modal approach to transportation. People are looking for connected trails and safe bike routes when choosing where to live, as new personal transportation devices grant more people opportunities to leverage trails. The AIM Norman Comprehensive Transportation Plan Update identifies future mobility projects in existing and new neighborhoods for motorists and active transportation users to cast a positive vision for mobility in Norman.

PARKS, RECREATION, AND CULTURE

Along with a comprehensive trail network, residents value cities with unique quality of life amenities — particularly parks, recreational opportunities, and special events. Norman has more parks per capita than many comparable cities. Maintaining these parks at a first-class level is a high priority that grows in difficulty as costs rise and resources decline. Residents desire a connection to nature and each other, along with vibrant cultural and community events and facilities for all ages and abilities. The AIM Norman Parks, Recreation, and Culture Master Plan aims to provide current and future residents with safe and engaging parks, recreation, events, and cultural activities to access and enjoy.

WASTEWATER

Reliable and resilient wastewater service is vital for existing and future homes, businesses, and industries. As more users are added and the wastewater collection system is expanded, adequate treatment facilities for quantity and quality must also be in place to meet environmental standards and water quality requirements. The AIM Wastewater Master Plan analyzes wastewater capacity needs and identifies improvements to the collection and treatment of wastewater to meet current and future needs in accordance with environmental regulations while minimizing costs to ratepayers.

WATER

Access to quality water supply is critical for existing and future homes, businesses, and industries. Currently, Norman's critical water supply comes from Lake Thunderbird, the Garber-Wellington Aquifer, and wholesale water purchases from Oklahoma City. With projected residential and commercial growth, future constraints on the water supply and infrastructure are expected and must be addressed. The AIM Norman Water Master Plan analyzes the water system's capacity and water supply needs and identifies improvements to meet existing and future demands.

INTEGRATING THE AIM NORMAN MASTER PLANS

A thoughtful, coordinated approach ensures that all seven elements of AIM Norman work together to create a balanced, sustainable, and thriving community for current and future residents. Together, they shape how Norman looks, feels, and functions. Major decisions in one component influence the others and determine the trajectory of land use development.

DEVELOPMENT PRINCIPLES

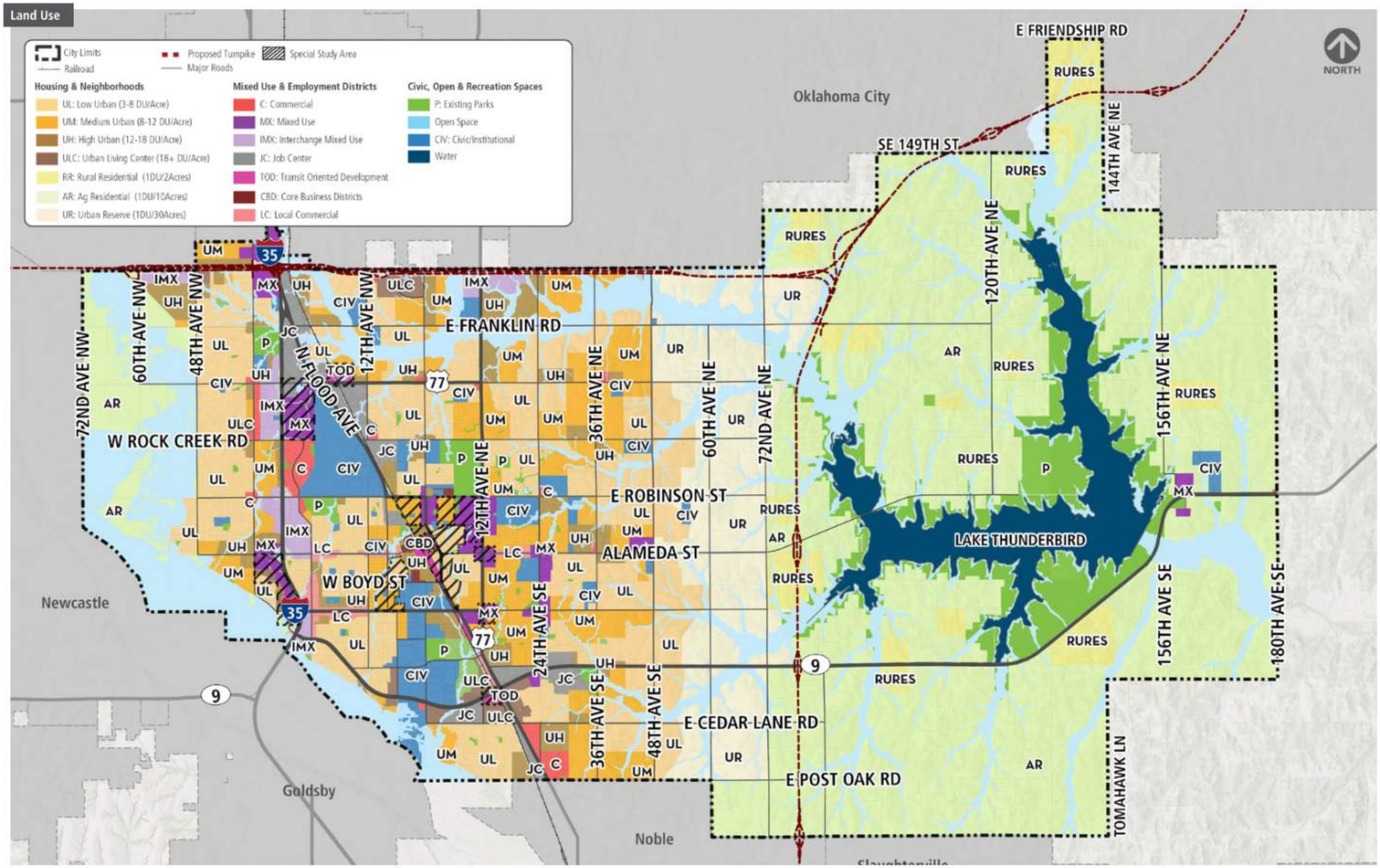
The AIM Norman Land Use Plan's Development Principles stem from Norman residents' input and Smart Growth for America's Principles of Smart Growth. The ten Development Principles align AIM Norman's plans and studies to guide Norman's evolution through 2045.

AIM NORMAN DEVELOPMENT PRINCIPLES

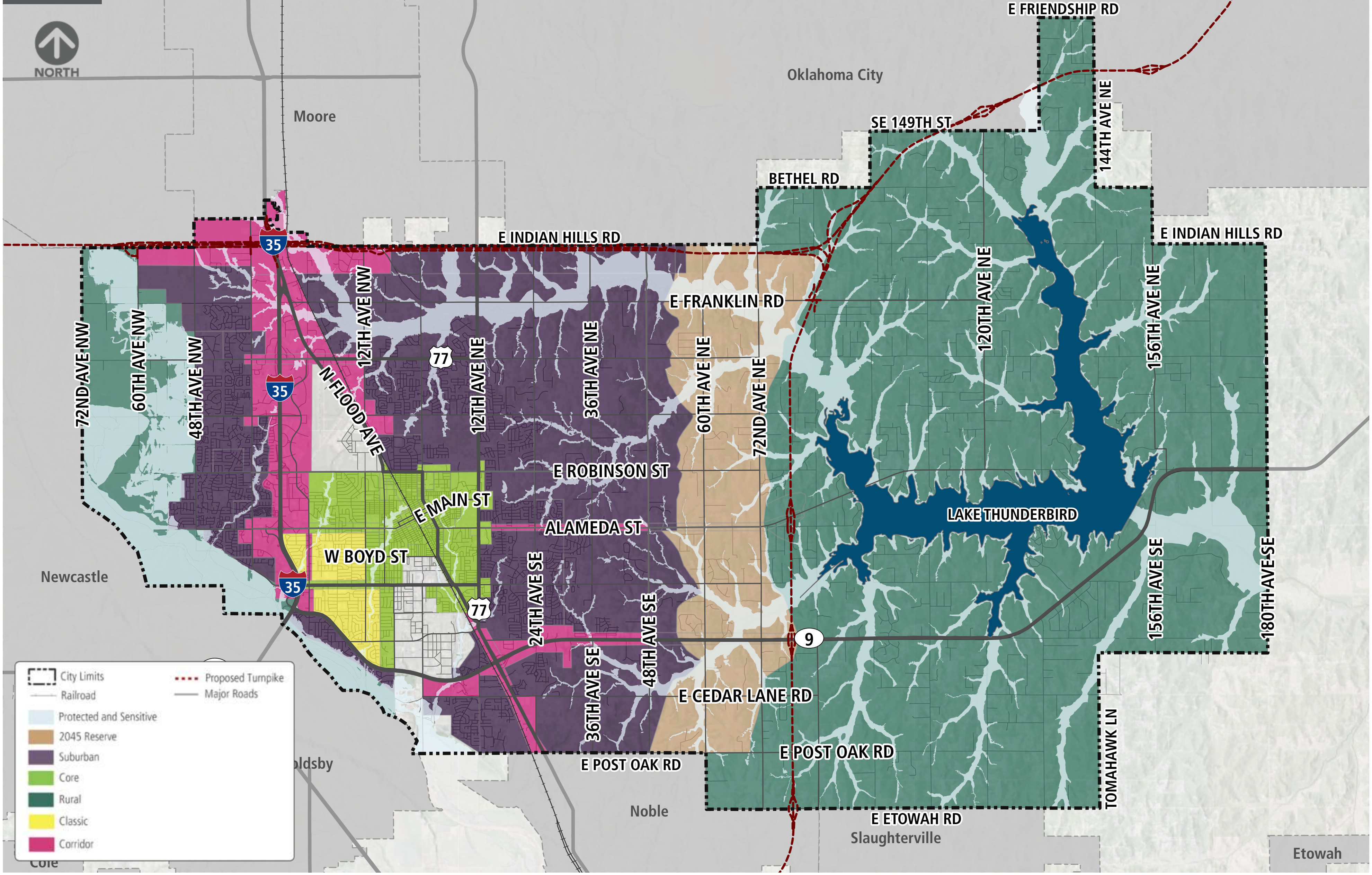
1. Manage urban services efficiently.
2. Promote diverse housing options.
3. Promote infill development and neighborhood reinvestment.
4. Protect the environment in all decision-making.
5. Enhance distinctive neighborhoods, business districts, and natural areas with a strong sense of place.
6. Provide a multi-modal and connected transportation network.
7. Enhance public safety and minimize hazards.
8. Encourage balanced and connected neighborhoods.
9. Make development decisions predictable, fair, and cost effective.
10. Make decisions in a transparent and collaborative manner.

Updated Comprehensive Land Use Plan

Please see the following pages for the Comprehensive Land Use Plan and the Character Area Map that were developed as part of the 2045 AIM Norman process.



Character Areas



Stormwater Master Plan Update Approach

The 2009 Stormwater Master Plan (SWMP) was instrumental in helping City staff understand the issues facing stormwater infrastructure and future development concerns. Many of the key issues identified in 2009 have been initiated or completed, and many others remain key issues facing the City into the future. The purpose of this SWMP Update is to clarify items that have been addressed in the time since the document was written, provide an update on issues that remain a concern for the City, and update costs anticipated for the capital improvement projects. This updated document also includes recommended stormwater policy items that were determined through the citizen input phase of the AIM Norman process.

Updated Report Organization

The SWMP Update is organized as closely as possible to the 2009 document (including section numbers and titles). The intention of City staff is to have an updated document that contains all relevant information in one location. This updated document is also condensed to be useful for stormwater management by staff and citizens moving forward from 2025 to a future SWMP Study. Each section of this SWMP Update includes an "Updates for 2025" section at the beginning, making note of any the substantial changes to that section.

There are some items that were not updated as part of this 2025 AIM Norman process. A note is included in those sections that the information is relevant but outdated. Most notably, section 10 (Financial Analysis) was not updated for this process. In the case of that section, several documents have been produced that investigate the financial analysis of a stormwater utility fee in more detail and with more context than what was provided in 2009. Future studies will be required to update the information further. In situations like Section 10 where the information is no longer relevant, the relevant document will be referenced in the text of this Update.

Updated Executive Summary of SW Master Plan

Introduction

Stormwater, or runoff generated by rain events, impacts Norman's environment and infrastructure by contributing to flooding, erosion, and surface water quality concerns across the city. As Norman updates its Land Use Plan through the Area and Infrastructure Master Plan (AIM Norman), it's essential to consider how these land use changes will affect stormwater management.

The 2009 Stormwater Master Plan (SWMP) examined the stormwater challenges facing the City at that time. This update process aligns the SWMP with industry standards of stormwater management in 2025 and integrates effective strategies into the AIM 2045 Land Use Plan to anticipate stormwater challenges and protect Norman's future.

Stormwater in Norman

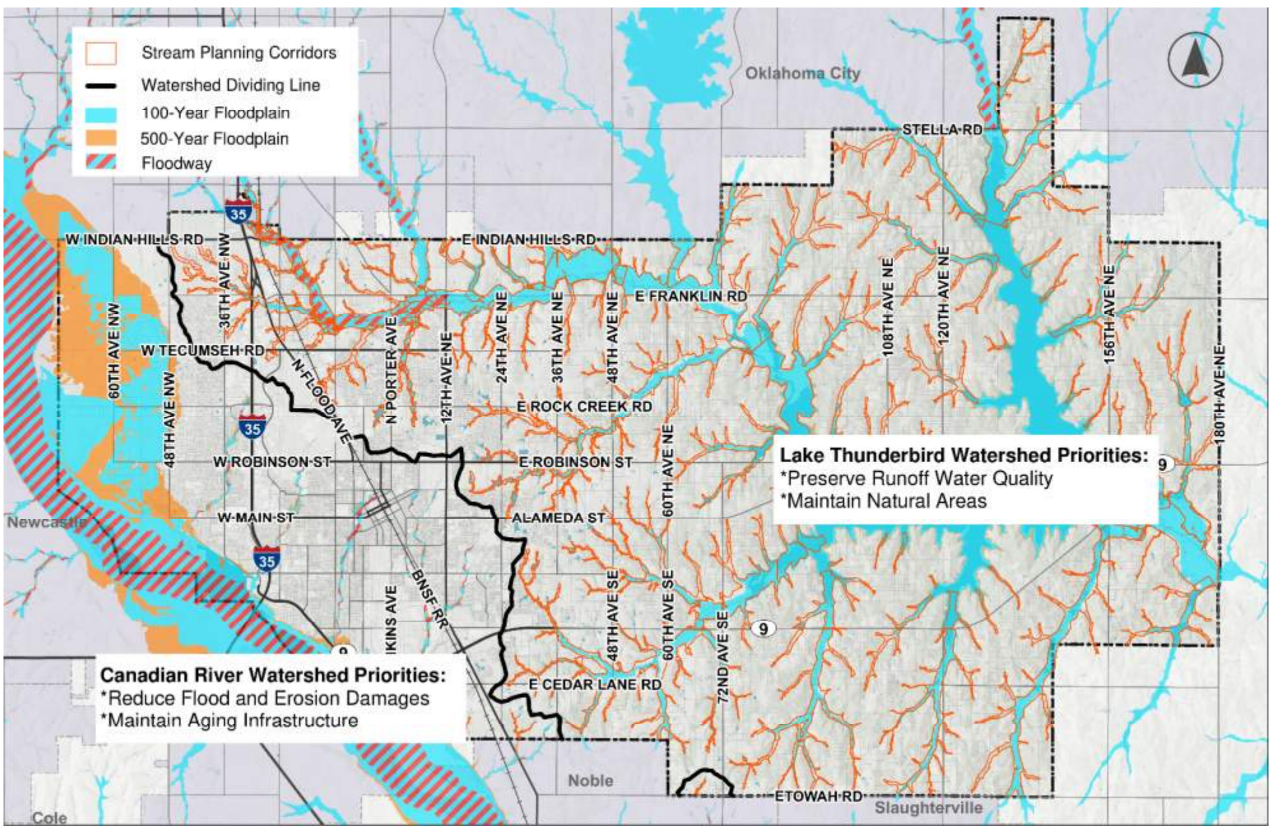


Figure 1: Norman's Stormwater Priorities

Figure 1 highlights Norman's main stormwater features. The ridgeline dividing the Lake Thunderbird Watershed and Canadian River Watershed delineates the city's stormwater challenges and priorities. The Canadian River Watershed has older, undersized infrastructure needing costly upgrades. The Lake Thunderbird Watershed priorities include maintaining water quality and sustainable development practices to protect the lake – Norman's primary drinking water source.

Norman Stormwater Overview

Quick facts about Norman's stormwater management:

- 2 primary watersheds: Lake Thunderbird and Canadian River
- Over 100 miles of mapped storm sewers
- 16 FEMA Mapped Streams
- 15,000+ acres of Stream Planning Corridors
- Approximately 53 stream miles of ODEQ-listed impaired waterbodies
  - Including Lake Thunderbird, Norman's primary drinking water source

Given the diverse elements of stormwater management, Norman must carefully prioritize both community and environmental needs as it moves forward with proposed land use changes.

Mission Statement

"The City of Norman's Stormwater Program is dedicated to maintaining stormwater infrastructure, enhancing runoff water quality, and investing in strategic capital improvements to protect our community and natural resources."

Goals

- GOAL 1: Protect the runoff water quality contributing to Lake Thunderbird and the Canadian River to preserve the natural and beneficial uses of these waterbodies.
- GOAL 2: Provide an understanding of the flood risk to citizens in our community and continue to implement and enhance the capital improvement program to help reduce flooding risks.
- GOAL 3: Enhance and preserve the ecological character of the unurbanized areas of Norman through stormwater management efforts.
- GOAL 4: Restore and rehabilitate riparian areas in the urbanized areas of Norman while expanding recreational access and opportunities that support ecological health of these areas.
- GOAL 5: Continue to prioritize community awareness and education regarding stormwater quality, City infrastructure, flood risk, and individual responsibilities to preserve and maintain both natural and manmade stormwater resources.
- GOAL 6: Prioritize stormwater projects using a transparent process that includes collaboration with all stakeholders.

Initiatives since 2009 Plan

After the adoption of the 2009 Stormwater Master Plan (SWMP), Norman has conducted several updates and studies to address immediate and long-term stormwater needs. These initiatives reflect proactive responses to changing environmental, regulatory, and community needs. This list of key studies and updates since the 2009 SWMP illustrate the collective progress toward a resilient stormwater management system that continues to evolve with the community. Additional information about these studies is included in Section 2.0 of this SWMP Update.

- 2011 – Adoption of Water Quality Protection Zone (WQPZ) Ordinance
  - *This is the only ordinance of this kind in the state of Oklahoma.*
- 2013 – Manufactured Fertilizer Ordinance
  - *This encourages reduction of Nitrogen and Phosphorous in residential and commercial fertilizer applications.*
- 2013 – Lake Thunderbird Watershed issued a Total Maximum Daily Load (TMDL)
- 2016 - City of Norman Total Maximum Daily Load (TMDL) Compliance and Monitoring Plan

-
    - *This was created for Lake Thunderbird. The lake is included on the state's list of impaired waterbodies and must meet specific water quality standards.*
- 2016 – First Stormwater Utility Fee Campaign (SWU)
- 2018 –Stormwater Citizen's Committee Reports
    - *These summarize of discussions and findings from the educational push leading to the second vote on a City-wide SWU. The vote was against the SWU, but the reports generated from this effort are valuable information regarding citizen's understanding of the stormwater challenges in Norman.*
- 2023 - Engineering Design Criteria Update
    - *Significant updates were made to the drainage design criteria including updated precipitation estimate requirements, detention requirements, and design storm criteria for roadway cross structures.*
    - *A section detailing the benefits of Stormwater Best Management Practice (BMPs) was added. These BMPS are intended to provide a guide for minimizing pollutants in stormwater and how to implement them during design and construction of new development.*
- 2023 - Mayor's Climate Protection Agreement Recommendations Update
- 2023 - Bishop Creek Watershed Based Plan
- 2024 - Stormwater Management Plan (most recent update)
    - *This document includes 5-year stormwater quality implementation, maintenance, and documentation plan.*

Recommended Studies

Norman should prioritize additional studies to address data gaps, emerging challenges, and long-term planning needs. The following list of studies are recommended to equip the city with the insights necessary for more effective stormwater management.

- Flood Warning System (in progress)
- Stormwater Infrastructure Inventory (in progress)
- Low Impact Development (LID) Optimization Study
    - Include 2009 OWRB Garber-Wellington Aquifer Recharge Study in LID Optimization Study
- Stormwater BMP-focused Geomorphology and Sediment Transfer Study within Lake Thunderbird Watershed
- Rain-On-Mesh Hydrologic and Hydraulic Modeling where appropriate to identify pluvial flooding issues in the urbanized areas
- Updated regulatory floodplain mapping for the city
    - Specifically Merkle Creek Subbasin to include effects of airport detention

Recommendations

The 2009 Stormwater Master Plan (SWMP) included key recommendations for improving stormwater infrastructure, mitigating floods, enhancing water quality, and engaging the community. Many of these recommendations remain relevant and are reaffirmed in the 2025 update, which also introduces new recommendations to support Norman's growth while protecting water resources. Below is a brief overview of each stormwater recommendation. Further information about these recommendations is included in Section 9.0 of this SWMP Update.

Continuing Recommendations

The following recommendation highlight items first identified in the 2009 SWMP that are most relevant to the Land Use Plan. These include updates and progress made since 2009 and policy strategies that remain valid. Additional detail can be found in the SWMP.

Stormwater Funding

- Explore long-term funding options such as a stormwater utility or bonds. Continue strategic outreach and planning to help residents understand the need for funding.

Future Meetings and Coordination

- Continue public outreach, adapt stormwater goals to changing needs, and maintain public engagement to ensure sustainable stormwater management.

Stream Planning Corridors

- For streams in the Lake Thunderbird Watershed with drainage areas over 40 acres, continue to dedicate Water Quality Protection Zones (WQPZs) and 100-year full-buildout floodplains through easement or title.
- Continue to restrict development and major land disturbances within these SPCs and floodplains, allowing only the exemptions permitted today.

Stormwater Quality Control

- Require large developments (over 1 acre) to capture and treat a minimum of 0.5 inches of runoff through the use of low impact development* (LID).
- Encourage LID on smaller development and infill development with an option to contribute to a regional water quality program.
- Include nonstructural measures like public education on fertilizer use, septic maintenance, and density limits to protect Lake Thunderbird.

Stream Bank Disturbance

- Require U.S. Army Corps of Engineers (USACE) permits for any stream bank work.
- Mandate mitigation measures like flowline stabilization, replacing vegetation and erosion control in accordance with language in USACE Nationwide Permits.

City-Wide Maintenance

- Acquire easements for streams and detention areas in new developments.
- Establish a maintenance program for stormwater infrastructure protecting critical facilities.
- Create an operations and maintenance guide for HOA’s* managing private stormwater management systems.

Dam Safety Issues

- Partner with state agencies to assess dam risks and ensure safety measures are installed and maintained.
- Conduct an assessment of dam safety (for all existing and proposed dams) based on projected development identified in the Land Use Plan.

Policy, Ordinances, and Criteria

- Regularly update development guidelines for rainfall, runoff, water quality, and erosion control as industry standards and best management practices change into the future.
- Develop standard city-wide “pre-development” runoff parameters to provide developers and city staff a documented baseline condition for detention analysis.

Stormwater Quantity and Quality Management

- Continue funding and developing the Stormwater Program with dedicated staff to support implementation of the SWMP recommended policies, TMDL compliance and construction of projects included in the Capital Improvement Plan.
- Regularly monitor problem areas, prioritize greenway opportunities, and engage regional partners to protect Lake Thunderbird.

Hydrologic and Hydraulic Modeling

- Schedule updates to regulatory hydrologic and hydraulic models citywide as precipitation estimates and hydraulic modeling techniques change.
- Create a centralized H&H model management system so that accepted models can be referenced by City staff, developers' engineers and CIP project consultants.

New Recommendations

Many of these recommendations build upon the 2009 SWMP, and were of particular focus for the 2025 AIM Norman Stormwater Subcommittee. Additional detail on these recommendations can be found in the SWMP.

Stormwater Management Plan

- Continue implementing the six Minimum Control Measures (MCMs) outlined in the 2025 Stormwater Management Plan.

Engineering Design Criteria

- Review and update the Engineering Design Criteria (EDC) every two years using third-party consultants.
- Require runoff treatment as described in the EDC section 7000 ("Water Quality Volume") in new developments, with stricter standards near Lake Thunderbird and other impaired water bodies.

Norman's Community Rating System

- Improve flood preparedness with real-time warning systems for rain, stream, and detention levels.
- Inventory stormwater infrastructure to improve maintenance, reduce repair costs, and increase flood insurance discounts for residents.

Norman's Water Quality Protection Zone Ordinance

- Update the Water Quality Protection Zone (WQPZ) Ordinance based on lessons learned since adoption in 2011.
- Updates should focus on protecting natural riparian areas during construction
- Prevent "alternative width" reduction of WQPZ widths in the "2045 Reserve" of the Land Use Plan Character Area Map.

Low Impact Development Incentivization

- Establish overlay districts with stricter runoff treatment standards for areas that could directly impact sensitive and impaired water bodies.
- Create incentives for projects exceeding stormwater management standards, including expense credits, annual best practice awards, and expedited permits.
- Establish a local cost-share or grant program for retrofitting urban stormwater infrastructure and providing technical support to neighborhoods seeking to maintain their stormwater.

Construction Site Inspections

- Strengthen oversight of construction site BMP compliance by having dedicated compliance officers.
- Ensure support of stormwater management enforcement across all stakeholders including city staff, officials, and citizens to enforce stormwater regulations and protect Norman's waterbodies.

Total Maximum Daily Load (TMDL) Monitoring Stations

- Install additional water quality monitoring stations for streams that may be affected by additional development allowed by the Land Use Plan or upcoming major transportation projects to understand the baseline pollutant loading and be prepared to take corrective action if pollution increases because of new development in the upstream watershed.

Tree Cover Protection

- Set a goal to preserve at least 60% of beneficial tree coverage post-construction within WQPZ riparian areas, offering incentive credits for meeting this target.

Accessory Structures

- To reduce the impact of increased impervious coverage in areas where stormwater management is an existing issue, require implementation of stormwater Best Management Practices when accessory structures are permitted.
- Develop a plan to improve stormwater infrastructure as Core Norman incrementally redevelops.

Stormwater Capital Projects

The 2009 Stormwater Master Plan (SWMP) proposed solutions and cost estimates for 59 flood-related and stream erosion issues. Since 2009, many of the proposed solutions have been constructed, but a majority have not due to lack of funding. **Figure 2** highlights the locations of planned and completed projects.

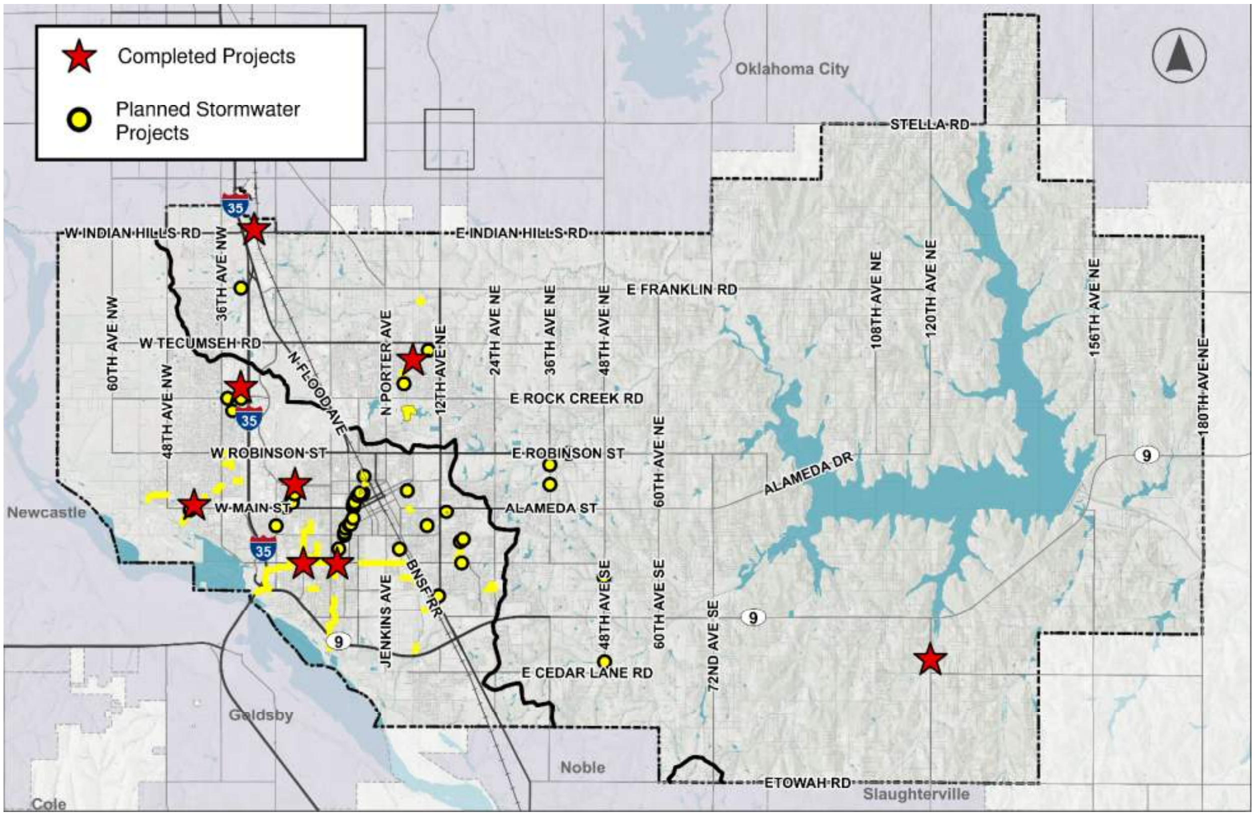


Figure 2. Stormwater Projects

–Projects from the 2009 SWMP were grouped by issues like flooding, erosion, water quality, and local drainage. Unfinished projects were included in the updated plan and reviewed to ensure they still meet current needs.

Based on input from the stormwater subcommittee, the project scoring criteria matrix was refined to better reflect community priorities. Additionally, a quantifiable way to measure each criterion was developed to enhance objectivity in the scoring process. More information about each project is included in Sections 5.0 and 6.0, as well as in Appendix K.

Table 0-1 below shows the comparison of the updated costs between 2009 and 2025.

Table 0-1: Comparison of Costs Remaining for CIP Projects

CIP Project Costs	
2009 Total Cost Identified	$82,530,490
2025 Total Cost Remaining*	$195,930,268

*The 2025 Total Cost has been updated by adjusting the unit costs for the problem area solutions identified in Section 6.0 of this report. The unit costs have been updated to reflect 2025 probable construction costs. Note that several projects that were identified in 2009 have been completed, and the 2025 cost remaining only includes projects that have not been completed.

PROMOTION OF THE DEVELOPMENT PRINCIPLES

AIM NORMAN DEVELOPMENT PRINCIPLES

1 Manage urban services efficiently.

2 Promote diverse housing options.

3 Promote infill development and neighborhood reinvestment.

4 Protect the environment in all decision-making.

5 Enhance distinctive neighborhoods, business districts, and natural areas with a strong sense of place.

6 Provide a multi-modal and connected transportation network.

7 Enhance public safety and minimize hazards.

8 Encourage balanced and connected neighborhoods.

9 Make development decisions predictable, fair, and cost effective.

10 Make decisions in a transparent and collaborative manner.

Identified below are the six stormwater goals for Norman. While these goals are specific to stormwater, they further promote the Development Principles of AIM Norman and will help the City realize the vision of the plan.

APPLICABLE DEVELOPMENT PRINCIPLES

GOAL 1

Protect the water quality runoff into Lake Thunderbird and the Canadian River to preserve the natural and beneficial uses of these water bodies

2 4 7

GOAL 2

Educated on the flood risk to residents and continue to implement and enhance the Capital Improvement Program to reduce flooding risks.

1 4 7 10

GOAL 3

Enhance and preserve the ecological character of Norman's unurbanized areas.

2 4 7

APPLICABLE DEVELOPMENT PRINCIPLES

GOAL 4

Restore and rehabilitate riparian areas in Norman's urbanized areas while expanding recreational access and opportunities that support their ecological health.

1 2 3 4 5 7 8

GOAL 5

Continue to educate and raise awareness to the community about flood risk, stormwater quality, City infrastructure, and individual responsibilities to preserve and maintain both natural and manmade stormmwater resources.

1 4 7 10

GOAL 6

Prioritize stormwater projects using a transparent process that includes collaboration with all stakeholders.

4 7 9 10

1.0 Introduction

1.1 Stormwater Master Plan Goals

The goals of the stormwater master plan as updated through the 2025 AIM Norman process are presented with more context in the executive summary of this document. These goals were determined through input from City Staff and the AIM Norman stormwater subcommittee:

- GOAL 1: Protect the runoff water quality contributing to Lake Thunderbird and the Canadian River to preserve the natural and beneficial uses of these waterbodies.
- GOAL 2: Provide an understanding of the flood risk to citizens in our community and continue to implement and enhance the capital improvement program to help reduce flooding risks.
- GOAL 3: Enhance and preserve the ecological character of the unurbanized areas of Norman through stormwater management efforts.
- GOAL 4: Restore and rehabilitate riparian areas in the urbanized areas of Norman while expanding recreational access and opportunities that support ecological health of these areas.
- GOAL 5: Continue to prioritize community awareness and education regarding flood risk, stormwater quality, City infrastructure, and individual responsibilities to preserve and maintain both natural and manmade stormwater resources.
- GOAL 6: Prioritize stormwater projects using a transparent process that includes collaboration with all stakeholders.

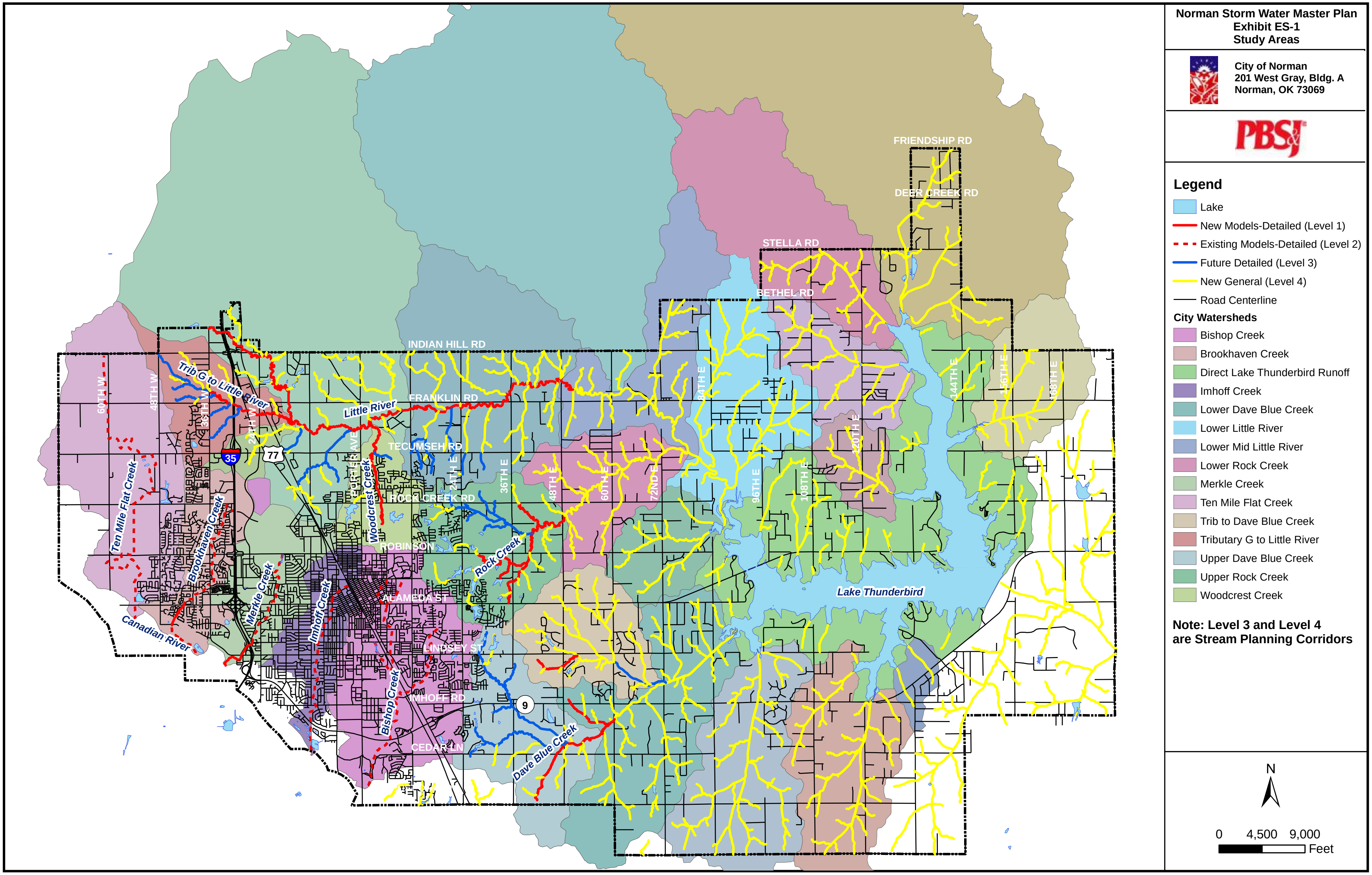
1.2 General Study Area Characteristics

The general stormwater characteristics of Norman are documented in the executive summary of this document.

1.3 Approach

The SWMP Update approach is documented in the introduction of this document. The information in the following paragraphs was written for the 2009 SWMP report and remains relevant for this Update.

Analyses for watershed/stream assessments, stream flooding, and stream erosion were performed at different "levels" or intensities based on the City's needs discussed below. However, as discussed further in Sections 5.0 and 6.0, water quality was studied using a different method - its characterization reflects overall citywide conditions tied to urban development activities. In order to focus on the primary stream systems and provide detailed analyses in the areas with the worst problems in an efficient manner, these varying levels of study were used. Again, all watersheds in the City were studied in some capacity but some were analyzed in detail while others were considered using more general methods. Descriptions of the four levels of study and the respective stream reach locations are provided below and shown on Exhibit ES-1.



Norman Storm Water Master Plan
Exhibit ES-1
Study Areas
City of Norman
201 West Gray, Bldg. A
Norman, OK 73069
PBSJ
Legend
Lake
New Models-Detailed (Level 1)
Existing Models-Detailed (Level 2)
Future Detailed (Level 3)
New General (Level 4)
Road Centerline
City Watersheds
Bishop Creek
Brookhaven Creek
Direct Lake Thunderbird Runoff
Imhoff Creek
Lower Dave Blue Creek
Lower Little River
Lower Mid Little River
Lower Rock Creek
Merkle Creek
Ten Mile Flat Creek
Trib to Dave Blue Creek
Tributary G to Little River
Upper Dave Blue Creek
Upper Rock Creek
Woodcrest Creek
Note: Level 3 and Level 4 are Stream Planning Corridors
N
0 4,500 9,000
Feet
FRIENDSHIP RD
DEER CREEK RD
STELLA RD
BETHEL RD
INDIAN HILL RD
FRANKLIN RD
TECUMSEH RD
ROCK CREEK RD
ROBINSON
ALAMEDA ST
LINDSEY ST
IMHOFF RD
CEDAR LN
60TH W
48TH W
36TH W
24TH W
12TH E
24TH E
36TH E
48TH E
60TH E
72ND E
84TH E
96TH E
108TH E
120TH E
144TH E
156TH E
168TH E
Trib G to Little River
Little River
Ten Mile Flat Creek
Brookhaven Creek
Merkle Creek
Imhoff Creek
Woodcrest Creek
Bishop Creek
Rock Creek
Dave Blue Creek
Canadian River
Lake Thunderbird
35
77
9

Level 1 (detailed) – Level 1 streams, including their respective watersheds, represent streams where detailed studies occurred for hydrology, hydraulics, and floodplain mapping. Hydrologic and hydraulic models were developed for these streams using multiple data sources: the 2007 City topography and aerial coverage (attached hereto as a critical element in the SWMP); field survey of road crossing structures and selected cross sections; field reconnaissance visits; and detailed delineations of drainage areas, land use coverages, impervious cover, soils, and updated U.S. Geological Survey (USGS) intensity-duration-frequency rainfall relationships. These models were then used to depict existing and future buildout (baseline) flooding conditions as well as the improved flooding conditions associated with the various solutions proposed. Watershed assessments were devised using City GIS files to obtain land use (or zoning), impervious cover, floodplain, soil, and other watershed data. Watershed and stream assessments used extensive field reconnaissance visits and the City's 2007 aerial and topographic data to document stream channel and overbank flow conditions and also locate and characterize stream erosion sites.

Level 1 stream reaches include:

- Brookhaven Creek Mainstem from the Canadian River bottom area to West Main Street, about 3,500 feet (ft),
- Dave Blue Creek from just upstream of 60th Avenue East along the main branch as well as Tributaries A and 1,
- Little River – from 48th Avenue East upstream to the city limits just west of IH 35,
- Tributary G to the Little River from its confluence with Little River to 36th Avenue West,
- Woodcrest Creek – from confluence with the Little River to upstream of East Rock Creek Road,
- Merkle Creek – from the Canadian River bottom area to IH 35, about 2,000 ft, and
- Rock Creek Mainstem and Tributaries A, B, C, and D.

Level 2 (detailed) – Level 2 streams, including their respective watersheds, represent streams where hydrologic and hydraulic models from past FEMA studies or study updates were used. Similar to the Level 1 streams, the City's 2007 topographic and aerial base maps were used in floodplain mapping. These FEMA models were generally reviewed and modified only if obvious errors surfaced during accomplishment of the project. The models were used to depict existing and future buildout (baseline) flooding conditions as well as the improved flooding conditions associated with the various solutions proposed. Watershed assessments were developed using City GIS files to obtain land use (or zoning), floodplain, impervious cover, soil, and other watershed data. Watershed and stream assessments used extensive field reconnaissance visits and the City's 2007 aerial and topographic data to document stream channel and overbank flow conditions and also locate and characterize stream erosion sites.

Level 2 streams include:

- Bishop Creek Mainstem and Tributaries A, B, and C,
- Brookhaven Creek Mainstem upstream of Main Street as well as Tributaries A and B,
- Imhoff Creek,
- Woodcrest Creek,
- Merkle Creek upstream of IH 35, and
- Ten Mile Flat based on limit of 2007 McArthur Study.

Levels 3 and 4 (general) – Generally, Level 3 and 4 stream reaches generally include those having more than 40 acres of drainage area and not located in the urban core where small drainage systems primarily consist of storm sewers and manmade channels. Level 3 and 4 stream reaches were all studied in the same manner although the Level 3 reaches have been identified by the City as having the highest priority for future detailed studies when funds allow. Level 3 and 4 streams, including their respective watersheds, represent those streams in which very general studies were conducted for hydrology, hydraulics, and floodplain mapping. As outlined further in Section 4.0, new hydrologic and hydraulic models were developed for these streams utilizing the 2007 City topography and aerial coverage, USGS 100-year peak flow equations (USGS, 1997), and a Rapid Floodplain Delineation (RFD) tool developed by PBS&J. This tool used general drainage area delineations, stream slopes, and urban development projections to estimate peak discharges. The RFD tool then used a digital elevation model of the respective areas to delineate the 100-year floodplain (also called Stream Planning Corridors) due to their general development nature. No solutions modeling was performed with these general models. Watershed assessments were developed using City GIS files for land use (or zoning), floodplains, soils, and other watershed data. Watershed and stream assessments were limited to providing general characteristics of the particular watersheds and stream reaches considered.

The 2025 AIM Norman process was developed in a way that the Parks, Transportation, Stormwater, Water and Wastewater Master Plans can be integrated together. This process allows for the City to address stormwater issues at the same time that other projects are being implemented across the City, if they interact with known stormwater concerns.

An important goal of the 2009 SWMP was to investigate ways to provide enhanced recreational opportunities by integrating greenbelt planning with stormwater solutions. A Greenway Master Plan was conducted by the City in parallel with the 2009 SWMP and is referenced in Section 2.0. It was determined that the best way to integrate stormwater and greenway planning was to look for opportunities to integrate the two in future improvement projects. The respective studies identify the locations throughout the City where overlaps exist on proposed projects. It is anticipated that final design planning will take advantage of the opportunities and the financial savings offered to build joint stormwater and greenway projects in these overlapping locations.

1.4 Stormwater Master Plan Report Organization

The SWMP comprises the collective work products as presented and discussed in this report. The report is organized into ten sections as listed below with various appendices added to provide study details:

Section 1: Introduction. The introduction presents the general project goals, provides general study area characteristics, and outlines the overall approach used to develop the SWMP. Additionally, a description is provided that outlines the varying levels of study intensity employed for the respective City watersheds and streams depending on the needs established in the project scoping phase.

Section 2: Data Sources and Collection. The primary data sources collected and used in performing the project's investigations are listed and briefly discussed.

Section 3: Watershed and Stream Assessments. Assessments of stream reaches and their contributing watersheds or watershed subareas are overviewed in terms of watershed physiographic conditions (e.g., soils, land uses, impervious cover, and number of detention facilities) and stream corridor environments (e.g., channel configuration, floodplain vegetation, number of stormwater outfalls, type of FEMA floodplain, and location of erosion problems). The relationships between urbanizing watershed conditions and the impacts that these changing land uses have on stream stability and the riparian environment are outlined.

Section 4: Hydrologic and Hydraulic Analyses. This section provides a thorough description of the hydrologic and hydraulic modeling and related analyses performed that was then used to determine stream flooding and local drainage conditions throughout the City for existing and future projected 2025 (baseline) conditions. The varying levels of investigations are outlined relative to the watershed areas receiving detailed analyses (Level 1 and 2 streams) and those receiving more general analyses (Level 3 and 4 steams).

Section 5: Stormwater Problems. Stormwater problems were identified in terms of stream flooding, stream erosion, and local drainage on a watershed-specific basis. Water quality problems were approached on a citywide basis due to their non-point nature. All problems were specifically located and quantified according to their significance or severity.

Section 6: Stormwater Solutions. Concept level solutions to the problems identified were developed and described in terms of performance (benefits or problem mitigation), solution elements (construction items or activities), costs, and prioritization ranking. The problem/solution prioritization rankings were provided according to watershed, City ward, and the City as a whole.

Section 7: Key Issues. This section overviews several key issues that were identified and considered either during scope of work development and/or while completing the SWMP. Recommendations, including implementation actions, were provided to the extent possible, although several of these issues will require further consideration by the City in order to develop implementation details and/or alternative approaches that also achieve the City's stormwater goals. These key issues include Stream Planning Corridors, structural and/or non-structural controls for stormwater, enhanced creek and detention facility maintenance, drainage easements in new and existing developments, and increased dam safety for existing and future detention facility dams.

Section 8: Financial Analyses. Financial analyses work items included providing stormwater utility background information, rate considerations, revenue requirements, and long-range financial planning.

Section 9: Recommendations and Implementation Plan. Recommendations and an implementation plan were developed that cover the range of topics analyzed and evaluated as part of the SWMP development. In certain instances, such as several of the key issues outlined in Section 7, the recommendations presented should be viewed with the understanding that further meetings, discussions, and considerations may be required.

Section 10: References. The works cited for the 2009 SWMP, plus additional references that are relevant and have been added for the 2025 AIM Norman SWMP Update.

2.0 Data Sources and Collection

2025 Data Sources and Collection Updates

Several important studies have been performed in Norman since the adoption of the 2009 SWMP. The following list summarizes the resources that were collected and referenced as part of the 2025 Update:

- 2011 – Adoption of Water Quality Protection Zone (WQPZ) Ordinance
- 2012 - City of Norman Greenways Master Plan
    - *Conducted at the same time as the 2009 Stormwater Master Plan and used to integrate future stormwater and greenway projects.*
- 2016 - City of Norman Total Maximum Daily Load (TMDL) Compliance and Monitoring Plan
    - *Created for Lake Thunderbird. This compliance and Monitoring Plan was developed to address the TMDL requirements from Oklahoma Department of Environmental Quality (ODEQ).*
- 2018 - Stormwater Citizen's Committee Reports
    - *Summary of discussions and findings from the educational push leading to a vote on a City-wide Stormwater Utility Fee. The vote was unsuccessful, but the reports generated from this effort are valuable information regarding citizen's understanding of the stormwater challenges in Norman.*
- 2018 - Stormwater Action Plan
    - *Reassessed the state of CIP stormwater projects throughout the City in preparation for a general obligation (G.O. Bond) stormwater funding vote.*
- 2019 - Norman Stormwater Division Policy Manual
    - *Provided a detailed description of stormwater maintenance and runoff water quality control tasks that would be funded by a potential stormwater utility fee.*
- 2023 - Engineering Design Criteria Update
    - *Significant updates were made to the drainage design criteria (Section 5000) including updated precipitation estimate requirements, detention requirements, and design storm criteria for roadway cross structures.*
    - *Section 7000 was added, detailing the benefits of Stormwater Best Management Practices (BMPs). These BMPs are intended to provide a guide for minimizing pollutants in stormwater and how to implement them during design and construction of new development.*
- 2023 - Mayor's Climate Agreement Recommendations Update

- *Provided an update to the 2009 document and the 12 "Recommended Actions" the City should implement to reduce global warming emissions and increase energy conservation.*
  - *The recommended actions were consolidated into 10 action items with each action item including general information about the subject, the benefits and needs for adopting it, accomplishments since the last document, and specific recommendations for action the City should strive to achieve over the next five years*
- 2023 - Bishop Creek Watershed Based Plan
  - *Includes a description of causes of water quality impairments to this urban watershed and an action plan for nonstructural and structural BMPs that may improve stormwater quality.*
- 2024 - Stormwater Management Plan Update
  - *Occurs annually*
  - *The city was reissued the Municipal Separate Storm Sewer Systems (MS4) General Permit outlining specific water quality goals for stormwater management in the City. This document includes 5-year implementation, maintenance, and documentation plan for stormwater quality minimum control measures (MCMs).*
- 2023 FEMA Base Level Engineering (BLE) Data
  - *Delineates approximated 100-year floodplain for all major streams in the City using approximate hydrology and hydraulic methods and current Lidar topography. Comparable to the methodology used in 2009 to delineate Stream Planning Corridors.*
  - *Provides a starting point for future hydraulic modeling and detailed floodplain mapping efforts for Levels 2-4 streams.*

2009 Data Sources and Collection Introduction

The many aspects of the SWMP require that data and information be identified, obtained, and used in order to accomplish the many tasks involved. Some of this needed data was generated during the SWMP work effort while other data was obtained from previous studies and general sources. In order to use available data, build on past work efforts and take advantage of the knowledge gained from previous studies, considerable effort was made to identify, collect, and use the best available data and information relating to stormwater in the Norman vicinity.

The primary data collected and used is presented below and organized by the primary work efforts that make up the SWMP development. These work efforts related to watershed and stream assessments, stream flooding, stream erosion, local drainage, and water quality.

2.1 Watershed/Stream Assessments, and Stream Flooding, and Local Drainage Problems

The following primary data sources cover a wide range of information that was used in characterizing the watersheds and streams, providing hydrologic/hydraulic modeling and floodplain mapping of the streams studied, and identifying stream erosion locations. Much of this data was obtained directly from the sources listed below but in several instances it was gathered from the City's GIS system.

- Rainfall depth-duration-frequency relationships from USGS (USGS, 1999).
  - 2025 Note: NOAA Atlas 14 has replaced USGS 1999 as the source of design rainfall for the City in the Updated 2023 Engineering Design Criteria
- Soils Survey geographic (SSURGO) database from U.S. Department of Agriculture, Natural Resources Conservation Service.
- Citywide 2007 1-ft (urbanized area) and 2-ft (rural area) topography and aerial photography from the City of Norman (incorporated hereto as an integral part of the SWMP).
  - 2025 Note: The "OK Panhandle" 2018 USGS Lidar Dataset was used for all updated analysis
- Land surveying for Level 1 streams performed by Lemke Surveying, Norman, Oklahoma.
- Land use maps and coverages from the City of Norman, including the Norman 2025 Land Use and Transportation Plan and the Oklahoma City Area Regional Transportation Study (OCARTS, 2007).

- 2025 Note: The AIM Norman process updated the Land Use Plan through a 2045 target date
- Easements and rights-of-way from the City of Norman.
- FEMA 2008 Flood Insurance Study Update (FEMA, 2008)
  - 2025 Note: There have been several updates to effective FEMA Special Flood Hazard Areas in Norman since 2008. Please refer to the most recent National Flood Hazard Layer Database.
- Various Letter of Map Revisions (LOMR) reports and associated hydrologic (HEC-1 and HEC-RAS) and hydraulic (HEC-2 and HEC-RAS) models provided by the City of Norman - used in Level 2 (detailed) stream analyses.
- Peak discharge (100-year event) equations from USGS - used in Level 3 and 4 areas (USGS, 1997).
- Field reconnaissance of Level 1 and 2 streams to obtain flow conditions as well as erosion locations and severity.
- Ten Mile Flat Conditional Letter of Map Revision (McArthur & Associates, Inc., 2007).
- Local drainage area problem information supplied by City staff.

2.2 Water Quality

The data and information for stormwater quality originates from past studies performed targeting the water quality of streams and lakes in Norman as well as from studies in other parts of the country. This, of course, includes and focuses on Lake Thunderbird, which constitutes Norman's primary drinking water supply.

- Stormwater Management Program for MS4 Compliance – 2011 to 2015 (PBS&J, 2008).
- Rock Creek Watershed Analysis and Water Quality Evaluation Report (COMCD, 2006).
- Final Bacteria Total Maximum Daily Loads for the Canadian River Area, Oklahoma (ODEQ, 2008b).
- Lake Thunderbird Watershed Analysis and Water Quality Evaluation. Prepared for the Oklahoma Conservation Commission. Oklahoma City (Vieux, Inc., 2007).
- 2016 Total Maximum Daily Load (TMDL) Compliance and Monitoring Plan

3.0 Watershed and Stream Assessments

2025 Watershed and Stream Assessments Updates

The watershed and stream assessment methodologies were not modified as part of the 2025 SWMP updates. One of the recommendations of the AIM Norman process (see section 9.0) is to perform a fluvial geomorphological assessment of the streams in the Lake Thunderbird watershed. This recommended study will use the information presented in the 2009 stream reach assessment forms and compare that information to current conditions. This study should be focused on identifying optimized stormwater best management practices (BMPs) that may be implemented in the City to minimize stream degradation due to increased impervious area associated with development.

One of the tasks included in the 2025 update was redelineating the subbasin data for the City based on the most recent publicly available lidar. The updated subbasin delineation is shown in Appendix E and will be provided to the City as a GIS (digital) file for reference as questions arise about where runoff comes from or goes to from a certain point or problem area. The watershed characteristics of these newly delineated subbasins should be updated with the 2045 Land Use data once it is finalized and adopted as part of the AIM Norman Process.

Modified 2009 Section Introduction

Understanding the present prevailing conditions that exist in each of Norman's watersheds and streams as well as those conditions projected to occur in the future are key factors in characterizing and managing stormwater in the City. The management of stormwater runoff is critical to protecting the health and safety of local citizens while also preserving the environment and ensuring that the City continues to add urban density in a sustainable manner. By utilizing the results of these assessments to identify and correct existing stormwater problems and combining those results with focused land use planning, the City of Norman can decrease the threat of flooding and reduce the amount of pollution entering its rivers and lakes. The stream reaches and their respective watersheds that received detailed assessments (Levels 1 and 2) and those that received general assessments (Levels 3 and 4) are listed and delineated in Section 1 of this report.

Identifying where potential flooding and stormwater pollution will likely occur depends on many things including a watershed’s topography, land use, impervious cover, soils, vegetation, and existing drainage infrastructure. The watershed and stream assessments describe each watershed's conditions with respect to the factors that influence runoff generation, magnitude, and quality. The watershed and stream assessments provided important information for the identification of stormwater related problems in the City (Section 5.0), the development of solutions for these problems (Section 6.0), and the future allocation of resources and planning needed to minimize and manage the impacts of stormwater runoff.

A specific focus of the assessments was to identify and quantify problems along Level 1 and 2 streams, especially erosion and bed/bank instability, and to recognize the likely causes of the problems originating in the respective watersheds. Field reconnaissance and the review of the City’s 2007 aerial photography were used as the primary elements in determining stream conditions and identifying problems. The compilation and analyses of various physiographic watershed data were used to develop existing and projected future watershed conditions. When reviewed together, the relationships between watershed and stream conditions became much more apparent. The stream reaches receiving stormwater from densely urbanized areas over a few years’ time were experiencing stream stability and erosion problems. These stream erosion problems were observed and documented for stream reaches such as the lower reaches of Imhoff Creek, Bishop Creek, Merkle Creek, and Brookhaven Creek.

As will be the case in subsequent report sections, a summary of the findings is initially presented and followed by discussions of the methods employed to obtain these findings.

3.1 Assessment Summaries

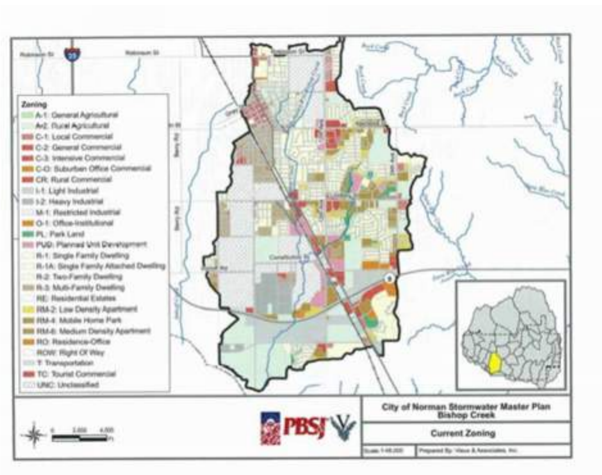
Watershed and stream assessments were developed for 36 watersheds that carry stormwater into, through, and/or within the City of Norman. Although most of the watersheds are located in the City of Norman, several also originate north of the City, flow into the Little River, and ultimately discharge into Lake Thunderbird. Exhibit 3-1 in Appendix E(map pocket) outlines the boundaries of these 36 watersheds and their numerous small contributing subareas. In addition to providing a means of determining and spatially locating the characteristics of watersheds that contribute stormwater to stream reaches, the delineation of watershed subareas also enables the City and others to more easily reference and locate areas of interest in the City. Thirdly, establishment of the stream reaches based on stream lengths with similar riparian corridor conditions also provided the basis for delineating watershed subareas. Once the relatively homogeneous stream reaches were located, the ArcHydro GIS program was used to delineate watershed subareas that bound or drain into the respective reaches. This link or relationship between subareas and stream reaches resulted in the use of the same identifier or “ID” for a subarea and the stream reach that flows through the subarea. As an example, stream reach BC-1 along lower Bishop Creek is contained within subarea BC-1 for that watershed as seen in Exhibit 3-1.

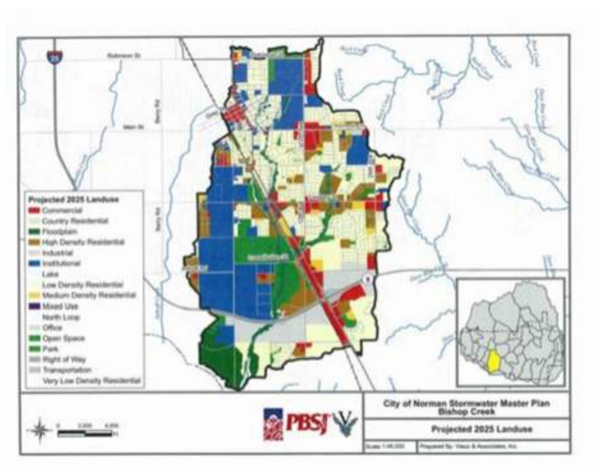
Utilizing numerous data sources described in Section 3.2.1 and field reconnaissance, various characteristics were developed for the numerous watershed subareas and the stream reaches that extend through these areas. The watershed and stream characterization numerical data and information developed was organized in several report appendices as outlined below. Note that Appendix D only covers Level 1 and 2 streams whereas the other appendices cover Level 1, 2, 3, and 4 streams.

- Appendix A (Citywide Subarea and Stream Reach Data)
    - Watershed subarea and stream reach IDs

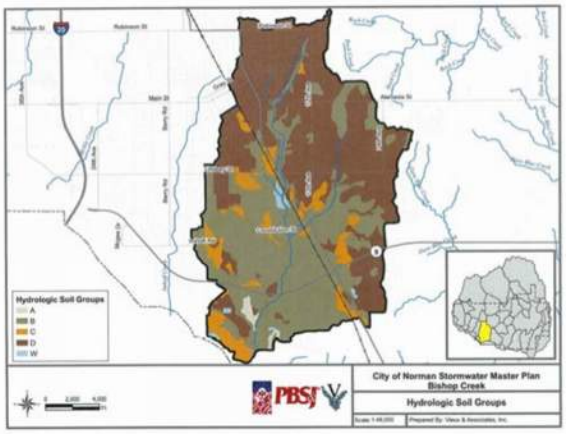
- – Cumulative watershed drainage area and impervious cover at the downstream point in respective subareas and stream reaches
- – Watershed subarea data
  - » Drainage areas
  - » Soil erodibility factors
  - » Hydrologic soil groups
  - » Number of detention facilities
- – Stream reach data
  - » Channel configuration
  - » FEMA floodplain type
  - » Floodplain vegetation
  - » Number of stormwater outfalls

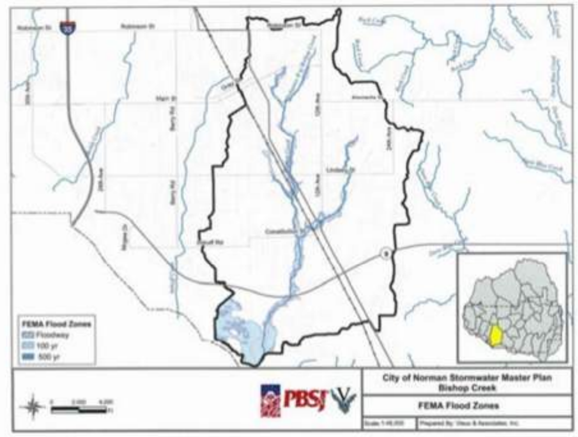
- Appendix B (Current Zoning)
- Appendix C (Projected 2025 Land Use)
- Appendix D (Reach Level Assessment Forms) – Level 1 and 2 streams only





Certain portions of the basic watershed-specific data and information presented in the appendices listed above were further refined and mapped for the 36 studied watersheds in terms of current zoning, projected 2025 land use, hydrologic soil groups (plus water), and FEMA flood zones. These watershed based maps are provided in Appendix E with examples shown in Figures 3-1 through 3-4 for the Bishop Creek Watershed. Appendix E also provides watershed or basin statistics, outlining the percent coverage of the mapped data including the percent of the respective watersheds located in the 100- and 500-year floodplains and floodway, where the respective data are available. An example of the watershed-specific statistical overview is provided in Table 3-1 for Bishop Creek.





Drainage Area (sq. mi.): 9.87

Current Zoning

Zoning	Percentage
A-1: General Agricultural	0.07%
A-2: Rural Agricultural	13.69%
C-1: Local Commercial	1.4%
C-2: General Commercial	3.95%
C-3: Intensive Commercial	0.77%
C-O: Suburban Office Commercial	0.67%
I-1: Light Industrial	4.95%
I-2: Heavy Industrial	2.67%
O-1: Office-Institutional	0.51%
PL: Park Land	1.36%
PUD: Planned Unit Development	2.61%
R-1: Single Family Dwelling	20.32%
R-1A: Single Family Attached Dwelling	0.02%
R-2: Two-Family Dwelling	2.08%
R-3: Multi-Family Dwelling	4.35%

Projected 2025 Landuse

Landuse	Percentage
Commercial	6.81%
Floodplain	5.85%
High Density Residential	8.02%
Industrial	4.98%
Institutional	20.38%
Lake/ Floodplain	0.75%
Low Density Residential	27.11%
Medium Density Residential	1.55%
Mixed Use	0.04%
Office	1.63%
Open	4.3%
Park	3.45%
Transportation	15.13%

Hydrologic Group	Percentage
A	0.7%
B	43.6%
C	7.7%
D	47.5%
W	0.6%

FEMA Flood Zone	Percentage
100	6.7%
500	7.9%
Floodway	2.4%

Impervious (%) : 31.8

City of Norman Stormwater Master Plan
Bishop Creek

Basin Statistics

Prepared By: Vieux & Associates, Inc.

The hydrologic soil groups shown in Figure 3-2 were developed by the Natural Resources Conservation Service (NRCS) and primarily reflects the rate at which water enters the soil at the soil surface (infiltration) and/or the rate of water moving within the soil column (transmission rate). The four soil groups are defined below. Although not a soil type, a “W” designation reflects water covering the ground surface.

Group A – Group A soils generally consist of sands, loamy sands, or sandy loams. Runoff potential is low with high infiltration/transmission rates (greater than 0.30 inches per hour [in/hr]).

Group B – These soils are generally composed of silt loams or loams and have moderate textures with infiltration/transmission rates of 0.15 to 0.30 in/hr.

Group C – Group C soils are typically sandy clay loams with moderate infiltration/transmission rates that vary from

0.05 to 0.15 in/hr.

Group D – These soils generally consist of clay loams, silty clay loams, sandy clays, silty clays, or clay. Runoff potential is high with low infiltration/transmission rates of 0.0 to 0.05 in/hr.

As mentioned at the beginning of the section, a key goal of the stream assessments was to identify the location and severity of significant stream problems in the Level 1 and 2 streams. The field reconnaissance and aerial photography reviews achieved this goal with these types of problems identified and quantified in Section 5 of this SWMP report. The overall assessments of the respective stream reaches leading to the problem identifications are presented here for the Level 1 and 2 streams studied as further discussed in Section 3.2.3. Utilizing a Unified Stream Assessment (Center for Watershed Protection, 2004) scoring methodology, all Level 1 and 2 stream reaches were scored and then classified as Poor, Fair, or Good in terms of their environmental soundness and condition. Exhibit 3-2 (map pocket) illustrates the classifications determined for each Level 1 and 2 stream reach using color coding as described in the exhibit. A few representative stream photos taken during field reconnaissance trips are also provided in Exhibit 3-2 to show typical conditions that exist along the City's streams.

3.2 Methods

The methods used to develop the general environmental assessments are provided in Appendix D. Discussions outlining the methods used follow the basic work procedures employed which includeed obtaining, developing, and/or evaluating data for watersheds, their component subareas, and the primary streams, and their component reaches that traverse the watersheds and subateas. With a majority of the overall effort focused on the stream corridors, the relationships between the stream stability conditions and watershed urbanization was documented.

The methods proposed to develop the assessments were discussed with City staff, the City Council and mayor, the SWMP Task Force, and the Greenbelt Commission on several occasions and feedback was obtained to guide the work effort. These watershed and stream assessments will allow the city to have a current baseline condition of all watersheds to assist in evaluating future stormwater conditions or problems by determining what has changed within the watershed through time and how the stream corridor is reacting to those changes.

3.2.1 Primary Data Sources

The City of Norman provided GIS data regarding current zoning and projected land use, FEMA flood zones, transportation networks, and storm sewer systems. The Oklahoma City Area Regional Transportation Study (OCARTS) GIS data was used for areas outside of the City of Norman. The United States Department of Agriculture (USDA) soil survey geographic (SSURGO) database was used to delineate hydrologic soil groups. The listing below provides the main datasets and sources used to create the watershed environmental assessments.

Watershed and Stream Reach Assessment Datasets

Feature Dataset	Data Sources
Current Zoning and Projected Land Use	City of Norman; Oklahoma City Area Regional Transportation Study (OCARTS)
Topography; Stormwater Outfalls; Detention Facilities; Impervious Cover	City of Norman
FEMA Flood Zones; Floodplain Vegetation and Channel Configuration	City of Norman, FEMA; Field Reconnaissance
Soils Data	USDA-NRCS
Watershed and Subarea Boundaries	PBS&J

3.2.2 Watersheds and Subareas

Given the area's climate, the prevailing stormwater conditions in Norman are heavily influenced by the physiographic conditions and activities that occur in its many watersheds. These watershed physiographic conditions and activities also shape the stream environments including their stability, flood prone nature, and water quality. Therefore, the understanding and management of stormwater conditions in any particular watershed begin with the development of information and data that describe the conditions specific to that watershed. Numerous analyses were conducted on the 36 City watershed's regardless of whether they contained streams receiving Level 1, 2, 3, or 4 analyses. For certain stream reach analyses, additional work was performed for the Level 1 and 2 stream reaches as discussed further below and in the assessments summaries and related appendices discussed above.

Considering the basic needs to describe the watersheds and their stream environments, assessments were created using a Geographic Information System (GIS) and datasets describing:

- Watershed boundaries
- Watershed subarea boundaries
- Current zoning
- Projected 2025 land use
- Hydrologic soil group,
- FEMA floodplains (100-year and 500-year where available)
- FEMA floodways (where available)
- Watershed impervious cover
- Watershed subarea data
    - Drainage area
    - Soil erodibility factor
    - Detention facilities

In order to quantify and spatially locate certain physiographic characteristics within a watershed or subarea, the GIS datasets collected from the sources listed previously in subsection 3.2.1 were analyzed to develop watershed-specific tables and presentation maps of the respective information. These comprehensive tables and maps are presented in appendices A, B, C, and E. As is indicated in the column headings, certain data in the tables relate to subareas or the entire respective watershed (an areal compilation of information) while other data reflects conditions only along the stream reach or corridor traversing a subarea.

The main steps in creating these environmental assessment maps included:

1. Clipping datasets to each watershed boundary and its component subareas
2. Creating watershed specific maps of subareas, current zoning, projected 2025 land use, hydrologic soil groups, and FEMA flood zones
3. Computing physiographic statistics for each watershed

4. Preparing layout maps (Appendix E) for 36 watersheds showing the spatial locations of each watershed's characteristics

3.2.3 Stream Reaches

As part of each watershed's assessment, the stream reaches within that watershed were given particular attention in the SWMP development. The level of study detail varied with the Level 1 and 2 streams receiving detailed assessments and Level 3 and 4 streams receiving general assessments. A listing of the stream reaches receiving detailed studies (Level 1 and 2 streams) versus those receiving more general studies (Levels 3 and 4) is provided in Section 1. For the more-detailed Level 1 and 2 stream reach surveys, assessments included:

- Meeting with City staff to determine accessibility along the streams to be inventoried and evaluated and, where possible, obtaining access right/privileges from the City of Norman as required
- Carrying out field reconnaissance from road crossings with limited walking along creeks where readily accessible
- Using aerial photos in inaccessible or difficult to reach areas
- Obtaining pertinent information along the stream corridor including adjacent land use, bed/bank material, and erosion/stability conditions, channel configuration, FEMA floodplains, storm sewer outfalls, waterbodies/detention facilities, and existing greenbelts and parkland

Assessments within the more general Level 3 and 4 stream reaches included:

- Meeting with City staff to determine accessibility along the streams to be inventoried and evaluated and, where possible, obtaining access right/privileges from City of Norman as required;
- Surveying effort was very general in nature and much less intense than that for the Level 1 and 2 reaches described above;
- Carrying out field reconnaissance using only a very general approach along streets and roads;
- Using aerial photographs, NRCS soil survey data/information, and City GIS coverages to obtain a majority of the information
- Obtaining pertinent information along the stream corridor including adjacent land use, channel configuration, FEMA floodplains, storm sewer outfalls where available, waterbodies/detention facilities, and existing greenways and parkland.

For Level 1 and 2 assessments, "creek walks" (field reconnaissance trips) were conducted following the reach level Unified Stream Assessment (USA) method developed by the Center for Watershed Protection (2004). Although access was achieved for several of the Level 1 and 2 streams studied, creek reconnaissance trips were limited to public rights-of-way for the vast majority of the Little River, Rock Creek, and Dave Blue Creek study reaches due to the lack of creek (property) access. The assessments for Level 1 and 2 reaches characterized the average physical conditions over a specified survey reach, provided information throughout the entire stream corridor, and located stream restoration opportunities. As an example, Exhibit 3-3 in Appendix D provides a reach level assessment form used during field reconnaissance trips to evaluate and score Bishop Creek survey reach BC-1. Appendix D provides reach level assessment forms for all of the Level 1 and 2 stream reaches studied. As these assessment forms indicate, the reach level assessment included:

- General information
  - Rain in past 24 hours
  - Conditions on day of reconnaissance trip
  - Surrounding land use
- Average conditions
  - Base flow as % of channel width
  - Dominant substrate
  - Water clarity
  - Aquatic plants in stream

- Wildlife in or around stream
  - Stream shading
  - Channel dynamics
  - Channel dimensions
- Reach accessibility - Good, Fair, or Difficult
- Notes on primary problems encountered
- Overall stream conditions
  - Instream habitat
  - Vegetative protection
  - Bank erosion
  - Floodplain connection
- Overall buffer and floodplain condition
  - Vegetated buffer width
  - Floodplain vegetation
  - Floodplain habitat
  - Floodplain encroachment

As documented in Exhibit 3-3, and the numerous forms in Appendix D, each Level 1 and 2 stream reach was evaluated with separate scores for the overall stream conditions as well as overall buffer and floodplain conditions. These scores formed the bases for the overall stream classifications displayed in Exhibit 3-2 with color coding. Table 3-2 also provides the respective stream condition, buffer/floodplain condition, and total scores for the Level 1 and 2 streams.

Additional stream reach data were obtained for all streams studied (Levels 1, 2, 3, and 4) including channel configuration, FEMA floodplain type, and floodplain vegetation as shown in Appendix A. For each Level 1 and 2 stream evaluated, a GIS overlay was developed to spatially locate where key photos were taken during field reconnaissance. Global positioning surveying (GPS) technology was used to map the locations where respective key photos were taken. Each mapped photo location was then hyperlinked to an image so that the City and other computer desktop users can view the photos while reviewing the descriptions, thereby taking a virtual creek walk of these streams as illustrated in Exhibit 3-4 in Appendix D.

4.0 Hydrologic and Hydraulic Analyses

2025 Hydrologic and Hydraulic Analysis Updates

Hydrologic modeling refers to the study and calculation of how much runoff is collected at a particular location within a watershed. Hydraulic modeling refers to the determination of what happens to that water when it flows through a particular location. While the 2009 SWMP used sophisticated hydrology and hydraulics (H&H) modeling techniques that were cutting edge in 2009, the industry standard of H&H modeling has continued to advance in the 15 years since this report was adopted. The following recommendations were developed as part of the Update process:

- Update FEMA regulatory H&H models and mapping throughout the City for Level 1 and 2 streams that have not been recently updated (see below for a discussion of models that have been recently updated).
- Develop a City-wide rainfall model that demonstrates where "pluvial" (or local-rainfall-induced) ponding is a public safety concern.

Hydrology Updates:

Subbasins that were delineated as part of the 2009 study were re-delineated using the most recent publicly available detailed Light Detection and Ranging (LiDAR) datasets. These subbasin delineations are included in the GIS digital deliverable portion of this SWMP Update.

Since 2009 there have been major updates to precipitation estimates across the United States with the publication of NOAA's Atlas 14 point precipitation estimates. Three streams in the City have been analyzed by previous studies to include modern precipitation estimates in the watershed-wide model. These watersheds are Ten Mile Flat Creek, Brookhaven Creek, and Imhoff Creek. The models developed for these previous studies are provided to the City with the digital deliverable for this SWMP Update. No hydrologic models have been updated as part of this specific study, but the subbasin delineation were updated.

Hydraulic modeling Updates:

Several streams that were studied in 2009 were remapped with updated hydrology and hydraulic modeling techniques before this Update was initiated. Imhoff Creek was studied with a detailed hydrologic model as part of the design of the Imhoff Creek "IC-1" and "IC2" project design in 2017. Ten Mile Flat Creek and Brookhaven Creek were both studied in detail and included in a FEMA map revision in January 2021. Merkle Creek and Bishop Creek hydraulic models were updated from the US Army Corps of Engineers' HEC-2 model to the industry standard HEC-RAS model as part of this 2025 Update. These updated models may be used as a starting point for future projects along these streams.

Floodplain mapping was updated with the most recent LiDAR topography for Dave Blue Creek, Woodcrest Creek, Rock Creek, and Little River. This updated floodplain mapping is not sufficient to be submitted as a FEMA map revision, as the models require additional current conditions survey data at crossing structures. The updated hydraulic models have been provided to the City for future reference as part of the digital deliverable of this SWMP Update.

Original 2009 Hydrologic and Hydraulic Analysis Sections:

4.1 Hydrologic Analysis

Three complementary approaches were used in the development of flows for the master plan. The most detailed of the three methods used either the USACE HEC-1 (existing models) or HEC-HMS (some existing and all new models) software. The second approach, used for the development of flows for the Stream Planning Corridors, was the USGS regression equation method as defined in USGS Water Resources Investigation Report 97-4202, “Techniques for Estimating Peak Streamflow Frequency for Unregulated Streams and Streams Regulated by Small Floodwater Retarding Structures in Oklahoma” (Tortorelli, 1997). The third approach, used in limited cases for site-specific drainage issues, was the Rational Method per the City of Norman design criteria. Each of these approaches is described in detail in the following sections.

Watershed-specific existing condition hydrologic models were developed for each of the Level 1 watersheds and adapted from existing models for Level 2 watersheds. Peak discharges and design hydrographs (as required for solutions) were developed for a range of storm events (10-, 50-, 100- and 500-year events) at key locations in each of the watersheds. Key locations included: significant tributary inflow point, subwatersheds, stream crossings and other areas of particular concern.

4.1.1 Detailed Hydrologic Modeling for Level 1 and 2 Streams

Detailed hydrologic models were used for all Level 1 and 2 streams studied as part of the master plan. New HEC-HMS models were built for the Level 1 watersheds while existing models were either used directly or updated to reflect new information for the Level 2 watersheds. Table 4-1 provides a summary of the hydrologic models used for the master plan and a brief description of their origins and subsequent modifications. The models for these watersheds are discussed in more detail under the individual sections for each watershed. The major studied watersheds are shown in Exhibit 4-1. The models and associated data developed in support of the hydrologic and hydraulic analyses for the master plan are included on CD in a supplement to the master plan report.

4.1.1.1 Hydrologic Modeling Methodology

The general methodologies used for the various Level 1 and 2 models are similar. However, since existing models from a variety of sources were used for the Level 2 streams, there are some differences between the specific methodologies used for the various components of the hydrologic models. The model types and methodologies used for the individual watersheds are listed in Table 4-2. The methodologies and associated differences between study models are discussed in detail in the following sections.

Design Rainfall

Several combinations of design rainfall totals and distributions have been used in the various hydrologic models for the City of Norman. The USACE Frequency Distribution was the most commonly used hyetograph method and was used for all new modeling. Brookhaven Creek was the only model to use an alternate (NRCS Type 2) distribution. The rainfall distributions and totals for the models included in the master plan are listed in Table 4-3.

The deign event rainfall used in the hydrologic analysis for the Level 1 watersheds was based on the rainfall maps in USGS Water Resources Investigation Report 99-4232, "Depth-Duration Frequency of Precipitation for Oklahoma" (Tortorelli et al., 1999). This report provides estimates of rainfall totals based on period of record data for Oklahoma gages through 1996. The design event rainfall totals listed in the Drainage Criteria for the City of Norman and used in the existing studies in the urbanized (Level 2) creeks were based on values obtained from TP-40 (Hershfield, 1961) and Hydro-35 (Frederick et al., 1977). The USGS study incorporates considerably more data than the previous studies and used several advances in the statistical analysis of extreme events. A comparison of the rainfall totals for the two approaches is shown in Table 4-3.

Areal Reduction

The precipitation estimates from USGS WRI 99-4232 and TP-40 are point estimates. However, intense rainfall is not likely to be distributed uniformly over a large watershed. For a specified frequency and duration, the average rainfall depth over an area is less than the depth at a point. To account for this, the U.S. Weather Bureau (1958) derived factors by which point rainfall depths may be reduced to yield areal-averaged depths (USACE, 2008). These factors have been incorporated into the HEC-HMS model and are available for use with the frequency-based hypothetical storm hyetograph.

In accordance with the recommendation of the World Meteorological Organization (1994), point values should be used without reduction for areas less than 9.6 square miles. The Little River watershed is the only studied watershed with a total area greater than this lower limit and was the only watershed for which areal reduction was applied. The depth-area analysis available in Version 3.1.0 of the HEC-HMS model was used to determine the areally reduced flows for Little River. This option allows the user to input a series of HEC-HMS computational points (junctions in this case) at which areally reduced flows are to be calculated. The HEC-HMS junctions with contributing areas greater than 9.6 square miles along the main stem of Little River were selected for the depth-area analysis. The results from the Little River model with no areal reduction were used to generate the flows for Woodcrest Creek and Tributary G to Little River.

Table 4-1: Summary of Hydrologic Models for Level 1 and 2 Watersheds

Detailed Streams	Study Level	Hard Copy of Model	Hydrology Model	Program	Year	Company	Purpose	Source	Comments
Ten Mile Flat Creek	2	Y	Y	HEC-HMS	2005	MacArthur	CLOMR	CoN	
Bishop Creek	2	N	Y	HEC-1	1995/ 1996	Mansur-Daubert-Strella Engineers	Floodplain Update	CoN	Based on 1996 version. 1995 and 1996 versions are the same except the 1995 version uses the Snyder UH while the 1996 version uses the SCS UH.
Trib A to Bishop Creek	2	N	Y	HEC-1	1995/ 1996				
Trib B to Bishop Creek	2	N	Y	HEC-1	1995/ 1996				
Trib C to Bishop Creek	2	N	Y	HEC-1	1995/ 1996				
Brookhaven Creek	2	Y	N	HEC-HMS	1993/ 2007	Clour (1993) C.H. Guernsey (2007)	LOMR (1993); Design of 36th Avenue NW bridge (2007)	Guernsey	HEC-HMS model based on Clour HEC-1 model (upstream of Robinson). The HEC-HMS model added the area downstream of Robinson to Willow Grove.
Trib A to Brookhaven Creek	2	N	N	HEC-HMS	1993/ 2007				
Trib B to Brookhaven Creek	2	N	N	HEC-HMS	1993/ 2007				
Imhoff Creek	2	Y	Y	HEC-1	1997/ 2001	Baldischwiler (1997) Baldischwiler (2001)	LOMR (2001)	CoN	2001 LOMR version incorporates Phase A portion of 1997 McGee/Lindsey Drainage Study by Baldischwiler. Additional subdivision of catchments and correction of areas made for master plan.
Merkle Creek	1/2	Y	Y	HEC-1	1994/ 1995	Clour (1994) JWB for Clour (1995)	LOMR	CoN	Original 1994 LOMR model modified by 1995 LOMR to include Ponds I & II upstream of Robinson. No change in 1996 LOMR. PBS&J extended model from IH 35 to mouth (2 additional subbasins), added new detention in headwaters and made associated subbasin modifications.
Little River	1			HEC-HMS	2008	PBS&J	Master Plan	New	New modeling based on delineations from new topographic data.
Woodcrest Creek	1			HEC-HMS	2008	PBS&J	Master Plan	New	New modeling based on delineations from new topographic data.
Tributary G	1			HEC-HMS	2008	PBS&J	Master Plan	New	New modeling based on delineations from new topographic data.
Rock Creek	1			HEC-HMS	2008	PBS&J	Master Plan	New	New modeling based on delineations from new topographic data.
Dave Blue Creek	1			HEC-HMS	2008	PBS&J	Master Plan	New	New modeling based on delineations from new topographic data.
Tributary to Dave Blue Creek	1			HEC-HMS	2008	PBS&J	Master Plan	New	New modeling based on delineations from new topographic data.

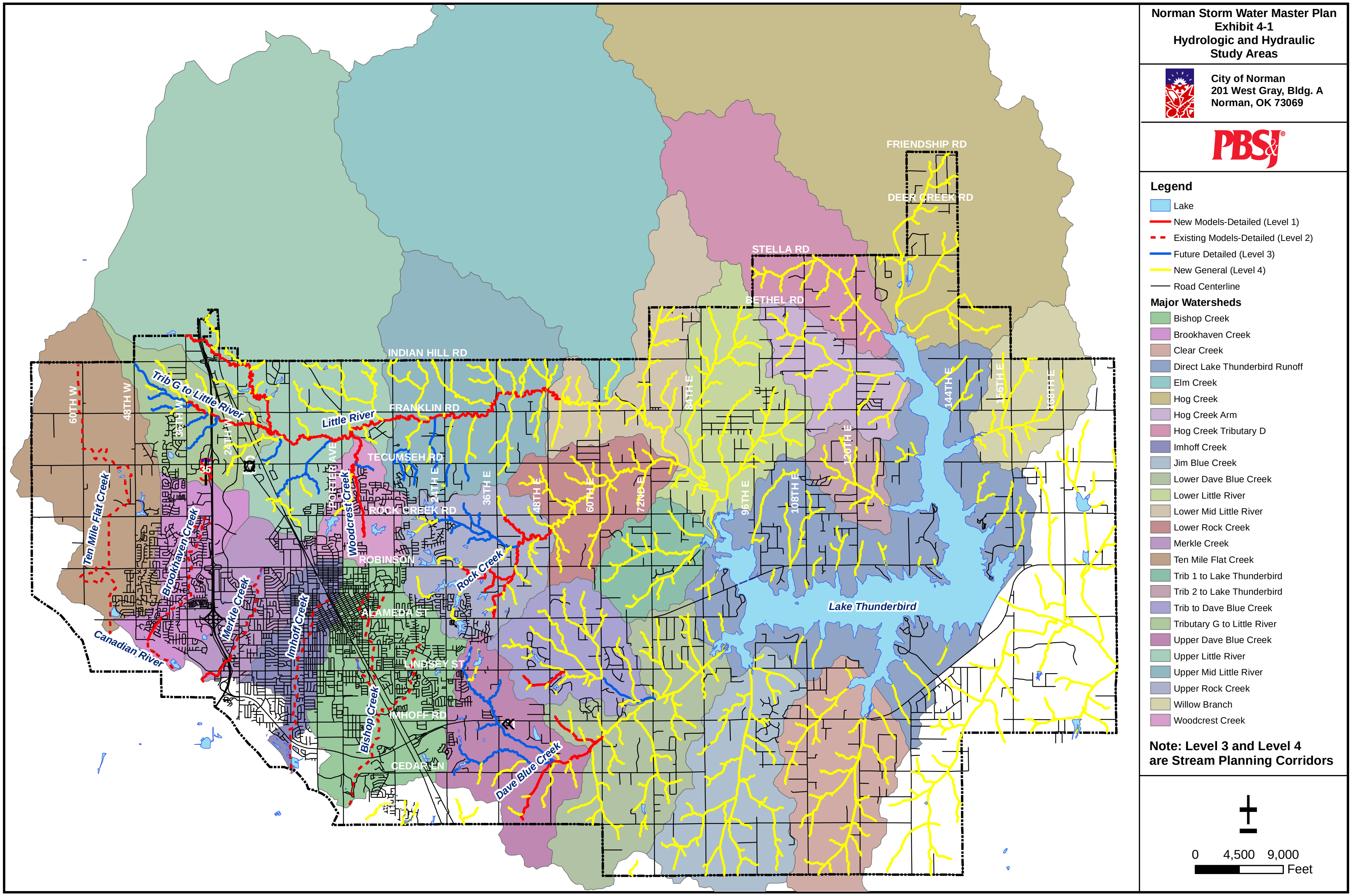

Norman Storm Water Master Plan
Exhibit 4-1
Hydrologic and Hydraulic
Study Areas
City of Norman
201 West Gray, Bldg. A
Norman, OK 73069
PBSJ
Legend
Lake
New Models-Detailed (Level 1)
Existing Models-Detailed (Level 2)
Future Detailed (Level 3)
New General (Level 4)
Road Centerline
Major Watersheds
Bishop Creek
Brookhaven Creek
Clear Creek
Direct Lake Thunderbird Runoff
Elm Creek
Hog Creek
Hog Creek Arm
Hog Creek Tributary D
Imhoff Creek
Jim Blue Creek
Lower Dave Blue Creek
Lower Little River
Lower Mid Little River
Lower Rock Creek
Merkle Creek
Ten Mile Flat Creek
Trib 1 to Lake Thunderbird
Trib 2 to Lake Thunderbird
Trib to Dave Blue Creek
Tributary G to Little River
Upper Dave Blue Creek
Upper Little River
Upper Mid Little River
Upper Rock Creek
Willow Branch
Woodcrest Creek
Note: Level 3 and Level 4 are Stream Planning Corridors
0
4,500
9,000
Feet
FRIENDSHIP RD
DEER CREEK RD
STELLA RD
BETHEL RD
INDIAN HILL RD
FRANKLIN RD
TECUMSEH RD
ROCK CREEK RD
ROBINSON
ALAMEDA ST
LINDSEY ST
IMHOFF RD
CEDAR LN
60TH W
48TH W
24TH
PORTER AVE
24TH E
36TH E
48TH E
60TH E
72ND E
84TH E
96TH E
108TH E
120TH E
144TH E
156TH E
35
Trib G to Little River
Little River
Ten Mile Flat Creek
Brookhaven Creek
Merkle Creek
Imhoff Creek
Woodcrest Creek
Bishop Creek
Rock Creek
Dave Blue Creek
Canadian River
Lake Thunderbird

Table 4-2: Summary of Hydrologic Modeling Methodologies

Watershed	Model Type	Rainfall Distribution	Source for Rainfall Totals	Intensity Duration (JXMIN)	Storm Duration (Days)	Intensity Position	Storm Area	Unit Hydrograph	Loss Rate	Routing
Ten Mile Flat	HEC-HMS 2.2.2	Frequency	CoN Criteria (TP-40 and HYDRO-35)	5	1	50%	11.738	Snyder (Tulsa Method)	CN	M-C
Brookhaven Creek	HEC-HMS 3.1.0	SCS	CoN Criteria (TP-40 and HYDRO-35)	NA	1	NA	0	NRCS UH	CN (with I%)	KW, M, MP
Merkle Creek	HEC-1	Frequency (PI)	CoN Criteria (TP-40 and HYDRO-35)	5	1	50%	0	NRCS UH	CN	M
Imhoff Creek	HEC-1	Frequency (PI)	CoN Criteria (TP-40 and HYDRO-35)	5	1	50%	0	NRCS UH	CN	M
Bishop Creek	HEC-1	Frequency (PI)	CoN Criteria (TP-40 and HYDRO-35)	10	1	50%	0	NRCS UH	CN	M
Little River	HEC-HMS 3.1.0	Frequency	USGS WRI 99-4232	15	1	50%	Freq-based Areal Reduction	NRCS UH	CN (with I%)	MP, M-C
Tributary G to Little River							0			
Woodcrest Creek							0			
Rock Creek	HEC-HMS 3.0.1	Frequency	USGS WRI 99-4232	15	1	50%	0	NRCS UH	CN (with I%)	MP, M-C
Dave Blue Creek	HEC-HMS 3.0.1	Frequency	USGS WRI 99-4232	15	1	50%	0	NRCS UH	CN (with I%)	MP, M-C
Tributaries to Dave Blue Creek	HEC-HMS 3.0.1	Frequency	USGS WRI 99-4232	15	1	50%	0	NRCS UH	CN (with I%)	MP

Key to Abbreviations:

- Loss Rates
  - CN = Curve Number
  - I% = Impervious Percentage
- Routing Methods
  - M-C = Muskingum-Cunge
  - KW = Kinematic Wave
  - M = Muskingum
  - MP = Modified Puls

Table 4-3: Total Precipitation Depths for Design Events

	USGS WRI 99-4232**							TP-40 / HYDRO-35***							Atlas 14						
Duration *	2-yr	5-yr	10-yr	25-yr	50-yr	100-yr	500-yr	2-yr	5-yr	10-yr	25-yr	50-yr	100-yr	500-yr	2-yr	5-yr	10-yr	25-yr	50-yr	100-yr	500-yr
5-min								0.48	0.56	0.62	0.72	0.79	0.86	1.01	0.50	0.61	0.71	0.85	0.97	1.08	1.37
10-min								0.84	0.99	1.11	1.27	1.41	1.54	1.83	0.73	0.90	1.04	1.25	1.42	1.59	2.01
15-min	0.90	1.17	1.33	1.56	1.75	1.95	2.50	1.01	1.20	1.34	1.54	1.70	1.86	2.23	0.89	1.10	1.27	1.52	1.73	1.94	2.45
30-min	1.28	1.66	1.92	2.29	2.58	2.90	3.75	1.40	1.73	1.96	2.29	2.55	2.81	3.39	1.30	1.61	1.87	2.25	2.55	2.85	3.61
1-hr	1.57	2.16	2.58	3.10	3.55	4.00	5.10	1.81	2.28	2.60	3.07	3.44	3.80	4.58	1.73	2.15	2.52	3.06	3.49	3.95	5.09
2-hr	1.93	2.65	3.15	3.88	4.40	5.00	6.60	2.13	2.80	3.30	3.85	4.44	5.00	6.12	2.15	2.69	3.17	3.87	4.44	5.04	6.57
3-hr	2.16	2.96	3.55	4.34	5.01	5.70	7.60	2.28	3.13	3.63	4.25	4.83	5.43	6.60	2.41	3.02	3.58	4.40	5.08	5.81	7.69
6-hr	2.55	3.52	4.20	5.15	5.90	6.70	8.80	2.71	3.64	4.30	5.08	5.71	6.40	7.80	2.86	3.58	4.26	5.28	6.14	7.07	9.53
12-hr	2.95	4.05	4.85	5.90	6.75	7.60	9.90	3.23	4.31	5.10	6.00	6.71	7.55	9.20	3.32	4.13	4.90	6.08	7.10	8.21	11.2
1-day	3.35	4.67	5.65	6.95	8.00	9.20	12.00	3.75	5.15	5.88	7.00	7.78	8.75	10.68	3.81	4.72	5.59	6.94	8.10	9.37	12.8

* HEC-HMS models developed for the master plan use the 15-min, 1-hr, 2-hr, 3-hr, 6-hr, 12-hr and 1-day duration totals to define the Frequency Storm.

** Rainfall totals derived from USGS Water Resource Investigation Report 99-4232.

*** Rainfall totals derived from U.S. Weather Bureau Technical Paper No. 40 and HYDRO-35 (from Table 5004.1 of the City of Norman design criteria).

Table 4-4: Variation in Subbasin Areas Across Both Level 1 and Level 2 Watersheds

			Summary of Subbasin Areas (square miles)					Summary of Subbasin Areas (acres)				
Watershed	Study Level	Number of Subbasins	Minimum	Maximum	Average	Total	Standard Deviation	Minimum	Maximum	Average	Total	Standard Deviation
Bishop Creek	2	32	0.050	0.680	0.270	8.630	0.147	32.0	435.2	172.6	5,523.2	94.1
Brookhaven Creek	2	33	0.016	0.244	0.105	3.471	0.056	10.2	156.3	67.3	2,222	36
Dave Blue Creek	1	21	0.101	1.017	0.482	10.124	0.281	64.6	650.9	308.5	6,479	180
Dave Blue Creek - Tributaries	1	9	0.017	0.109	0.056	0.501	0.026	10.9	69.8	35.6	321	17
Imhoff Creek	2	34	0.000	0.530	0.099	3.380	0.119	0.0	339.2	63.6	2,163	76
Little River	1	62	0.022	4.640	0.876	54.318	1.072	14.1	2,969.6	560.7	34,764	686
Merkle Creek	1/2	36	0.020	0.380	0.104	3.760	0.085	12.8	243.2	66.8	2,406	54
Rock Creek	1	26	0.019	1.028	0.260	6.763	0.271	12.2	657.9	166.5	4,328	173
Ten Mile Flat Creek	2	24	0.103	1.523	0.488	11.701	0.322	65.9	974.7	312.0	7,489	206

Watershed and Subbasin Delineation

Level 1 Streams

The watershed and subbasin delineations for the Level 1 study watersheds were developed in a two-stage process. The first step used the automated delineation capabilities of the Arc Hydro tool set to produce a draft set of subbasin delineations. These subbasins were then refined by hand based on visual inspection of the new 1 and 2 ft contours for the City and the various storm drainage networks in the watersheds. The initial draft subbasins were aggregated or split as necessary in order to ensure that the models would produce flows at key locations for input into the hydraulic models.

The sizes of the subbasins for the various watersheds varied based on the level of development or potential development and the need for coupling with detailed hydraulic modeling. Little River watershed subbasins to the north of Little River, especially outside of the city limits tended to be larger than the subbasins for other areas. The variation in subbasin areas across both Level 1 and Level 2 watersheds is shown in Table 4-4. The subbasins for both Level 1 and Level 2 watersheds are shown in Figures 4-1, 4-2, and 4-3.

Level 2 Streams

The watershed and subbasin delineations for Level 2 watersheds were based on the delineations developed for the original models. The subbasins boundaries, as shown on the maps provided with the associated existing studies, were digitized into GIS shape files. These digitized delineations were generally checked against the new topographic data collected for the City. However, only limited modifications were made to the delineations in order to address specific requirements for the master plan or to correct obvious issues. Many of the Level 2 watershed boundaries have a small amount of overlap or undershoot when compared to the adjacent watersheds. Since the existing models were to be modified as little as possible, these types of discrepancies were not corrected. The slight changes in contributing area that would result from correcting these issues would probably not have a significant impact on the overall flows. Specific changes are discussed under the sections that describe each Level 2 watershed.

Unit Hydrograph Methodology

An evaluation of various hydrologic methods was performed by Vieux, Inc. (2008) as part of the SWMP. The NRCS method and V_{flo}® appeared to provide the best results. The NRCS (SCS) unit hydrograph was selected for use in the HEC-HMS models for the Level 1 streams. This approach is consistent with a majority of the previous modeling for the City and produces reasonable runoff responses compared to previous studies and general expectations (on a per square mile basis) for the model areas. The NRCS unit hydrograph uses a single user-defined parameter, the lag time response of the watershed, along with a set peaking or shape coefficient to define the shape of the outflow hydrograph.

Lag Time Calculations

The lag times used for the NRCS (SCS) unit hydrograph transforms in the Level 1 HEC-HMS models were calculated based on the procedure outlined in TR-55 (Soil Conservation Service, 1986). This procedure separates the longest representative flow path in a particular subbasin into three different types of flow. These flow types are sheet flow, shallow concentrated flow and channelized flow. For the purposes of the Level 1 master plan models, the longest representative flow path was identified and broken into three segments, one of each type. The initial derivation of the longest flow path and the flow type delineations was based on an automated routine in the HEC-GeoHMS pre-processing application. This routine determined the longest flow path for each delineated subbasin and provides an initial delineation of the three different flow paths. The automated procedure was configured so that it would provide sheet flow segments with lengths of 300 ft. This length, which represents the upper end of the recommended range according to TR-55, is reasonable for the predominantly undeveloped areas in the Level 1 watersheds. A Manning's roughness coefficient of 0.24, which represents dense grasses, was selected to represent the conditions in these sheet flow segments.

The longest flow paths were reviewed manually to ensure that the segments were determined properly; the slopes were reasonable; and the upper, sheet flow segments were representative of the topography in the area rather than simply the longest flow path. Some manual adjustments were made to both the points at which the flow regimes were determined to change and to the sheet and shallow concentrated flow segments to provide more representative slope estimates.

For the future condition HEC-HMS models, the lag time calculations were modified to account for the projected changes in land use according to the City of Norman 2025 projections. Specifically, the assumptions for the sheet and shallow concentrated flow segments under future conditions were revisited. The general assumption was that, in areas projected for relatively dense development, the 300-ft-long sheet flow paths assumed under existing conditions should be shortened to 110 ft. In these areas, the n-value for sheet flow was modified to 0.41 (Bermuda grass) to represent the turf grass that would be typical in such developed areas. In areas projected for low density development (cres, vlres, open, park and fplain), the 300-ft sheet flow length was retained.

The shallow concentrated flow path was also reviewed to determine whether it was predominantly within one or more of the low-density categories. If it was determined to be in such an area, the shallow concentrated flow path was considered to remain unpaved. For other, more densely developed land uses, the shallow concentrated flow path was considered paved.

Since much of the area in the Level 1 watershed area is projected for low density development, many of the future condition lag times change very little compared to the existing conditions. The assumption of a higher sheet flow n-value (based on dense grass, which corresponds to yards or other maintained/manicured spaces) for developed areas also tends to reduce the potential change in the lag time due to development. However, the lag times do generally tend to decrease for most subbasins when comparing existing and future lag times. The existing and future lag times along with other HEC-HMS parameters are shown in Appendix F.

Loss Rate Parameters

The NRCS (formerly SCS) Curve Number methodology was used to develop the loss rate parameters for all detailed hydrologic modeling. The curve numbers used for the study were derived from the curve number values provided in the NRCS TR-55 document with the assumption of antecedent moisture condition II.

Existing Condition Curve Numbers

The existing condition NRCS curve numbers for Level 1 study areas were developed from a combination of a base curve number combined with a percentage of impervious cover. The curve number and impervious percentage were then input into HEC-HMS and the model was allowed to calculate the composite curve number. This approach was selected over the alternative of selecting pre-weighted curve numbers that are available from TR-55 and a variety of other sources because of the availability of detailed impervious cover data for the City of Norman. The availability of this data allowed for a more detailed accounting of impervious cover that would be possible from average values from a table. For the studied portions of the Little River watershed north of the City of Norman and outside of the area with available impervious cover data, the percentage of impervious cover was estimated based on 2006 aerial photography.

The Level 2 studies, which directly adapted existing hydrologic models provided by the City, retained the existing condition curve numbers included in those models. Revised, future condition curve numbers were calculated for these watersheds. The development of future condition curve number for the Level 1 and 2 studies is described in a subsequent section.

The base curve number used for the existing condition determinations were derived from the TR-55 values for “Pasture, grassland, or range – continuous forage for grazing” and “Woods.” The pasture category is equivalent to the “Open space (lawns, parks, golf courses, cemeteries, etc.” and is appropriate for both open spaces in developed areas and non-wooded, undeveloped areas. The curve numbers for these classifications and the four hydrologic soil groups are shown in Table 4-5. Good hydrologic conditions were assumed for both classifications.

Table 4-5: Existing Conditions Base Curve Numbers

Cover Type	Hydrologic Condition	Curve Number of Hydrologic Soul Group			
		A	B	C	D
Pasture, grassland, or range – continuous forage for grazing	Good	39	61	74	80
Woods	Good	30	55	70	77

The base, existing condition curve numbers were developed in GIS by combining the Cleveland County SSURGO soils data (hydrologic soil groups), City of Norman land cover (identifies wooded areas), National Land Cover Dataset (NLCD – identify wooded areas outside of the City of Norman) and subbasin polygons developed for the Level 1 study areas. The weighted curve number for each subbasin was calculated as a weighted average from the intersection of the subbasin polygons, woods land cover (all areas not covered by woods are assumed to be pasture/open space), and hydrologic soil groups.

The impervious cover percentage was developed from the impervious layers (roads, buildings and paved areas) provided by the City of Norman. These layers were intersected with the final subbasin boundaries to determine the impervious area within each subbasin. The impervious percentage was then calculated from this area. All of the impervious cover indicated in the City's data layers was assumed to be directly connected for the purposes of the hydrologic modeling. This assumption will tend to produce slightly conservative flows. The loss rate and unit hydrograph parameters for the Level 1 watershed subbasins are shown in Appendix F.

<u>Future Condition Curve Numbers</u>

The future condition NRCS curve numbers were calculated with a somewhat different approach compared to the existing condition curve numbers. This is due to the nature of the data available for the determination of future conditions. The primary dataset used to define the future conditions was the City of Norman 2025 land use projections. This polygon dataset extends beyond the city limits of Norman and provides the projected land use for all areas within the master plan study area. In addition to the future land use layer, the process used to develop the future curve numbers also incorporated the final subbasin boundaries and the hydrologic soil groups.

Since detailed estimates of impervious cover are not available for the 2025 projections, the land use dataset was used as a proxy for this information. Each 2025 land use type was associated with a corresponding TR-55 cover with its accompanying set of curve numbers. These curve numbers already incorporate an estimate of the impervious percentage based on typical values for such land uses. The cover types and curve numbers associated with the 2025 land use are shown in Table 4-6. This table has also been updated with the AIM Norman 2045 Future Land Use and suggested CN's that correspond to the land use types. That data can be found in Table 4-7.

Table 4-6A: (Superseded) "2025 Land Use Plan" Curve Number Table

2025 Land Use Value	Description	Corresponding Classification (Norman Drainage Criteria – Table 5005.2)	Corresponding SCS Classification (TR-55)	A	B	C	D
open	Open	Park, Cemeteries	Open Space (Fair)	49	69	79	84
comm	Commercial	Business – Commercial Areas	Urban District (Commercial & Business)	89	92	94	95
cres	Country Residential (1D/10ac)		Open Space (Good)	39	61	74	80
flplain	Floodplain	Park, Cemeteries	Open Space (Good)	39	61	74	80
hres	High-Density Residential	Residential – Multi-unit (attached)	Residential (1/8 acre)	77	85	90	92
ind	Industrial	Industrial – Heavy uses	Urban District (Industrial)	81	88	91	93
inst	Institutional	Business – Neighborhood Areas	Urban District (Commercial & Business)	89	92	94	95
lake	Lake	Water	Water	99	99	99	99
lres	Low-Density Residential (4D/ac)		Residential (1/4 acre)	61	75	83	87
mres	Medium-Density Residential (8-10D/ac)		Residential (1/8 acre)	77	85	90	92
mu	Mixed Use	Business – Neighborhood Areas	Urban District (Commercial & Business)	89	92	94	95
nloop	North Loop	Streets – Paved, Unpaved Area	Streets & Roads (Paved & Storm Sewers)	98	98	98	98
office	Office	Business – Commercial Areas	Urban District (Commercial & Business)	89	92	94	95
park	Park	Park, Cemeteries	Open space (Good)	39	61	74	80
row	Right-of-way	Streets – Paved, Unpaved Areas	Streets & Roads (Gravel)	76	85	89	91
trans	Transportation	Streets – Paved	Streets & Roads (Paved & Open ditches)	83	89	92	93
vlres	Very Low-Density Residential (1D/2ac)		Residential (2 acre)	46	65	77	82

Table 4-6B: Suggested 2045 Future Land Use Curve Numbers

2045 Land Use Value	Description	Corresponding Classification (Norman Engineering Design Criteria– Table 5005.2)	Corresponding SCS Classification (TR-55)	A	B	C	D
OP	Open Space	Park, Cemeteries	Open Space (Fair)	49	69	79	84
AR	Agricultural Residential	Undeveloped Areas - Pasture	Open Space (good)	39	61	74	80
RR	Rural Residential		Open Space (Good)	39	61	74	80
UR	Urban Reserve		Open Space (Good)	39	61	74	80
UL	Urban Low		Residential (1/4 acre)	61	75	83	87
UM	Urban Medium		Residential (1/8 acre)	77	85	90	92
UH	High Urban		Residential (1/8 acre)	77	85	90	92
ULC	Urban Living Center	Business – Neighborhood Areas	Urban District (Commercial & Business)	89	92	94	95
MX	Mixed-Use	Business – Neighborhood Areas	Urban District (Commercial & Business)	89	92	94	95
IMX	Interchange Mixed-Use	Business – Neighborhood Areas	Urban District (Commercial & Business)	89	92	94	95
TOD	Transit Oriented Development	Business – Neighborhood Areas	Urban District (Commercial & Business)	89	92	94	95
LCC	Local Commercial Corridor	Business – Commercial Areas	Urban District (Commercial & Business)	89	92	94	95
C	Commercial	Business – Commercial Areas	Urban District (Commercial & Business)	89	92	94	95
CBD	Core Business Districts	Business – Commercial Areas	Urban District (Commercial & Business)	89	92	94	95
JC	Job Center	Industrial – Light Uses	Urban District (Industrial)	81	88	91	93
CIV	Civic	Schools	Urban District (Commercial & Business)	89	92	94	95
Water	Water	Water	Water	99	99	99	99
P	Parks	Park, Cemeteries	Open Space (Fair)	49	69	79	84

The future condition curve numbers were calculated based on the intersection of the 2025 land use layer, the hydrologic soil group layer and the final subbasin delineations. These curve numbers were calculated for both the Level 1 and Level 2 study areas. The calculated future condition curve numbers were then compared to the existing condition curve numbers to ensure that they either increase or were equal to the existing condition curve numbers. This comparison required the computation of impervious cover weighted curve numbers for the existing condition dataset. Due to the two methods used to develop the existing and future curve numbers, it is possible for this to occur in limited cases. If the calculated future condition curve number was lower than the existing condition value, the existing condition curve number was retained. The future condition curve numbers are shown in Appendix F.

Hydrologic Routing

The hydrologic routing of flows between combination points in the HEC-HMS model can have a significant impact on the magnitude and timing of the peak flows in a watershed. Routing typically causes some attenuation of the peak flow, although the attenuation is not always significant. The type of routing selected and the parameters used for that routing can have a significant impact on the level of attenuation produced by the hydrologic routing. The models used for this master plan included a variety of routing methodologies. The Level 1 models used Modified Puls and Muskingum-Cunge routing exclusively. The Level 2 models primarily used Muskingum Routing.

The Modified Puls routing approach was used in the Level 1 models for all stream reaches for which HEC-RAS modeling was available. The Modified Puls method provides the most direct accounting of the available storage within the floodplain of any of the methods available in HEC-HMS. The HEC-RAS models developed within the watershed were used to develop the storage-discharge curves required for the method. In order to generate these curves, a set of routing flows bounding the full range of anticipated flows was developed, the cross sections bounding the various routing reaches were identified and coded into the Storage Outflow option of the DSS export from HEC-RAS and the results were saved to a HEC-DSS file for use with HEC-HMS. The storage-discharge curves generated by HEC-RAS were check to ensure that there were no significant discontinuities or abrupt changes in the curve. Any such changes were smoothed out to provide a more stable routing curve. In addition to the routing curves, the average channel velocities in HEC-RAS models were used to develop the number of routing steps to be used for each routing reach.

Muskingum-Cunge routing was used for routing reaches in Level 1 watersheds that were not covered by HEC-RAS models. The 8-point cross section version of this routing method was used based on representative cross sections derived from the new 2007 topographic data.

A variety of routing methodologies were used in the various Level 2 hydrologic models. For all Level 2 watersheds, the routing used in the available models was retained for the purposes of the master planning effort. The most commonly used routing method for these models was the Muskingum method. This method was used exclusively for the Bishop Creek, Imhoff Creek and Merkle Creek watersheds and for a majority of the routing reaches in the Brookhaven Creek model. The Brookhaven Creek model also used the Kinematic Wave and Modified Puls routing methods to a limited extent. The Ten Mile Flat Creek model used the Muskingum-Cunge method exclusively. The Muskingum routing method tends to produce very little attenuation of the peak flow through a routing reach. It is quite possible that the hydrologic models for the watersheds that predominantly use this method could be under-predicting the capacity of the channel and associated floodplain to attenuate peak flows.

4.1.1.2 Summary of Hydrologic Modeling for Level 1 Watersheds

The Level 1 watersheds were modeled with the HEC-HMS model as described in the methodology sections above. These watersheds are illustrated in Exhibit 4-1 and Figures 4-1 and 4-2. The models for these watersheds were developed from scratch based on the new, 2007 topographic data for the City of Norman with parameters developed as described in the preceding sections. Unique aspects of the hydrologic modeling for each Level 1 watershed are discussed in detail in the following subsections. Both existing and future or ultimate buildout (baseline) conditions were developed for each watershed.

Dave Blue Creek

The Dave Blue watershed is located on the developing eastern edge of the urbanized portion of the City of Norman. The watershed is characterized by considerably steeper slopes than those of the core urban area. The 10.1-square-mile portion of the Dave Blue Creek watershed upstream of 60th Avenue was modeled in detail with HEC-HMS. The watershed modeling for Dave Blue Creek followed the methodology outlined above and did not include any significant complications.

Dave Blue Creek - Tributaries

The Dave Blue Creek Tributaries watershed is located just to the north of the main Dave Blue Creek watershed described above. The watershed drains to Tributary 1 to Dave Blue Creek, which ultimately flows into the main stem just downstream of 72nd Avenue. The hydrologic modeling performed for this watershed a part of the master plan encompassed 0.5 square mile and extended to a point approximately 2,400 ft downstream of 48th Avenue. The watershed modeling for Dave Blue Creek Tributaries followed the methodology outlined above and did not include any significant complications.

Little River

The Little River watershed is by far the largest watershed modeled as part of the master plan. The Little River model includes the Woodcrest Creek and Tributary G to Little River watersheds and encompasses a total drainage area of approximately 54.5 square miles upstream of 48th Avenue East (downstream limit of detailed study). The westernmost portion of the watershed along the IH 35 corridor has relatively flat slopes while the eastern portions of the watershed, except for the wide floodplain of Little River, is similar in character to the Rock Creek watershed. The Tributary G watershed is located predominantly in the flatter, western portion of the overall watershed. The Woodcrest watershed is located in the transitional zone between the flatter westerns and the steeper portions of the overall watershed.

The primary difference between the hydrologic modeling for the Little River watershed and the other Level 1 watersheds was the need to account for areal reduction of the design rainfall due to the size of the watershed. Areal reduction was applied to combination points along the main stem of Little River as described in subsection 4.1.1.1.. Cumulative areas in the model with less than 10 square miles did not have areal reduction applied to develop the design flows. Such areas included Tributary G to Little River and Woodcrest Creek.

Rock Creek

The Rock Creek watershed, located to the northeast of the currently urbanized portion of the City of Norman, is similar in characteristics to the Dave Blue Creek watershed. Like the Dave Blue watershed it has relatively steep slopes over most of the drainage area. The headwater reaches that border the Bishop Creek watershed are more developed (primarily residential) than similar areas in Dave Blue Creek. The modeled watershed encompassed 6.7 square miles and extended to a point on the main stem of Rock Creek approximately 900 ft downstream of 48th Avenue East. The watershed modeling for Rock Creek followed the methodology outlined above and did not include any significant complications. The existing small ponds in the vicinity of Robinson Street and 24th and 36th avenues were not directly modeled in the HEC-HMS model. However, they were accounted for in consideration of the time of concentration developed for the corresponding subbasins.

4.1.1.3 Summary of Hydrologic Modeling for Level 2 Watersheds

As described above, the Level 2 hydrologic models were adapted directly from existing watershed models provided by the City of Norman. The origins of these models were described in Table 4-1. The Bishop Creek, Imhoff Creek and Merkle Creek models were provided by the City in HEC-1 format while HEC-HMS models were provided for Brookhaven Creek and Ten Mile Flat Creek. HEC-HMS version 3.1.0 was used to develop the final flows for these two models. Some of the models were modified slightly so that they could more easily be used to evaluation potential solutions, to correct minor issues found in the models and to extend the models into previously unstudied areas. Specific details related to the modeling of each watershed are described in the subsections below.

The most significant modification made to the Level 2 hydrologic models was the creation of a full build-out version to represent the anticipated level of development of the watersheds as presented in the Norman 2025 plan. The models for full build-out (baseline) conditions were developed as described in the preceding methodology sections. For the Level 2 watersheds, only the curve number was modified in order to represent the increased levels of impervious cover anticipated. A majority of the area encompassed by these watersheds is either already developed, or in the case of much of the area in the Ten Mile Flat Creek watershed, marginally developable. As a result, the lag times for the subbasins in these models were not expected to change significantly. The Imhoff Creek watershed is the most heavily developed of the watersheds in the City with only minimal area available for additional development. Existing conditions in this watershed were assumed to be equivalent to the full build-out condition.

Bishop Creek

The Bishop Creek HEC-1 model used for the master plan was based on a 1996 model developed by Mansur-Daubert-Strella Engineers. The model uses the NRCS (SCS) unit hydrograph methodology. This version replaced a 1995 HEC-1 model, also by Mansur-Daubert-Strella Engineers, that used the Snyder unit hydrograph methodology. The report and associated documentation for the Mansur-Daubert-Strella Engineers study was not available for review during the preparation of the master plan.

The HEC-1 model provided for the Bishop Creek watershed consisted of 32 subbasins and covered approximately 8.64 square miles. This watershed area of 8.64 square miles reflects the watershed area modeled, based on the HEC-1 model obtained from the City as the starting point for the master plan analyses. The supporting report and watershed map associated with this model were not available to the project team during the development of the master plan. An approximate subbasin delineation based on the new topographic data for the City, with minor modifications made by hand (delineation shown in Figure 4-3), produced a somewhat larger area. The area shown as subwatersheds B26B and B27B in Figure 4-3 (essentially the area south of Timbrell and west of Jenkins) does not appear to be included in the HEC-1 model. This area only contributes flow at the downstream end of the hydraulically modeled stream so it was not used in the hydraulic modeling. This point is essentially at the edge of the Canadian River floodplain. In other locations in the report, such as in Section 5, a larger drainage area is given for Bishop Creek (9.87 square miles), which reflects the area downstream of where subwatersheds B26B and B27B join the main branch. This area included the drainage to the main stem and Tributaries A, B and C to Bishop Creek. Since existing drainage area maps were not available for the Bishop Creek watershed, the subbasins were delineated using automated routines and the topography for the area. These subbasins were then modified slightly to better conform to the areas in the model and used as a reference for the placement of flows and development of solutions. These subbasins were not intended to match the model exactly and should not be assumed to accurately reflect the delineations made for the original model. Five existing detention ponds are modeled in the Bishop Creek HEC-1 model.

Brookhaven Creek

The Brookhaven Creek model used for the master plan was based on a 2007 HEC-HMS model provided by C.H. Guernsey. This HEC-HMS model was developed by C.H. Guernsey based on a 1993 Letter of Map Revision HEC-1 model by Clour Engineers. The Guernsey model was used for the design of the 36th Avenue NW bridge. The 2007 model added the additional area between Robinson Street and Willow Grove Drive to the extent of the 1993 model.

The HEC-HMS model for the Brookhaven Creek watershed consisted of 33 subbasins and covered approximately 3.5 square miles. This area included the drainage to Tributaries A and B in addition to the main stem of Brookhaven Creek. The Brookhaven model includes a single detention pond.

Imhoff Creek

The Imhoff Creek model used for the master plan was based on the HEC-1 model from the 2001 LOMR by Baldischwiler. This LOMR incorporates refinements to the subbasin delineations and connectivity in the Lindsey and McGee area based on the Phase A improvements constructed as documented in the 1997 Baldischwiler study. The Phase A improvements provide additional drainage capacity to the south of Lindsey.

The 2001 LOMR HEC-1 model for Imhoff Creek consisted of 33 subbasins and covered approximately 3.4 square miles. This includes the area surrounding the Lindsey and McGee intersection, which has a long history of flooding issues. The subbasins in this portion of the model are quite small since they were used in the sizing of the three phase improvements proposed for the area in the 1997 Baldischwiler report. During the initial review of this model for use in the master plan, small discrepancies were found in these subbasin areas. These discrepancies were corrected with the additional of approximately 27.7 acres to subarea I-10A and the inclusion of Subarea I-11 (5.4) acres that was missing in the model. In addition to these corrections, subbasin I-2 was split into two pieces in order to facilitate the input of flows into the Imhoff HEC-RAS model and to facilitate the hydrologic modeling of proposed detention in the upper portion of the Imhoff Creek watershed. The final HEC-1 model used in the master plan included 34 subbasins.

Merkle Creek

The Merkle Creek model used for the master plan was based on the 1995 LOMR HEC-1 model developed by JWB for Clour Engineering. The 1995 LOMR model replaced the 1994 LOMR model developed by Clour Engineering and included the modeling of two detention ponds (I and II) upstream of Robinson. A subsequent LOMR in 1996 did not produce any additional changes in the HEC-1 model.

The 1995 HEC-1 model for Merkle Creek consisted of 36 subbasins and covered approximately 3.2 square miles. The 1995 model stopped at IH 35. As part of this master plan, the model was extended downstream to the confluence with the Canadian River floodplain. This extension of the model included the addition of two subbasins (M-10 and M-11). Subbasin M-10 incorporates the drainage directly to the main stem of Merkle Creek downstream of IH 35. Subbasin M-11 includes the drainage along the IH 35 corridor from the north. The contributing area of subbasin M-20 was also modified slightly to incorporate additional contributing area to the south. These changes resulted in an increase to the overall watershed area of approximately 0.56 square miles for a total area of 3.76 square miles. An additional Muskingum routing reach was also added to the model to route flows through subbasin M-10.

The Merkle Creek model includes four detention pond structures (actually five, Ponds I and II are modeled together) and four reaches of storage routing to account for the impact of backwater upstream of Robinson Street. A larger pond has recently been constructed upstream of Robinson Street. This pond will replace Pond III and will be considerably larger. The modeling for this detention facility is discussed in detail under the solutions modeling section.

Ten Mile Flat Creek

The Ten Mile Flat Creek model used for the master plan was based on the recently completed MacArthur Engineering CLOMR model. The HEC-HMS model for this study was completed in 2005. However the CLOMR was not ultimately approved until 2007. The Ten Mile Flat model is the only model used in the master plan that employs the Snyder unit hydrograph methodology. The unit hydrograph parameters used in the model were developed based on the USACE Tulsa District methodology. The MacArthur model for Ten Mile Flat also exclusively used the Muskingum-Cunge routing method.

The 2005 Ten Mile Flat HEC-HMS model consisted of 24 subbasins and covered approximately 11.7 square miles. The Ten Mile Flat watershed is located at the far western end of the City of Norman and is considerably different in character from the other watersheds in the City. The terrain in the watershed is very flat and much of the total area is effectively located in either the 100-year or 500-year floodplain of the Canadian River.

Much of the flow pattern within the Ten Mile Flat watershed is determined by the orientation and elevation of the existing roads. The model includes four detention ponds that are effectively formed by the backwater created by Franklin Road (ponds 2, 3 and 4) and Indian Hill Road (pond 1). Overflows along 60th Avenue NW and Tecumseh Road also have a significant impact on the hydraulic modeling for the watershed.

4.1.2 Hydrologic Modeling for Level 3 and 4 Streams

Level 3 and 4 streams, which included a majority of the streams in the undeveloped northern and western portions of the City of Norman, were analyzed with the goal of producing planning level floodplains or "Stream Planning Corridors." The hydrologic analysis used to develop flows for these streams was based on the U.S. Geological Survey regional regression equations for the State of Oklahoma. The USGS equations were used with a series of

GIS tools to produce a grid of flow values. This grid was then used with the Rapid Floodplain Delineation (RFD) tool to produce basic hydraulic models and delineate floodplains for the streams. The details of this approach are described in the following subsections.

4.1.2.1 Methodology – Rapid Floodplain Delineation (RFD) Tool

The Rapid Floodplain Delineation (RFD) tool is software that automates many aspects of floodplain modeling and delineation. The program can automatically generate cross-sections, perform a backwater calculation, and delineate a floodplain in a single step. The primary goal of the program is to perform its calculations quickly and with minimum input required by the user. For example, once the stream centerline and topography have been created, a typical reach of 10 miles with cross sections spaced at 250 ft takes about 10 seconds to model and delineate. Shorter reaches can be done in 2 to 4 seconds.

The calculation method used by RFD is similar to the approach used in HEC-RAS, although much more simplified. A backwater calculation is performed that considers Manning's roughness coefficients (using one Manning's value per cross-section) and expansion and contraction losses. The version of the program used for the master plan work allowed for the input of an energy loss at stream crossings. The program currently does not include the capability to model bridges or structures in detail.

RFD also has a number of options to further facilitate rapid modeling. It can automatically generate cross-sections, and it has numerous configurable options to adjust the orientation, spacing, and width of the cross-sections. An important feature is that RFD can generate floodplains even when the cross-sections intersect, regardless of whether the intersection occurs in the floodplain or not. Since cross-section intersection is common with automatically generated sections, this is an important feature which allows a floodplain to be generated quickly without modification to the cross-sections.

Compared to a detailed hydraulic model such as HEC-RAS, RFD has some simplifying assumptions. For example, a single n-value is assigned for each cross-section, a single reach length is assigned between any two cross sections, and some other assumptions are made to speed the computation. Despite these simplifications, it is conceptually and computationally superior to any estimates of water surface elevations using normal depth approximations.

Preparation of Topography

The topography must be in raster (grid) form, using the gridfloat format. Gridfloat is a simple format that requires two files, one with an. hdr extension, and the other with a .flt extension. The .hdr file is a short text file which contains information about the grid cell size, size of the grid, and coordinate location of the grid. The .flt file is a binary file containing the elevation of each grid cell as single precision floating-point value. ArcMap rasters can be converted to gridfloat format using ArcMap or ArcInfo.

If different streams in a large region are being modeled, it may not be practical to mosaic all the topography available for the region into one large grid or to create numerous versions of the topography for the various streams. If the user has a "checkerboard" of topography, then RFD can select the correct topography, and if needed, mosaic topography on-the-fly.

The 2007 topographic data was used with the RFD tool to develop the floodplains for the Level 3 and 4 streams. A tiled set of grids (10-ft spacing) was generated from the topographic dataset. The tiling allowed the RFD tool to use only the portions of the topographic data required for a particular stream and facilitated more rapid development of the models and floodplains.

Preparation of the Stream Centerline

A stream centerline or hydraulic baseline must be developed for each stream upon which the RFD tool is used. The stream centerline must be:

1. A shapefile with only one single-part line.
2. Drawn in an upstream to downstream fashion.

3. Projected (i.e., have a .prj) file, and the coordinate system must be in feet.

If the stream centerline file has more than one line, only the first line will be used by RFD. If the first line is a multi-part line, only the first part will be used by RFD as the streamline.

Traditionally, the streamline follows the thalweg — or low-flow channel — along the stream. It is also possible to use NHD (National Hydrography Dataset) centerlines or other pre-existing streamlines as the source. However, be sure the line goes from upstream to downstream — for example the NHD lines go from downstream to upstream.

The hydraulic baselines used in the RFD modeling for the City of Norman were developed directly from the 2007 topographic data. Arc Hydro tools were used to develop flow accumulation grids which were then converted into streamline grids based on an upper threshold of 40 acres. The resultant streamline grid was converted to a set of lines and minor refinements made to produce the final set of stream lines for the modeling.

Reading Discharges from a Grid

RFD can read discharges from a raster and assign these discharges automatically to the cross-sections. The Q-grid must be in gridfloat format (same format as the topography). *The discharge grid must be in geographic coordinates, NAD83*, regardless of the projection of the other files.

The RFD tool includes several options to facilitate the use of the Q-grid. The qmin option specifies the minimum flow to be used. If the value read from the grid falls below the value, the qmin value is used instead. If no minimum is desired, then specify qmin = 0.

The qdsignore option tells RFD for how many feet at the downstream end of the reach to ignore the discharges from the grid. This option appears because many times at the downstream end of a reach, there are q values that are from a larger river nearby, and RFD may grab these unintended larger discharges. When this option is used, the first cross-section upstream from the point that is the qdsignore from the downstream limit of the streamline will be used to assign discharges to all cross-sections downstream. For example, say cross section 520 is the first cross-section more than 500 ft from the downstream limit of the centerline. The discharge at this cross-section is read from the nearest non-null cell on the Q-grid and is 1,760 cfs. This 1760 cfs will be assigned to all cross-sections downstream (lower numbered) of the cross-section 520.

The discharge or Q-grid itself must be a raster that is in the same coordinate system and datum as the stream centerline shapefile. RFD locates the grid cell where the streamline and the cross-section intersect, and checks if there is a discharge specified at that cell. If there is, that discharge is assigned to the cross-section. If not (e.g., the cell is a null cell), then RFD looks at neighboring cells and searches in larger neighbors (e.g., 1 cell away, 2 cells away) until a discharge is found. If more than one discharge is found during the search of a “neighborhood” then the highest discharge is selected.

A sample flow raster is shown in Figure 4-4. The black cells are discharge values, and the white cells are null values. In any discharge raster, the vast majority of the cells should have a null value; only those cells associated with streamlines should have discharge values.

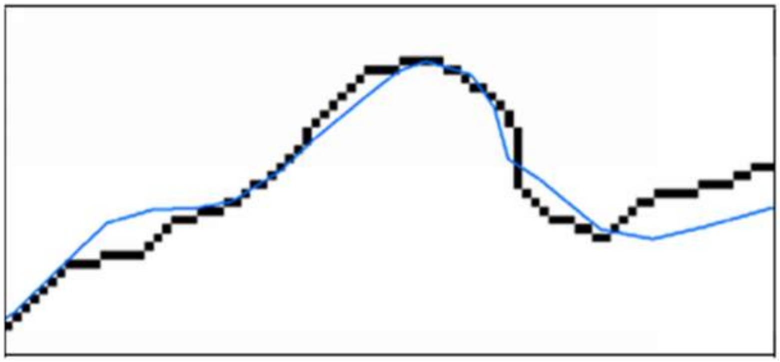


Figure 4-4. River centerline overlaid on sample flow raster.

If RFD reads a lower discharge in the downstream direction that was read upstream, RFD will assume this lower discharge is in error and will use the higher upstream discharge — thus RFD will not allow flows to decrease when going in the downstream direction.

4.1.2.2 USGS Regression Equations

USGS regression equations were used to develop full build-out condition flows for the delineation of Stream Planning Corridors on Level 3 and 4 streams. The regression equations were adapted from the Water Resources Investigation Report 97-4202, “Techniques for Estimating Peak-Streamflow Frequency for Unregulated Streams and Streams Regulated by Small Floodwater Retarding Structures in Oklahoma” (Tortorelli, 1997). This report describes the derivation of regional regression equations based on statistical analysis of historical records at gages and the characteristics of the watersheds draining to those gages within the State of Oklahoma. No significant regionalization effects were observed in the data, so a single set of equations was developed for the state.

The 100-year discharge for rural areal is defined as follows:

Q100(r) = 35.6 A0.614 S0.202 P0.907

Where:

A = Drainage area – the contributing drainage are of the basin, in square miles.

S = Main-channel slope – the slope measured at the points that are 10 percent and 85 percent of the main-channel length between the study site and the drainage divide, in feet per mile.

P = Mean-annual precipitation – the point mean-annual precipitation at the study site, from the period 1961–1990, in inches.

The WRI report suggests that the equations not be used outside of the range of predictor parameters used in the derivation of the equations. These ranges are defined in Table 4-7.

Table 4-7: Recommended Parameter Ranges for the USGS Regression Equations

Parameter	Lower Limit	Upper Limit
A	Equal to or greater than 0.144 mi^2	Less than or equal to 2,510 mi^2
S	Equal to or greater than 1.89 ft/mi	Less than or equal to 288 ft/mi
P	Equal to or greater than 15.0 in	Less than or equal to 55.2 in

The recommended lower limit for the area parameter is 92 acres. The lower limit of drainage areas used in the derivation of the Stream Planning Corridors was 40 acres. Even though this area threshold falls below the suggested lower limit, the extrapolation was considered reasonable given the purpose of the analysis (provide preliminary future condition 100-year floodplains) and the need to develop planning corridors for hundreds of miles of streams. Further, the Stream Planning Corridors developed with these flows matched well in overlapping areas that also received a Level 1 analysis.

The report also provides a methodology to adjust the regression-based flows to account for the level of development within a watershed. This method requires estimates of the percentage of impervious cover in the basin and the percentage of the basin served by storm sewers. The Norman 2025 land use layer was used to identify the anticipated land use types in the areas to be mapped with Stream Planning Corridors. Each 2025 land use type was related to a classification in Table 5005.2 of the City's drainage criteria. The percentage of impervious cover for each land use classifications was established as the average of the upper and lower limits listed in Table 5005.2. The percentage of the area served by storm sewers was estimated based on a review of existing storm sewers in the City of Norman and similar experience from other master planning efforts.

The 100-year discharge adjusted for urbanization is defined as follows:

$\mathbf{Q_{100(u)}} = 2.27\ (R_L-1)\ Q_{2(r)} + 0.0167\ (7-R_L)\ Q_{100(r)}$

Where:

$\mathbf{R_L}$ = Urban adjustment factor – defined by a figure in WRIR 97-4202. The values determined for impervious percentage and percentage of area served by storm sewer are used to enter the figure and determine a value of $\mathbf{R_L}$ from a series of curves.

$\mathbf{Q_{x(r)}}$ = The regression estimate of peak discharge for ungauged sites on natural unregulated streams, for recurrence interval x, in ft^3/s.

Q2(r) = 0.075 A0.615 S0.159 P2.103

4.1.2.3 Development of Discharge Grid (Q-Grid) for RFD Tool

As described above, a gridded representation of flows along the study streams is used as the hydrologic input for the RFD tool. This grid is hereafter referred to as the Q-Grid. A set of spatial processing tools was used to automate the process of deriving flow values at each grid point along the study streams. This process was based on an analysis of a gridded version of the topographic data for the area. The USGS National Elevation Dataset (NED) 30-meter DEM data was used as the basis for this analysis. This data was sufficiently accurate for the derivation of the Q-Grid, especially since the areas analyzed were typically in undeveloped areas with steeper terrain, and could be processed much more efficiently.

The multi-stage process included the development of a flow direction grid based on the elevation grid, followed by the development of a flow accumulation grid and finally a stream grid based on flow accumulations above the threshold of 40 acres of contributing area. The flow accumulation and stream grids were used to calculate the contributing area **(A)** and slope **(S)** at all points along the stream grid. A grid of the mean annual precipitation was developed for the City of Norman Area. The stream grid was then intersected with the mean annual precipitation grid in order to assign a value of mean annual precipitation **(P)** to each grid cell. These steps provided the variables required to calculate the rural regression flows based on the USGS regression equations. The value of the 2-year and 100-year rural flow was calculated for each stream cell.

The urban adjustment factor **(R_L)** was required in order to complete the calculations for the urbanized regression flows. This required that the drainage accumulation grid be intersected with a grid of land use values based on the Norman 2025 data layer. This intersection was used to compute the percentage of impervious cover and the percentage of area served by storm drains at each point along the stream grid. This was then used with a discretized version of the **R_L** table from WRIR 97-4202 to determine the urban adjustment factor at each stream cell. The grid of **R_L** factors was then used with the grids of 2- and 100-year rural flows to calculate the urbanized, 100-year regression flow Q-Grid.

4.1.3 Hydrology for Local Drainage Issues

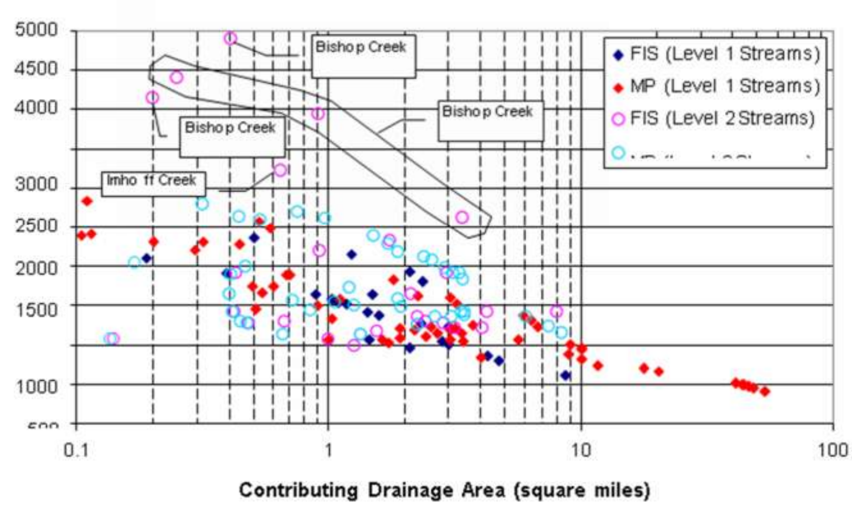
In several cases, it was necessary to develop flows for localized drainage issues. In most cases, these areas were either not covered by a detailed hydrologic model or the model in the particular area was too coarse for the specific drainage issue. In such cases, the Rational Method, as outlined in the drainage criteria for the City of Norma, was used to develop flow values.

4.1.4 Hydrologic Modeling Results

The hydrologic analyses for the master plan produced flows that were generally consistent with previous studies. Flows at selected locations in the various study watersheds are shown in Table 4-8. Flows from the recent countywide Flood Insurance Study (FIS) at comparable locations are shown in Table 4-9. As would be expected given the sources of the Level 2 models, the flows for the master plan are almost identical to the FEMA flows in most cases. Figure 4-5 shows a comparison of the unit discharges for taken from the 2008 effective FIS report and the master plan hydrologic models. The values for Level 1 and 2 watersheds are shown with separate symbols in order to better compare the results.

As the figure shows, the results for the Level 1 streams are generally consistent with those from the FIS for the same streams. The Level 2 results are also generally consistent with the exception of the significant outliers highlighted on the figure. Each of these outliers has an exceptionally high unit discharge. The two Bishop Creek Tributary outliers are simply conservative repetitions of the full basin flow at the upstream end of the studied

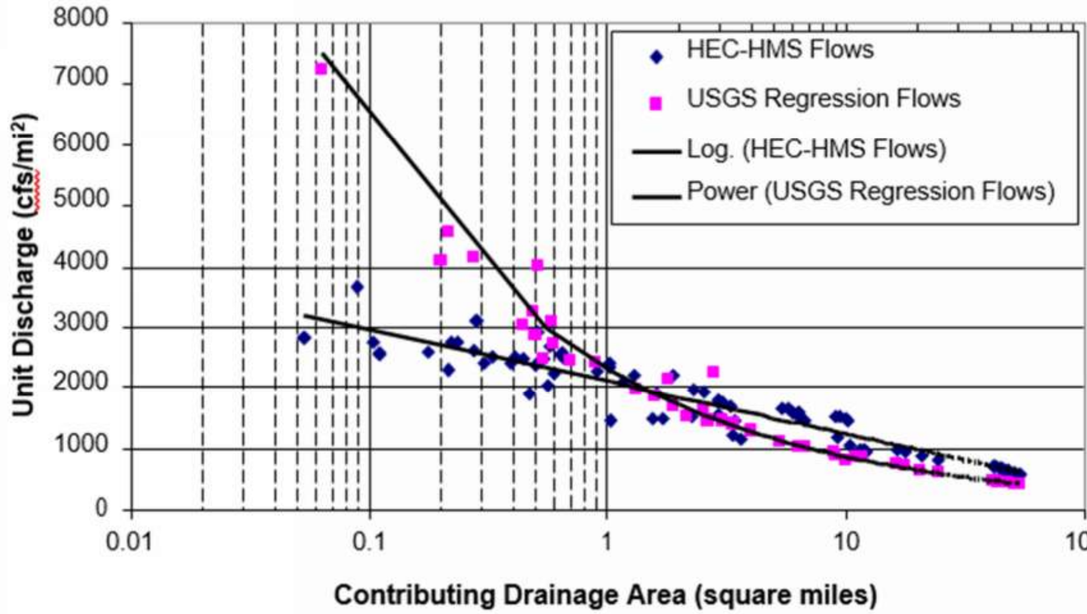
Figure 4-5: Comparison of Unit Discharges for Level 1 and Level 2 Watersheds



stream. The Imhoff Creek outlier was corrected through the modifications made to the Imhoff HEC-1 model (refer to the preceding discussion of the Imhoff Creek hydrology modeling in this section and the memorandum included in Appendix F). The Bishop Creek outliers are exceptionally high when compared to the bulk of the modeling results. The Bishop Creek model used in the master plan produced significantly lower unit discharges for comparable areas. The discrepancy may be the result of a difference between the models used for the master plan and FIS (the flows reported in the 2008 FIS report match those in the 1999 FIS report). The full documentation of the Bishop Creek model was not available for consideration as part of this master plan. However, the version of the Bishop Creek model used for the master plan produced flows that were more reasonable in comparison to similar watersheds in the urbanized portions of the City of Norman.

The flows generated with the detailed hydrologic models also were compared to the Q-grid results derived based on the USGS regression equations. The USGS regression equations for Oklahoma tend to produce higher flows (considerably higher than HEC-HMS) for smaller areas and lower flows for larger areas. For small areas (<0.5 square mile) the USGS flows tend to be conservatively high. Simplifying the comparison to two curves (unit discharge versus area), the USGS curve rises much more quickly than the HMS curve and produces much higher flows for small areas. The USGS curve then tends to flatten out more quickly than the HMS curve. These unit discharge curves for the HEC-HMS models and USGS regression equations are shown in Figure 4-6. As shown in the figure, the two curves tend to cross in the 1- to 3-square-mile range.

Figure 4-6: Comparison of Unit Discharges between Level 1 Models and USGS Regression Equations



4.2 Hydraulic Analysis

Hydraulic modeling of the study streams provided the primary basis for the identification or confirmation (areas previously identified by the City) of flooding issues, for the development of flood and erosion control solutions and the identification of floodplain planning corridors. The U.S. Army Corps of Engineers HEC-RAS version 3.1.3 modeling system and the PBS&J RFD were the primary tools used in this analysis. The following sections provide details of the approach and methodologies used in the hydraulic analyses produced for the Level 1, 2, 3 and 4 streams in the study.

4.2.1 Detailed Hydraulic Modeling for Level 1 and 2 Streams

Detailed hydraulic models were developed or adapted from existing models for all Level 1 and 2 streams studied as part of the master plan. New HEC-RAS (version 3.1.3) models were built for the Level 1 watersheds while existing models were updated to HEC-RAS version 3.1.3 and modified as necessary to reflect new information for the Level 2 watersheds. Table 4-10 provides a summary of the hydraulic models used for the master plan and a brief description of their origins and subsequent modifications. The models for these watersheds are discussed in more detail under the individual sections for each watershed.

Table 4-10: Summary of Hydraulic Models for Levels 1 and 2 Watersheds

Detailed Streams	Study Level	Hard Copy of Model	Hydraulic Model	Program	Year	Company	Purpose	Source	Comments
Ten Mile Flat Creek	2	Y	Y	HEC-RAS	2017	Meshek		CoN	Updated models in 2017 by Meshek under OWRB's CTP contract
Bishop Creek	2	Y	Y	HEC-RAS	2025	Garver	Master Plan	New	New modeling based on new topographic data and survey.
Trib A to Bishop Creek	2	Y	Y	HEC-RAS	2025	Garver	Master Plan	New	New modeling based on new topographic data and survey.
Trib B to Bishop Creek	2	Y	Y	HEC-RAS	2025	Garver	Master Plan	New	New modeling based on new topographic data and survey.
Trib C to Bishop Creek	2	Y	Y	HEC-RAS	2025	Garver	Master Plan	New	New modeling based on new topographic data and survey.
Brookhaven Creek	½	Y	Y	HEC-RAS	2017	Meshek		CoN	Updated models in 2017 by Meshek under OWRB's CTP contract
Trib A to Brookhaven Creek	2	N	N	HEC-RAS					Converted from HEC-2 (Clour) to HEC-RAS (Guernsey), probably without modification. Junctions modeled improperly.
Trib B to Brookhaven Creek	2	N	N	HEC-RAS					Converted from HEC-2 (Clour) to HEC-RAS (Guernsey), probably without modification. Junctions modeled imporperly.
Imhoff Creek	2	Y	Y	HEC-RAS	2015	Meshek		CoN	Updated models by Meshek for the Lower Imhoff Creek H&H Study Project
Merkle Creek	½	Y	Y	HEC-RAS	2025	Garver	Master Plan	New	New modeling based on new topographic data and survey.
Little River	1			HEC-RAS	2008	PBS&J	Master Plan	CoN	New modeling based on new topographic data and survey.
Woodcrest Creek	1			HEC-RAS	2008	PBS&J	Master Plan	CoN	New modeling based on new topographic data and survey.
Tributary G	1			HEC-RAS	2008	PBS&J	Master Plan	CoN	New modeling based on new topographic data and survey.
Rock Creek	1			HEC-RAS	2008	PBS&J	Master Plan	CoN	New modeling based on new topographic data and survey.
Dave Blue Creek	1			HEC-RAS	2008	PBS&J	Master Plan	CoN	New modeling based on new topographic data and survey.
Tributary to Dave Blue Creek	1			HEC-RAS	2008	PBS&J	Master Plan	CoN	New modeling based on new topographic data and survey.

4.2.1.1 Field Reconnaissance

Field reconnaissance was performed for each of the Level 1 and 2 study streams. This reconnaissance included walking of almost the entire lengths of the urban streams; limited creek walks and visits to key locations in the more rural areas; and photographs of structures, typical channels (for n-value determinations and erosion assessment) and other key features. The notes and photographs from this effort were used to facilitate the modeling of structures and the assignment of n-values in the hydraulic models.

4.2.1.2 Field Survey

Detailed field survey was performed at a number of stream crossings and other key structures for the Level 1 streams. This includes the small segments of Level 1 study at the downstream ends of Merkle Creek, Brookhaven Creek and on Brookhaven Creek Tributary A. Table 4-11 provides a summary of the stream crossings surveyed for each Level 1 study reach.

Table 4-11: Detailed Survey for Level 1 Streams

Level 1 Stream	Number of Surveyed Crossings
Brookhaven Creek (Downstream End)	2
Brookhaven Creek Tributary A	1
Dave Blue Creek	2
Dave Blue Creek Tributary 1	1
Dave Blue Creek Tributary 2	1
Dave Blue Creek Tributary 3	1
Little River	12
Little River Tributary G	5
Merkle Creek (Downstream End)	2
Rock Creek	4
Rock Creek Tributary A	1
Rock Creek Tributary B	1
Rock Creek Tributary C	2
Woodcrest Creek	4

4.2.1.3 Datum Adjustment

The vertical datum used for the elevation information in the models was a key consideration in the study. The vertical datum used in the hydraulic modeling for the City of Norman prior to this master plan and the recent countywide FIS study was the National Geodetic Vertical Datum (NGVD) of 1929. The floodplains defined for the countywide study were adjusted to the North American Vertical Datum (NAVD) of 1988. All new survey data and modeling for the master plan was developed on the NAVD88 datum. In order to ensure consistency between all models, the hydraulic models provided by the City and used as the basis for modeling of the Level 2 streams was adjusted to the NAVD88 datum. This adjustment is relatively easy to make directly in the HEC-RAS model. A conversion factor of 0.369 ft (NGVD29 to NAVD88) was added to all elements in the Level 2 hydraulic models. This correction is consistent with the adjustment made in the countywide FIS study.

4.2.1.4 Determination of Flow Change Locations

The key interaction point between the hydrologic and hydraulic models for a watershed is at the flow change locations selected for the HEC-RAS model. It is at these points that the flows generated by the hydrologic model are input into the hydraulic model. For the existing Level 2 models, these flow changes were checked and general not modified. The flow change locations for Imhoff Creek are the one exception to this. They were found to be overly conservative and were modified to produce a more reasonable representation of the flows in the upper half of the hydraulic model. For the Level 1 models, the flow change locations were determined based on an overlay of the hydraulic model cross sections on the subbasin and stream network delineations for the hydrologic model. In the case of tributary confluences at the mouths of subbasins, the corresponding flow was input at the next downstream cross section (occasionally a section or two upstream if the main stem and tributary near the confluence was modeled with a single, wide cross section). For flow changes that resulted from the inflows of subbasins contributing directly to the modeled stream, the flow change was generally located between one third and one half of the distance along the modeled stream within the subbasin. This location varied depending on the location of the majority of the inflow within the subbasin.

4.2.1.5 Level 1 Streams

Hydraulic models for Level 1 streams were initially developed with the HEC-GeoRAS application and then modified to incorporate structures, ineffective flow areas, blocked obstructions, expansion and contraction coefficients, final roughness coefficients, flow change locations and boundary conditions. The 2007 aerial topographic data for the City of Norman was used to develop the basic geometry of the model cross sections. This information was augmented by survey data at structures and other key locations. The extent of hydraulic modeling for Level 1 Streams is shown in Exhibit 4-1. The existing and future/full buildout condition profiles for the Level 1 hydraulic models are shown in Appendix J.

Brookhaven Creek (Downstream End)

The segment of the main stem of Brookhaven Creek between Main Street and Willow Grove Drive was restudied as part of the master plan. This section of the existing model (refer to section 4.2.1.6.2 for a discussion of the existing Brookhaven model) did not adequately represent the flooding issues along Brookhaven Creek in this reach. The existing cross sections were relatively narrow and did not properly represent the overflows that are predicted to occur in the larger design events. These cross sections were replaced with new, extended sections based on the 2007 topographic data collected for the City. These new cross sections were extended much farther on both the right and left overbanks (looking downstream) so that overflows from the main channel could be properly represented.

Based on the revised modeling, flooding in this reach was found to occur primarily in the right overbank. Flows begin to escape the channel at Main Street and flow toward the wide, relatively flat area in the right overbank. The left bank at Main Street and for a few hundred feet downstream of Main Street is considerably higher than the right bank, which prevents overflows along the left overbank immediately downstream of Main Street. The bulk of the overflows occur in this area just downstream of Main Street. This water flows to the west, into the lower-lying flat area and then south along a smaller ditch until it intersects the channel that flows along the northern limit of the Canadian floodplain and confluences with Brookhaven Creek just upstream of Willow Grove Drive. The floodplains in this area can be seen on Exhibits 4-2 through 4-4 in Appendix H. The spillage into the right overbank reduces the flow and water surface in the main channel sufficiently that the left overbank along the reach is not overtopped.

Dave Blue Creek

Two streams were modeled in the Dave Blue Creek watershed. The main stem of Dave Blue Creek was modeled from 60th Avenue SE to just downstream of Post Oak Road. The model includes the crossings at 60th Avenue SE, 48th Avenue SE, and Cedar Lane. The crossing at 48th Avenue East was modeled as a multiple opening structure with the flows from the tributary immediately to the north contributing at the multiple opening. Tributary A to Dave Blue Creek was modeled from the confluence with Dave Blue Creek (approximately 1,000 ft upstream of 60th Avenue) to approximately 500 ft upstream of State Highway 9 (SH 9). The tributary model included a single culvert crossing at SH 9.

Dave Blue Creek - Tributaries

Tributary 1 to Dave Blue Creek, which flows to the east just south of Lindsey Street, was included in the HEC-RAS project for the overall Dave Blue Creek watershed. Tributary 1 was modeled from a point approximately 2,400 ft downstream of 48th Avenue (at the confluence with another tributary that flows west to east on the north side of Lindsey) to a point approximately 3,300 ft upstream of Cedar Lane. The model included a single culvert crossing at 48th Avenue. The model was not extended to the confluence with the main stem and is not directly connected to the main stem and tributary network in the HEC-RAS geometry for the watershed.

Little River

Little River and its tributaries effectively dominate the northern portion of the City of Norman from the boundary of the Ten Mile Flat Creek to the west to approximately 96th Avenue in the east. The main stem of Little River was modeled in detail from a point approximately 2,400 ft downstream of 48th Avenue NE to approximately 1,900 ft upstream of IH 35. The model included 12 stream crossings, 10 of which were modeled as bridges. Survey data was used to develop the information required to model these structures. The 13.8-mile length of Little River included in the study was modeled with 103 cross sections with an average spacing of just over 700 ft.

Tributary G to Little River

Tributary G flows from west to east into Little River approximately 2,700 ft upstream of 12th Avenue NW. The Tributary G watershed includes the developing areas along and to the west of the IH 35 corridor. The modeled portion of the stream extends from the confluence with Little River to a point just downstream of 36th Avenue NW. The model included 5 culvert crossings. The BNSF Railroad culvert crossing, which was the downstream-most modeled crossing, exerts a significant backwater impact for a considerable distance upstream. This is discussed in greater detail in Section 5.

Woodcrest Creek

Woodcrest Creek flows from south to north into the Little River approximately 2,100 ft downstream of Porter Avenue. The modeled portion of the stream extends from the confluence with Little River to a point approximately 2,700 ft upstream of Rock Creek Road. The Woodcrest model included four culvert crossings. The downstream-most of these crossings at an unnamed dirt road is a small, low-water crossing.

Merkle Creek (Downstream End)

The downstream end of the existing Merkle Creek model was extended from IH 35 to a point approximately 1,700 ft downstream of Lindsey Street. The extension included the culvert crossings at IH 35 and Lindsey Street. Cross sections for this reach were added based on the 2007 topographic data while the culverts were added based on survey data. The full Merkle Creek model is described in greater detail below in section 4.2.16.

Rock Creek

The main stem of Rock Creek and four tributary streams were modeling in the Rock Creek watershed. The main stem and tributaries were modeled in a single, networked HEC-RAS geometry file. The main stem model, which consists of five reaches, extended from approximately 1,000 ft downstream of 48th Avenue NE to a point approximately 2,000 ft upstream of the confluence with Tributary A. The upstream limit of study on the main stem is just downstream from a small dam. The main stem model includes three culvert and one bridge crossing.

The four modeled tributaries were spaced out along the length of the main stem. The most upstream tributary, Tributary A, flows into the main stem approximately 1,800 ft downstream of its crossing of Robinson Street. The Tributary A model reach extends from the confluence to just downstream of Robinson Street. There were no stream crossings modeled on Tributary A. The Tributary B model reach extends from the confluence with the main stem approximately 400 ft upstream of 36th Avenue NE to Silverado Way just downstream of a small dam. The reach does not include any stream crossings. The Tributary C model reach extends from the confluence with the main stem approximately 1,100 ft upstream of Robinson Street to the downstream face of Alameda Street (just downstream for a subdivision detention facility). The reach includes a bridge crossing at Ackerman Road and a culvert crossing at 36th Avenue NE. The Tributary D model reach, downstream-most of the four tributaries, extends from the confluence with the main stem approximately between the Robinson Street and 48th Avenue NE crossings on the main stem to the downstream face of Rock Creek Road. The reach includes no modeled stream crossings.

4.2.1.6 Level 2 Streams

The hydraulic models for the Level 2 streams were adapted from existing hydraulic models for the watersheds. A majority of these models, as indicated in Table 4-10, were HEC-RAS models. However, the Brookhaven Creek and Merkle Creek models were HEC-2 models. These HEC-2 models were converted to HEC-RAS with the modeling of structures updated as necessary in order to make the models compatible with and accurate in HEC-RAS. All final Level 2 hydraulic models for the master plan were updated and run with HEC-RAS version 3.1.3. The extent of hydraulic modeling for Level 2 Streams is shown in Exhibit 4-1. The existing and future/full buildout condition profiles for the Level 2 hydraulic models are shown in Appendix J.

Bishop Creek and Tributaries A, B, and C

The Bishop Creek HEC-RAS model used for the master plan was based on a 1997 HEC-RAS model provided by City Staff. The HEC-RAS models for Tributaries B and C were also derived from the 1997 study. Presumably, these models were developed as part of the Mansur-Daubert-Strella Engineers study that produced the 1996 HEC-1 model for the watershed. However, documentation was not available to confirm this. The report and associated documentation for the Mansur-Daubert-Strella Engineers study was not available for review during the preparation of the master plan. The HEC-RAS model for Tributary A to Bishop Creek was derived from a pair of LOMRs for the stream. A LOMR in 2003 updated the lower portion of the stream, while a 2004 LOMR updated the upper portion of the stream.

The HEC-RAS model for the main stem of Bishop Creek extends from a point approximately 5,700 ft downstream of SH 9 (approximately at the edge of the Canadian River floodplain) to approximately 600 ft upstream of Cockrell Street. The model includes a total of 14 stream crossings, one of which (Constitution) is a multiple opening structure.

The model for Tributary A to Bishop Creek model extends from a point approximately 550 ft downstream of the BNSF railroad crossing to approximately 260 ft upstream of Sinclair Street. The actual confluence with the main stem of Bishop Creek is just downstream of Constitution. However, the Constitution crossing of Tributary A is modeled as part of the multiple-opening structure in the main stem model. The Tributary B model extends from the confluence with the main stem approximately 380 ft downstream of Alameda Street to just downstream of Main Street. The model includes a single stream crossing at Alameda Street. The Tributary C model extends from the confluence with the main stem approximately to just downstream of the BNSF Railroad. The model includes four stream crossings, one of which crosses the series of ponds on the east side of the University of Oklahoma campus just upstream of Lindsey Street.

Brookhaven Creek

The Brookhaven Creek HEC-RAS model used for the master plan was based on the 2007 HEC-RAS model developed by C.H. Guernsey for the design of the 36th Avenue NW bridge. The Guernsey model was based on the 1993 LOMR model developed by Clour, which was in turn based on the 1979 FIS study with the incorporation of LOMCs and the correction of stream lengths. The Clour model provided information for the portion of Brookhaven Creek upstream of Robinson Street. The Guernsey study extended the model from Robinson Street downstream to Willow Grove Drive. The portion of the Brookhaven Creek main stem downstream of Main Street was restudied as part of the master plan. This segment of the HEC-RAS model was replaced with new cross sections cut from the 2007 topographic data for the City along with new survey data for the two crossings in this reach. Details of this update and the complex nature of the flooding in this area are provided in the Level 1 section above.

The Guernsey and Clour models directly incorporated Tributaries A and B into the main stem model for Brookhaven Creek. The contributing drainage areas for the tributaries and main stem at their respective confluences are comparable, so the assumption of coincident peaking required by their inclusion was not unreasonable. However, the tributaries were incorporated by Guernsey exactly as they were represented in the Clour HEC-2 model. As a result, the HEC-RAS model included a repeated main channel section for each of the tributaries. This resulted in reach lengths and lengths across the two junctions that are not completely accurate and geometry at the downstream end of each tributary that is not fully representative of the tributary stream. This issue should not have a significant impact on the water surface elevations in the stream and, as a result of the desire to directly incorporate the existing models, was not corrected.

The HEC-RAS model for the main stem of Brookhaven Creek extends from just downstream of Willow Grove Drive (effectively to the Canadian River floodplain) to its upstream limit just upstream of Rock Creek Road. The modeled reach for Tributary A to Brookhaven Creek extends from the confluence with the main stem (approximately 460 ft downstream of Pendleton Drive on the tributary) to just upstream of Rock Creek Road. The modeled reach for Tributary B extends from the confluence with the main stem (approximately 940 ft downstream of Rock Creek Road along the main stem) to the downstream face of the south-bound Interstate 35 frontage road. The model includes a total of 7 stream crossings on the main stem, two on Tributary A and none on Tributary B.

Imhoff Creek

The Imhoff Creek HEC-RAS model used for the master plan was based on a combination of two LOMR models. The 1997 Baldischwiler Engineering Consultants LOMR model, which included the full modeled length of the stream was combined with the 2001 Baldischwiler LOMR model for the portion of the creek between Whispering Pines and Lindsey Street. This truncated model represented the improvements associated with the trapezoidal articulated block channel constructed in this reach.

Once combined, the model was reviewed based on site visit photographs, the new 2007 topographic data and the general modeling procedures used. A number of issues were identified and corrected as a result of this review. A summary of the identified issues is provided below. These issues are more fully documented in the memorandum in Appendix F:

- The downstream boundary condition was switched from a known water surface to normal depth.
- The overbank Manning's roughness coefficients were generally too low in the overbanks and in the natural portions of the main channel and were increased.
- The HEC-1 flow input locations in the HEC-RAS model were overly conservative and were revised.
- The distances and cross section geometries in the vicinity of the school footbridge downstream of Main Street, along with the length of the Main Street culverts and immediately adjacent alley were corrected.
- Forced water surface elevations at cross section 11840 and unnecessary ineffective area settings upstream of Lindsey Street were removed.

- The culvert models were modified so that the model no longer forced the selection of inlet control and the roadway weir coefficients for culverts and bridges was changed from 1.0 to 2.6.

These and other minor changes resulted in a general increase in the water surface elevation along the majority of the modeled length of Imhoff Creek.

In addition to the changes described above, the portion of the model downstream of Imhoff Road was replaced based on the new 2007 topographic data. The SH 9 culvert crossing in this reach was adapted from the original model. The occurrence of flooding during large design events in the subdivision on the left bank (looking downstream) between Imhoff Road and SH 9 necessitated the re-visitation of this portion of the model. The original cross section location and geometries were not adequate to clearly determine the nature and extent of the flooding in this area. These flooding issues and the proposed solutions to address them are discussed in Sections 5 and 6.

Merkle Creek

The Merkle Creek HEC-RAS model used for the master plan was based on a series of LOMR models, the latest of which was the 1996 LOMR by Baldischwiler Engineering Company. This LOMR model was based on a 1995 LOMR model prepared by JWB engineers for Clour. The JWB model was based in-turn on thee 1994 LOMR model prepared by Clour. The 1995 LOMR modified the original Clour model to include improvements at 24th Avenue SW and Robinson Street, channel improvements in the reach between 24th Avenue SW and Main Street and updated topographic data. The 1996 LOMR included an additional 450 ft of channel modifications upstream of Main Street, a new culvert at Crestmont and correction of the low chord at Main Street. The 1996 LOMR HEC-2 model was converted to HEC-RAS version 3.1.3 for us in the master plan.

The converted model was reviewed based on site visit photos, aerials and the new 2007 topographic data. As a result of this review a couple of minor modifications were made to the model, primarily to facilitate the evaluation of solutions. The modifications included additional cross sections downstream of 24th Avenue SW to better define the shape and extent of the concrete lined channel and upstream of Crestmont Street where the 2007 topography indicated that a hump in the channel represented in the model was not actually present. In addition to these minor modifications, the downstream end of the Merkle Creek model was extended from IH 35 to a point approximately 1,700 ft downstream of Lindsey Street. The downstream extension of the model is described in more detail in Section 4.2.1.5. The extended Merkle Creek model included six culvert and 1 bridge crossing.

Ten Mile Flat Creek

The Ten Mile Flat Creek hydraulic model used for the master plan was adapted from the HEC-RAS model developed for the 2005 MacArthur Associated Consultants study of Ten Mile Flat Creek in support of a CLOMR for the watershed. This model extends from approximately 500 ft downstream of the Main Street crossing to a point approximately 4,900 ft upstream of the Franklin Road crossing. The Ten Mile Flat Creek floodplain is quite wide and flat as its name implies. Much of the area is dominated by the Canadian River floodplain. However, there are wide portions of the Ten Mile Flat Creek floodplain proper and fairly complex overflow situations that occur at various places along the length of the stream. Significant reaches of the stream have been straightened and channelized.

The Ten Mile Flat Creek model includes a main channel with six stream crossings and two overflow/bypass channels with one stream crossing each. The main stem crossings at 60th Avenue NW, Franklin Road, and Tecumseh Road were modeled as multiple openings. The northeast overflow channel roughly parallels the main stem for several hundred feet upstream and downstream of 60th Avenue NW. Prior to the reconstruction and elevation of 60th Avenue NW, this area was modeled with a lateral weir (60th Avenue NW) to pass overflows into the parallel channel. The improvements to 60th Avenue NW eliminate these overflows. The second overflow area occurs at 60th Avenue NW and Tecumseh Road. Flows that do not pass through the structure at 60th Avenue NW continue to flow south and overtop Tecumseh, which was modeled as a lateral weir. These overflows continue south along the west side of 60th Avenue NW until some of the flow overtops 60th and returns to the main channel between Rock Creek Road and Robinson Street. The remainder of the overflow enters the Canadian River floodplain.

4.2.2 Hydraulic Modeling for Level 3 and 4 Streams

The hydraulic modeling for Level 3 and 4 streams was performed with the Rapid Floodplain Delineation (RFD) tool that was initially described in Section 4.1.2.1. The RFD tool provided the ability to rapidly generate floodplains for the over 300 miles of Level 3 and 4 streams with a minimal amount of initial input data.

4.2.2.1 RFD Inputs and Outputs

The RFD tool required the following inputs:

1. A short configure file specifying input parameters.
2. The ground surface as gridfloat raster which was generated from the 2007 topographic data as previously described.
3. A shapefile representing the stream centerline (e.g., hydraulic baseline).
4. A shapefile representing a set of cross-sections, attributed with Manning's n values and discharges. For the Level 3 and 4 streams the RFD option to automatically generate the cross-section locations based on the centerline and some parameters specified by the user was employed. The Q-grid also described above was used with the RFD tool to automate the attribution of flows to the generated cross sections.
5. (Optional) A shapefile which contains flow limits. These represent obstructions or ineffective flow areas. It is not required that any particular section have flow limits assigned to it.

Given these inputs, the RFD tool performs the following functions:

1. Creates a cross-section shapefile using the hydraulic baseline (if requested in the configuration file).
2. Projects (cuts) the cross-sections onto the topography and creates a hydraulic model.
3. Calculates water surface elevations by using a backwater analysis.
4. Creates a shapefile of the cross-sections with the calculated water surface elevations and other hydraulic parameters in the attribute table.
5. Creates elevation plots of the cross-sections as pages of a PDF.
6. Creates profile plots of the cross-sections as pages of a PDF.
7. Delineates a floodplain polygon as a shapefile which can be viewed using GIS software.

All these steps are performed sequentially in batch mode, without user intervention.

4.2.2.2 RFD Processing

For each generated cross-section, RFD extracts the raster elevations along the surface and generates station – elevation points for each cross-section. The downstream distance in feet to the next cross-section is obtained by calculating the difference in station between each cross-section and the next lower section.

In addition to cross sections, RFD allowed for the identification of stream crossings based on the intersection of the hydraulic base line and a road layer. An energy grade line drop of 1 ft was specified between bounding cross sections at each of these crossings in order to represent the impacts of structures on the water surface profile.

Once RFD has developed the required cross section information and associated the flows from the Q-grid, it performs a backwater calculation to determine the water surface elevations. RFD uses the 1-D energy equation to compute the water surface elevations. This is done using an iterative procedure, where the upstream water surface elevation is assumed, and the error in the energy equation is the calculated, then the water surface is refined until the error in the energy is reduced below a certain tolerance.

RFD uses the cross sections and associated water surface elevations in concert with the underlying topographic grids to calculate a depth grid for the stream. All values that have a positive depth are assigned the value 1 (inundated) while all other cells are assigned the value 0. This results in a "pixilated" grid representing a crude floodplain. RFD at this point interpolates a floodplain boundary between each pair of cells along the gridded floodplain boundary. This is essentially similar to a contouring algorithm.

The results have been compared to HEC-RAS + HEC-GeoRAS results both in terms of delineated floodplain and water surface elevation. The water surface elevations are generally within 0.1 ft of the HEC-RAS water surface elevations.

4.2.2.3 RFD Application for Level 3 and 4 Streams

The RDF tool was applied for each of the Level 3 and 4 streams identified in the City of Norman. A stream centerline or hydraulic baseline was established for each and the basic parameters for application of the RFD tool were set. The RFD tool was then run, and the steps described above followed for each stream. The resultant cross sections and floodplain polygons were reviewed for reasonableness and then the floodplains were combined to form a single stream planning corridor layer for the City. The stream planning corridor floodplains are shown on Exhibit 4-4.

4.2.3 Hydraulics for Local Drainage Issues

Several local drainage issues identified by City staff of citizen complaint were investigated as part of the master plan. In cases where a detailed hydraulic model was not available for such an area, alternative methodologies were used for the evaluation and recommendation of solutions. Undersized roadway crossings in these areas were evaluated and resized with the Haestad Culvert Master application. Flows for these analyses were derived from either the detailed hydrologic model when available or from the Q-grid developed for the RFD when detailed hydrologic models were not available.

In the case of issues related to closed systems or requiring such systems in order to address the identified problem, a full flow analysis of the system capacity was used. An example of such an analysis is the sizing of the diversion system to carry ponded flood water from the Lindsey and McGee area to the ditch along the IH 35 right-of-way. Flows for such analyses were derived from detailed hydrologic models where available and from the Rational method when otherwise necessary.

4.3 Hydrologic and Hydraulic Modeling for Solutions

The hydrologic and hydraulic models developed or adapted for the study watersheds as described in the preceding sections were the primary tools used for the evaluation of structural solutions for identified flooding issues. They were also used to define the parameters and constraints used in the development of solutions for erosion control and channel restoration. The specific problem areas identified and the solutions evaluated to address them are described in detail in Sections 5 and 6. The following subsections describe the general approach and methodologies used in the design and evaluation of the proposed solutions and the additional or specialized analyses required for specific solutions.

The proposed solutions were evaluated in a two-step process. A proposed solution would first be evaluated in isolation when possible. For some watersheds and study streams such as Imhoff Creek, it was not practical to evaluate all potential solutions by themselves due to the density of flooding issues. Once a potential solution was developed for the isolated issues along a study stream, they were combined so that their interactions could be evaluated. In some cases, such interactions necessitated revisions to the evaluated solutions. In many cases, a downstream improvement was first required in order to achieve the full desired benefit for an upstream solution impacted by backwater from the downstream issue. In the case of detention, it was necessary to evaluate the impacts of the proposed pond on other downstream solutions. The locations of the proposed solutions and the associated floodplain modifications for each study stream are shown on Exhibits 6-1 through 6-19 in Appendix H. These exhibits also include profile views to show the extent and impact of the improvements.

4.3.1 Hydrologic Modeling General Approach

The hydrologic modeling associated with the development of solutions focused on the evaluation of detention facilities and consideration of flow diversions. The hydrologic evaluation of potential detention solutions ranged from the relatively straight-forward adaptation of existing detention plans for the pond on Merkle Creek upstream of Robinson Street to a complex analysis of interconnected pond in the area of Andrews Park in the upper Imhoff Creek watershed. The general approach to such detention analysis proceeded as outlined below:

1. Flooding issues were identified within the subject watershed.
2. Properties with sufficient open space for detention facilities were identified.
3. The identified properties were evaluated to determine whether they could realistically be considered for purchase.
4. Potential detention areas were maximized for properties identified for further consideration.
5. Reasonable assumptions were made for the layout, depth, side slopes, and inflow and outflow structure locations and types.
6. Elevation-storage curves were developed for the evaluated facilities based on the assumptions made for the layout of the pond.
7. Inflow rating curves were developed in the case of facilities not directly in-line with their contributing storm drains.
8. Parameters for the ponds were entered into HEC-HMS and initial outlet structures were assumed.
9. Outflow structures (typically an orifice for low flow and weir for high flows) were optimized to maximize the potential flood control benefits.
10. The revised flows based on the presence of the detention facility were entered into the associated hydraulic model to evaluate the potential downstream benefits.

A majority of the detention facilities evaluated for the master plan were located in or near the headwaters of the study stream or portion of the watershed related to a specific local problem area. Such facilities were typically in-line ponds that directly accepted flow from a contributing drainage channel rather than off-line facilities connected to the drainage channel via a side weir along the bank of the channel. The detention facilities considered for the Imhoff Creek watershed are the most notable exception to the general procedure outlined above. The analyses for these facilities will be discussed in greater detail in the watershed-specific discussions below.

The consideration of diversion channels or closed systems was a more straight-forward process than that used for evaluation of detention options. The diversion systems were sized to either carry the maximum possible flow given the constraints on the potential system or a target flow based on the conditions in the channel from which the flow was to be diverted. A diversion rating curve was then developed based on the characteristics of the preliminary conceptual design for the diversion. The size of the diversion system and the characteristics of the diversion rating curve were then optimized through HEC-HMS runs to achieve the target flow or the maximum potential benefit.

4.3.2 Hydraulic Modeling General Approach

Solutions evaluated with the hydraulic models developed or adapted for the master plan were generally of three types. The most common was the evaluation and sizing of enlarged stream crossings. The second was the evaluation of enlarged channel sections to provide additional flow capacity. The third and simplest was the evaluation of the impacts of the reduced flows provided by the various detention options.

As discussed subsequently in Section 5, each study watershed has at least one existing undersized stream crossing. These inundated crossings were first identified with the hydraulic models and then resized to accommodate the requisite design flows per the City's drainage criteria (culvert to pass the 50-year flow and bridges to pass the 100-year flow with 1 ft of freeboard). In some cases, it was not possible or practical to achieve the full criteria requirements. In these cases, culvert designs were typically reduced to the 10-year event and bridge designs reduced to the 50-year event. This is especially true for Imhoff Creek where the density of stream crossings and limited width available for improvements limits the target design event. Where possible, crossings were first resized in isolation from other improvements and then integrated to evaluate the interactions of improvements and to optimize the designs. In many cases, downstream improvements were necessary in order to be able to achieve the design goals for an upstream structure.

A majority of the structures for which solutions were proposed were culverts. When practical, the proposed solution preserved the existing barrels and added one or more parallel barrels. In many cases this was not possible and the entire structure was proposed to be replaced. The initial culvert sizing for proposed solutions was based on the required capacity to pass the design flow. The design was then optimized to allow for downstream backwater or other conditions and to achieve the target design criteria. In some cases, bridges were proposed to replace culverts. These proposed bridges and other pure bridge enlargements were evaluated with an approach similar to that applied for culverts.

Channel modifications were proposed in a number of areas to both reduce flooding directly and to improve downstream backwater conditions so that reasonable designs for stream crossings could be achieved. The proposed channel modifications generally used a typical section that provided a more natural channel appearance than existing channel modifications. In some cases, such as along Imhoff Creek, these natural channel sections would be more difficult to achieve but remain an alternative to consider during preliminary design engineering for such improvements. However, retaining the WPA channel type appears to be the preferred design choice given the space limitations and the historic nature of this design type. The design considerations for such channel modifications are discussed in greater detail in Section 6.

Channel modifications were optimized to the extent practical in order to minimize the required improvement footprint. The modifications were typically developed in HEC-RAS with the channel modification option. An initial improvement layout was determined based on the availability of right-of-way and an estimate of the required capacity. Iterations of the improvement size were then made until the design criteria were achieved. In the case of limited channel modifications required downstream of structures, the modifications to the channel geometry were made directly for the impacted cross sections.

4.3.3 Specific Modeling Considerations for Study Watersheds

Alternative analyses beyond the general methodologies outlined above were required in order to evaluate certain solutions. There were also special considerations involved in the standard approach for specific solutions. Such exceptions and special considerations are described in the following subsections. The discussions are organized by major study watershed.

4.3.3.1 Imhoff Creek

The solutions developed for the Imhoff Creek watershed required the most extensive analyses of any of the study watersheds. The density of stream crossings and associated flooding issues effectively required the proposed improvements for a majority of the stream to be evaluated as a single, interconnected solution. This solution integrated detention in and near Andrews Park, extensive channel modifications from downstream of Lindsey Street to James Garner Avenue and diversion of flows from the vicinity of the Lindsey and McGee intersection in the west central portion of the Imhoff Creek watershed. Once the comprehensive solution was developed, it was divided into logical, smaller increments as described in Section 6.

Detention Analysis

The most complex analysis was associated with the conceptual design for detention at Andrews Park. The final configuration of the Andrews Park detention and the alternative detention upstream of Acres Street was modeled in HEC-1. However, the configuration was optimized based on a Surface Water Management Model (SWMM) developed specifically for the design of the detention facility and associated flow diversions. The EPA SWMM 5 model was used to perform this analysis. The SWMM model was constructed with three storage areas for the base solution. These consisted of detention in Andrews Park proper (2 storage areas) and in the triangular area bounded by Webster Avenue, Park Avenue and Imhoff Creek. A fourth storage area was added for the simulation of the proposed detention upstream of Acres Street.

The use of the SWMM model allowed for direct representations of the inflow diversions, connections between ponds and outflow structures. The primary inflow to the facility was a diversion from the Imhoff Creek channel near the intersection of Beal Road and Jones Avenue. Three reinforced concrete pipes carried flow from the Imhoff channel, under the railroad and James Garner Avenue to flow into in the Andrews Park detention facility. This inflow occurred at the location of the existing concrete water tank, which would be removed as part of the proposed improvement. Inflows also entered the facility from the drainage area and existing channel to the north of Andrews Park. The portion of the park to the east of the existing drainage channel (including the removed concrete tank) was simulated a one storage area with a weir connecting this storage area to the primary portion of the Andrews Park detention to the west of the existing channel. Low flows into the first storage area were allowed to pass through an outlet structure along the alignment of the existing channel. High flow passed over the weir into the primary detention area. From this area, flows passed through a reinforced concrete pipe outfall into the triangle area detention component. From the triangle, flow discharge directly to the main channel through either a reinforced concrete pipe or via an overflow weir.

Once the geometry for the detention facility was established, the inlet and outlet structures were optimized to provide significant flow reductions while not overtopping the facility. The flows used to drive the SWMM model were adapted from the hydrographs produced by the HEC-1 model for the watershed. The output from the SWMM model was used to develop diversion and outflow rating curves for the facility that could be used in the HEC-1 model. The final geometry and rating curves were then entered into the HEC-1 model for the generation of the reduced flows for the solution. These reduced flows were then considered in the designs for the downstream channel and stream crossing improvements.

Channel and Stream Crossing Improvements

Much of the Imhoff Creek channel, especially in the Work Projects Administration (WPA)-constructed reaches, is considerably undersized. The rectangular channel either constructed by the WPA or constructed to roughly match the WPA channel begins just downstream of Boyd Street and extends to the upstream limit of the study at the BNSF Railroad crossing. The existing concrete v-shaped channel between the upstream end of the articulated block lining (approximately 1,250 ft downstream of Lindsey Street) and the beginning of the WPA-style channel is undersized to a lesser degree. The flooding issues at the lower end of this reach (downstream of Lindsey) are in large part caused by the constricted overbanks in the area. The stream crossings in both reaches are correspondingly undersized for the required design events. There are a total of 21 stream crossings of Imhoff Creek. Enlarged solution designs were developed for 16 of these crossings. The channel and crossing solutions were developed under the assumption of reduced flows as a result of the proposed Andrews Park detention (without the portion above Acres Street). The solutions were then checked against unreduced flows. In order to fully accommodate the unreduced flows and still achieve the design targets, additional enlargement and optimization would be required for some of the crossings and stream reaches. The various flooding issues and solutions related to the channel and crossings are described in greater detail in sections 5 and 6.

An iterative approach was used to develop the flood control solutions for the channel reaches and associated crossings described above. The target design solution, as agreed upon with the City, focused primarily on the 10-year event for a majority of the channel and crossings. Exceptions to this were the solutions for the Lindsey Street and Main Street crossings, which were sized to accommodate the 100-year event, and the Boyd Street crossing, which was sized to accommodate the 50-year event. The first step in the modeling of the proposed solutions was to establish an upper limit for the sizes of the stream crossings. These were determined based on the assumption of full flow through a corresponding set of box culverts. Culvert and bridge crossings are typically more efficient than a simple assumption of full flow in a culvert, so the final solutions tended to be considerably smaller than these maximums. The maximum opening sizes also provided an estimate of the maximum channel width that could be required from a hydraulic perspective. The available land along the length of the channel to be improved and the desire to minimize the required width resulted in channels that were considerably smaller than the maximum sizes.

Once the maximum potential sizes were determined, an initial approximation of the required width of the channel modifications and the width (bridge) or number of barrels (culverts) was made. The width assumed for the channel and bridge modifications was increased with each significant addition of flow from the hydrologic model. The cut widths and the variables required to properly align the channel cuts were developed in a spreadsheet and then transferred to the HEC-RAS channel modification table in order to develop a revised set of channel geometry. Culverts and bridges were then sized to match the modified channel. This process was repeated several times until a channel modification solution that met the 10-year design target was generally achieved. The culverts and bridges and associated segments of channel were then optimized to meet higher design goals specified for Lindsey, Boyd, and Main streets.

West Central Imhoff Creek Watershed Improvements (Lindsey and McGee Diversion)

The flooding issues in and around the Lindsey and McGee intersection and the area between this intersection along Lindsey Street to Imhoff Creek are well known and have been documented and evaluated through a number of studies. The solutions developed for the master plan considered some new approaches that either built on previous studies or introduced new solution concepts. The evaluated solutions included detention and associated flow diversions in selected locations and a diversion directly to the Canadian River. The details of the issues and proposed solutions are discussed in sections 5 and 6.

The primary solution proposed in this master plan for the flooding in the area of the Lindsey and McGee intersection is a large diversion system and associated storm drainage improvements that would carry the bulk of the flow at the intersection directly to the Canadian River. The closed-system diversion would run west along Lindsey Street to Murphy, south along Murphy to Briggs, west along Briggs to the IH 35 right-of-way and outfall to the IH 35 drainage ditch near the junction of the SH 9 ramp with the north-bound IH 35 main lanes. The solutions also included enlargements of the roadside ditch and an additional culvert under SH 9. In addition to the diversion, a modified version of the Phase C storm drainage system described by Baldischwiler (1997) was proposed to carry the flows from north of Lindsey Street and east of McGee Drive to Imhoff Creek.

In order to model the solutions, it was necessary to modify the HEC-1 model so that flows to the various portions of the proposed system could be directly considered. Subbasin I-10A in the original HEC-1 model was subdivided into four smaller subbasins. Three of these subbasins (roughly the portion of I-10A west of Wylie Road) drained to the diversion system while the fourth drained to the proposed Wylie/Lindsey system improvements that drain directly to Imhoff Creek at Lindsey Street. The subdivision of subbasin I-10A also was configured to allow for consideration of detention at Whittier Middle School. Detention at the school was modeled in the HEC-1 model based on a rough determination of the available volume. However, this option was not recommended in the final set of solutions. The proposed diversion was modeled in the HEC-1 model and the resultant decreases in the Imhoff Creek main channel flows were evaluated in the development of solutions for the channel.

The proposed sizes for the diversion system were based on the consideration of full flow in the proposed box culverts for a 10-year flood event. The allowable slopes for the various segments of the proposed system were effectively set by the elevation at the outfall of the system, which allowed for a maximum 0.3% composite slope for the total length of the system. The sizes for the proposed systems along McGee Drive north of Lindsey Street (draining to the diversion) and along Wylie Road and Lindsey Street (draining to Imhoff Creek) were initially based on the sizes proposed in the Baldischwiler (1997) report. The sizes were then checked based on the HEC-1 flows and modified as necessary.

4.3.3.2 Merkle Creek

The hydrologic and hydraulic modeling of the solutions for Merkle Creek included the modeling of a large detention facility currently under construction upstream of Robinson and a set of interdependent channel and crossing modifications. A large detention facility has recently been constructed in the area between the airport and

Robinson Street in the upper portion of the Merkle Creek watershed. Since the pond was not complete at the time of the master plan, it was modeled under the solutions rather than as part of the existing conditions. This pond significantly enlarges the existing pond at the site and takes in considerable additional area adjacent to Robinson Street. The two small ponds adjacent to the airport were not modified. The existing pond and two associated routing reaches in the HEC-1 model were replaced with the new enlarged pond. The storage-area-elevation curves and outlet structure parameters for the pond were obtained from the PondPack modeling used in the design of the facility (SMC Consulting Engineers, 2006). The impact of the pond is discussed in greater detail in Section 6.

The other complication to the solution model for Merkle Creek was the interdependency of the flood control solutions for the Main Street, Crestmont Street, and Iowa Street crossings. Both the Crestmont Street and Iowa Street culvert crossings were heavily impacted by the backwater conditions caused by Main Street. Without the proposed Main Street improvements, the Crestmont and Iowa improvements were found to be cost prohibitive if not completely unfeasible. In addition to the Main Street improvements, channel modifications between Main Street and Crestmont Street were also required in order to develop a reasonable solution at Crestmont. These improvements were modeled both individually and together with the HEC-RAS model in order to develop the final solution recommendations.

4.4 Floodplain Mapping

Floodplain mapping was an essential component for the identification of flooding issues and the quantification of the benefits provided by the various solutions proposed in this master plan. For Level 1 and 2 streams the 100-year and 500-year floodplains were delineated for existing conditions while the 10-year and 100-year floodplains were delineated for the future or full-buildout conditions. These floodplains are shown in Exhibits 4-2 and 4-3 in Appendix E. The stream planning corridor floodplains developed with the RFD tool for Level 3 and 4 streams are shown in Exhibit 4-4 in Appendix E. The floodplain modifications produced by the various proposed solutions are shown on Exhibits 6-1 through 6-19 in Appendix H. The following sections describe the procedures used to map the floodplains for the various study streams.

2025 Update: As part of the 2025 SWMP update, floodplain mapping was updated with the most recent LiDAR topography for Dave Blue Creek, Woodcrest Creek, Rock Creek, and Little River. This updated floodplain mapping is not sufficient to be submitted as a FEMA map revision, as the models require additional current conditions survey data at crossing structures.

4.4.1 Level 1 Streams

HEC-GeoRAS was the primary tool used to delineate the floodplains for the Level 1 and 2 streams. HEC-GeoRAS allowed for the direct import of the modeling results from the fully geo-referenced Level 1 streams and automated the subsequent generation of floodplains based on the modeled water surface elevations. The floodplains generated by HEC-GeoRAS were smoothed to eliminate the stair-stepped floodplain boundary created by the use of a grid-based elevation dataset. The floodplains were then revised manually to reduce small “islands” inside (dry) and outside (inundated) of the primary floodplain boundary. Any areas cut-off by the bounding polygon generated by HEC-GeoRAS from the cross section extents were fixed and any extraneous artifact “appendages” to the floodplain were removed.

4.4.2 Level 2 Streams

A more manual process was required to generate the floodplains for the Level 2 streams. Geo-referenced cross sections were not readily available for the existing models for these streams. Work maps showing the cross section locations were available for the Ten Mile Flat Creek watershed, but not for any of the other Level 2 watersheds. The lettered cross sections from the FEMA data layers were the only know cross section locations for these streams. These cross sections, augmented by additional cross sections added upstream and downstream of structures and at other key, identifiable locations were used as the base layer for delineation of the Level 2 floodplains.

Once the cross section layer was established for a Level 2 stream, the floodplain delineation process was essentially a manual version of the process employed by HEC-GeoRAS. The simulated water surface elevations were added to the cross section layer as attribute fields. A script linking a series of ArcGIS tools was then used to develop a water surface TIN, convert the TIN to a grid, intersect the water surface grid with the topography grid, determine inundated grid cells, generate floodplain polygons and smooth the resultant floodplain polygons. Once the raw floodplain polygon was generated, the same procedure employed for the Level 1 streams was used to clean the floodplains.

4.4.3 Level 3 and 4 Streams

The floodplain mapping for Level 3 and 4 streams was performed with the RFD tool as described in Section 4.2.2.

5.0 Stormwater Problems

2025 Stormwater Problems Updates

The AIM Norman process provided an opportunity to reevaluate the list of stormwater problems that were identified during the 2009 SWMP process. This includes removing problems from the list that have been addressed. There is one problem area that was included in the 2025 list that was not included in the 2009 list of problems. That is TMF-101, or "Ten Mile Flat 101". This TMF-101 problem location is otherwise known as "Midway Drive" and has been studied through a flood mitigation study in 2023 due to repetitive flooding damages in this area.

This is not a comprehensive list of problems in the City, and more problem areas may be added to the list of concerns. Section 6.0 (Stormwater Solutions) includes the solutions that were developed for each problem area. To improve readability of this SWMP document, the graphics of the proposed problems and solutions have been removed from the overall document and placed in an Appendix. The AIM Norman process has also added one-page descriptions of each problem area, called "Business Case Evaluations (BCEs)" that present the basic elements of each problem and proposed solution, along with the anticipated cost of the solution as discussed in Section 6.0. Additionally, a GIS layer with all of the problem locations has been provided to the City for future reference. This GIS layer includes the physical location of the problem area, and the additional information included in the BCEs. This information will help the City Public Works staff coordinate these projects with other significant City projects such as transportation, utilities, and parks projects.

Original 2009 Stormwater Problems Introduction

A key component in completing the SWMP was the identification of stormwater related problems within the City. Similar to municipalities throughout the country, Norman is experiencing a variety of challenges and problems associated with stormwater that is generated within its jurisdictional limits in addition to stormwater it receives from neighboring cities and unincorporated areas. For this City-wide undertaking, these problems are generally grouped into stream flooding, stream erosion, water quality, and local drainage to assist in understanding and evaluating their respective nature. A few of the problems or problem areas have more than one characterization type. For instance, there are some problem areas that have flooding and stream erosion issues. The identification of problems was primarily accomplished by a variety of means including reviewing and evaluating items such as: the City's GIS data, past water quality studies, past hydrologic and hydraulic modeling, and other information and data collected (Section 2); watershed assessments including field reconnaissance trips (Section 3); hydrologic, hydraulic, and floodplain mapping efforts (Section 4); the City staff knowledge of past problems; input obtained from the various committees and the SWMP Task Force; and input received from the general public as provided through the City staff.

A watershed-specific approach in identifying problems was followed as the nature of stormwater problems relate directly to the characteristics and activities occurring, or expected to occur, in the watersheds in which the problems are located. As discussed subsequently in Section 6, solutions were developed considering that the potential exists to positively or negatively affect other locations within that respective watershed. In order to focus on the more critical areas and respect budget limitations, the level of study and analysis varied throughout the City as discussed in Section 2. To recap previous discussions herein, stormwater analyses were analyzed in more detail for Level 1 and Level 2 stream reaches in comparison to Level 3 and Level 4 reaches. Further, differing study levels within watersheds focused efforts and study detail on those areas experiencing, or expected to experience, the worst problems.

The identification and evaluation of problems were performed for existing and future watershed conditions. Although existing conditions were reviewed and considered, the identification and evaluation of flooding along major streams primarily focused on future watershed conditions that reflect the City's 2025 Plan. The identification of stream erosion problems was primarily based on existing conditions consistent with the watershed assessments.

Due to their "non-point source" nature, water quality problems were evaluated on a citywide scale similar to what has been done in many similar studies conducted throughout the country. The extent of water quality problems

focused on urbanized areas with some distinction being made between the areas that drain directly into the Canadian River versus those that drain into Lake Thunderbird, the City's drinking water source.

5.1 Summary of Problems

Fifty-nine flood-related and stream erosion problems were identified within the City from many investigations and evaluations performed. The problem locations are spread over a large part of the City, but all are located along, or west of 48th Avenue East. Each problem (and matching solution), also referred to as a "project" at times, has been given an identification number such as "IC-1," which is a specific problem in the Imhoff Creek watershed. Again, the identification numbers, location and nature of these problems coincide with the matching solutions presented in various watershed/stream-specific exhibits in Section 6. As discussed above, water quality problems are dispersed throughout the City, including the urban core area and the area that drains into Lake Thunderbird. Due to the nature of the water quality problems, as defined by federal and state regulations, individual problems or problem locations were not identified other than the City as a whole with a focus on urbanized areas.

Of the 59 problems or problem areas identified, 34 (58%) have an element related to stream flooding (structures and/or roadway crossings) along Level 1 and 2 streams, 14 (24%) involve stream erosion along Level 1 and 2 streams, and 12 (20%) are local drainage problems. One of the problems (BHC-1) has a flood related and a stream erosion aspect. Of the 34 flood related problems on Level 1 and 2 streams, 26 involve structure or building flooding, and 28 include road crossings that are flooded (overtopped by flood waters). Most problems occur on property with insufficient or no drainage easements or rights-of-way. Some of the problem areas cover an extended length of stream while others affect a relatively short stream reach.

Table 5-1 provides a citywide overview of problem types and locations by watershed. As anticipated, this information documents that almost 84% of the problems occur in the urbanized watersheds that include Bishop Creek, Brookhaven Creek, Imhoff Creek, Merkle Creek, and Woodcrest Creek. In addition to the discussions in this section, the flood prone nature of the Level 1 and 2 study reaches and the City in general is presented with the 100- and 500-year existing condition floodplains provided in Exhibit 4-2, the 10- and 100-year baseline (future conditions) floodplains presented in Exhibits 4-3 and 4-4, and the various plan view and stream flood profile exhibits in Appendix E.

Table 5-1: Number of Watershed-Specific Problem Locations Experiencing Respective Problem Types*

Watershed	Structures Flooded	Road Crossings Overtopped	Stream Erosion	Local Drainage	Totals
Bishop Creek	6	4	6	5	21
Brookhaven Creek	1	4	4	3	12
Canadian River Area	0	0	0	1	1
Clear Creek	0	0	0	1	1
Dave Blue Creek	0	2	0	0	2
Imhoff Creek	9	9	2	1	21
Little River Mainstem	1	0	1	0	2
Little River - Trib G	0	1	0	0	1
Little River - Woodcrest Creek	3	2	1	0	6
Merkle Creek	4	3	0	0	7
Rock Creek	2	3	0	0	5
Ten Mille Flat	0	0	0	1	1
Total Problem Types	26	28	14	12	80

*Several problem locations have multiple problem types.

Table 5-2 (Appendix H) provides key watershed-specific information related to the respective problems such as their type and description, and as applicable, basic information related to flooding and/or stream erosion such as the number of structures in the baseline (future conditions) 100-year floodplain, the number of road crossings that are overtopped with floodwaters, and the length of stream erosion problems identified. By concurrently reviewing Table 5-2 and the exhibits in Section 6 that locate associated improvements, the baseline 100-year floodplain, and/or show flood profiles relative to road crossing elevations, an understanding of each problem can be gained. The watershed plan view and/or stream profiles exhibits in Section 6 show the location and extent of the problems as the problems mirror the recommended solutions shown therein. Discussion beyond that provided in Table 5-2 is provided below for some of the more significant problems throughout the City organized by the watersheds in which the problems exist. *Again, the stream flooding and stream erosion problem areas identified are only for the Level 1 and Level 2 stream reaches studied. Localized problems are problems identified throughout the watersheds beyond the Level 1 and 2 reaches as identified by the City.*

Bishop Creek

As shown in Table 5-2 (Appendix H) and Exhibits 6-1a, 6-1b, 6-2a, and 6-2b in Appendix H(Bishop flood profile), Bishop Creek has a greater number of individual problem areas than any other watershed in the City with 17 that represent all of the various problem types. One reason is that the Bishop Creek watershed, at 9.87 square miles, is the largest of the urban core watersheds and much of the watershed has been developed for a relatively long time. There are all types of problems with many being relatively small and scattered throughout the watershed.

Overall, in the watershed, there are 69 buildings/structures in the baseline floodplain, five flood prone road crossing structures (some may also be a localized problem), and 1,350 ft of eroding stream length. Of the 17 problems identified, six have flooded structures, five have one or more flooded roadways, six result from stream erosion, and five are localized drainage problems. Only four of the 17 problems occur along the mainstem of Bishop Creek with the others being located in Tributaries A and C and in various localized areas. The most significant problem along the mainstem is a stream flooding problem, BC-4, in which 49 homes are located in the baseline (100-year) floodplain but these homes also flood from more frequent events such as the 10-year event. In this upper reach, Bishop Creek consists of a small mortared rock channel built during the WPA program about 70 years ago. The capacity of this WPA channel is woefully inadequate which results in the flooding problem.

Tributary A has six problems with the most prominent one being the BC-10 problem where seven homes are in the baseline floodplain upstream of the road crossings at Sinclair Drive and Beaumont Drive. Many of these homes will flood during more frequent events as the capacity of Tributary A is significantly undersized and homes have been built near the creek. Additionally, the culverts beneath the Sinclair Road and Beaumont creek crossings are significantly undersized and are flood prone. A significant problem in Tributary C is the BC-12 problem where the undersized Brooks Street culvert system causes several apartments buildings to be in the baseline (100-year) floodplain upstream of the roadway.

WPA Channel downstream of Carter Avenue – Bishop Creek

Stream erosion caused by the increased flow volumes attributable to urbanization is also occurring in individual short reaches of the mainstem such as described for BC-1, BC-2, BC-5, BC-7, BC-9, and BC-11. Until stabilized, these stream erosion problems collectively totaling 1,350 ft will very likely worsen until the stream reaches stabilize themselves.

Eroding stream upstream of SH 9 - Bishop Creek

Brookhaven Creek

Ten problems have been identified in Brookhaven Creek as shown in Table 5-2 (Appendix H) and Exhibits 6-3, 6-4a, and 6-4b in Appendix H. Of the ten problems identified, one has flooded structures, four have one or more flooded roadways, four result from stream erosion, and three are localized drainage problems. These problems are scattered throughout the urbanized watershed.

Overall, in the watershed, there are 276 buildings/structures in the baseline floodplain, four flood prone road crossing structures, and 3,150 ft of stream experiencing erosion. Six of the ten problems occur along the mainstem of Brookhaven Creek with two in Tributary A and three in various localized areas.

2025 Update: The BHC-1 project was addressed as part of the Main Street Bridge over Brookhaven Creek project completed in 2017-18. The language in this paragraph has been made past-tense to reflect the problem as it was before the 2018 project was completed. The 2018 project included replacement of the metal arch pipes with a concrete box structure and included channel widening and stabilization for the downstream reach.

The most significant problem along the mainstem was a stream flooding and erosion problem, BHC-1, in which 276 homes (including numerous mobile homes and residences north of Main Street and west of the creek) were located in the baseline (100-year) floodplain. In this problem area, flows overtopped the Main Street pipe arch opening and spread out over a large area on the west side of the creek due to capacity limitations of the opening and the downstream creek. Some home flooding also occured east of the creek downstream of Main Street. Since this area transitions into the Canadian River floodplain, it is generally wide and flat resulting in shallow flooding over a large area. Once flows exited the creek, especially on the west side, they did not return to the main channel as they spread out over the floodplain and flowed toward the Canadian River.

Stream erosion downstream of Main Street – Brookhaven Creek

In addition to having inadequate flow capacity in this most downstream natural reach (BHC-1), the Brookhaven Creek mainstem is also experiencing significant stream erosion alternating from one side of the creek to the other over a distance of about 2,000 ft. Three other stream erosion problems (BHC-2, BHC-3, and BHC-4) are located between Main Street and 36th Avenue NW further revealing such problems in the lower stream reaches of the watershed.

Eroding stream and drainage outfall downstream of 36th Street NW – Brookhaven Creek

Clear Creek

No stream flooding or stream erosion were identified in the watershed. However, one localized problem area was identified in this primarily undeveloped watershed located along 120th Avenue SE south of Highway 9 and near Lake Thunderbird. The culvert system near 120th Ave SE and E Cedar Lane is undersized and the road profile is very near the adjacent road grade, which increases its flood prone nature. Further, the creek parallels the 120th Avenue SE roadway downstream of the culvert system and its limited capacity in this reach causes flood levels to inundate the roadway regardless of the culvert capacity limitations.

2025 Update: The proposed project of replacing the existing structure under 120th SE Avenue has since been completed.

Canadian River

The investigation of problems along the Canadian River was not a primary consideration for this SWMP. Floodplains developed by FEMA provide the basis of describing flooding along the river with that floodplain being reflected in Exhibit 4-4 located in a map pocket in Appendix E in this report.

One localized problem area was identified in a small drainageway that drains into the Canadian River. This problem resides at Westbrooke/Terrace Road and Hollywood Street intersection where a traffic calming circular island was installed in the past. Stormwater generated from developed areas flows into the intersection from the north, west, and south directions and floods the area before slowly draining off. The traffic island likely slows the flow of water exacerbating the problem but flooding would likely occur even without the island.

Dave Blue Creek

The Dave Blue Creek watershed is primarily undeveloped although urbanization is occurring in its north and western areas. Slopes are relatively steep compared to Norman watersheds in its urban core and western areas. Only two problems were identified in this watershed and both (DBC-1 and DBC-2) are related to stream flooding caused by inadequate road crossing culvert systems along 48th Avenue SE.

Culverts upstream of 48th Avenue SE – Dave Blue Creek

No stream erosion or localized problems were identified in the watershed.

Imhoff Creek

Numerous significant problems were identified in the Imhoff Creek watershed. In fact, the full scope of problems in this watershed outweigh the collective problems in other individual watersheds. This watershed is fully developed and generates high runoff rates and volumes that, in turn, cause stream flooding, stream erosion, and local drainage problems in numerous locations along the creek and at specific areas in the watershed. Although only six problem areas were originally identified, many of them cover long stretches of the creek and/or large localized areas. Five out the six problem areas are located along the mainstem of Imhoff. One of the problem areas (IC-3) has been subdivided into eight contiguous sub-reaches (IC-3A through IC-3H) due to its length, significance, and need to have phased improvements as it extends from the upper reaches of the creek near Andrews Park to a point downstream of the watershed's middle, approximately 1,200 ft downstream of Lindsey Street. When looked at in this context, dividing IC-3 into eight sub-reaches results in Imhoff Creek watershed having 13 problem areas. Table 5-2 (Appendix H) and Exhibits 6-7a, 6-7b, and 6-8 in Appendix H provide descriptions of the problems and their locations. Problems IC-4 and IC-4A are being considered as two "problems" although they both primarily relate to the need to reduce flows throughout Imhoff Creek and reflect the need for a one- or two-celled stormwater detention facilities in and around Andrews Park to accomplish that purpose.

Overall in the watershed, there are 360 buildings/structures in the baseline (100-year) floodplain footprint (although the finished floor of many structures could well be above the baseline flood levels), 15 flood prone road crossing structures, and 5,000 ft of stream length with erosion problems. Of the 13 problems identified, nine relate to flooded structures (two being generally related to reducing flows using stormwater detention), seven have one or more flooded roadways, two depict stream erosion, and one identifies a very large localized drainage problem in the Lindsey Street-McGee Drive intersection area.

WPA channel in Andrews Park – Imhoff Creek

From a stream flooding standpoint there are problems in the lower, middle, and upper reaches of the creek. In the lower natural channel reaches of the creek, 154 structures are located in the baseline (100-year) floodplain near Highway 9 with 49 structures being downstream of the highway (40 of which are east of the creek) and 105 located immediately upstream of the highway and on the east side of the creek. This problem area has been identified as, or linked to, IC-4/IC-4A as these structures can be removed from the floodplain with sufficient detention provided in the Andrews Park area in combination with the diversion of flow in the Lindsey – McGee intersection area proposed as solution IC-5. Exhibit 6-7a in Appendix H shows these flooded structures and the IC-4 and IC-4A proposed detention facilities. These structures were not historically shown in the floodplain by FEMA but SWMP corrections to the hydraulic model previous used in FEMA studies along the creek resulted in these structures being located in the floodplain footprint. Finished floor elevations for many of these structures are likely above the flood elevations since flood waters only exceed the creek top of bank by small amounts in the affected areas and spread out over the flat floodplain area at shallow depths. This problem reach of creek is co-located with stream erosion problems IC-1 and IC-2 that are subsequently discussed below.

Stream flooding problems in the middle and upper reaches are depicted by IC-3 and its A through H sub-reaches that extend from about 1,200 ft below Lindsey Street up to Webster Avenue near Andrews Park. The IC-3 problem can best be described by looking at the sub-reach problems as discussed below and shown in Exhibits 6-7a and 6-8 in Appendix H.

IC-3A (From near the Elmwood Drive dead end upstream, about 1,200 ft downstream of Lindsey St., to near Madison St. dead end, including a road crossing upgrade at W. Lindsey St.)

This most downstream sub-reach of IC-3 includes a triangular shaped cross section with a concrete pilot channel. Flooding caused by medium sized events, such as a 10-year event, and large events, such as the 100-year (baseline) event, exceeds the creek's flow capacity and extends onto properties adjacent to the creek. In this sub-reach, 14 structures (homes) are located in the baseline floodplain footprint although a majority of these structures are on the fringe or edge of the floodplain with finished floor elevations likely higher than the baseline flood elevation. The Lindsey Street culvert system comprised of three 8-x-6-ft reinforced box culverts (RCBs) is undersized and flood prone as indicated in the flood profiles shown in Exhibit 6-8 in Appendix H. This is an important east-west traffic carrier which results in potentially dangerous conditions and significant inconvenience when flooded.

IC-3B (From near the Madison St. dead end upstream to a location about 150 ft downstream of W. Boyd Street, including a crossing at W. Brooks Street)

The triangular shaped cross section with a concrete pilot channel continues for a majority of this sub-reach upstream to a point about 300 ft below W. Boyd Street where the concrete bottom continues but the side slopes become vertical masonry block walls. Flooding caused by medium sized events, such as a 10-year event, and larger events, exceeds the creek's flow capacity and extends onto properties adjacent to the creek. In this sub-reach, 32 structures (homes) are located in the baseline (100-year) floodplain footprint although a few of these structures are on the fringe or edge of the floodplain with finished floor elevations likely higher than the baseline flood elevation. The existing W. Brooks Street bridges spans 30 ft and is undersized and flood prone as indicated in the flood profiles shown in Exhibit 6-8 in Appendix H.

Concrete-lined channel upstream of Lindsey Street – Imhoff Creek

Concrete lining and vertical walls downstream of Boyd Street – Imhoff Creek

IC-3C (From a location about 150 ft downstream of W. Boyd St. upstream to just below McNamee St., including road crossing upgrades to W. Boyd Street and S. Pickard Ave.)

The undersized creek channel in the IC-3C sub-reach consists of a concrete bottom with vertical mortared rock sides built as a WPA project over 70 years ago. Flooding caused by small sized events, less than a 10-year event, and larger events exceeds the creek's flow capacity and extends onto properties adjacent to the creek. In this sub-reach, 13 structures (homes) are located in the baseline (100-year) floodplain footprint with only a few of these located on the fringe or edge of the floodplain with finished floor elevations higher than the baseline flood elevation. The Boyd Street concrete slab bridge is only 12 ft wide with a 6 ft height and is undersized and flood prone as indicated in the flood profiles shown in Exhibit 6-8 in Appendix H. This is an important east-west traffic carrier which results in potentially dangerous conditions and significant inconvenience when flooded. The Pickard Avenue crossing over the creek is a 12-x-5-ft concrete slab bridge that is also significantly undersized and floods often as Exhibit 6-8 in Appendix H reveals.

IC-3D (From just below McNamee St. upstream to just upstream of Symmes St., including road crossing upgrades to McNamee St., S. Flood Ave., and W. Symmes St.)

The creek channel in the IC-3C sub-reach is also undersized and consists of a concrete bottom with vertical mortared rock sides built as a WPA project over 70 years ago. Flooding caused by small events, less than a 10-year event, and large events exceeds the creek's flow capacity and extends onto properties adjacent to the creek. In this sub-reach, 29 structures (homes) are located in the baseline (100-year) floodplain footprint with most well inside the floodplain likely with finished floor elevations that are below the baseline flood elevation. The McNamee Street concrete slab bridge is only 12 ft wide with a 5-ft height and is undersized and flood prone as indicated in the flood profiles shown in Exhibit 6-8 in Appendix H. The Flood Street and Symmes Street crossings over the creek are both 15-x-5-ft concrete slab bridges that are also significantly undersized and flood often as shown in Exhibit 6-8 in Appendix H.

IC-3E (From just upstream of W. Symmes St. upstream to just below Main St.)

The IC-3E sub-reach also consists of a concrete bottom with vertical mortared rock sides built as a WPA project although the channel is somewhat deeper and narrower than in downstream sub-reaches as it is approximately 5 ft deep. As shown in Exhibit 6-7a in Appendix H, properties are flooded by small events with large events causing severe flooding damage in this sub-reach. Twenty five (25) structures (homes) are located in the baseline floodplain footprint with most (such as along Lahoma Avenue and Symmes Street) being well inside the floodplain with finished floor elevations that are below the baseline flood elevation. Many of these structures are in the FEMA floodway and have backyard fences that impede flow in the overbank.

WPA channel downstream of Flood Avenue – Imhoff Creek

IC-3F (A Main St. road crossing upgrade plus a small amount of adjacent channel improvements)

The IC-3F sub-reach consists solely of the Main Street crossing that presently has a 12-x-5.5-ft opening. This opening is much too small and causes overtopping of the roadway for small, medium, and large events as seen in Exhibits 6-7 and 6-8 in Appendix H. The creek cross section on both sides of the crossing consist of narrow mortared rock WPA channels less than 10 ft wide and approximately 3–4 ft deep.

IC-3G (From just above Main St. upstream to just above W. Tonhawa St., including road crossing upgrades to W. Gray St., N. Lahoma St., and W. Tonhawa St.)

This relatively short sub-reach consists of a narrow mortared rock WPA channels less than 10 ft wide and approximately 3–4 ft deep. There are three small flood prone road crossing openings built as concrete slabs at Gray Street (10 x 5 ft), N. Lahoma Street (10 x 5.1 ft), and W. Tonhawa Street (10 x 5 ft) as shown in Exhibits 6-7a and 6-8 in Appendix H. These road crossings and the small WPA channel do not have near enough capacity and flood often. In this sub-reach, there are 22 structures (homes) that are located in the baseline floodplain and flood often with most being located along W. Tonhawa Street.

IC-3H (From just above W. Tonhawa St. upstream to just above N. Webster Ave., including road crossing upgrades at W. Daws St., N. University Blvd., and N. Webster Ave. – N. Park Ave. crossing upgrade not included as this street is assumed removed as part of the Andrews Park stormwater detention modifications)

Sub-reach IC-3H is the most upstream length of IC-3 and, like other downstream reaches, it consists of an undersized narrow and shallow WPA channel that often overflows and floods local residences. Adding to the problems are undersized and flood prone road crossing openings (slab bridges) at W. Daws Street (10 x 4 ft), N. University Boulevard (10 x 4 ft), and N. Webster Avenue (10 x 3 ft) as Exhibits 6-7a and 6-8 in Appendix H indicate. Given these conditions, 64 structures (homes) are located in the baseline floodplain with some of the worst flooding occurring along W. Tonhawa Street west of the creek.

WPA channel downstream of Daws Street – Imhoff Creek

Imhoff Creek has the worst stream erosion problems in Norman that extend approximately 5,000 ft as indicated in Exhibit 6-8 in Appendix H. These erosion problems begin approximately 1,000 downstream of Highway 9, near the creek's confluence with the Canadian River, and extend upstream to a point about 2,000 ft upstream of Imhoff Road. Specifically, the IC-1 problem area is located below Highway 9 and IC-2 extends upstream of the highway. These two problem areas are somewhat similar in nature and represent a significant stream degradation process that includes down cutting of the streambed, widening of the creek between its banks through ongoing bank failure and collapse, as well as destruction of numerous trees, backyard fences, and loss of usable property. In the past, many of the fallen trees have trapped other fallen trees, tree branches, and other debris which have periodically blocked the creek flow.

These types of creek blockages cause further erosion as flows move around the sides of the blockage and further erode adjacent properties. This erosion process will continue until the creek re-stabilizes in an enlarged condition.

These problems are a direct result of upstream urbanization of the watershed including increased impervious cover and more efficient drainage systems which, in turn, have led to increased runoff volumes and rates that the creek is trying to accommodate by enlarging.

Stream erosion and fallen trees upstream of Imhoff Road – Imhoff Creek

2025 Update: The following paragraph describes the problem that was colloquially known as "Lake McGee" in Norman. Through the identification of this problem in the 2009 plan, and integrating its solution with other projects, the project was able to be funded and solved. The language in this paragraph remains in this document as reference to that project.

One of the biggest problems in the Imhoff Creek watershed was the IC-5 localized problem located in the west-central portion of the Imhoff Creek watershed in the vicinity of Lindsey Street and McGee Drive as located on Exhibit 6-7b in Appendix H. Historically, this problem has been one of the worst flooding problems in Norman as it occurs often and lingers for hours due to the flat nature of the local topography, the high intensity of local development, and the lack of adequate drainage infrastructure. During even small storm events, traffic in the local area was slowed and brought to a halt due to high water around the intersection. Local businesses suffered from frequent flooding events that drove away potential customers. In this area, stormwater flows overland from the north along McGee Drive and other north-south aligned streets and into the Lindsey Street area in several locations. Behind the shopping center located just south of Lindsey and east of McGee, the City has built a concrete channel that collects excess storm flows and delivers it to a large storm sewer system that then takes the flows to Imhoff Creek, outfalling approximately 1,200 ft south of Lindsey Street. Also, at some point between McGee Drive and Wylie Road, a small storm sewer system along Lindsey picks up some runoff and takes it eastward to Imhoff Creek. Although these two systems helped some with drainage in the area, they were significantly undersized resulting in the severe flooding problem in the localized area.

Little River Mainstem

2025 Update: The LR-2 Problem that is mentioned in this section has been solved through buyouts of the affected property.

There are two problems (LR-1 and LR-2) that have been identified along the Little River mainstem for which CIP projects have been conceptualized. These two problems are located in Exhibit 6-9 in Appendix H and described in Table 5-2. LR-2 is a stream flooding problem consisting of an approximate 40 unit mobile home park that is flooded by medium and large events thusly endangering residents and causing considerable damage. A majority of the units or lots are in the baseline (100-year) floodplain although a few may be outside of this floodplain.

LR-1 is a severe stream erosion problem located about 2,000 ft upstream of 12th Avenue NW. The river bank has eroded along about 350 ft of river presently although additional erosion is likely in the future. The eroded bank is within approximately 70 ft of a residence and could eventually threaten the structure.

Eroding stream bank upstream of 12th Avenue NW – Little River

No localized problems were identified in the watershed.

However, there are other stream flooding and stream erosion problems beyond these two CIP projects that exist and deserve some consideration. These mainstem problems relate to road crossing flooding or overtopping (see Exhibit 6-10) and stream erosion that appears to be accelerating along the river. The potential flood-related problems were not added to the CIP list since a more comprehensive transportation system upgrade of Franklin Road and its many intersecting roadways is badly needed. This upgrade would include roadways extending from 24th Avenue NW to a point beyond the eastern limit of the Level 1 analysis reach at 48th Avenue NE.

Franklin Road generally parallels Little River between 24th Avenue NW and 48th Avenue NE and is inundated by the river's 100-year baseline floodplain for almost 2.7 miles within in this six mile road length, primarily east of N. Porter Avenue. Additionally, numerous small tributaries cross the roadway, and are a flood hazard to the roadway, as they flow toward the river from the north. To alleviate flooding along Franklin Road and the numerous intersecting streets in this area, a significant road upgrade program well beyond this SWMP, would be required.

Such a program would likely be a combination of raising the roadway while also increasing the bridge and/or culvert openings at road crossings. Design for such a roadway upgrade would need to consider the potential for increased peak flows in downstream areas as a result of enlarging a number of upstream bridge and culvert openings as well as reducing river flow capacity due to a raised roadway blocking flows at crossings and where the road runs parallel to, and near, the river.

The Level 1 study reach of Little River is also beginning to reveal significant stream erosion problems as a result of its urbanizing watershed and the related increased runoff peak flows and volumes. All indications are that stream erosion will become an even greater problem along Little River and its tributaries in the future as its watershed further develops. Access is limited along the river due to its rural nature and difficulty in obtaining approvals to enter properties along the river so there are likely undetected erosion problems that exist now and will get progressively worse for a long time in the future.

Little River - Tributary G

As shown in Table 5-2, Tributary G to the Little River has only one significant problem area and it is associated with stream flooding upstream of Franklin Street just west of the IH 35 highway corridor. Flood levels are increased by the IH 35 culvert system which, in turn, increases the flood levels at Franklin Street as shown in Exhibits 6-11 and 6-12 in Appendix H . As development occurs in this fast growing area of Norman, traffic along Franklin Street is increasing raising concerns about flooding dangers at this crossing.

No stream erosion or localized problems were identified in the watershed.

Little River - Woodcrest

Four problems (WC-1A, WC-1B, WC-2, and WC-3) have been identified for the Woodcrest tributary to Little River, three of the problems reflect stream flooding and one is a stream erosion problem. Twenty (20) homes are located in the baseline floodplain and Sequoyah Road (WC-2) and E. Rock Creek Road crossings over the creek are flood prone as shown in the floodplains and flood profiles respectively shown in Exhibits 6-13 and 6-14 in Appendix H. However, the City is presently upgrading the E. Rock Creek Road crossing so it is not considered further as a problem. WC-1A identifies the fact that peak discharges exceed downstream stream and road crossing opening flow capacities. WC-1B focuses specifically on the lack of stream flow capacity in the overgrown and undersized natural channel downstream of Sequoyah Road. The 200 ft of stream erosion (WC-3) upstream of Sequoyah Road is a moderate problem that will likely get worse in the future although upstream flow control (flood detention) targeting small frequent runoff events could help in controlling the erosion.

Culvert view downstream side of Franklin Road – Trib. G to Little River

Stream erosion downstream of Sequoyah Trail – Woodcrest Creek

No localized problems were identified in the watershed.

Merkle Creek

Four problems have been identified in the Merkle Creek watershed as described and located in Table 5-2 and Exhibits 6-15 and 6-16 in Appendix H. Of the four problems identified, all four have flooded structures, two have one or more flooded roadways, although no stream erosion or localized problems were identified. It is noted that a stormwater detention facility being constructed during the SWMP project and located immediately upstream of

Robinson Street was not considered part of existing conditions but, rather, has been considered as a future (proposed) conditions although no costs will be associated with the privately funded improvements.

Overall in the watershed, there are 51 buildings/structures in the baseline floodplain (see Exhibit 6-15 in Appendix H) and two flood prone road crossings (see Exhibit 6-16 in Appendix H). The most significant problem along the creek is a stream flooding problem (MC-2) in which the Main Street culvert system and adjacent undersized creek conveyance contributes to flooding of upstream structures (homes) and road crossings at Crestmont Street and Iowa Street. In addition to the backwater caused by the Main Street culvert system and adjacent channel, the Crestmont Street (MC-2A) and Iowa Street (MC-2B) crossing are undersized and cause flooding of numerous structures upstream of those crossing openings. These three problem areas are contiguous and somewhat related as their problem identification numbers indicate. Combined, there are 36 structures that are in the baseline (100-year) floodplain in these three problem areas. The MC-1 problem is also significant as 15 structures upstream of 24th Street SW are in the baseline floodplain due to the inadequate capacity of the road crossing opening there, plus creek conveyance limitations that currently exist upstream of the road crossing. Exhibit 6-15 in Appendix H clearly shows the backwater impact of the 24th Street culvert system on the 50- and 100-year flood profiles as water levels increase by 3–4 ft through the culvert system.

Rock Creek

The Rock Creek watershed is primarily undeveloped although it is undergoing urbanization in its headwater (upstream) areas. As shown in Exhibits 6-17a, 6-17b, 6-17c, 6-18a, and 6-18b in Appendix H, three problems (RC-1, RC-2, and RC-

3) were identified in the watershed with two being located along the mainstem and one problem (RC-3) located along Tributary C on which one structure was shown to be in the baseline floodplain. All three of the problems relate to stream flooding with all also including flood prone road crossings and one (RC-3) also involving creek capacity problems. Traffic is increasing along the roadways in the watershed making road crossings over creeks much more dangerous to the general public. The Robinson Street (RC-1) and 36th Avenue NE crossings over Rock Creek and the 36th Avenue NE crossing over Tributary C to Rock Creek are all overtopped for the 10-year and greater floods under baseline conditions.

No stream erosion or localized problems were identified in the watershed.

Culvert outlet downstream of Main Street – Merkle Creek

No culvert headwall downstream of 36th Street NE – Rock Creek

Ten Mile Flat

With its overall flat slopes, shallow channels, and rural character, the nature of stream flooding, stream erosion, and localized flooding in the Ten Mile Flat watershed is significantly different from that in other Norman watersheds. As shown in Exhibit 6-19 in Appendix H and as presented in a FEMA Floodplain/Floodway Conditional Letter of Map Revision (CLOMR) for Ten Mile Flat Creek (MacArthur Associated Consultants, Ltd., 2005), flooding is a general problem in the watershed but the rural land use results in less flooding damage compared to those Norman watersheds that are predominately urbanized. The flooding, most of which is shallow, occurs from runoff generated within the watershed and from periodic Canadian River overflows. Exhibit 6-19 in Appendix H indicates structures that are in the 100-year floodplain according to the FEMA CLOMR (approved by FEMA in 2007), which also shows the lower watershed's flooding from the Canadian River. Many of the structures are farm buildings although there are some residence structures that flood. Given that development in most of this watershed has been projected to be low density in the City's 2025 Land Use Plan, future flooding was assumed to be similar to existing flooding.

Typical broad and flat floodplain area in Ten Mile Flat Creek watershed

According to the MacArthur (2005) report, roadways such as W. Main Street, W. Robinson Street, and W. Rock Creek Road are flooded by the 100-year event. W. Tecumseh and 60th Avenue NW are shown as passing such a large event with little, or no, flooding following the completion of ongoing or scheduled drainage and/or roadway projects by the City or local land developers. Given the work associated with the CLOMR and the ongoing projects, TMF-1, located in Exhibit 6-19 in Appendix H, is the only watershed specific stormwater problem identified in this SWMP.

5.2 Problem Identification Methodology

As stated above, Table 5-2 in appendix H presents a summary description of each problem identified with problem locations tracking with respective solutions in Section 6 exhibits. The methodology for identifying problems associated with stream flooding, stream erosion, water quality, and local drainage is provided below. As discussed previously, water quality conditions are approached on a citywide basis and, therefore, are approached in a more broad manner.

5.2.1 Stream Flooding

The identification of flooding problems is presented on a watershed and stream reach basis according to various levels of study detail consistent with the SWMP objectives. As specified above, there are stream flood related aspects in 34 of the 59 overall problems identified. The identification of flooding problems along the major Level 1 and Level 2 streams uses the results of the baseline 100-year floodplain which is based on future full buildout urbanization according to the Norman 2025 Plan. As discussed in Section 1, Level 1 stream reaches were selected by City staff as those reaches in which existing problems need better definition and/or new detailed flooding information is needed in order to assess flooding risks as new development occurs near those stream reaches.

Budget limitations prohibited the inclusion of numerous stream development reaches as Level 1 study reaches. Level 2 streams represent those stream reaches in Norman's urban core that have been studied previously and the basic models developed in those earlier studies were used in the SWMP development.

Additional streams presently needing studies at a Level 1 degree of detail are represented as Level 3 stream reaches. Certain Level 4 reaches expected to see local land development may also be in need of detailed analyses. Although specific problem areas were not identified in Level 3 and Level 4 stream reaches, the future 100-year floodplains (also referred to as "Stream Planning Corridors" and discussed in Sections 4 and 7) are presented along those streams for waterways with 40 acres or more of drainage area. These Stream Planning Corridors present a very approximate estimation of the future 100-year floodplain that identifies areas inundated by such an event. A map (Exhibit 4-4) delineating the estimated 100-year floodplain for all study reaches (Levels 1, 2, 3, and 4) is provided in a map pocket in this report. Exhibit 4-4 in Appendix E provides a general overview of areas subject to flooding throughout the City and represents the only extent of flood identification for Level 3 and 4 stream reaches.

An extensive review of the SWMP hydrologic and hydraulic analyses presented in Section 4 allows for the identification of flood related problems for Level 1 and 2 stream reaches. Specifically, these analyses provide a means of estimating where homes, businesses, and other structures lie within the respective stream reach baseline 100-year floodplains and where road crossings are inundated by the baseline 50-year flood elevations. Although the baseline (future, full development buildout) provides the basis of identifying flood related problems, the existing floodplains and flood profiles have also been reviewed and included in the overall problem identification process. The baseline 100-year floodplains and 50-year flood profiles for Level 1 and 2 stream reaches are presented in Section 6 so that they can be viewed concurrently with the respective floodplains and profiles that correspond with the recommended solutions developed. These floodplains and flood profiles are presented together for each Level 1 and 2 stream reaches to present the flooding locations within each watershed.

5.2.2 Stream Erosion

Stream erosion is a major problem in several stream reaches in the City. The identification of stream erosion problems is based on existing conditions although it should be considered that new problems will likely surface in the future due to increased runoff rates and volumes associated with Norman's urbanization. The watershed assessments (Section 3) provided excellent data and information to locate stream erosion problems. The field reconnaissance, review of the new aerial photography, and spatial analysis of the land use, impervious cover, and soils associated with the watershed assessments allows for the determination of the location and severity of the major stream erosion problem sites in the City. Thirteen (14) of the 59 problems identified have a stream erosion component some of which are very severe threatening homes, fences, roadways, utilities, and trees. Such locations include the downstream portions of Bishop Creek, Imhoff Creek, and Brookhaven Creek which are all streams draining areas that have been urbanized or urbanizing over the last few decades. Lower Merkle Creek just downstream of W. Lindsey Street also had an emerging erosion problem until a local development project added rubble/riprap to in an attempt to stabilize the area. This location will need to be monitored to see whether this riprap protection will be adequate and the modified stream reach remains stable.

5.2.3 Water Quality

Water quality problems have been determined to exist in Norman's stormwater systems located in its "urbanized areas" by the United States Environmental Protection Agency's (EPA) National Pollutant Discharge Elimination System (NPDES) program. These urban stormwater systems are referred to as municipal stormwater separate storm sewer systems (MS4s). In Oklahoma, mandatory compliance with this program is being implemented by the Oklahoma Department of Environmental Quality (ODEQ) and its Oklahoma Pollutant Discharge Elimination System (OPDES) program. The City of Norman has initiated a stormwater quality monitoring program targeting numerous locations to assist in identifying water quality problems in the city. A listing of the monitoring and visual screening sites shown in Figure 5-1 is provided below. In an effort to better define water quality conditions in the City and to assist in meeting their regulatory obligations, the City is presently providing quarterly sampling for total suspended solids, chemical oxygen demand, ammonia, phosphate, and nitrate at the monitoring locations. Pesticides and metals scans are also run once a year for samples taken at these locations. Further, the City has started sampling Bishop Creek for fecal coliform in response to the recent Total Maximum Daily Load (TMDL) study for the Canadian River (which includes Bishop Creek as a tributary and possible contributor to the bacteria problem) and added two sample points at tributaries of Little River coming from the Moore and Oklahoma City urbanized areas. The City should also consider expanding their monitoring program to include other creeks that contribute runoff and pollutants into Lake Thunderbird such as Hog Creek, Rock Creek, and Dave Blue Creek.

ODEQ also recently completed a Total Maximum Daily Load (TMDL) study for the Canadian River that identified Norman and the University of Oklahoma as contributors to non-attainment for fecal coliform in Bishop Creek, a local tributary to the Canadian River. Additionally, ODEQ is also concerned that urban development, without appropriate mitigation of its environmental impact, will further degrade Lake Thunderbird's water quality. The agency is presently developing a watershed management plan that will identify management practices and their implementation in the lake's watershed to help achieve beneficial uses of the lake waterbody.

Monitoring Station	Locations
Bishop 1	Bishop Creek @ Marshall Avenue
Bishop 2	Bishop Creek @ Classen Boulevard
Bishop 3	Bishop Creek @ Boyd Street
Bishop 4	Bishop Creek @ Oklahoma Avenue
Imhoff 1	Imhoff Creek @ SH 9
Imhoff 2	Imhoff Creek @ Flood Street
Merkle 1	Merkle Creek @ Lindsey Street
Merkle 2	Merkle Creek @ Main Street
Brookhaven 1	Brookhaven Creek @ G Street
Brookhaven 2	Brookhaven Creek @ Havenbrook Street
Woodcrest 1	Woodcrest Creek @ Tecumseh Road
Little River 1	Little River @ 1600 West Franklin Road
Litte River 2	Little River @ 600 East Franklin Road

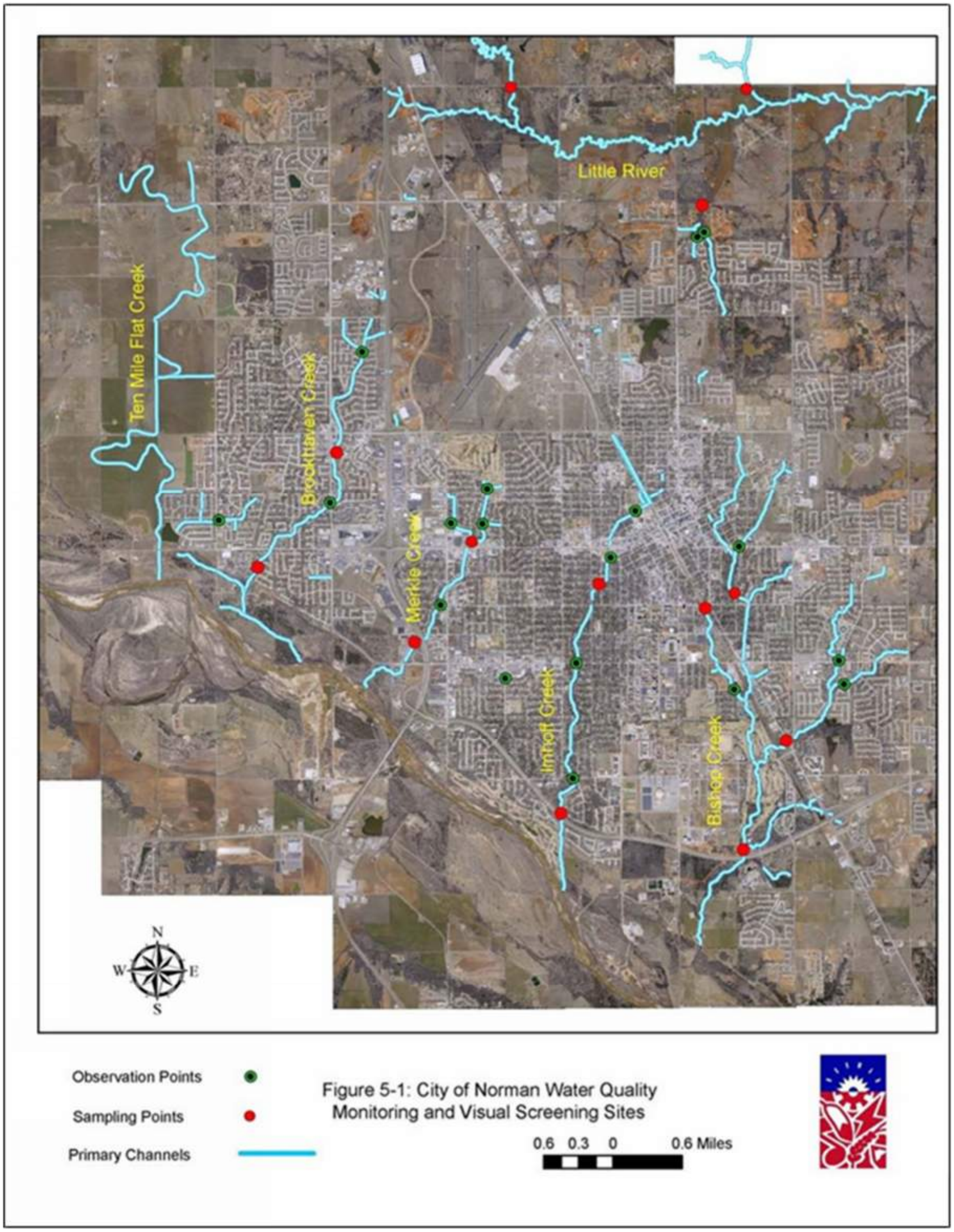


Figure 5-1: City of Norman Water Quality Monitoring and Visual Screening Sites

Existing studies and determinations made by EPA and OPDES provide the determination of water quality problems in Norman. The existing studies considered include a Rock Creek watershed study for the Central Oklahoma Master Conservancy District (Vieux, 2006), a Lake Thunderbird Watershed modeling and analysis for the Oklahoma Conservation Commission (Vieux, 2007), an ongoing watershed plan developed by the Oklahoma Department of

Environmental Quality for Lake Thunderbird (ODEQ, 2008a), and the recently completed Canadian River Bacteria TMDL (ODEQ, 2008b). As part of this master plan development effort, Vieux has provided an overview of these past studies entitled Stormwater Quality Assessment, which is included in Appendix G. A brief summary, much of it verbatim, of that overview is provided below.

Rock Creek Watershed Study

This analysis and water quality evaluation study was performed for the Rock Creek watershed, a significant tributary to Lake Thunderbird, by Vieux for the Central Oklahoma Master Conservancy District (Vieux, 2006). This study estimated the potential impact of land use changes in Rock Creek on nutrient and sediment loading from stormwater runoff to Lake Thunderbird. Rock Creek, with an area of 11.9 square miles, drains to the Little River arm of the lake, located entirely within the corporate limits of the City and the Lake Thunderbird watershed. COMCD supplies drinking water derived from the reservoir to the City and two other communities, Del City and Midwest City. Sampling of the water quality in the lake was conducted and reported by OWRB (2001, 2002, 2004a, 2004b, and 2005) in fulfillment of state water quality programs and for COMCD. Lake eutrophication caused by persistent nutrient loading and consequent algae proliferation is a serious concern because the waterbody is designated as a sensitive water supply (SWS) by the State of Oklahoma. The lake exceeds the SWS chlorophyll *a* water quality standard (WQS), 10 µg/l, by as much as three fold due to algae growth. Some species of algae found in the lake can produce toxins. Though toxins have not been found in the lake as reported by OWRB (2004), incidence of toxins produced by these species is known to increase as chlorophyll *a* concentrations exceed the WQS of 10 µg/l (Downing et al., 2001). Besides the risk of toxins in the finished drinking water, excessive algae production also leads to taste and odor complaints about the finished water product.

In support of the COMCD (Vieux, 2006) study, local sampling of tributary runoff in Rock Creek was performed by the OWRB in conformance with EPA standards. The constituents and concentrations were monitored and used to assess the impacts from urbanization within Rock Creek where there is a range of undeveloped to highly developed land use. This study revealed significant differences between locally sampled data and National Stormwater Quality Database (NSQD) constituent concentrations. In general, nutrients and TSS were elevated significantly in comparison to expected values based on land use in the NSQD database.

Oklahoma Conservation Commission Lake Thunderbird Watershed Study

Since water quality in Lake Thunderbird currently does not meet water quality standards, chlorophyll *a* and turbidity, the Oklahoma Conservation Commission (OCC) completed a study that assessed and quantified the impact of projected future land development on stormwater quality loadings to the lake and targeted management practices within the watershed that would reduce loadings from nonpoint source pollution and achieve water quality standards established for this Sensitive Water Supply. Watershed modeling and analyses for the OCC was performed using the Soil Water Assessment Tool (SWAT) and reported by Vieux (2007). Both baseline (2000) and projected (2030) water quality impacts were modeled to assess the impacts of land use conversion through urban development. The major findings can be summarized as follows:

- Both runoff and constituent concentration affects the annual load of nutrients or suspended solids that stormwater conveys to the lake. Increase in runoff is partially driven by impervious cover.
- Algae growth in Lake Thunderbird is increased by nutrients, in particular, phosphorus. Total phosphorus (T-P) loadings were determined to increase with urban land development. Algae growth and chlorophyll a. concentrations are a major concern of ODEQ, OCC, COMCD and the water supply users. Since T-P is a limiting nutrient for algae growth and resulting concentrations of chlorophyll a, increases in T-P would very likely exacerbate those problems.
- T-N is a source of nutrients that can also accelerate algal growth in the lake, but is not considered a limiting nutrient.
- SWAT modeling revealed considerable potential for reducing phosphorus loadings into Lake Thunderbird using structural and non-structural water quality controls. Structural controls included detention basins, constructed wetlands, retention basins, and bio-retention filters. Non-structural controls included voluntary and mandatory urban fertilizer use restrictions. As discussed in Section 7.2, wetlands, stream

buffers, and other means of using protected vegetation for water quality protection are often categorized together as they use many of the same soil, water, and vegetative processes to enhance water quality (see Table 7-4).

ODEQ Lake Thunderbird Study

An ongoing study by the ODEQ (2008a) is developing a watershed plan that assesses the water quality in watershed tributaries and the impacts of nutrient and sediment loading on water quality in the lake. Lake Thunderbird is listed on the State's 2006 303(d) list for impaired uses of aesthetics and warm water aquatic community. The causes of the impairments are low dissolved oxygen (DO) and high turbidity. The draft 2008 303(d) awaits EPA approval, but does list Lake Thunderbird as being impaired for chlorophyll *a*, DO, and turbidity. The sources of these impairments are listed as "unknown." While there are no permitted point sources of discharge, nutrients and sediment loadings from nonpoint sources discharging during runoff events through tributary streams are believed to be the major cause of the impairments. Another factor, though of lesser importance, is good agricultural practices in rural areas that can affect the lake's water quality. The goal of the watershed study is to determine acceptable loading rates for nutrients and suspended solids that will help allow the intended beneficial use of Lake Thunderbird to be achieved. In light of the unique challenges associated with reducing nonpoint source contributions, ODEQ intends to use a watershed-based plan in lieu of a TMDL for Lake Thunderbird.

Several agencies are cooperating in the development of this watershed plan. The partner agency/organization that ODEQ will work with to develop the plan are the Oklahoma Conservation Commission (OCC) and the COMCD. OCC is the state's main agency for nonpoint source pollution control, and COMCD is the lake's managing organization. OCC will perform watershed stream monitoring in its Priority Watershed Program, and COMCD will fund the data collection effort in the lake through their ongoing contractual agreement with the Oklahoma Water Resources Board (OWRB) and a legal settlement with the ODEQ regarding a stormwater permit in the watershed. ODEQ will perform the modeling work using the data collected by OCC and OWRB.

Lake Thunderbird

Water quality modeling goals for this study will be used to establish key nutrient (phosphorus and nitrogen) and turbidity reduction goals for the watershed. The modeling work will also provide information on sources of loadings and potential management options implemented in the watershed. When the ODEQ establishes the watershed management plan the Cities of Oklahoma City and Norman could be required to implement management practices to reduce nutrients and sediment in stormwater runoff that drains to the lake.

ODEQ Bacteria TMDL for the Canadian River

Recently, ODEQ (2008b) completed a Total Maximum Daily Loads (TMDL) study for the Canadian River. Elevated levels of pathogen indicator bacteria in aquatic environments indicate that receiving water is contaminated with human or animal feces and that there is a potential health risk for individuals exposed to the water. Pollutant load allocations for indicator bacteria in the Canadian River are currently being established. Waterbodies in the study area are listed on the ODEQ 2004 303(d) list because there is evidence of nonsupport of primary body contact recreation (PBCR), resulting in the development of a TMDL for the Canadian River and certain tributaries including Bishop Creek. Bishop Creek failed to support PBCR due to fecal coliform (FC) concentrations. Seventy-five percent of samples collected at Bishop Creek and Jenkins Avenue exceeded permissible FC concentrations for single samples. The MS4 permit for small communities in Oklahoma became effective on February 8, 2005. Two such MS4 permit holders discharge to Bishop Creek; they are the City of Norman and the University of Oklahoma. The major contribution of FC to Bishop Creek is believed to be from nonpoint sources, though point sources have been identified from sanitary sewer overflows (SSO) that have occurred in Bishop Creek. The estimated FC loads for the four major nonpoint source categories, which contribute to elevated bacteria concentrations in Bishop Creek are estimated to be Commercially Raised Farm Animals (82.26%), Pets (17.66%), Deer (0.04%), and Septic Tanks (0.04%) (ODEQ, 2008b, pg. 3–20 ff).

Compliance with the TMDL requirements under the MS4 program will require that stormwater permit holders develop strategies designed to achieve progress toward meeting the reduction goals established in the TMDL. The City of Norman and the University of Oklahoma may be required to participate in a coordinated monitoring program or develop their own for purposes of documenting the effectiveness of the selected best management practice (BMP) and for demonstrating progress toward attainment of water quality standards. Reporting requirements include documentation of actions taken by the permittee that affect MS4 stormwater discharges to the impaired waterbody segment (ODEQ, 2008b).

5.2.4 Local Drainage

The identification and location of local drainage problems were provided by the City of Norman based on citizen complaints and observation of the various problems. These problems typically result from inadequate drainage system infrastructure including inlets, street gutters, storm sewers, and/or channels that are undersized. Each problem is distinct in its causes with some being relatively small and straightforward while some are more complex such as the West Central Imhoff Creek watershed (Lindsey Street-McGee Drive intersection) problem. Descriptions of the local problems are provided in Table 5-2 organized by the watershed in which each is respectively located. Numerous photographs were taken in each of these problem areas; the photos will be made available to the City as a separate project deliverable.

6.0 Stormwater Solutions

2025 Stormwater Solutions Updates

Generally, the solutions identified in 2009 have not been updated as part of this AIM Norman process. The major update to this section is a reconsideration of the prioritization process of the stormwater solutions. The process of scoring stormwater projects has been revised to better reflect what Norman prioritizes as a community today and provide objectivity to the scoring method. The scoring of these projects for this SWMP Update should not be used as a final chronological list of projects that must be constructed according to the order of their score. There are other significant factors that affect the City's decision making process, such as the project being combined with another infrastructure project, grant funding, or access to the required right of way.

A quantifiable way to measure each criterion was developed to provide objectivity of the scoring of the stormwater capital projects. Some examples of data that will now be used to measure the criteria are the City's GIS data, 2025 project cost estimates, stormwater solution floodplain mapping from the 2009 solutions analysis, census data, FEMA Special Flood Hazard Areas (SFHAs), and the state's list of 303d impaired waterbodies. Section 6.2.1 includes a detailed discussion the updated capital project scoring process. Appendix j contains the scoring for each project.

An additional update to the stormwater solutions is the update to the cost estimates. The original 2009 project costs have been updated to reflect 2025 prices. For the detailed cost estimates, please refer to Appendix I. Table 2 below shows the updated estimated costs and updated scoring.

Table 6-1: Summary of Stormwater Projects

Project ID	Watershed	Estimated Cost	Scoring
BC-1	Bishop Creek	$1,856,431	57
BC-2	Bishop Creek	$1,270,592	62
BC-3	Bishop Creek	$916,050	61
BC-4	Bishop Creek	$9,126,776	57
BC-5	Bishop Creek	$1,482,686	57
BC-6	Bishop Creek	$1,831,286	68
BC-7	Bishop Creek	NA	Completed Project
BC-8	Bishop Creek	$1,792,804	59
BC-9	Bishop Creek	$111,902	68
BC-10	Bishop Creek	$3,499,620	67
BC-11	Bishop Creek	$1,440,615	62
BC-12	Bishop Creek	$1,186,014	61
BC-13	Bishop Creek	$1,444,271	52
BC-14	Bishop Creek	$169,000	58
BC-15	Bishop Creek	$1,003,170	58
BC-16	Bishop Creek	$10,981,327	48
BC-17	Bishop Creek	$1,341,696	43
BHC-1	Brookhaven Creek	NA	Completed Project
BHC-2	Brookhaven Creek	NA	Completed Project
BHC-3	Brookhaven Creek	$498,974	56
BHC-4	Brookhaven Creek	$1,784,333	58
BHC-5	Brookhaven Creek	$200,000	62
BHC-6	Brookhaven Creek	$978,985	37
BHC-7	Brookhaven Creek	$255,159	43
BHC-8	Brookhaven Creek	$1,046,247	47
BHC-9	Brookhaven Creek	$1,046,247	51
BHC-10	Brookhaven Creek	$2,353,788	52
CC-1	Clear Creek	NA	Completed Project
CR-1	Canadian River	$964,793	47
DBC-1	Dave Blue Creek	$3,812,633	40
DBC-2	Dave Blue Creek	$962,965	42
IC-1	Imhoff Creek	$340,501	60
IC-2	Imhoff Creek	$21,766,421	59

Project ID	Watershed	Estimated Cost	Scoring
IC-3A	Imhoff Creek	NA	Completed Project
IC-3B	Imhoff Creek	$7,651,181	50
IC-3C	Imhoff Creek	$7,224,931	68
IC-3D	Imhoff Creek	$10,589,229	60
IC-3E	Imhoff Creek	$7,007,577	50
IC-3F	Imhoff Creek	$4,516,957	45
IC-3G	Imhoff Creek	$7,681,852	59
IC-3H	Imhoff Creek	$8,773,251	63
IC-4	Imhoff Creek	$8,383,274	46
IC-4A	Imhoff Creek	$13,517,589	57
IC-5	Imhoff Creek	NA	Completed Project
LR-1	Little River	$486,496	57
LR-2	Little River	NA	Completed Project
TGLR-1	Trib. G to Little River	$2,709,433	43
WC-1A	Woodcrest Creek	$6,606,432	41
WC-1B	Woodcrest Creek	$1,140,599	62
WC-2	Woodcrest Creek	$756,682	53
WC-3	Woodcrest Creek	$228,672	61
MC-1	Merkle Creek	$1,980,525	62
MC-2	Merkle Creek	$13,180,793	69
MC-2A	Merkle Creek	$6,295,059	52
MC-2B	Merkle Creek	$1,230,781	66
RC-1	Rock Creek	$2,456,179	44
RC-2	Rock Creek	$2,423,244	42
RC-3	Rock Creek	$1,923,873	49
TMF-1	Ten Mile Flat Creek	$488,334	53
TMF-101	Ten Mile Flat Creek	$3,240,020	49

Original 2009 Stormwater Solutions Introduction

A variety of conceptual solutions have been developed for the stream flooding, stream erosion, water quality, and local drainage problems identified in Section 5. It is anticipated that many of these solutions will be included in a City capital improvement program (CIP) as outlined in this section and in Section 8 for the financial planning requirements. To the extent possible, integrated solutions were developed in order to address stormwater issues in the most comprehensive way possible. In most but not all instances, the problems tended to be of one major type such as stream flooding and the primary emphasis of the solution primarily addressed that stormwater aspect. However, in solving such one-dimensional problems or in instances in which more than one type of problem occurred in one location, care was taken to develop a solution that further improved other stormwater aspects. For instance, if a conceptual stream flooding solution was developed, it was done so in a manner to also protect the stream from future erosion.

Other considerations were also made to incorporate items such as improving and/or protecting the stream's environmental integrity by using bio-engineering and natural channel design techniques, preserving the historical character of an existing solution type such as a WPA channel found in the upper Imhoff and Bishop Creek watersheds, improving water quality, and/or identifying greenway opportunities. Solutions were developed in a way to recognize and respect the conditions and character of the respective watershed in which the problem exists. In addition to considering the opportunities of preserving or enhancing environmental and recreational conditions, the solution development process included the consideration of possible alternatives or options and reviewing preliminary findings with City staff as well as the project Task Force to obtain their feedback and guidance.

As with the identification of problems, a watershed-specific approach in developing conceptual solutions was followed to respect the conditions that exist in the various watersheds. Solutions were developed for Level 1 and 2 streams as well as local drainage problems considering that the potential exists to positively or negatively affect other locations within that respective watershed. Solution development targeted future watershed development conditions projected in the City's 2025 Land Use Plan. In this manner, solutions and programs developed will better serve the City of Norman in addressing their stormwater needs in the future and will provide a more complete "blue print" for managing stormwater.

Similar to the approach for identifying water quality problems and due to their "non-point source" nature, solutions for water quality problems were evaluated on a citywide scale consistent with what is required for cities throughout the country. This citywide approach to addressing water quality involves using a programmatic approach which is now ongoing with the City's MS4 Program with the potential to be expanded due to Canadian River TMDL concerns and the ODEQ Watershed Plan that is being developed for the basin area draining to Lake Thunderbird.

Other important aspects of developing solutions included the development of cost estimates for the improvements as well as the prioritization of the many solutions. While the cost estimates are general in nature to match the conceptual design level of the solutions, they were developed to provide a good approximation of the costs that can be expected to design, permit, construct, and implement the solutions. Details of project cost estimating and prioritization development are subsequently provided in Section 6.2 that follows the summary of results provided immediately below. Comprehensive financial planning associated with the City's overall stormwater needs is provided in Section 8.

6.1 Summary of Solutions

Conceptual solutions for the 59 flood-related and stream erosion problems have been developed for the Level 1 and 2 streams evaluated as well as specific local drainage area problems identified. Estimated costs for these projects or solutions totaled $82.6 million, which can be rounded to $83 million. As discussed in Section 5, approximately 84% of the problems were located in the urban watersheds of Bishop Creek, Brookhaven Creek, Imhoff Creek, Merkle Creek, and Woodcrest Creek. Solution costs for these same urban watersheds represent over 90% of the total citywide costs. Table 6-1 provides a breakdown of watershed costs listed in order of costs and the percentage of total costs that each watershed represents.

Table 6-2: Watershed Capital Improvement Project Costs

Watershed	Costs ($M)	% of Total Cost
Imhoff Creek	$97.5	49.80
Bishop Creek	$39.5	20.17
Merkle Creek	$22.7	11.59
Woodcrest Creek	$8.7	4.44
Brookhaven Creek	$8.1	4.14
Rock Creek	$6.8	3.47
Dave Blue Creek	$4.7	2.40
Ten Mile Flat	$3.7	1.89
Trib G, Little River	$2.7	1.38
Canadian River Area	$0.9	0.46
Little River	$0.5	0.26
Totals	$195.8	100.0

The solution locations are spread over a large part of the City but, like the problems that they solve, are located along, or west of, 48th Avenue East. Each solution (and matching problem), also referred to as a "project," has been given an identification number such as "IC-1" which provides, in this case, a reference name for a specific solution (and problem) in the Imhoff Creek watershed. Again, the solution identification numbers match those for the respective problems presented in Section 5. As discussed above and in Section 5, water quality problems are dispersed throughout the City, including the urban core area and the area that drains into Lake Thunderbird. Due to the nature of the water quality problems, as defined by federal and state regulations, solutions to address them are applied to the City as a whole and need to be implemented as a program or overall plan. This is discussed further below.

Certain solutions address overlapping problems, such as stream flooding and stream erosion. Mirroring the problems identified and considering the 59 solutions developed:

- 34 (58%) address stream flooding along Level 1 and 2 streams
- 14 (24%) involve stream erosion along Level 1 and 2 streams
- 12 (20%) resolve local drainage problems

Table 6-2 highlights the problems and solutions on a watershed basis that is discussed further below. On a citywide scale and as totaled at the bottom of Table 6-2, the collective performance of all solutions:

- Removes 652 of 830 structures in the 100-year baseline floodplain
- Removes 36 out of 36 flood prone road crossings
- Stabilizes 10,050 ft of eroding streams

The solution for BHC-1 along Brookhaven Creek targets flood related and stream erosion aspects, both as primary solutions. Recognizing that many consist of multiple problem types, of the 34 flood related solutions on Level 1 and 2 streams:

- 26 target structure or building flooding
- 29 include road crossings that are flooded (overtopped by floodwaters)
- 12 have a structure/parcel buyout component

Although varying approaches, methods, and analytical tools were used to develop solutions for flooding, stream erosion, and water quality, these solutions were also looked at on a watershed, ward, and City-wide basis to better understand their relationships on various spatial, environmental, and political scales. Table 6-2 concisely presents the following summarized information for each of the individual solutions (or projects):

- General location within the City, watershed, and ward
- Solution type(s) including the integration of solution types
- Problem description
- Solution overview
- Key items in defining problem elements and solution results in terms of flood control (structures removed from 100-year baseline floodplain and roadway crossings protected from flooding), stream stabilization (length stabilized), and greenbelt integration opportunities
- Conceptual level cost estimate (see Appendix H for more detail)
- Prioritization score (see Appendix I for prioritization spreadsheets of individual problems/solutions)
- Prioritization score ranking within the City, respective watershed, and respective ward(s)

In addition to Table 6-2 and on a watershed basis, Exhibits 6-1a through 6-19 in Appendix H, respectively, present the location and extent of stream flooding solutions for those watersheds within which a Level 1 or 2 analyses were carried out. It is pointed out that Table 6-2 includes the number of proposed buyouts in the solution values given for structures removed from the baseline floodplain although the exhibits do not identify the buyouts in the color coding for structures removed from the floodplain. **Solution flood profiles are only provided in this report section for those Level 1 or 2 streams in which a solution is being proposed that alters the flood profile. However, sets of flood profiles (10-, 50-, 100-, and 500-year) are presented in Appendix J for existing and baseline or future (full build-out) conditions for all Level 1 and 2 streams.** The odd numbered exhibits provide a very good watershed-specific overview (plan view) of the flooding conditions before and after solutions are in place by delineating and overlaying the floodplains for 100-year baseline (full buildout or future watershed conditions) and 100-year solutions conditions.

In addition to showing the differences that the solutions make in the floodplain, the exhibits presented show the structures that are in the baseline and solutions floodplains thusly outlining the problem and the effect of the proposed solution. **Figure 6-A provides a map index that shows the layout of the respective exhibits throughout the city**. The even numbered exhibits provide watershed-specific flood profiles for baseline and post-solution conditions and show the difference that the solutions make in the 100-year and 50-year flood profiles. The 50-year profile was included since City design criteria (i.e., no roadway overtopping) for culverts are based on this event. Additionally, these exhibits provide the respective locations of stream erosion and local drainage solutions in the various watersheds. When Table 6-2 is used in conjunction with these exhibits, a clear picture emerges on each project's location, type or character, magnitude, and comparison with other solutions within its respective watershed, its ward(s) and the City as a whole. For easy reference, the listing below presents the exhibit numbers for the various watersheds.

	Exhibit Numbers	
Watershed	Plan	Profile
Bishop Creek (Mainstem)	6-1a	6-2
Tributary A	6-1b	6-2a
Tributary B	6-1a	-
Tributary C	6-1a	6-2b
Brookhaven Creek (Mainstem)	6-3	6-4a
Tributary A	6-3	6-4b
Tributary B	6-3	-
Dave Blue Creek (Mainstem)	6-5a	6-6a
Tributary A	6-5a	-
Tributary 1	6-5b	6-6b
Imhoff Creek	6-7a	6-8
Imhoff/Canadian Area	6-7b	-
Little River	6-9	6-10 (reserved)
Tributary G	6-11	6-12
Woodcrest Creek	6-13	6-14
Merkle Creek	6-15	6-16
Rock Creek	6-17a	6-18a
Tributaries A and B	6-17b	-
Tributary C	6-17a	6-18b
Tributary D	6-17c	-
Ten Mile Flat Creek	6-19	-

Discussion beyond that provided above, in Tables 6-1 and 6-2, and in the plan and profile descriptions of the proposed solutions (Exhibits 6-1 through 6-19 in Appendix H) is provided below for some of the more significant solutions organized by the various City watersheds. *The stream flooding and stream erosion solutions developed are only for the Level 1 and Level 2 stream reaches studied. Water quality solutions are more programmatic and generally apply broadly across the City as a whole. Localized solutions are scattered throughout the watershed beyond the Level 1 and 2 reaches.*

Bishop Creek

With 17 individual problem areas, Bishop Creek also has that same number of solutions which exceeds the totals in any of the other respective watersheds. These solutions are discussed in Table 6-2 with results shown in Exhibits 6-1a, 6-1b, 6-2a, and 6-2b in Appendix H that cover the range of problem types discussed in Section 5. The proposed solutions in the watershed collectively provide protection for and/or removal of, 33 of the 69 buildings/structures in the baseline floodplain, the six flood prone road crossing structures, and 1,350 ft of eroding stream length. Only four of the 17 solutions occur along the mainstem of Bishop Creek, with six along Tributary A, two within Tributary C, and five in various localized areas.

The most significant solution located along the mainstem is BC-4, a stream flooding problem, in which the selected solution calls for 15 of 49 homes to be bought out since many of them flood as a result of small and medium flood events such as the 10-year event. The small mortared rock channel in this upper reach of Bishop Creek is significantly undersized and the floodplain is very flat so overflows spread out over a relatively wide floodplain area. Any channel conveyance improvements would have to be very wide and costly due to the shallow channel and flat overbank area so a solution to buyout the most flood prone 15 structures was selected. By removing these 15 structures that are in the primary flow path of flooding events, the flood levels could be reduced somewhat which will also lessen flooding on the remaining structures. It is recognized that buying out properties is a difficult process and involves significant time, effort, and costs to complete. Therefore, this method of flood protection was used sparingly for this solution and only targeted 15 out of 49 flooded structures for buyout. These 15 structures are those that are the most flood prone in the area and flood significantly from the 10-year future conditions event.

As described in Table 6–2, the solution for BC-10 along Tributary A consists of channel enlargement downstream of Beaumont Drive and the upgrading of road crossing openings at Beaumont Drive and Sinclair Drive. These improvements effectively remove seven homes from the baseline (100-year) floodplain located upstream of the road crossings. Exhibit 6–1a in Appendix H shows the reduction in the baseline floodplain and Exhibit 6-2a in Appendix H displays how the improvements effectively reduce the flood levels at Beaumont Drive by about 4 ft and by over 2 ft at Sinclair Drive preventing overtopping of the roadway crossings. As shown in Exhibits 6-1a and 6-2b in Appendix H, the BC-12 solution along Tributary C at Brooks Street involves enlarging the culvert system as specified in Table 6-2 which reduces flood levels by over 2 ft and removes five of the six flooded apartment buildings located upstream of the road crossing from the baseline (100-year) floodplain.

Stream erosion stabilization solutions BC-1, BC-2, BC-5, BC-7, BC-9, and BC-11 were developed for these six individual locations. Channel widening and/or down cutting in these areas have left unstable channels and the solutions address each of these problems by stabilizing the bank and bottom, where needed, utilizing natural channel design and bio-engineering techniques. More specifically, the stabilization techniques used laying back channel side slopes to a more stable angle (3:1 horizontal to vertical) or using mechanically stabilized structures that use geogrid soil reinforcement depending on the situation and the local restraints. These design techniques are discussed subsequently in Section 6.2 which discusses methodologies for developing solutions.

Stream erosion threatening wastewater infrastructure

Stream stabilization with MSE design; wastewater infrastructure protected

The BC-16 solution to the localized problem along Lindsey Street between College Avenue and Tributary A consists of adding capacity to the roadway's storm sewer system. Unless more detailed design suggest otherwise, the added storm sewer will parallel the existing system along Lindsey Street and remove the excess flow from the street for the design event. The basic design and cost estimate for this solution was developed by the City staff in the past and supplied for the SWMP.

Brookhaven Creek

Solutions for the ten problems in the Brookhaven Creek watershed are provided in Table 6-2 and Exhibits 6-3, 6-4a, and 6-4b in Appendix H. Solution BHC-1 addresses the most significant problem along the mainstem that includes stream flooding and erosion by removing 266 of the 276 homes (including numerous mobile homes) located in the baseline (100-year) floodplain. This solution will prevent flows from overtopping the Main Street pipe arch opening and spreading out over a large area on the west side of the creek by increasing capacity of the opening and the downstream creek channel. BHC-1 also removes all of the homes from the baseline floodplain located east of the creek.

The BHC-1 solution also stabilizes the stream erosion that has been occurring below Main Street for a distance of about 2,000 ft by utilizing mechanically stabilized earth structures and slope layback techniques where possible as discussed in Section 6.2 below. Similar solutions were developed for the three other stream erosion problems (BHC-2, BHC-3, and BHC-4) which are located between Main Street and 36th Avenue NW.

Typical stream erosion beginning

Erosion halted, stream stabilized

Clear Creek

The CC-1 solution was developed to provide protection for a 10-year flood event since using a larger event would require that 120th Avenue SE be raised by several feet over a distance of approximately 1,500 to 2,000 ft and very large culverts would be required to pass the flows below the raised roadway without raising upstream water levels. The recommended solution requires that the roadway be raised by 2.5 ft at its lowest elevation over approximately 1,800 ft and larger culverts as specified in Table 6-2.

Canadian River

No solutions were developed along the Canadian River as the investigation of problems along the Canadian River was not considered for this SWMP. Floodplains developed by FEMA form the basis of describing flooding along the river with that floodplain being reflected in Exhibit 4-4 located in Appendix E of the map pocket in this report.

A solution to one local problem area near Westbrooke/Terrace Road and Hollywood Street intersection was developed to rectify flooding in the intersection that is at least partially caused by an existing traffic calming circular island that was previously installed. The solution includes a custom-designed, low-profile (7-x-2-ft) box in order to convey the runoff from the inlets, under the street, and to the outfall channel in the flat street area. Additional inlet capacity was added to the system in order to carry the stormwater generated from the developed areas that flows into the intersection from the north, west, and south and floods the area.

Dave Blue Creek

Although the only solutions in this watershed are DBC-1 and DBC-2 which are relatively straight-forward road crossing designs as outlined in Table 6-2. The baseline 100-year floodplains and flood profiles for Dave Blue Creek and its two tributaries studied are shown in Exhibits 6-5a, 6-5b, 6-6a, and 6-6b in Appendix H. No stream erosion or localized problems were identified in the watershed.

Imhoff Creek

Solutions for problems in the Imhoff Creek watershed are by far the most significant compared to solutions in other watersheds. As Table 6-1 shows, solution costs to alleviate problems in this watershed amount to approximately $43.7 million and account for almost 53% of the total costs for the entire City. Additionally, costs in this watershed are 3.7 times larger than those in the next most costly watershed (Bishop Creek). Originally, six primary problems were identified in the watershed although one of them, IC-3, was so large it was subdivided into eight sub-reaches (IC-3A through IC-3H) resulting in a total of 13 problems. As shown in Exhibit 6-7a in Appendix H and overviewed in Table 6-2, evaluation of the baseline 100-year floodplain determined that 360 structures are within the footprint of the event with the proposed solutions removing 265 of these structures from the floodplain. Structures elevated above surrounding ground that are within the floodplain's footprint may not be actually flooded. Solutions for 15 road crossings in IC-3 were also conceptually developed to significantly reduce their flooding. Two significant solutions were also developed for stream erosion problems in the lower mile of the stream to alleviate a problem that has been getting worse for many years. Finally, a major solution for a very significant local flooding problem in the area of the Lindsey Street and McGee Drive intersection was conceptually developed as discussed subsequently below.

It is important to note that the Imhoff Creek watershed is fully developed for practical purposes so flooding for existing watershed development conditions were assumed to be identical with baseline (full build-out development) conditions. Also and importantly, solutions in the Imhoff Creek watershed targeted the 10-year flood event, rather than the baseline 100-year event, as improvements at the 100-year level would add significantly to the watershed's already high solutions costs due to the significantly undersized drainage system along the creek as well as right-of-way and easement constraints. There are exceptions at road crossings where many of the crossing openings were designed for the 50- or the 100-year event at the City's direction as discussed below. The design flows assume maximum detention provided to the IC-4A solution level in the Andrews Park area as outlined below and the reduction in flow caused by the flow diversion at Lindsey Street and McGee Drive.

Table 6-2 as well as Exhibits 6-7a and 6-8 in Appendix H provide problem locations, descriptions, and respective solutions. Solutions IC-4 and IC-4A are being counted as separate solutions although they both primarily relate to reducing flows throughout Imhoff Creek and reflect the need for a one- or two-celled stormwater detention facilities in the Andrews Park vicinity. From a stream flooding standpoint, solutions are needed to solve problems in the lower, middle, and upper reaches of the creek. Structure flooding occurs along the entire reach of Imhoff Creek as documented in Table 6-2. There are approximately 154 structures located in the baseline floodplain near Highway 9 with 49 structures being downstream of the highway (40 of which are east of the creek) and 105 located immediately upstream of the highway and on the east side of the creek. As stated in Section 5, the structure flooding and its solution have been linked to IC-4 or IC-4A as conceptual hydrologic modeling indicates that these structures can be removed from the floodplain with sufficient stormwater detention provided in the Andrews Park area and the implementation of the IC-5 solution for the Lindsey Street – McGee Drive intersection area discussed subsequently below. The reduction in downstream flows with the IC-4A and IC-5 solutions alleviates flooding in the lower natural channel reaches of the creek near SH 9. It also reduces the size of proposed creek channel and road crossing openings (IC-3) in the middle and upper reaches of Imhoff Creek. Exhibit 6-7a in Appendix H shows these flooded structures in the lower portion of the creek and the IC-4 and IC-4A proposed detention facilities in the upstream reaches of the creek. Exhibit 6-7b in Appendix H locates the IC-5 solution which is subsequently discussed below. These flood prone structures were not historically shown in the most recent FEMA floodplain update but SWMP corrections to the hydraulic model used in FEMA studies resulted in these structures being located in the floodplain footprint. Finished floor elevations of many of these structures may be above the 100-year flood elevations since flood waters only exceed the creek top of bank by small amounts in the affected areas and spread out over flat floodplain areas.

The IC-4 and IC-4A solutions were developed as options with IC-4 using the open portions of Andrews Park (approximately 7.7 acres) along with a two acre area near its southwest corner (north of Daws Street and West of Webster Avenue) to store approximately 36 acre-feet (ac-ft) of runoff during the 100-year baseline flood and reduce flows from 1,165 cubic feet per second (cfs) to 763 cfs (35% reduction) in Imhoff Creek near the facility's downstream outlet. Option IC-4A uses that same area as IC-4 plus a mostly triangular area (6.5 acres) located to the north of Acres Street and west of the Burlington Northern and Santa Fe Railroad (BNSF) to store approximately 48 ac-ft of runoff and a peak flow reduction from 1,165 cfs to 666 cfs (43% reduction) in Imhoff Creek for the 100-year baseline event. Reductions for the 10-year event are from 714 cfs to 436 cfs (39% reduction) for the IC-4 solution and down to 364 cfs (51% reduction) for the IC-4A solution. It is noted that the effect of the stormwater detention as represented above as a percent reduction in flows will progressively decrease as you move downstream from the facility. Details of the modeling are provided in Section 4. Other key design elements of the detention facilities are:

- IC-4: Primary detention areas (approximately 7.7 acres) are the existing water tank (to be removed) location and the open park space adjacent to, and south of, Acres Street
  - Area that drains to IC-4 is 858 acres
  - Inflows at the northeast corner of the facility from flow along BNSF railroad and diversion from near intersection of Jones and Beal under BNSF railroad and across James Garner Blvd. though three 36-inch RCPs, 220 ft long
  - Low flows will bypass the facility in order to reserve runoff storage to the high runoff periods
  - If flows are high enough, water elevation will rise in the existing water tank area (following tank removal) providing runoff storage.
  - If flows are high enough, water elevations will rise above elevations 1,166 ft, then excess flows will inflow into the lowered/excavated open space (detention) area adjacent to Acres Street via an overflow weir or wall
  - The detention area will generally slope toward the southwest at 1% grade with several small concrete pilot channels
  - Facility side slopes will be between 3:1 and 4:1 (H:V) and grassed lined
  - Top of facility at elevation 1171
  - Outfall through 36-inch RCP at southwest corner of the facility
  - Overflow (50 ft weir in water tank area) to modified existing channel
- IC-4: Secondary detention areas (approximately 2.0 acres) in open areas (only) bounded by Webster Avenue, University Avenue, and the Imhoff Creek channel
  - Inflow from primary detention area through a 330-ft-long, 36-inch RCP at northeast portion of detention area
  - Two houses to be acquired and removed near intersection of Park and Daws
  - Abandon and remove Park Avenue from its intersection with Webster Avenue to Daws Street (approximately 350 ft in length)
  - Detention area to generally slope (1%) toward the southwest
  - Facility side slopes will be between 3:1 and 4:1 (H:V) and grassed lined
  - Top of facility at elevation 1163
  - Outflow through 36-inch RCP, 50 ft long, with backflow preventing flap gate
  - Overflow over 50-ft-long weir near Park Street intersection with Imhoff Creek
- IC-4A: Additional detention north of Acres Street
  - Area that drains to IC-4A is 352 acres
  - Includes all of IC-4 detention facility components
  - Large secondary detention area (6.5 acres)
  - Inflow from local subareas along BNSF railroad ditch plus intercepted flow piped from the intersection of University Avenue and Highland Street
  - Pond bottom at 1% slope to the southeast
  - Concrete pilot channel along eastern edge of facility
  - Facility side slopes will be between 3:1 and 4:1 (H:V) and grassed lined
  - Outflow through a 24-inch RCP, 200-ft length
  - Overflow via a 100 ft weir at elevation 1,175 ft into the ditch adjacent to the railroad
  - Top of facility at elevation 1,176 ft

IC-3 constitutes another very significant solution for stream flooding in the middle and upper reaches with costs of almost $21 million. As mentioned previously this long and complex solution has been divided into eight sub-reach solutions (IC-3A through IC-3H) that collectively extend from about 1,200 ft downstream of Lindsey Street upstream to Webster Avenue near Andrews Park. The IC-3 modifications include all bridges/culverts and the entire length of creek channel. The IC-3 solution and its impacts on the water surface elevations can best be described by looking at it on a sub-reach basis as discussed below and as shown in Exhibits 6-7a and 6-8 in Appendix H.

Recreation and flood control in park setting

For channel improvements proposed for the IC-3 sub-reach solutions, space to make the improvements is a significant consideration due to the associated costs to acquire and clear such space needed. Although targeted protection for road crossings varied between the 10-, 50-, and 100-year levels, the channel improvements for all of the sub-reaches targeted the 10-year flooding event since protection for larger events was judged to require too much property acquisition and utility adjustments. Additionally, there are serious property owner inconveniences and difficulties associated with acquiring the related property in terms of easements or right-of-way. These difficulties include the time, effort, and costs to negotiate settlement terms, at times, with reluctant property owners, possible displacement of residents, locating alternative housing, possible negative public perception, and disruption of businesses among other things. The difficulties must be weighed against the benefits which include things such as citizen safety, property protection from flooding, and traffic improvements during flooding periods.

Due to these space limitation concerns, improvements requiring the smallest footprint such as a WPA-type mortared wall with a concrete bottom were selected for detailed analysis and cost estimating. The use of a more natural (rock, earth) channel design, which typically requires a relatively larger footprint, constitutes a possible design alternative even though space requirements would be greater and costs could be somewhat higher compared to an enlarged WPA-type channel. Further, the proposed channel enlargement in the affected sub-reaches having the existing WPA channel will consist of removal of one or both sides of the channel bank (side various depending on location), widening along that side of the channel, and reconstruction of a similar, mortared rock wall (unless an alternative natural channel solution with rock is determined to be preferable during project design). In some locations, the channel bottom will be saw-cut at a safe distance of any remaining wall and repaired and extended to fit the new channel. In providing cost estimates it was assumed that 75% of the WPA channel walls would be replaced and the remaining 25% would be preserved. Preserving certain select portions of these channel walls is proposed due to their historical nature, the concern that replacing certain sections would possibly impact existing infrastructure and/or homes, as well as the fact that certain portions of the existing walls appear stable and are functioning well. During final design, value engineering should be performed to insure that any of the retained sections of the existing WPA channel walls are structurally sound. Final selection of the channel type should be made during the project engineering design process. Channel design options are discussed further in Section 6.2.

Finally, there is considerable interest in the possibility of advancing the idea of acquiring a much larger portion of the flood prone area, such as the FEMA floodway, along the IC-3 reach. The prevailing thought of this idea would be to expand the property buyout approach to include large numbers of the most flood prone structures in this reach. Further investigation beyond the scope of this SWMP will be required to fully understand the costs and benefits of this approach.

Due to the numerous changes in channel improvements within the eight sub-reaches, the HEC-RAS stationing is used below in certain instances to describe the beginnings and ends of the improvements.

IC-3A (From near the Elmwood Drive dead end upstream, about 1,200 ft downstream of Lindsey St., to near Madison St. dead end, including a road crossing upgrade at W. Lindsey St.)

The IC-3A solution calls for replacing the existing culvert system (three 8-x-6-ft RCBs) at Lindsey Street with a 20 inch depth box beam bridge consisting of two 30 ft spans, a middle bent, a concrete bottom, and a raised roadway (2 ft) which, collectively, prevents overtopping for the 100-year baseline event. The raised road profile requires 375 ft of reconstructed roadway and five reconstructed driveways.

The proposed channel improvements in this sub-reach vary according to the following:

- Road crossing HEC-RAS stations:
  - Lindsey Street - 10944
- HEC-RAS stations 9700 to 10650:
  - Trapezoidal, 15 ft channel bottom width
  - 1:5:1 side slopes
  - Articulated block lining
  - Overbank benching
- 10650 to 10994:
  - Channel transitions into a rectangular channel downstream of Lindsey Street
  - 40 ft bottom width at 10876, further transitions to 60 ft at Lindsey Street bridge
  - Vertical side slopes
  - Articulated block lining on channel bottom except concrete lined under proposed Lindsey Street bridge
  - Overbank benching from 10650 to 10876
- 10994 to 11320 (end of IC-3A sub-reach):
  - Trapezoidal, 20 ft channel bottom width
  - 1:5:1 side slopes

As discussed above, typical cross sections for various proposed channel designs is presented in Section 6.2. The bridge and channel improvements remove 11 of the 14 structures (buildings) from the baseline floodplain.

Stream conveyance improvements and stabilization in urban setting

IC-3B (From near the Madison St. dead end upstream to a location about 150 ft downstream of W. Boyd Street., including a crossing at W. Brooks Street)

The IC-3B solution involves replacing the existing concrete slab bridge at Brooks Street with a 20-inch-depth box beam bridge consisting of one 50-ft span, a concrete lined trapezoidal cross section through the bridge with a 20 ft bottom width and 4:1 side slopes which prevents overtopping for the 10-year event.

The proposed channel improvements are:

- Road crossing HEC-RAS stations:
  - Brooks Street – 12351
- 11320 to 12980
  - trapezoidal, 20 ft channel bottom width
  - 1:5:1 side slopes
- 12980 to 13637
  - Transitions from trapezoidal channel (20 ft bottom width, 1:5:1 side slopes) to rectangular channel, 40 ft channel bottom width and vertical side slopes at 13637
  - Articulated block lining used from 12980 to 13458
  - At 13458, bottom width at 30 ft and 1:1 side slopes
  - Concrete bottom and sides used from 13458 to 13637

The bridge and channel improvements remove 19 of the 32 structures (homes, businesses) from the baseline floodplain.

IC-3C (From a location about 150 ft downstream of W. Boyd St. upstream to just below McNamee St., including road crossing upgrades to W. Boyd Street and S. Pickard Ave.)

IC-3C includes replacing the existing slab bridge at Boyd Street with a 20-inch-depth box beam bridge consisting of one 50-ft span, concrete-lined bottom, and the roadway being raised by 1 ft. Raising the roadway elevation results in street reconstruction of 375 ft along Boyd Street and 550 ft along Pickard Avenue. Five driveway modifications will be required along Boyd Street and four will be required along Pickard Avenue. Proposed modifications also call for Pickard Avenue's existing slab bridge to be replaced with a four 10-x-6-ft RCB culvert system. The Pickard Avenue expansion will primarily occur on the right side of the channel which will expand to 43 ft to accommodate the culvert system. Pickard's top of road will be raised to approximately 1,145.1 ft elevation to accommodate the culvert system and local roadway work. These bridge improvements prevent overtopping for 50-year flood event at Boyd Street and for the 10-year event for Pickard Avenue.

The proposed channel throughout this entire reach will be expanded to a bottom width of 40 ft, except at road crossings, with a concrete bottom and vertical side slopes constructed of mortared rock in WPA style. The bridge, culvert, and channel improvements remove 6 of the 13 structures (buildings) from the baseline floodplain.

IC-3D (From just below McNamee St. upstream to just upstream of Symmes St., including road crossing upgrades to McNamee St., S. Flood Ave., and W. Symmes St.)

This sub-reach solution involves replacing the existing road crossing openings at McNamee Street with four 10-x-6-ft RCBs, Flood Avenue with three 10-x-6-ft RCBs, and Symmes Street three 10-x-6-ft RCBs which accomplishes 10-year overtopping protection at all three locations. For the McNamee Street crossing, the expansion will occur primarily occur on the right side of the channel, which will expand to 43 ft to accommodate the RCBs. The top of road will be increased to approximately elevation 1,146.5, which will require the reconstruction of approximately 205 ft of the roadway (transition to existing intersection with Pickard) and will impact one or two driveways and may impact Lions Park sidewalks adjacent to the construction. For the Flood Avenue crossing area, the expansion will be to the right side of the channel and the section through the bridge will have a 32 ft bottom width in order to accommodate the RCBs. The top of road elevation will also be raised by 1 ft from 1,147 ft to 1,148 ft elevation. This raising of the road will require the reconstruction of approximately 170 ft along Flood Avenue which will impact three to four driveways. For the Symmes Street crossing, the expansion will be to both sides of the channel and the section through the bridge will have a 32 ft bottom width in order to accommodate the RCBs. The top of road elevation will also be raised by 1 ft from 1,148 ft to 1,149 ft elevation. This raising of the road will require the reconstruction of approximately 110 ft along Symmes Street impacting two driveways.

The proposed channel throughout this entire reach will be expanded to a bottom width of 30 ft with vertical side slopes constructed of mortared rock in WPA style. There are proposed buyouts upstream of Flood Avenue (4 structures) at a significant cost of almost $800,000 out of the total sub-reach cost of near $3.2 million. The culvert and channel improvements remove 17 of the 29 structures (buildings) from the baseline floodplain.

IC-3E (From just upstream of W. Symmes St. upstream to just below Main St.)

This sub-reach solution does not include any bridges or culverts. The proposed channel throughout this entire reach will be expanded to a bottom width of 30 ft with vertical side slopes constructed of mortared rock in WPA style. This solution also calls for replacement of a school footbridge at station 16300 with a new bridge. There are 12 proposed buyouts in this sub-reach at a cost of almost $2.2 million out of a cost of more than $3.4 million. The replacement of the school bridge and channel improvements remove 21 of the 25 structures (buildings) from the baseline floodplain.

IC-3F (A Main St. road crossing upgrade plus a short length of adjacent channel improvements)

The IC-3F solution consists of upgrading the Main Street crossing that presently has a 12-x-5.5-ft slab bridge opening to a three 10-x-6-ft RCB culvert system. In order to correctly reflect the flooding improvements associated with this solution, certain modeling actions were required. The baseline model developed from the previous LOMR models includes an abrupt 2.8-ft drop in the channel bottom immediately downstream of the Lahoma Avenue crossing. This drop is not reflected in the new, detailed topography for the City of Norman or in the photographs taken of the stream during this study. The topographic data does show a drop of approximately 2-ft between the downstream end of the Main culverts and the downstream end of the alley crossing immediately adjacent to the Main Street culverts. It appears that this drop was modeled in the wrong location in the previous LOMR models. For the proposed solution, it was assumed that the channel would be lowered from the alley crossing to just upstream of Gray Street to roughly correspond to the situation reflected in the baseline model. However, the drop was moved away from the downstream face of Lahoma Avenue in order to smooth out the impacts of the drop through critical depth caused by the abrupt change in the bottom elevation of the channel. Cross sections 17225 and 17230 were added to the model in order to reflect the new location of the drop. The approximately 2-ft drop in the channel is necessary in order to pass the 100-year baseline flows at Main Street without overtopping. Without the additional vertical clearance, the crossing would have to be made wider than is realistically possible given the presence of businesses immediately adjacent to the Main Street culverts.

IC-3G (From just above Main St. upstream to just above W. Tonhawa St., including road crossing upgrades to W. Gray St., N. Lahoma St., and W. Tonhawa St.)

IC-3G calls for constructing new culvert systems at W. Gray Street (three 9-x-5-ft RCBs), N. Lahoma Street (three 9-x-5-ft RCBs), and W. Tonhawa Street (three 7-x-5-ft RCBs) which provides overtopping protection for the 10-year flood at all three crossings. The Gray Street upgrade includes the lowered channel bottom discussed above for the Main Street upgrade and does not require raising the roadway. The proposed channel will be expanded according to:

- Road crossing HEC-RAS stations:
- W. Gray Street – 17140
- N. Lahoma Avenue – 17357
- W. Tonhawa Street – 17559
- 16970 to 17370
- Rectangular, 30 ft bottom width
- Vertical side slopes, mortared rock walls
- 17370 to 17574
- Rectangular, 25 ft bottom width
- Vertical side slopes, mortared rock walls

Proposed buyouts in this sub-reach include three structures upstream of W. Gray Street that cost about $316,000 whereas the total costs are almost $1.7 million. The culvert and channel improvements remove 12 of the 22 structures (buildings) from the baseline floodplain.

IC-3H (From just above W. Tonhawa St. upstream to just above N. Webster Ave., including road crossing upgrades at W. Daws St., N. University Blvd., and N. Webster Ave. (N. Park Ave. crossing upgrade not included as this street is assumed removed as part of the Andrews Park stormwater detention modifications)

Solution IC-3H calls for replacing the existing bridge slabs at W. Daws Street (three 7-x-4-ft RCBs), N. University Boulevard (three 7-x-4-ft RCBs), and N. Webster Avenue (three 7-x-3-ft RCBs). The proposed rectangular channel will be expanded to a bottom width of 25 ft throughout the entire sub-reach. The sides shall be constructed of mortared rock in WPA style. Proposed buyouts in this sub-reach include two structures that cost about $157,000 out of the total costs of almost $1.5 million. The culvert and channel improvements remove 48 of the 64 structures (buildings) from the baseline floodplain.

Solutions to stabilize stream erosion problems in lower Imhoff Creek extend for over 5,000 ft and are substantial. Two solutions (IC-1 and IC-2) have been developed and are somewhat similar as both are aimed at stabilizing a significant stream degradation process that includes down cutting of the streambed, widening of the creek between its banks through ongoing bank failure and collapse, destruction of numerous trees, backyard fences, and the loss of usable property. The stabilization solutions are based on using natural materials, laying back slopes where possible, and adding mechanically stabilized earth (MSE) structures in other locations where there are space limitations. In an effort to save costs, the conceptual solutions basically try to stabilize the eroded stream cross sections in their present condition although excavation will be required in certain locations. As shown in Exhibit 6-7a in Appendix H, Solution IC-1 begins approximately 800 ft downstream of Highway 9, upstream of the creek's confluence with the Canadian River, and extends upstream to SH 9. IC-2 begins at the highway and extends upstream to a point about 2,000 ft upstream of Imhoff Road. Section 6.2 provides a discussion of these recommended stabilization techniques including typical design sections.

Stable stream section using low-flow channel and vegetated side slopes

As outlined in Section 5 and generally located in Exhibit 6-7b in Appendix H, the local area in the vicinity of the Lindsey Street and McGee Drive intersection, including a large part of the west-central Imhoff Creek watershed area, represents one of the worst localized flooding problems in Norman. The IC-5 solution, herein referred to as the “West Central Imhoff Creek Watershed Improvements,” was developed to a 10-year flood level and will alleviate this problem for all but very large storm events. The 10-year protection level was selected instead of a higher level such as the 100-year level in order to generally balance the costs of the required improvements with benefits received. Since the flooding problem occurs frequently, the main goal was to stop the frequent flooding while also providing significant, though not total, protection during even large events such as a 100-year event (1% annual chance). Additionally, for events greater than the 10-year event, some additional drainage relief is provided by a relatively new system referred to as the Phase I Baldischwiler system that drains local runoff to Imhoff Creek through a concrete channel located just south of the Lindsey-McGee intersection that connects to a large storm sewer system that flows to the creek, outfalling approximately 1,300 ft south of Lindsey Street. IC-5 improvements discussed here would take the place of Phases II and III as proposed in the Baldischwiler (1997) and Baldischwiler (2001) reports previously developed for the City of Norman to alleviate the Lindsey-McGee flooding problem.

As presented in Figure 6-1, which provides system sizes, the IC-5 solution basically provides protection to this west-central area of the Imhoff Creek watershed by collecting stormwater into a large storm sewer system that begins at Camden and Rosedale in its north subsystem, extends south along Rosedale, then west to McGee, continues south along McGee to Lindsey, picks up flows from the eastern subsystem in the intersection area, then flows from the Lindsey-McGee intersection westward along Lindsey to its intersection with Murphy, goes south along Murphy to Briggs, heads west along Briggs to a drainage channel adjacent to IH 35, then flows south in the drainage channel to SH 9, passes under SH 9, and finally completes the diversion to the Canadian River just downstream of the IH 35 crossing of the river. A key IC-5 subsystem begins at the junction with a local neighborhood storm drain system located approximately 800 ft east of the Lindsey-McGee intersection, flows westward along Lindsey to the Lindsey-McGee intersection where it joins the north subsystem in the intersection area. The total amount of area diverted from Imhoff Creek amounts to almost 310 acres. Many local residents are convinced that at least a portion of this 310-acre area was previously diverted to Imhoff Creek from Merkle Creek as the area was developed. Another significant aspect of the IC-5 diversion is that it removes a significant amount of stormwater from lower Imhoff Creek where serious stream flooding and erosion problems exist. Finally, the IC-5 solution proposes a separate new storm drain system that collects stormwater along Wylie Avenue then along Lindsey Street, ultimately extending to Imhoff Creek near the Lindsey Street creek crossing as shown in Exhibit 6-7b in Appendix H and Figure 6-1.

Stream protection along steep bank

Little River Mainstem

Two solutions (LR-1 and LR-2) have been conceptually developed along the Little River mainstem. These two solutions are located in Exhibit 6-9 in Appendix H with pertinent information provided in Table 6-2. The LR-2 solution alleviates a stream flooding problem by acquiring a mobile home park area that is flooded by medium and large events which endangers residents and causes recurring damage. A majority of the units or lots are in the baseline (100-year) floodplain although a few may be outside of this floodplain. It is realized that it is difficult to displace residents as they will be required to find another home but their safety is also of concern.

The LR-1 solution addresses a severe stream erosion problem located about 2,000 ft upstream of 12th Avenue NW. The stream stabilization improvements will protect the river bank from the erosion that is occurring along about 350 ft of river. This solution will also protect a residence that will soon be threatened by the erosion.

No localized problems were identified in the watershed.

Little River - Tributary G

The TGLR-1 solution outlined in Table 6-2 and shown in Exhibits 6-11 and 6-12 in Appendix H provides protection for a stream flooding problem at Franklin Street located west of the IH 35 highway corridor. The solution will significantly enlarge the undersized road crossing opening from the existing 10.5-x-7 ft corrugated metal pipe (CMP) to five 10-x-10-ft RCBs. The much larger culvert system was required to offset the upstream backwater effects associated with raising the local roadway in the crossing area by approximately 1.5 ft. The roadway was raised to be above the flood levels caused by the capacity limitations of the IH 35 culverts. Preliminary and final design should further investigate additional downstream improvements to the IH 35 culvert system to reduce flood levels in the Franklin Street area.

No stream erosion or localized problems were identified in the watershed.

Little River - Woodcrest Creek

As shown in Table 6-2 and Exhibits 6-13 and 6-14 in Appendix H, the solutions in the Woodcrest Creek watershed include a proposed stormwater detention facility on the creek upstream of E. Rock Creek Road (WC-1A), channel improvements downstream of Sequoyah Trail (WC-1B), a provisional upgrade to the culvert opening for Sequoyah Trail (WC-2) to be included only if WC-1A is not built, and stream erosion protection south (upstream) of Sequoyah Trail (WC-3). These improvements cost approximately $3.3 million and are needed to address the watershed's problems that include 20 homes in the baseline (100-year) floodplain footprint, two road crossings that flood (Sequoyah Trail and Nantucket Road), and a stream erosion location. The E. Rock Creek Road crossing was initially considered a problem but an ongoing improvement project and the WC-1A detention facility will alleviate this problem. Again, the WC-2 upgrade to Sequoyah Trail will not be needed if the WC-1A facility, or equal, is built. The WC-1A detention facility impacts the other remaining stream flooding solution (WC-1B) as modeling indicated that it could reduce 100-year baseline peak flows at its discharge point above E. Rock Creek Road from 2,050 cfs to a 510 cfs. This peak flow reduction progressively dissipates in downstream reaches but the facility still has a significant impact on peak flows and proposed improvements in downstream reaches. Other pertinent information conceptually developed for the WC-1A facility includes:

- Contributing drainage area – 576 acres
- Facility footprint – approximately 43 acres
- Outflow pipe – one 72-inch RCP, with invert elevation at 1,151.5 ft
- Elevations:
  - Top of Dam – 1,175 ft
  - Spillway elevation/width – 1,170 ft, width 28 ft
  - Outflow invert – 1151.5 ft
  - Peak storage elevation for 100-year baseline event – 1,168.2 ft
- Dam height – 18.5 ft
- Peak Inflow – 2,050 cfs
- Peak outflow – 510 cfs
- Peak stormwater storage – 144 ac-ft

The WC-1A facility was conceptually designed as a "dry" detention facility so that the area could basically remain in its natural state for a vast majority of the time. The facility area would be inundated only briefly (a few hours) following large runoff events. Recreational trails could be built in the facility area including along the dam's top which would offer a point to view the general area. Due to the significant nature of the WC-1A facility, it is realized that a more detailed look at stormwater detention design options in the upper Woodcrest Creek watershed may result in the facility being downsized or replaced with the possibility of making up the needed detention from other locations. One such location to incorporate future stormwater detention might be in the existing lake in the Sutton Wilderness area to the east of the WC-1A facility. Additionally, ultimate designs will need to insure that water does not back up into upstream areas outside of the facility area without making accommodations. It is pointed out that costs to purchase the property is included in the solution's cost estimate even though the City may have recently obtained a large portion of the needed land area. Including the land cost was done since use of the property as a detention facility may require that the area be funded with stormwater funds. If the City wants to forego that "purchase" with stormwater funds for a large part of the needed land area, the costs could be reduced by over $600,000 of the estimated $2.5 million project total as shown in the cost estimate for WC-1A in Appendix H.

The WC-1B channel improvements consist of a benched channel with 3:1 side slopes for a 1,200 ft stream reach below Sequoyah Trail. These improvements were sized assuming that the upstream WC-1A detention facility is in place which indicates the magnitude of the flooding condition along the creek in this reach. Section 6.2 below outlines the types of stream stabilization techniques typically planned for such improvements.

As mentioned above, the WC-2 solution for flood overtopping of Sequoyah Trail was developed for a provisional solution if the WC-1A detention facility was not built. If the detention facility is built, then the WC-2 upgrade would not be needed. This solution calls for adding one 8-x-7-ft RCB to the existing culvert system in order to provide protection for the 10-year flood event. It was determined that protection to a higher level would require raising the roadway profile which would block high flows requiring a very large culvert system to be built.

The WC-3 stream erosion (WC-3) solution is located in a short 200-ft reach upstream of Sequoyah Road and represents only a moderate problem although it could get worse in the future. If final design of the WC-1A solution includes control of small frequent runoff events, future stream erosion could be significantly reduced in the downstream reaches of the creek including the WC-3 reach.

No localized problems were identified in the watershed.

Merkle Creek

An important part in assessing the impact that proposed solutions make in Merkle Creek involves the consideration of the large stormwater detention facility recently completed by private interests and located immediately upstream of W. Robinson Street. Since this detention facility has such a positive impact on reducing peak flows and downstream flooding, it was decided that it should be considered when determining the impact that proposed solutions make on reducing flooding in the watershed. Therefore, the hydrologic and hydraulic models developed and used for analyzing flooding conditions for post-solution conditions included the flow reductions caused by the detention facility. Primary performance information about the stormwater detention facility is:

- Peak 100-year baseline inflow – 1,642 cfs
- Peak 100-year baseline outflow – 580 cfs
- Maximum stormwater storage volume, 100-year event – 155 ac-ft

There are 51 structures that are located in the 100-year baseline floodplain and two road crossings that are overtopped by floodwaters. As shown in Exhibit 6-15 in Appendix H, the four solutions developed for Merkle Creek involve alleviating or mitigating these stream flooding problems and all take advantage of the peak flow reduction afforded by the stormwater detention facility located immediately upstream of W. Robinson Street. The 100-year and 50-year baseline flood profiles shown in Exhibit 6-16 in Appendix H indicate the degree in which the solutions drop the baseline water surface elevation along the creek through the reaches impacted by the watershed's four solutions. Property acquisitions for the solutions conceptualized in the Merkle Creek watershed are quite expensive so later, more detailed, design efforts should further evaluate the costs versus benefits associated with these buyouts and look for ways to avoid some or all of these costs, if possible.

The MC-1 solution addresses the 15 structures that are in the baseline 100-year floodplain footprint and located between 24th Avenue SW and Main Street. Currently, there are three 10-x-11-ft RCBs that span 80 ft across 24th Avenue SW. The proposed solution is to add an additional box of the same size on the left side of the existing culvert.

In addition, channel modifications downstream of the culvert to accommodate the additional culvert are proposed. The length of the channel improvements extends approximately 135 ft downstream of 24th Avenue SW and includes a bottom width of 30 to 50 ft and 3:1 side slopes. These improvements remove eight of the 15 flooded structures from the baseline floodplain.

The MC-2 solution in the Main Street area is by far the biggest and most expensive solution in the watershed at a cost of over $6 million. This solution is related to the MC-2A and MC-2B solutions as the upstream road crossings at Crestmont Street and Iowa Street experience flooding simply from a moderate amount of backwater caused by the existing Main Street culverts. However, the principal problem is that the Crestmont Street and Iowa Street top of road elevations are several feet lower than Main Street top of road elevation. In fact, the Crestmont and Iowa Street tops of road are both lower than the culvert opening top elevation at Main Street. This means that it is possible for stormwater to be flowing through the culverts at Main Street near, but below, the top of its culvert opening while at the same time Crestmont and Iowa Streets would be inundated.

There are 14 structures located in the 100-year baseline floodplain footprint between Main Street and Crestmont Street that the MC-2 solution addresses. The MC-2 solution at Main Street involves removing the existing three 10-

x 11.5-ft RCB system, replacing it with a three 12-x-12-ft culvert system, providing 1,500 ft of stream capacity improvements, and buying out four flood prone properties. The additional height of the proposed culvert can be accommodated due to the proposed lowering of the culvert invert. The culvert inverts can be lowered since there is a fairly steep drop in the creek bottom just downstream of Main Street. To maximize the benefit from the creek bottom changes, channel modifications were made beginning approximately 300 ft Street downstream of Main Street and extending upstream to the downstream face of Crestmont. This will give the channel a nice gradual slope. The costs for acquiring the four most-expensive properties amount to about $2.4 million, which represents almost 40% of the near $6.1 million total costs of the solution. The long runs of large box culverts also contributes heavily to the total costs for MC-2 shown in Table 6-2 with details provided in Appendix H. The MC-2 solution improvements remove eight of the 14 structures from the baseline floodplain although four of these structures were removed due to buyouts. Although this solution lowers water surfaces considerably, when considered alone it does not prevent Crestmont and Iowa Street from overtopping during the 50-year design storm.

The MC-2A solution at Crestmont Street includes removing the existing three 10-x-7.5-ft RCB system, replacing it with a three 12-x-8-ft RCB system, raising the Crestmont roadway by 1 ft in order to provide overtopping protection for a 50-year flood event, and acquiring two properties. These two properties targeted for acquisition cost almost $1.2 million, which is almost 70% of the total $1.75 million costs for the solution (see Appendix H). Again, without making improvements at Main Street, the solutions for Crestmont and Iowa Streets will not be sufficient even with the proposed changes. Combined with the MC-2 solution, MC-2A removes 14 of the 21 homes located in the baseline floodplain. This overall solution allows the culverts at Crestmont to pass the 50-year design flows.

The MC-2B solution at Iowa Street calls for removing the existing two 10-x-5-ft RCB system, replacing it with a three 11-x-6-ft RCB system, and raising the roadway by 1 ft. The MC-2 improvements at Main Street assist the solutions for Crestmont and Iowa Streets in mitigating the problems, to the extent possible. This solution, while combined with solutions MC-2A and MC-2B will remove the one structure presently located in the baseline floodplain and allow the Iowa Street culverts to pass the 50-year design flows.

Table 6-2 along with Exhibits 6-17a, 6-17b, 6-17c, 6-18a and 6-18b in Appendix H adequately discuss these solutions and display the associated benefits.

No stream erosion or localized solutions were required in the watershed.

Ten Mile Flat

The TMF-1 localized solution, located in Exhibit 6-19 in Appendix H, is the only solution developed for this watershed and is fairly simple with channel capacity being increased with cross section enlargement and laying back of the channel side slopes. As shown in Exhibit 6-19 in Appendix H, the 100-year baseline and solution floodplains are considered to be the same for Ten Mile Flat Creek since future development is projected to be very limited. Additionally, the floodplain shown was taken directly from the 2007 CLOMR study performed by MacArthur Associated Consultants, Ltd. (2005). The CLOMR was approved by FEMA in 2007. Any detailed use of this information should use the 2007 CLOMR study and any updates since the information presented herein was geo-referenced and digitized from that earlier work.

No stream erosion or stream flooding solutions were required in the watershed.

6.2 Solutions Development Methodology

The solutions development methodologies discussed below cover stream flooding, stream erosion, local drainage and water quality. Stream flooding, stream erosion, and local drainage are discussed together as in most instances the proposed improvements involve providing stormwater detention to reduce downstream peak flows or a modification of the creek channel and/or drainage system conveyance system. In one instance, BC-6, a floodwall was selected as the best solution to provide flood protection. A floodwall simply acts in the same manner as a levee and prevents flooding from the source (likely a creek) from reaching otherwise flood-prone structures. It is designed to look like a typical concrete or rock wall, but it is water tight with a solid foundation and length to hold back floodwaters. Water quality is discussed separately and, as discussed above, is more programmatic in nature.

6.2.1 Stream Flooding, Stream Erosion, and Local Drainage

Beginning with the problem areas identified in Section 5, a screening process was developed for those stream flooding problems for which a solution was not obvious. For situations where there was not an obvious solution, alternative solutions were conceptualized and then “screened” based on their applicability and practicality with the goal of selecting the best solution for each respective problem. Solutions for some problems were straight-forward and did not require consideration of alternatives. For the problem areas for which more than one viable solution held promise, possible alternatives were generally evaluated in terms of their applicability. This process led to the ultimate selection of the most preferred solution or option to solve the problem.

Once preferred solution alternatives were identified, hydrologic and hydraulic modeling/analyses (see Section 4) and/or stream stability considerations based primarily on field reconnaissance were used to design and size the respective improvements such that the structures, roadways, and stream environment were protected to the targeted level. The solutions ranged from complex solutions that covered reaches extending for thousands of feet to small conveyance improvements for identified localized problem areas. Although HEC-1 or HEC-HMS models were used to identify and solve stream flooding problems in the larger stormwater systems, general hydrologic (Rational Method) and hydraulic (Manning Equation) methods were used for localized drainage analyses. For each respective stream flooding project or solution, the design conditions (locations, sizes, improvement types, characteristics, etc.) were converted to hydrologic and/or hydraulic modeling input and evaluated with the models to develop the project’s performance. The solutions developed include property acquisitions, creek modifications (natural, bio-engineered, historic WPA-type, grass lined, and concrete lined), bridge/culvert upsizing, creek bed and bank stabilization, stormwater detention ponds, flow diversions, storm sewer size increases, street storm inlet additions, property buyouts, drainage easement and/or rights-of-way acquisition, and others.

The level of protection for most stream flooding solutions varied somewhat although improvements associated with channel capacity and roadway bridge openings used projected 100-year baseline (future) peak discharges while roadway culvert openings used 50-year peak flows. Exceptions occurred in special cases where 10-year protection was judged to be preferred due to limited space and the costs associated with larger improvements. Such cases included channel improvements and certain roadway crossings along Imhoff Creek, the west-central Imhoff Creek watershed area (Lindsey Street – McGee Drive intersection flooding problem), and a few others. **An important consideration is pointed out here involving the planning and engineering needed to ensure that problems in one area are not created or made worse while solving a problem in another area. This is often a concern and consideration when creek conveyance is improved to lower flood levels by improving creek channels and/or opening up constricted culvert/bridge openings. Proper design considerations must be addressed and related hydrologic and hydraulic analysis must be performed during project design phases to prevent increased flooding in any areas as a result of project “improvements.”**

The natural and/or bio-engineered design solutions used for certain stream flooding situations and all stream stabilization projects use a combination of techniques including channel grade (slope) control, streambank armoring, slope flattening, and bank toe protection. Stable channel designs to stop and/or prevent existing and future stream erosion/instability need to incorporate sediment discharge principals in concert with hydrologic and hydraulic considerations. The design of stable streams requires sediment transport analyses. These analyses include the determinations of design stream longitudinal slopes and cross-section configurations to handle the channel-forming flows (often less than a 2-year event), sediment discharges, and flood discharges.

The materials used to achieve these techniques include rock riprap, erosion protection fabric, “geogrids” to hold the structure together, and select vegetation. As shown in Figure 6-2, one stabilization type involves “laying back” the streambank slope to achieve stabilization. As presented in Figure 6-3, another method used is commonly referred to as a mechanically stabilized earth (MSE) structure in which the layered geogrids and construction methods allow the structure to function as a single stable mass rather than an area that can erode away in pieces.

Finally, stream grade control structures as illustrated in Figure 6-4 were used where needed to flatten slope and control flow velocities to non-erosive levels. Photos of these types of solutions that use natural materials and a more environmentally sensitive footprint are also shown here to better indicate these types of improvements.

Typical cross sections for improvements along key locations, including Bishop Creek between State Highway 9 and Constitution, Brookhaven Creek downstream of Main Street, and Imhoff Creek upstream of Boyd Street, are provided in figures 6-5, 6-6, and 6-7, respectively.

As provided in Table 6-2, general cost estimates for each selected or recommended project solution were developed using unit costs and estimated quantities for the construction bid items required to construct the respective projects. Appendix H contains a detailed cost estimate breakdown of each project's cost estimate including the applicable bid items, estimated quantities, units of measurement, unit costs, and bid item costs. These bid item costs are summed then a 20% contingency was added to obtain a total costs for each project. The unit costs were developed from bid tabulations obtained from ODOT, the City of Norman, and contractors. Quantities were obtained using a variety of means such as obtaining channel cut and fill as well as culvert/bridge sizing from HEC-RAS modeling, measuring heights and distances of improvements from the local GIS maps, estimating stream erosion stabilization needs based on field measurements and design water levels (2-year event), and estimating general contractor costs and other project costs from standard relationships. These standard relationships used were based on the following percentages of the total bid item costs not including any of the costs from these items themselves and before including the 20% contingency.

- Mobilization – 15%
- Preparation of ROW – 4%
- Utility relocation – 5%
- Barricades/signs/traffic handling – varies 3%–6%
- Site stabilization – 7%
- City project management – 10%
- Design engineering – 15%
- Significant permitting (U.S. Army Corps of Engineers [USACE] CWA Section 404, etc.), where required – 5%

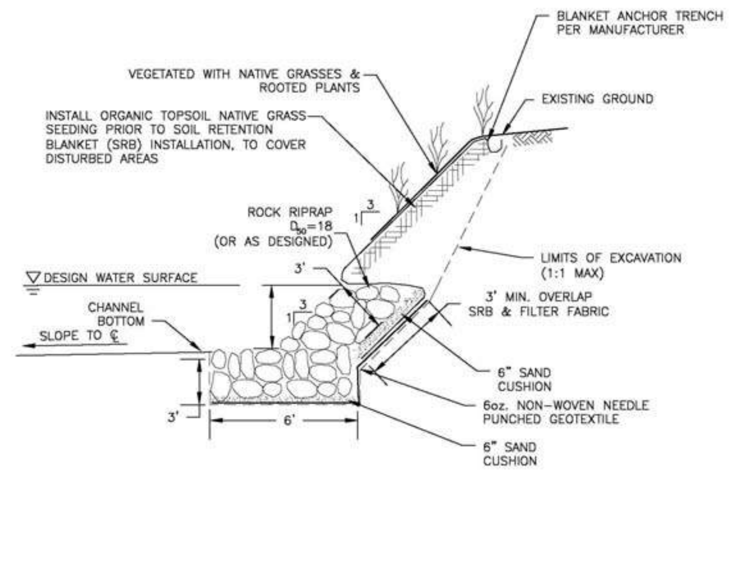


FIGURE 6–2
TYPICAL SLOPE LAY–BACK & ROCK RIP–RAP BANK STABILIZATION
N.T.S.

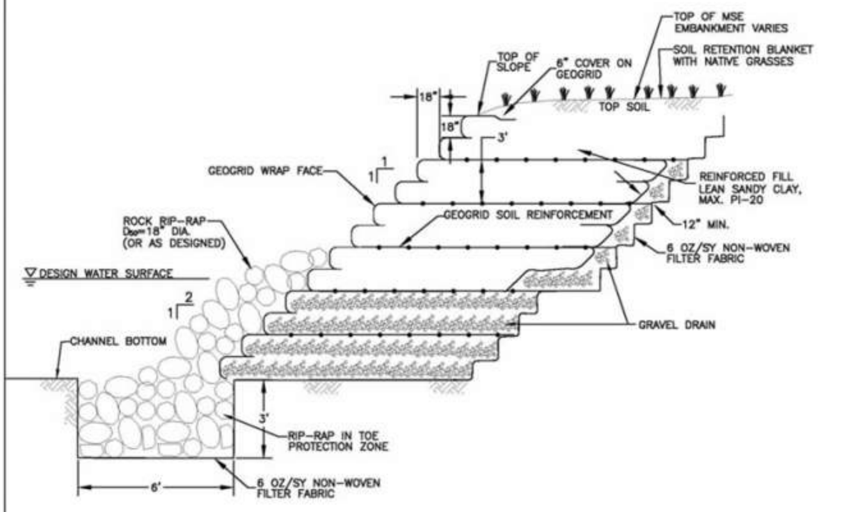


FIGURE 6–3
TYPICAL MECHANICALLY STABILIZED EARTH (MSE) SECTION
N.T.S.

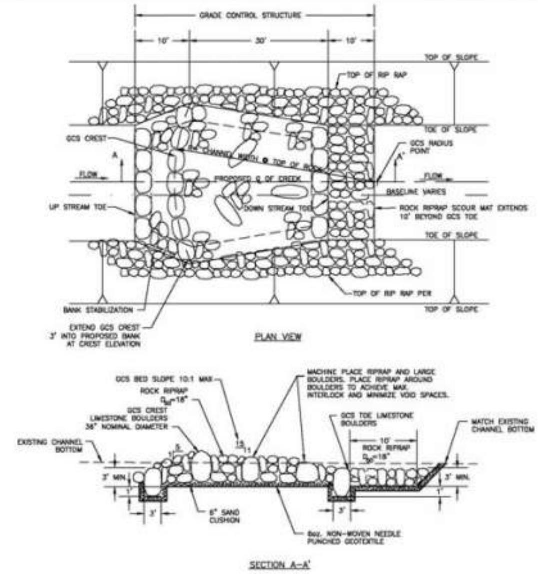


FIGURE 6-4
ROCK GRADE CONTROL STRUCTURE
N.T.S.

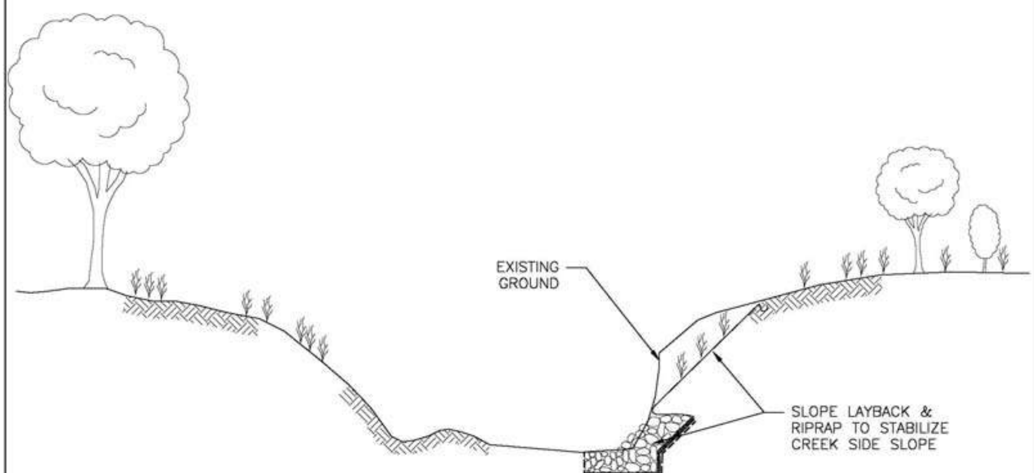


FIGURE 6–5
BISHOP CREEK STABILIZATION BETWEEN STATE HWY 9 & CONSTITUTION
N.T.S.

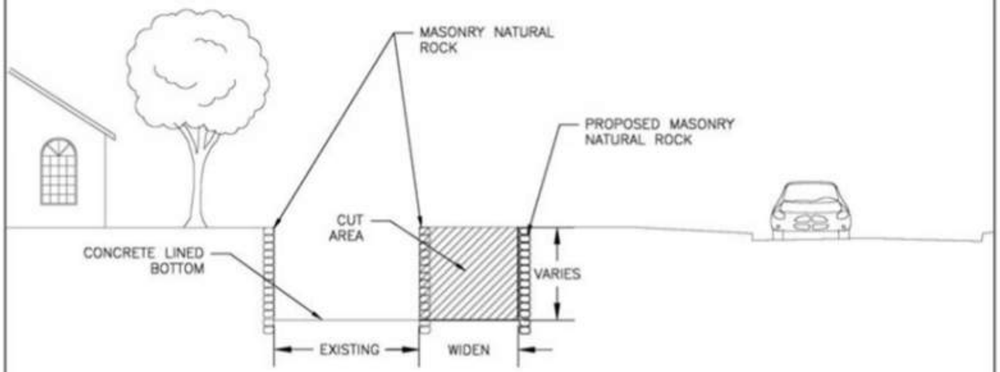


FIGURE 6–6
IMHOFF CREEK WIDENING UPSTREAM OF BOYD STREET
N.T.S.

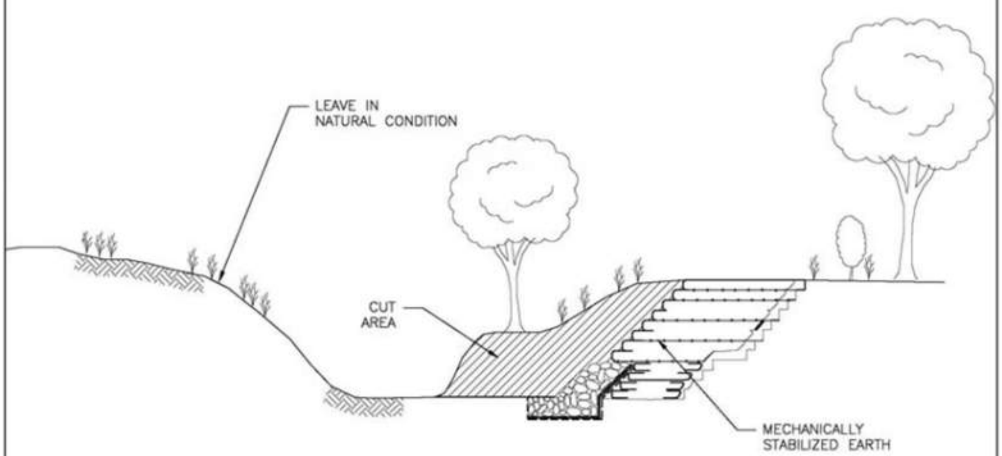


FIGURE 6–7
BROOKHAVEN CREEK STABILIZATION/WIDENING DOWNSTREAM OF MAIN STREET
N.T.S.

Stabilization using rock riprap

MSE stabilization with rock riprap

MSE stabilization with gabions and ledge rock in dense urban setting

Another key issue and cost item involved developing project costs for new drainage easements and/or rights-of-way needed in order to assure construction of project improvements on property either owned by the City or made available through City easements. These easements will be needed for a variety of purposes including gaining access for construction, the construction footprint needed to make the improvements, inspections, and maintenance. Costs were obtained from the City staff based on historical costs and were based on the location of the problems and the adjacent local land use. In a few locations with special circumstances, easement costs were increased somewhat to cover possible difficulties. The types of easement needed to be purchased and the cost per square foot is given below:

- Agricultural – $0.35/SF
- Residential – $2.00/SF
- Commercial – $3.50/SF

Citywide, there was one project requiring an agricultural easement, 14 projects that required residential easements, and 12 projects requiring commercial easements. The size of the respective project easements were determined based on the area needed for future construction, maintenance, and inspections. In many instances, existing drainage or stormwater easements and/or rights-of-way were available to satisfy part or all of project needs. The cost estimates in Appendix H outline the type, quantity, and costs for drainage easements for each individual project.

Although an effort was made to minimize property buyouts, 12 of the projects include entire property buyouts since additional area was needed to build the improvements or it was impractical to make the improvements large enough to protect the property’s structures. As shown in the cost estimates in Appendix H, a total of 62 properties located throughout the City were identified for buyout in the proposed solutions. Since the solution designs are conceptual, the exact properties are not specified to avoid controversy and can be better defined in subsequent more detailed engineering and design efforts if the City wants to pursue such acquisitions.

2025 Stormwater Project Prioritization Criteria

An important aspect of the Capital Improvement Program for the identified stormwater problems involved a prioritization of the solutions. This prioritization process allows the city to identify the most critical projects for addressing the stormwater needs in Norman. This prioritization process is an important tool for the City to use along with other information in recommending the order that solutions might be implemented or how they might be financed. The prioritization system developed and evaluated each project's solution in terms of its ability to solve the problem being considered, provide for public safety, provide sustainability, use funding advantages, impart positive impacts on affected neighborhoods and the environment, assist in other important issues like transportation, and determine its overall price affordability.

Each prioritization criterion was given a weight based on its importance and input from the Stormwater Subcommittee. As part of the 2025 plan update, the factors were split into three categories to better understand where points are coming from for each project. Those categories include economic, social, and ecological concerns. The various factors are shown in Table 6-3 along with scoring example of a project with a perfect score.

When evaluating a project using this prioritization matrix, each factor was evaluated by giving it a score between 1 and 3, with the highest score being three, a moderate score being two, a low score being one, and a rating of zero given is there was no relevance for the factor whatsoever. Once each criterion was scored for a project, the factor weight was multiplied by the rating to give a total score. The individual factor scores were then totaled to give a total prioritization score for the project. The higher the score, the greater the importance of the subject project.

After project prioritization scores were obtained, the total project scores were compared on a watershed, Ward, and city-wide basis as show in Appendix K.

One significant difference between the original 2009 prioritization method and the current version is using quantitative metrics to measure each of the factors. Those metrics are associated with a specific score and assigned to each factor. The descriptions below describe the methodology of how each factor is measured and what the associated score is for each metric.

Price Affordability

The Price Affordability criterion was measured based on the estimated total cost of the project. For the breakdown of each induvial cost per challenge area, please refer to Appendix I. For this specific criterion, having a lower estimated cost would make the project a higher priority. The only data needed to calculate the project specific score is the total estimated cost. The total score was then compared to the set ranges associated with each rating number shown in the table below.

Score	Price Ranges
0	> $4M
1	$2M-$4M
2	$600K-$2M
3	< $600K

Once the total cost was placed in the applicable price range, the final rating is given to the project. Price Affordability is identified as a “Most Important (Level 4)” prioritization criteria and, therefore, will have the highest-ranking factor weight number of 4.

Low Operations & Maintenance Cost

The Low Operations & Maintenance Cost criterion is used to rank what the potential operational and maintenance requirements a project will have. The higher the project score, the lower the anticipated operations and maintenance cost over the project lifetime. Therefore, each project starts at a rating of 3 and points are deducted according to the table below. The table describes the types of structures that would require long term maintenance and the associated points to be deducted.

Structures	Deductible Points
Detention Pond	3
Concrete Channel	2
Sag Inlet	1

If the project does not contain any of the structures, then it will remain at a rating of 3 and given a higher priority. If the project contains multiple structures from the list, the highest point value is used for deduction. In other words, if a project contains both a sag inlet and a concrete channel, it will receive a deduction of 2 points for the concrete channel only.

Degree of Economic Impact on Local Businesses

The Degree of Economic Impact on Local Businesses criterion is used to rank projects based on how local businesses are affected by potential flooding. If a proposed project is within an area that has a higher flooding chance, then that project will be given a higher priority. This is measured by the total area of each commercial building within the 100-year (1% Annual Exceedance Probability) FEMA Base Level Engineering (BLE) mapping. The AIM Norman 2045 Land Use plan was used for the locations of current and future commercial areas and Norman GIS Buildings layer for building locations. The overall project location boundary is used to determine the total number of buildings within the area and thus, the total area of the buildings. However, only the buildings affected by the 100-yr BLE mapping are used to calculate the total area of commercial buildings.

Once the total building area is calculated from the GIS layers, the final score for the project can be determined. See the table below for the breakdown of building area ranges and the corresponding score.

Score	Building area (sq ft)
0	>50K
1	50K – 100K
2	100K – 150K
3	> 150K

Funding Sources (potential leverage of available grant opportunities)

The Funding Sources criterion is used to rank projects based on whether the surrounding community area might qualify for grant funding due to low income. The data used to determine low-income percentages within Norman is from the Climate and Economic Justice Screening Tool. This tool was developed by the Council on Environmental Quality (CEQ) to show information about the burdens that communities experience. For the specific criteria, the data from the screening tool used was the low-income percentage. The data is easily exported from the website into a usable GIS layer. Within the layer, the "low medium household income as a percent of area income (percentile)" is coded as “LMI_PFS” and that data was used to measure the percentages for the proposed projects.

The higher the percentage of low median household income within the project area, the higher the score of the project. This is because of the higher chance of receiving potential grant funding with a larger percentage of low-income households.

Using the LMI_PFS data, each project area has an associated percentage. The percentages were divided into ranges that correspond to a project rating score according to the table below.

Score	Range of Low-Income Household Percentages
1	<40%
2	40% - 75%
3	>75%

Improve Economic Development/Redevelopment Potential

The Improve Economic Development/Redevelopment Potential criterion is measured by determining what type of land use the proposed project is located within. This measurement utilizes the AIM Norman 2045 Land Use Plan layer for the measurement. For this criterion, the higher the score, the higher the priority of the project. For each project, the following categories were applied to determine the number of points to assign:

- If the proposed project falls within Core Norman, 3 points
- If the proposed project area intersects a commercial zone, 2 points
- If the proposed project area intersects a Job Center (industrial zone), 1 point
- If none of the above, 0 points

Time to Implement or Construct

The Time to Implement or Construct criterion is used score projects based on the length of time it is estimated to take to construct the proposed project. There are many different reasons why a project will take longer or have delays. One measurable factor that is used to estimate this timeline is the total cost of the project. The higher the cost of a project usually means there is more to construct, or the level of construction is more complex. Other factors to consider are any permitting that needs to be completed before construction can start.

To measure this criterion, the total cost is considered to assign an initial score, and then points are deducted based on further criteria. See the table below to see how the project costs are associated with the initial scores.

Score	Total Cost Ranges
0	>10M
1	5M-10M
2	2M-5M
3	<2M

Once the initial score is determined, the project location is evaluated using GIS data to determine if there is either a *floodplain, railroad, or blue-line stream* present. If there is, the one point is deducted from the initial score. Only one deduction is allowed even if there is more than one potential deduction.

Ease of Right of Way Acquisition and Utility Relocation

The Ease of Right-of-Way Acquisition and Utility Relocation criterion is used to rank projects based on the expected complexity of constructing the project based on the project location. The less complex the project is expected to be, the higher score the project will receive. For this specific criterion, all projects start at a rating at 3 and the score is reduced depending on if the project location has any of the following categories present within the project area:

Categories	Deductible Points
Property Buyouts	1
Sewer Lines	1
Watermain	1

These categories were chosen due to their potential right-of-way acquisition and utility relocation complexity. If a proposed project has multiple categories, then the deductible points allowed to be additive. In other words, if the project would intersect both a City mapped sewer and water main, it would be deducted 2 points. If a project does not contain any of the categories, it will be given a higher rating and overall score.

Public Safety

The Public Safety criterion was quantified by calculating the total number of critical infrastructure facilities within the project area location buffer. The more critical facilities within a boundary, the higher priority the project. The following critical facility GIS layers were identified for this scoring using Normans' public GIS data and aerial imagery:

- Schools
- Medical Centers
- Police and Sheriff Stations
- Fire Stations
- Nursing Homes
- Bridges

The project area buffers were then overlaid with these identified layers and each type of critical facility was counted for each area. The number of critical facilities was added together to get the final score, with a maximum of three.

Potential for Recreation/Open Space/Connectivity for Linear Parks

The Potential for Recreation/Open Space/Connectivity for Linear Parks criterion is used to rank the projects based on the proximity to a City park. There is expected to be potential for collaboration with the proposed stormwater project to be designed within an existing park. Also, if there are flooding issues at or near a park, it could be preventing citizens from using the park space.

The closer the project is to a park, the higher the priority the project is and the higher the score is. The breakdown of scores associated with distances from a park are shown in the table below.

Score	Distance to nearest park (miles)
1	0.5 – 0.25
2	0.25 – 0.01
3	0

Beneficial Neighborhood Impacts

The Beneficial Neighborhood Impacts criterion was measured by the number of residential buildings within the 100-yr FEMA BLE mapping. The objective of this criterion was to determine how many residential homes are affected by potential flooding. The higher the project specific score, the higher the priority the project will be. Additionally, if any project includes stream stabilization, then it automatically gets the highest score value of 3. This stream stabilization score is included because significant stream erosion in a neighborhood setting has high potential for public safety risks

To find the total number of residential buildings, the Norman GIS Buildings layer was overlaid with the AIM Norman 2045 Land Use plan. The number of residential buildings that intersect both the project area buffer and the 100YR BLE boundary were counted.

The table below shows the ranges of counted buildings used to determine the score for this criterion.

Score	Ranges based on number of residential buildings
0	<5
1	6 to 12
2	13 to 22
3	> 23

Mobility or Effects on Transportation System

The Mobility or Effects on Transportation System criterion is used to rank projects based on their proximity to a major transportation route. If there is a potential flooding issue along a major transportation route, it is likely critical to repair to keep Norman's citizens safe.

The list below shows the scores associated with the effects on an intersecting transportation route. The score is not cumulative, so if the project intersects several of the transportation routes, then the highest score is used.

- *If the project location intersects a road that has an ACOG functional classification of “Collector” or greater, 1 point*
- *If the project location intersects the Sidewalk Completion Plan & Bike and Pedestrian Facilities, 2 points*
- *If the project location intersects the Transit Oriented Development (TOD) from the AIM Norman 2045 Land Use plan layer, 3 points*

GIS layers from the AIM Transportation plan were used for the road classifications and for the Sidewalk completion Plan & Bike and Pedestrian Facilities.

Integration with Other Projects

The Integration with Other Projects criterion is used to measure whether a project potentially correlates with another capital project planned in the same location by a different Master Plan. If there is a potential correlation, then that specific project is prioritized higher. To measure this criterion, the following criteria were used:

- *If the proposed project interests a planned roadway project, 3 points*
- *If the proposed project is within a park, 2 points*
- *If the proposed project interests a planned Water or Wastewater project, 1 point*

These criteria were chosen due to all three having a high possibility of integrating with a stormwater project. GIS layers from the AIM Transportation Plan, AIM Water Plan, and AIM Wastewater Plan were used to identify the potentially correlated projects. The Norman GIS data was used to locate the City parks.

The maximum score for each project is three, and the highest score was used.

Flood Risk Reduction

The Flood Risk Reduction criterion is used to measure a proposed project's potential to reduce the number of structures that flood during a 100-yr storm event. The floodplain mapping created for the solutions in the 2009 Stormwater Master Plan showed what structures would be removed from the 100-yr flooding if the solution was implemented. The number of structures to be removed was used to measure this criterion. The higher the number of structures removed, the higher the priority the project and score.

The table below shows scores associated with the number range of structures removed.

Score	Structures Removed from 100YR Flooding
1	1
2	2-5
3	>5

Erosion and Water Quality Significance

The Erosion and Water Quality criterion is used to rank projects based on its potential to improve known erosion issues and improve water quality. If the project can lead to improvements, then it was ranked as a higher priority project.

This criterion is measured by determining if the project has the following conditions:

- *If the proposed project area discharges directly into an impaired water body within three stream miles, 3 points*
- *If the proposed project area has known erosion issues in existing conditions, 2 points*
- *If the proposed solution does not contain concrete (gray infrastructure) solutions, 1 point*
- *If the proposed solution does contain concrete solutions, 0 points*

To determine if the proposed solution discharges directly into an impaired water body, the Oklahoma Department of Environmental Quality (ODEQ) GIS were utilized to identify where those water bodies are located. The 2022 303d Waterbodies GIS layer was downloaded from ODEQ and used determine this criterion score.

A project location's known erosion issues can be determined using the Reach Assessments included in Appendix D.

Once the proposed project location is determined to contain any of the possible conditions, then the associated rating is applied to the project score.

Environmental Enhancement and Resilience

The Environmental Resiliency and Enhancement criterion is used to measure a project's potential to improve the surrounding environment’s resiliency and ecological enhancement. If it does contribute to improvement, then it will be ranked as a higher priority project.

This criterion is measured by determining if the proposed project contains specific types of structures that can be categorized as green infrastructure and assigning a rating to each type of structure. The table below shows the types of structures, and the corresponding rating associated with them.

Rating	Structure Type
0	None
1	Benched Channel (floodplain restoration)
2	Vegetated Channel
3	Detention Pond

The projects were scored based on the highest potential score. The scores for this category are not cumulative.

Table 6-3: Project Prioritization Table

Prioritization Ranking Factors	Ranking Factor Weight	Project Specific Score	Project Specific Weighted Score
Economic			
Price Affordability	4	3	12
Low Operations & Maintenance Cost	3	3	9
Degree of Economic Impact on Local Businesses	2	3	6
Funding Sources	2	3	6
Improve Economic Development Potential	2	3	6
Time to Implement or Construct	1	3	3
Ease of ROW Acquisition and Utility Relocation	1	3	3
Social			
Public Safety	4	3	12
Potential for Recreation/Connectivity for Parks	4	3	12
Beneficial Neighborhood Impacts	2	3	6
Mobility or Effects on Transportation System	1	3	3
Integration with Other Projects	1	3	3
Ecological			
Flood Risk Reduction	4	3	12
Erosion and Water Quality Significance	3	3	9
Environmental Enhancement and Resilience	3	3	9
"Perfect Project" Total Score			111

For the prioritization scoring sheet of each project, please refer to Appendix J.

[From the 2009 SWMP Report]:
The integration of the proposed stormwater solutions with proposed greenbelt routes was another key element of the SWMP. As part of the 2009 SWMP consultant team, Halff Associates, finalized the greenbelt trails plan for Norman. Coordination throughout the project has occurred to ensure that stormwater projects could be integrated with greenbelts whenever possible. During the design effort for any particular project, its integration with greenbelts can be considered further and incorporated into the project if the City desires.

6.2.1.1 Capital Improvements Program

In order to perform the City duties associated with managing a CIP program and the projects undertaken in the program, provisions to supply the needed design and construction oversight need to be accommodated. The two best options for the City appear to be either: 1) hiring or reassigning City staff or 2) retaining a consultant or consulting firm to perform or assist with the work. Both have merits and the City could even use a combination of the two approaches. It may also be advantageous for the City to begin with one method, such as hiring a consultant, and then ramping up with staff over time to take over the program.

The basic driving factor is the amount of program management work to be done and the budget to perform that work. For estimating purposes, the general obligation (GO) bonding and annual CIP project funding needs provided in Table 8-4 in Section 8 were used to estimate the amount of work budget required for stormwater improvements in Norman over the first 5 years of such a program. Additionally, it was assumed that the GO bonds would be used in the first five years of the program. It was decided to use Option 1 in Table 8-4 in order to not overestimate the amount of work and funds needed.

Utilizing information provided in Table 8-4, the following calculations were made to generally estimate the amount of program work needed and, therefore, the staffing required.

1. GO Bonding = $30,000,000 assumed to be spent over the first 5 years of the program
2. CIP funding through a stormwater utility = $2,650,000 annually over the first 5 years of the program
3. Total funding over the first 5 years of the program = $30,000,000 + 5($2,650,000) = $43,250,00
4. Average annual funding = $43,250,000/5 = $8,650,000
5. Consistent with the project cost estimates assumption in this Section of the report, assume 10% for City program and project management = $865,000/year
6. After the first 5 years, the GO bonding funds would no longer be available. The annual needs would be reduced to $2,650,000 which would yield a program and project management budget of $265,000 at the 10% management rate used.

Therefore, the City would have $865,000 per year to manage the program and the projects being constructed during the first 5 years of the program. That amount would drop to $265,000 after that time period to only include the CIP funding amount.

As mentioned above, the City could approach this work in a number of different ways. A "middle ground" approach was used here to assist the City in making possible program/project staffing decisions if this amount of funding becomes available. A solid approach that the City could follow would be to only hire enough staff to perform about $265,000 annually and hire consultants to perform the remaining program/project work. In that manner, the City would not be overstaffed at the end of the 5 year period when the GO bonding funds begin to decrease as projects are designed and constructed. The very approximate annual costs are estimated to be:

1. One senior engineering manager = $100,000
2. One engineer/engineer-in-training or technician/inspector = $75,000
3. Part time administration assistance = $25,000
4. Non-labor expenses and fees = $50,000
5. Total annual costs = $250,000

These staffing costs are very approximate and could vary, but this provides a general basis for beginning a program and project management group at the City to fulfill the duties of such an endeavor. Additionally, these prices are from 2009 and are likely to have increased.

6.2.2 Water Quality

2025 Water Quality Updates

Note that the discussion of water quality in Norman has been considerably updated since 2009 with several studies mentioned in the Data Collection section of this Update. Specifically, the 2016 TMDL Compliance and Monitoring Plan along with the 2024 Stormwater Management Plan identify the current water quality concerns in detail. The text below has not been removed from this Update because it provides a valuable context to the timeline of water quality concerns in Norman.

Original 2009 Water Quality Discussion

Programmatic water quality solutions are presently being implemented in Norman's "urbanized areas" as part of the City's compliance with ODEQ's Oklahoma Pollutant Discharge Elimination System (OPDES) "MS4" program. Noman is also required to continue complying with their Lake Thunderbird Total Maximum Daily Load (TMDL) Compliance and Monitoring Plan. This plan was created in 2016 in response to ODEQ's TMDL requirements. Additional future water quality compliance will also be required as part of the previously mentioned TMDL requirements for Bishop Creek. As part of this (2009) SWMP, a "Stormwater Management Program for MS4 Compliance – 2011 to 2015" (PBS&J, 2008) was developed and submitted to the City of Norman in February 2008 and is made part of this SWMP by reference. This document outlines an MS4 program that the City has begun undertaking to address the need to protect and improve water quality in the City. The TMDL study for the Canadian River involves the City of Norman and the University of Oklahoma as contributors to fecal coliform problems in Bishop Creek which will require compliance activities by the City and University. The City will also continue to be comply with the Lake Thunderbird Total Maximum Daily Load (TMDL) Monitoring and Compliance Plan to protect Lake Thunderbird's water quality.

With its ongoing MS4 program, the City is presently complying with OPDES MS4 permitting requirements. In summary, the state permit requires the City to comply with a number of administrative and legal requirements and to develop, implement, and enforce a stormwater management program designed to reduce the stormwater discharge pollutants from its MS4 area to the maximum extent practicable for water quality protection purposes. The SWMP must address six areas, called Minimum Control Measures (MCMs), as follows:

- Public Education and Outreach Program
- Public Participation and Involvement
- Illicit Discharge Detection and Elimination
- Construction Site Stormwater Runoff Control
- Post-Construction Management in New Development and Redevelopment
- Pollution Prevention/Good Housekeeping for MS4 Operations

General Permit OKR04 for small MS4s, most recently dated in 2021, authorizes discharges of stormwater and certain non-stormwater discharges from small MS4s. The permit number assigned by ODEQ for the NOI is OKR040015.

For each MCM the City must:

- Select appropriate BMPs, which are various methods of reducing pollutants in stormwater runoff.
- Define measurable goals for each BMP.
- Establish an implementation schedule.
- Assign a responsible person or persons for implementing all activities.

Additionally, the City of Norman is in the process of developing a program to assess the condition and repair needs of the City's underground storm sewer system and to locate any illicit (illegal) connections/discharges of the system. This program will use a video camera system operated by trained City maintenance personnel.

Under the TMDL process for the Canadian River, ODEQ has also identified Norman and the University of Oklahoma as contributors to non-attainment for fecal coliform in Bishop Creek, a local tributary to the Canadian River. Bishop Creek failed to support the designated water use due to fecal coliform concentrations, and thus actions must be taken to meet the water quality standard. Where the TMDL has been developed, additional sampling becomes part of the implementation requirements for regulated MS4 discharges such as those from the City of Norman. Significant monitoring and reporting of water quality and implementation of BMPs are expected to result.

These ongoing and upcoming programs assist in addressing water quality solutions for the City of Norman as they encompass the entire city, examine water quality conditions in Lake Thunderbird, and even consider the stormwater quality entering the City of Norman from areas outside of Norman's city limits as is being done with

ODEQ's watershed management plan development. As these programs progress and mature, additional compliance requirements and actions will be defined and become part of the City's normal operations. Additional actions are already warranted by the City to protect Lake Thunderbird's water quality.

The use of structural and non-structural stormwater quality controls as discussed in Section 7.2 of this report are needed to provide significant water quality protection throughout Norman and especially for the City's drinking water supply, Lake Thunderbird. The need for such controls is evident in the State of Oklahoma's action to designate Lake Thunderbird as a sensitive water supply lake (ODEQ, 2002). Lake Thunderbird has been added to the State of Oklahoma's 303(d) list of impaired waterbodies due to high levels of chlorophyll-a, an accepted measure of algal content, which has caused non-attainment of designated uses in the lake. A major component of this SWMP is to provide further understanding and awareness of the critically important need to protect Lake Thunderbird's water quality and to recommend measures that will assist in accomplishing the needed protection. As land development progresses in the Lake Thunderbird Watershed, further degradation of the lake's water quality can be expected as reported in a report developed by Vieux, Inc., entitled "Lake Thunderbird Watershed Analysis and Water Quality Evaluation" for the Oklahoma Conservation Commission (Vieux, 2007). This 2007 study assessed and quantified the impact of future land development on stormwater non-point nutrient and sediment loadings to the lake and analyzed the potential effectiveness of management practices (i.e., structural and non-structural controls) in preserving and protecting the lake's water quality.

Modeling reported in the Vieux report (Vieux, 2007) generated results of water quality conditions associated with baseline (2000) and build-out (2030) conditions which clearly point out that watershed nutrient loadings to the lake are high and will increase (phosphorus more than doubling) with future urbanization. As explained in some detail in this 2007 report, these nutrient loadings and especially those from phosphorus have already contributed significantly to algal growth in the lake. Additionally in 2000, the Central Oklahoma Master Conservancy District (COMCD) and the Oklahoma Water Resources Board (OWRB) in cooperation with the cities of Norman, Del City, and Midwest City, set an upper limit goal of 20 µg/L of chlorophyll-a, a pigment or molecule commonly used to indicate algal content, for open water sites during the growing season (OWRB, 2001). The 20 µg/L concentration goal for chlorophyll-a is regarded as the boundary between eutrophic (high) and hypereutrophic (excessive) algal growth. Using projected phosphorus loadings and an in-lake relationship between phosphorus and chlorophyll-a, estimates of potential algal growth (i.e., in-lake chlorophyll-a concentrations) in the lake were made for baseline and build-out watershed conditions. As the projected nutrient loading and associated chlorophyll-a results clearly show, the increased nutrient loadings projected to occur with future urbanization without sufficient mitigating measures will further exacerbate the algal growth in the lake significantly above the in-lake level set as the goal (i.e., the 20 µg/L chlorophyll-a concentration). Modeling in the Vieux report reveals that (in 2007) chlorophyll-a concentrations exceeded the existing water quality goal of 20 µg/L for the lake, averaging 30.8 µg/L for baseline conditions. For the build-out conditions, the average chlorophyll-a concentration is projected to be as high as 44 µg/L, which is an increase of 43% above existing conditions and well above the water quality goal set for the lake. This increase in potential algal growth greatly increases the threat of toxins being produced in the lake from the algal masses, exacerbates taste and odor problems, and decreases recreational potential. It is clear that the City of Norman is confronted with the significant potential for an ever worsening unclean, unhealthy, and unsafe water supply.

The 2007 Vieux analyses further present that implementation of multiple management practices (structural and non-structural water quality controls) for both existing and build-out conditions such as statutory fertilizer reductions, existing wetlands protection, and structural controls (e.g., detention basins, retention or sedimentation basins, constructed wetlands, and bioretention filter basins) can result in significant reductions of phosphorus loading and chlorophyll-a concentrations within the lake. Combinations of several management practices throughout the entire Lake Thunderbird Watershed were shown to reduce the lake's total phosphorus load to a level where the chlorophyll-a concentration in the lake would remain close to the set water quality goals. However, limiting the application of management practices within the limits of the City of Norman alone would not meet the water quality goals set for the lake. If statutory fertilizer reduction, wetlands, and structural controls are applied only to the area within the City of Norman under baseline conditions, the modeled chlorophyll-a concentration in the lake was estimated to be 24 µg/L which is still above the goal of 20 µg/L. For the build-out condition and management practices applied only in Norman, the chlorophyll-a concentration in the lake equated to 36 µg/L principally due to watershed loadings from outside of Norman's city limits. This indicates significant hyper-eutrophic water quality conditions and still well above the 20 µg/L water quality goal.

While implementing non-structural and structural controls for previously developed areas would be difficult, the implementation of such controls including stream buffers or related floodplain dedications (e.g., Stream Planning Corridors) as well as water quality facilities (e.g., extended detention) in future developments will greatly assist Norman in improving the water quality in Lake Thunderbird. According to the Environmental Protection Agency (EPA), the use of stream buffers has the potential to control nutrient loadings by reducing loadings to streams by 30–40% (EPA, 1993). Fisher and Fischenich (2000) reported literature values for phosphorus removal due to "buffer zones and corridors for water quality considerations" as high as approximately 80%. Extended detention, an often used structural water quality control, has been reported to reduce phosphorus loadings by approximately 50% (Vieux, 2007).

Along with several other studies, reports, and programs (e.g., requirements of the City's MS4 Program), results of the Vieux (2007) analyses and report were strongly considered when selecting and recommending structural and non-structural controls for areas that could potentially undergo future development within the City of Norman. These results were also considered when making our recommendation to coordinate stormwater protection initiatives with the cities of Moore and Oklahoma City which also have areas that drain to Lake Thunderbird and contribute to the water quality problems therein. It is also recognized that in certain circumstances these water quality controls may also be implemented in previously developed areas depending on the conditions and applicability.

The Vieux report clearly reveals that a combination of controls will be needed to protect Lake Thunderbird's water quality. The SWMP recommendations and implementation plan presented in this report serve to provide an outline of recommended stormwater management practices or controls for the Lake Thunderbird Watershed that, among other items, include Stream Planning Corridors (SPCs), structural controls (dry extended detention basins), fertilizer use education, fertilizer use controls, a continuation of present development density controls, and the encouraged use of effective low impact development measures. Recommendations of these particular controls are being made since they have demonstrated in numerous locations that they have the ability to significantly assist in protecting water quality and are recognized by EPA as viable management practices or controls. If implemented properly, these management practices will significantly assist in preserving and protecting Lake Thunderbird's water quality and the City's primary water source which, in turn, will protect the health, safety, and welfare of Norman's citizenry.

Construction erosion protection with silt fence

As the largest municipal area draining into Lake Thunderbird, the City of Norman should take affirmative steps to address water quality issues. In order to assure the continued viability of the City's primary water source, it is recommended that the City implement the key non-structural and structural water quality controls selected herein in areas of future development and work to ameliorate conditions in existing developments that are reported to be contributing to the degradation of water quality.

7.0 Key Issues

2025 Key Issues Updates

The key issues facing Norman from a stormwater perspective are very similar to what they were in 2009. For the Canadian River watershed, reducing flood and erosion damages, and maintaining aging infrastructure are the highest priorities. In the Lake Thunderbird watershed, preserving runoff water quality and maintaining natural areas are the highest priorities. These priorities drive the key issues facing the City, and the approach the City will take to solve them. The studies and updates to City regulations that have been completed since 2009 change the language that is used in some of the sections below. For example, the Stream Planning Corridors that were identified and recommended to be preserved as part of the 2009 SWMP have been preserved by ordinance through the Water Quality Protection Zone (WQPZ) Ordinance in 2011. Additional changes have come through the comprehensive update to the City's Engineering Design Criteria in 2023. The following sections highlight the modified key issues that have been identified through the input of citizens and City staff as part of the AIM Norman process. A complete list of recommendations for the City to meet the 2025 SWMP goals is included in section 9.0.

2009 Original Key Issues Introduction

During development of the SWMP, several key issues emerged that warranted a considerable amount of time due to their complexity and the need to have various stakeholder groups offer their guidance on how best to resolve the issues. Numerous discussions with City Council members, the SWMP Task Force, City staff, and other stakeholders produced a variety of good ideas about the various issues. Although recommendations are included in this report (this section and Section 9), consideration will be needed to resolve details on moving forward with several of these recommendations. Therefore, this section provides pertinent background on the issues, discussion topics considered in the stakeholder meetings, and recommendations on how the City should move forward in the future on each of the issues. Several of these issues came up as the consultant team brought suggestions forward specifically targeting certain City goals established for the SWMP. A breakdown of the major issues into “considerations” is presented below along with options, respective discussions, and recommended actions. It is anticipated that the recommended actions will allow the City to ultimately reach a consensus or understanding on the best approach to follow in the future on each respective issue.

Several possible concepts were considered in an effort to meet certain City’s SWMP goals of providing public safety from flooding, protecting water quality including Lake Thunderbird, meeting OPDES permitting requirements, protecting stream corridor environments, capitalizing on greenway and open space expanding opportunities, and generally improving the “quality of life” in Norman. These concepts included:

- incorporating floodplain dedications and/or “Stream Planning Corridors” in new developments,
- utilizing structural (e.g., sediment trapping basins, wet ponds, porous pavement, grass swales) and non-structural (e.g., stream buffers or floodplain dedications, fertilizer application controls, development density limitations, street sweeping) water quality controls in new developments, including low impact development,
- providing enhanced maintenance of creeks and stormwater detention facilities in existing and new developments,
- ensuring that existing and any new policies are followed in obtaining drainage easements and rights-of-way in new developments,
- acquiring drainage easements and rights-of-way, as needed, in existing developments, and

- providing dam safety throughout the City.

The City Council and SWMP Task Force assisted the consultant team and City staff in the consideration and discussion of these stormwater-related elements.

7.1 Stream Planning Corridors

2025 Updates to Stream Planning Corridors Section

The concept of Stream Planning Corridors (SPCs) was visionary for the City of Norman when it was introduced in the 2009 SMWP. The idea was quickly codified in the 2011 Water Quality Protection Zone Ordinance and it remains a integral part of the City's plan to preserve stormwater runoff quality as flows approach Lake Thunderbird. The WQPZ should continue to be implemented as urbanization pushes further east into the Lake Thunderbird watershed. Please reference the WQPZ ordinance found in the City's Municipal Code online records for more information about the details of the law.

2009 Stream Planning Corridors Section

One particular element considered to help meet the City’s SWMP goals involved the dedication of floodplain areas and/or stream corridors in new developments. Numerous municipalities (e.g., City of Austin, Texas; City of Stow, Ohio; Burke County, North Carolina; and Cobb County, Georgia) throughout the country presently use this environmentally sensitive approach to:

- Protect water quality by removing sediments, nutrients, and other contaminants from runoff
- Infiltrate runoff and store floodwaters, thereby providing for public safety and reducing property damage
- Reduce channel bottom degradation and stream bank erosion
- Maintain habitat for fish and other aquatic organisms
- Provide terrestrial habitat
- Improve aesthetics, possibly improving property values
- Maintain base flow in streams
- Offer opportunities for greenway development

The appropriateness of dedicating floodplain areas or “Stream Planning Corridors” received considerable discussion during development of the SWMP. A great many discussions were held with the City Council in work session, the SWMP Task Force, City staff, and other stakeholders (including City Council presentations) in an effort to obtain input and reach a consensus about using such a method to meet some of the City’s water quality, environmental, flood control, and recreational goals. A very wide range of opinions was received with some stakeholders enthusiastically favoring the corridors and others totally against them.

Stream Planning Corridors and Greenways

The Stream Planning Corridors (SPCs) is defined as the area of land along both sides of a stream or natural drainage corridor that encompasses the area projected to be inundated by the 1% chance flood event (i.e., the 100-year floodplain) in any given year assuming full buildout watershed conditions plus possibly including an additional buffer width or strip. This additional buffer strip, if added, would aid in further filtering runoff and expanding opportunities for incorporating greenbelts/recreational trails within land areas being developed. SPCs without any added buffer strip have been developed for those areas with 40 or more acres of drainage area for Level 3 and 4 streams as shown in Exhibit 4-4 in Appendix E. Projected ultimate buildout development conditions consistent with the Norman 2025 Plan, as well as future projected growth for areas that drain into Norman, were used to develop the peak flow rates used to delineate the 1% or 100-year floodplains and SPCs. FEMA floodplains were considered but not used since they were not available when the analysis was performed, were not developed assuming ultimate development conditions, and in many locations were not based on the recent 2007 LIDAR-based topography at the time of the analysis. The SPCs reflect full buildout development flow rates in order to respect conditions expected in the future rather than the present or past.

The use of floodplains or SPC dedications in the headwaters areas of watersheds (up to the 40-acre drainage area size) is important as SPCs have the greatest potential to provide water quality protection in these areas. In these headwater areas, the flows are relatively small and dispersed (shallow flow) in any one location and therefore offer the best opportunity to filter runoff and infiltrate it into the ground surface. SPCs (or "buffer strips") adjacent to larger streams with large drainage areas also help filter runoff and provide many other environmental functions and recreational opportunities. However, once the runoff makes it into these larger stream reaches, the chance for filtration through vegetation, absorption, and infiltration decreases as a factor due to the larger flows and resulting velocities in downstream reaches. These processes relate to streams left in their natural state, as such benefits are significantly reduced in most rectified channel (especially in concrete-lined or piped systems).

Establishing SPCs provides a means of approximating the floodplain areas along unstudied streams for possible dedication and/or other stormwater planning purposes. The floodplains for Level 1 and 2 streams should be used in the same manner when considering floodplain dedications. The main difference is that the Level 1 and 2 floodplains were developed with more comprehensive and detailed methods. Revisions to these Level 1 and 2 stream floodplains for future land development conditions could be allowed if a delineation problem was discovered during the land development process. In Level 3 and 4 streams, revisions to the SPCs should be allowed if superior floodplain information is presented. However, the SPCs as delineated in the SWMP should provide a reasonable approximation of the floodplain for the 1% flood in most locations. It is anticipated and expected that refined floodplain delineations will be developed by engineers as parcels are developed and compliance with subdivision regulations is achieved. Land developers can, at a minimum, use these SPCs as a planning tool when laying out their respective developments and City staff can use them in their review of development plans and other planning activities.

7.1.1 Stream Planning Corridors - Key Questions, Options, and Recommended Actions

Question 1: Does the City want future land developments to dedicate the ultimate development condition 1% chance (100-year) floodplain extending well upstream of a 1-square-mile area as an SPC to provide water quality protection, capitalize on greenbelt and open space expansion opportunities, protect stream corridor environments, and generally increase the “quality of life” in Norman?

Discussion: In general, requiring the dedications would be a positive step toward meeting the City’s goals for the SWMP. Floodplain dedications can provide for significant water quality protection, more stream base flow, improved neighborhood recreational opportunities, and a more sound, viable environment for wildlife and native vegetation. This will be a change from the way developments are presently planned in Norman so some will not want to make any significant change in the status quo. Some developers may feel that such a program is unfair and not needed. They may also believe that they can develop solutions that would be equivalent to the natural system in terms of flood control, water quality, and recreation. Some may embrace such dedications as long as exceptions or variances could be considered. To the degree that variances are allowed, the City must develop criteria to judge the adequacy of alternative approaches in lieu of the SPC dedications. One approach to consider would be to allow alternative approaches, including low-impact development techniques, but require studies to show that at least flood control and water quality are equivalent to that obtained through using the floodplain dedications. Alternative approaches should include requirements for developers to provide the City with documentation that the U.S. Army Corps of Engineers (USACE) was notified and a Section 404 permit was obtained when natural waterways are altered as part of the development.

Requiring these dedications could also potentially add a significant amount of additional area that the City might have to maintain to some degree, regardless of whether such dedications were in some sort of drainage, utility, or conservation easement. While these areas would require funding to maintain, if they were left natural, maintenance could be minimized.

The City must ultimately decide to require these dedications in a uniform manner throughout the City or apply them differently for areas draining directly to the Canadian River versus areas that drain into Lake Thunderbird. The City could also choose to vary the application of the dedications depending on whether the development was located in the current urban service area, the future urban service area, suburban residential area, and country residential area according to the Norman 2025 Plan.

Options:

1. Require such dedications up to the 40-acre drainage area limit for all new developments.
2. Require such dedications but only up to some other drainage area cut-off limit such as 80 acres, 160 acres, etc.
3. Select 1 or 2 above but apply the dedications differently depending on the development location within the City such as whether or not the area drains to Lake Thunderbird or directly to the Canadian River. Another process that could be used would be to vary the requirements or ability to obtain a variance based on whether a stream being considered has mapped flood prone soils by the Natural Resources Conservation Service. If such soils exist, the stream would be viewed as having an increased need for floodplain/SPC dedications.
4. Make no changes to the present land development regulations, requirements, and processes.

Recommended Actions: In order to meet the goals of protecting the water quality of Lake Thunderbird and its contributing waterways, Option 3 is recommended, which requires that floodplain and/or Stream Planning Corridor dedications extend into the headwater (upstream areas) of Lake Thunderbird watersheds. Option 4 is certainly not recommended given the worsening water quality conditions in Lake Thunderbird. For purposes of this Option 3 recommendation, the City should extend such dedications requirements to the 40-acre drainage area limit for all watershed areas that drain to Lake Thunderbird. Such dedications are not recommended for other portions of the city outside of the Lake Thunderbird watershed since (with the exception of the Ten Mile Flat Creek watershed) these watersheds have relatively small amounts of undeveloped area. Extending the requirement to the 40-acre drainage area size maximizes the water quality benefits afforded by the overland flow, increased infiltration, and vegetative filtering of runoff in these headwater areas. A review of Exhibit 4-4 in Appendix E provides visual observation of the relative areal coverage of the SPC areas versus those areas outside of the SPCs in these headwater areas. It is recognized that further discussions will be held on this subject and the City may eventually decide to select a larger (greater than 40 acres) drainage area limit.

In making this recommendation, it is realized that certain legal and political considerations may require discussion and resolution in the future. The resolution of any legal and political considerations will need to be made in conjunction with the public safety and environmental concerns that are facing the City presently and in the future. The SPC recommendation made here focuses on the actions needed to provide water quality, flood, and environmental corridor protection as well as increasing recreational opportunities. Lake Thunderbird's water quality constitutes the overriding concern since there is considerable evidence that the lake is already degraded (as discussed in Section 5) even though many areas and streams in the lake's watershed are presently in a natural or undeveloped condition. When development occurs in these areas and along the many local streams, it will be very hard to "hold the line" on water quality conditions and prevent further degradation of water quality in the lake and the Canadian River. The challenge to protect water quality in all of the City's steams and especially those contributing to the lake is enormous and will not be met unless significant controls are put in place to counter the impacts of future urbanization.

In an effort to better understand what other local governments throughout the country have done in similar situations, numerous floodplain and/or riparian buffer ordinances across the country were reviewed. While these ordinances have similarities and differences, they provided supportive approaches and information. In Austin, Texas there are requirements to provide "Critical Water Quality Zones" that extend out to the full buildout 100-year floodplain along streams with drainage areas greater than 64 acres in water supply watersheds. These water supply watersheds are similar to those that contribute to Lake Thunderbird in Norman, such as the Little River, Rock Creek, and Dave Blue Creek watersheds. There is also a further requirement in Austin to provide a "Water Quality Transition Zone" that extends from 100 to 300 ft beyond the Critical Water Quality Zone depending on the size of a stream's drainage area at any particular point. Development is all but eliminated in the Critical Water Quality Zone and severely limited in the Water Quality Transition Zone (City of Austin Code, 2009). In Stow, Ohio riparian setbacks from the banks of streams are 50 ft for areas as small as 32 acres and 30 ft for streams smaller than 32 acres (Chagrin River Watershed Partners, Inc., 2006). Douglas County, Georgia requires stream buffers in their water supply basins that extend 100 ft from the stream bank plus an additional 250-foot setback on "small tributaries" in which housing density is limited to one house per acre (Wenger and Fowler, 2000). Lastly, Platte County, Missouri (1992) (part of the Kansas City Metropolitan Area) designates "stream corridor buffer zones" of various total widths depending on drainage area sizes, including 100 ft for areas between 25 and 40 acres; 150 ft for areas between 40 and 160 acres; 250 ft for areas between 160 and 5,000 acres; and 300 ft for areas greater than 5,000 acres.

For those watershed areas that do not drain to Lake Thunderbird but drain more directly to the Canadian River, the recommendation is for the City to forego these dedications altogether instead of extending floodplain/SPC dedications to a larger drainage area limit such as 80 acres. A cursory review of developable land in areas that drain directly to the Canadian River reveals that these dedications would not impact a significant amount of area or stream length and would provide limited water quality benefit due to the existing disturbed nature of the area overall and stream corridors. However, as recommended later in this section, water quality structural and nonstructural water quality controls should be used in this area for future development activities. In terms of flooding in this more urban portion of the city, existing and herein proposed drainage/stormwater regulations should provide adequate protection. It is further felt that variance requests could be difficult to judge in these areas creating administrative problems. The Ten Mile Flat Watershed may be an exception to the above discussions since it does have a significant amount of undeveloped area, but existing housing density regulations and other drainage/stormwater regulations should provide ample protection for this area.

It is also recommended that the City consider allowing justifiable variances to this requirement that would allow alternative approaches that could be shown to achieve similar water quality, flood control, and recreational opportunity. In situations where a clearly defined riparian corridor of environmental significance and/or flood prone soils exist, it should be relatively more difficult to obtain such a variance. However, obtaining such variances should be less difficult in situations where a riparian corridor does not exist and the subject waterway flows through an area that has experienced significant past disturbance or change from natural conditions (such as past agricultural activities and/or activities associated with residential, commercial, transportation, or industrial uses).

Question 2: Does the City want to add an extra buffer width or strip to the 1% chance floodplain? If yes, how much extra width?

Discussion: Adding an extra buffer width basically has the same type of considerations that were presented above for the first issue. The benefit primarily relates to adding a “safety factor” to help protect the stability, water quality, and environmental integrity of the City’s streams. Adding an extra buffer strip would also provide more opportunity for greenbelts and trails although most trails could be included within an SPC. From a water quality standpoint, adding buffer width is important in areas where water quality degradation is occurring or is expected to occur such as is happening to Lake Thunderbird. Adding buffer width might make more sense in the City areas that are to subject to relatively less dense urban development such as the suburban residential areas and the country residential areas, especially those areas draining into Lake Thunderbird. In the current urban service area and the future urban service area, the Norman 2025 Plan discusses the need to provide for more dense development. In these more densely developing areas, it may be impractical and inconsistent to add buffer width.

Options:

1. Add an extra buffer width of 15 ft or some other amount to increase water quality protection.
2. Vary the buffer width with drainage area size, such as:
    a. 40 acres – 640 acres: none
    b. 640 acres – 5 square miles: 20 ft on each side of the creek
    c. >5 square miles: 30 ft on each side of the creek
3. Vary the width based on the development location within the City (see discussion above).
4. Do not add any buffer width.

Recommended Actions: It is recommended that additional buffers of 15 ft be added to each side of all waterways with 40 acres or greater drainage area in addition to, or beyond, all Stream Planning Corridors and/or ultimate buildout 100-year (1%) floodplains areas in those areas that are included in the Norman 2025 Plan as Suburban Residential Areas and Country Residential Areas. No additional buffer is recommended in other City areas. Variance provisions should be considered and allowed if similar water quality protection can be conclusively demonstrated, including provisions for future operations and maintenance.

When the City moves forward with changes to their ordinances and regulations related to floodplain/Stream Planning Corridor dedications and structural/nonstructural water quality controls (discussed subsequently below), the following ordinance considerations have been developed to initiate thoughts about the regulatory changes that might apply.

7.2 Structural and Nonstructural Stormwater Quality Controls

2025 Updates to Structural and Nonstructural Stormwater Quality Controls Section

Structural and nonstructural stormwater quality controls are critical to meeting the City's goals of preserving runoff water quality throughout the City, and especially in the Lake Thunderbird watershed. The citizen input gathered during the AIM Norman process overwhelmingly pointed to preserving runoff water quality as a top concern. The language in the sections below should be referenced alongside several water quality documents that have been developed since 2009 including:

- Lake Thunderbird TMDL Compliance and Monitoring Plan (2016)
- Engineering Design Criteria Sections 6000 and 7000 (2023)
- Stormwater Management Plan (2024)

The updated stormwater quality recommendations are discussed in more detail in Section 9.0 of this document. Generally, it is recommended that a stormwater utility fee be implemented to fund the non-structural stormwater quality inspection and maintenance activities of City Staff. Additionally, structural stormwater quality BMPs should be installed with new developments to mitigate the impact of increased impervious areas.

Watershed modeling was conducted as part of the 2016 Lake Thunderbird TMDL Compliance and Monitoring Plan documentation. The modeling was used to determine potential reductions of nutrients and sediments from implementation of recommended best management practices (BMPs). Within the document, there are tables containing data showing the amount of pollutants reduced when applying structural and non-structural BMPs. Appendix O provides a link to the full document for reference.

The 2023 Engineering Design Criteria (EDC) Section 7000 outlines a method for determining a "Water Quality Volume" for new development areas, but that water quality treatment is not currently required. It is recommended that Water Quality Volume (WQV) runoff treatment be required for each new development in accordance with the 2023 EDC. Going beyond the EDC, it is recommended that the WQV requirement be larger for those developments that have a greater impact on runoff water quality entering Lake Thunderbird by implementing a zone system shown on Figure 3.

The zones in the Figure were developed utilizing the Character Area Map of the AIM Norman Comprehensive Plan and the major stream lines within Norman that contribute to Lake Thunderbird. All areas east of the dividing line between the "Suburban" Character Area and the "2045 Reserve" Character Area have been included in Zone 1. Zone 1 provides the highest level of protection for downstream water quality. Zones 2 and 3 also provide increased protection, but to a lesser degree than Zone 1. Zone 1 has also been extended west along a 1000-foot buffer from the major contributing streams to Lake Thunderbird. Zone 2 is an additional 1000-foot buffer from the Zone 1 area.

Essentially, the WQV requirement zones would set a baseline initial precipitation volume ("first flush rainfall") that should be treated through a various low-impact development and stormwater BMP strategies. Recommended stormwater quality treatment strategies are described in detail in Section 7000 of the 2023 EDC. These strategies can be applied in series in the new development from small-scale to larger-scale BMPs to form a "treatment train." The implementation details of this requirement would need to be clarified by City staff including Legal and Public Works and be refined through discussion with City Council.

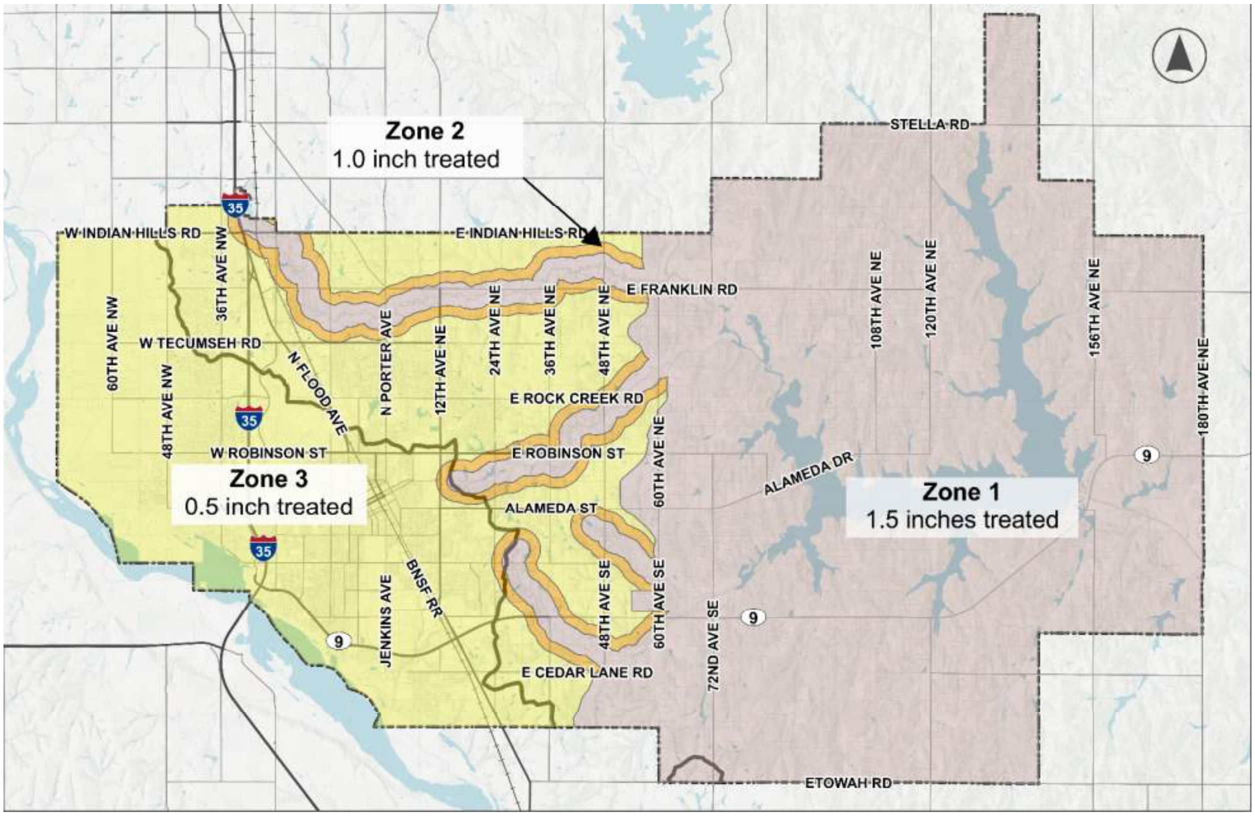


Figure 3. Water Quality Volume Treatment Zones

The Stormwater Program of the Public Works Department alongside the Division of Environmental Resilience and Sustainability of the Utilities Department have implemented several of the Stormwater Quality Control measures that are outlined in the original 2009 document below. Appendix N contains a full list of the stormwater quality control measures that the City identified during a 2018 study of the proposed Stormwater Utility Fee. However, that 2018 vote for the SWU was rejected by the voters of Norman. A SWU or other alternative funding for these stormwater quality control measures is critical to their successful implementation and protecting the runoff water quality entering Lake Thunderbird.

2009 Original Structural and Nonstructural Stormwater Quality Controls Section

As discussed in Section 6.2, programmatic water quality solutions are presently being implemented in Norman's "urbanized areas" as part of the City's compliance with ODEQ's Oklahoma Pollutant Discharge Elimination System (OPDES) "MS4" program. Additional future water quality compliance will also be required as part of the previously mentioned TMDL requirements for Bishop Creek and ODEQ's future watershed management plan development for Lake Thunderbird. As a supplement to the MS4 program, the upcoming ODEQ watershed management plan, and/or the Bishop Creek TMDL as well as to meet certain SWMP water quality goals, the City will need to require new developments to incorporate certain structural and/or nonstructural water quality controls. Structural and non-structural stormwater quality controls have the ability to help protect the water quality in Norman's streams and Lake Thunderbird. Typical structural controls include extended detention (sediment trapping) basins, wet ponds or retention basins, filtration basins, porous pavement, and grassed swales. Nonstructural controls include stream buffers, floodplain dedications, fertilizer application controls, street sweeping, and development density limitations. These types of structural and nonstructural controls (BMPs, or best management practices) are an integral part of the City's MS4 program. Discussions on this topic during the SWMP development have been much less involved compared to other issues such as stream planning corridor dedications and drainage easement/ROW needs.

Combination water quality and flood control facility

7.2.1 Structural and Nonstructural Stormwater Quality Controls - Key Questions, Options, and Recommended Actions

Question: Should the City of Norman adopt structural and nonstructural stormwater quality controls in its development standards and require new developments to provide these controls?

Discussion: First, a discussion of local conditions and ongoing programs underway or in various development stages is provided. This discussion is then followed by an overview of structural and nonstructural water quality controls, or BMPs, that could be used in Norman. In many instances the City will lead the efforts to provide nonstructural controls while developers will provide the structural controls as part of their development drainage infrastructure.

Stormwater runoff quality is affected by human activities, land use changes, and the alteration of natural drainage patterns. These urban conditions and activities add pollutants to rivers, lakes, and streams. Urban runoff has been shown to be a significant source of water pollution in locations throughout the country, causing declines in water quality and impairment of waterbodies as is the case for Lake Thunderbird. Examination of national stormwater quality data and local studies reveals that nutrients and total suspended solids (among other water quality parameters), runoff volumes, and flow rates increase with urbanization and impervious surfaces, thusly impacting Lake Thunderbird inflows and discharges to local streams and the Canadian River.

Though a limited dataset, a local study entitled “Rock Creek Watershed Analysis and Water Quality Evaluation” (COMCD, 2006), in the Rock Creek tributary to Lake Thunderbird showed that total phosphorus, total nitrogen and total suspended solids concentrations were several times higher than National Stormwater Quality Database values. This modeling and analysis study for the Central Oklahoma Water Conservancy District (COMCD, 2006) focused on estimating the impact of urban stormwater on nutrient and sediment loading into Lake Thunderbird, the water supply reservoir for the cities of Norman, Midwest City, and Del City. For the majority of events, the most highly developed areas in Rock Creek had the highest modeled constituent concentration of suspended solids, nitrogen and phosphorus. As urban development results in conversion of land use from open areas to residential or commercial classifications, the impervious area and urban activities will increase and result in higher nutrient and total suspended solids concentrations of nutrients and annual loading in stormwater to the lake. Increased nutrient loading has the potential to increase algal growth in the lake which, in turn, can create significant taste and odor problems in the lake's finished drinking water and cause the waterbody to be in non-compliance with the set water quality goal for chlorophyll *a* (an indication of lake eutrophication).

In a subsequent study for the Oklahoma Conservation Commission (OCC) entitled "Lake Thunderbird Watershed Analysis and Water Quality Evaluation" (OCC, 2007), an evaluation of structural and nonstructural stormwater controls were evaluated in terms of their ability to reduce nutrient and sediment loadings to the lake. Nonstructural controls included voluntary and statutory urban nutrient management while structural controls included grassed swales, constructed wetlands, extended detention – enhanced, retention basins, and bio-retention filters. Modeling indicated that use of all of these controls throughout the lake's watershed reduced total phosphorus loadings to the lake by more than 80% for full buildout development conditions. Although it may be impractical to assume that all of these controls would be implemented as part of any plan, it does show that it is possible to reduce loadings substantially.

ODEQ is concerned that urban development, without appropriate mitigation of its environmental impact, will exacerbate the water quality problems currently experienced by the lake. The watershed management plan being established by ODEQ will identify implementation of management practices in the Lake Thunderbird watershed to help achieve beneficial uses of water in the lake. This watershed management plan could require that the City of Norman develop a program and/or modifications to its land development policies and ordinances to reduce pollutant loadings commonly associated with urban development. Other cities, agencies, and entities that make land use changes within the lake's basin area will also have to follow requirements of the watershed management plan. Norman should increase its efforts to work cooperatively with the cities of Moore and Oklahoma City to improve water quality and protect Lake Thunderbird.

Under the TMDL process for the Canadian River, ODEQ has also identified Norman and the University of Oklahoma as contributors to non-attainment for fecal coliform in Bishop Creek, a local tributary to the Canadian River. Bishop Creek failed to support the designated water use due to fecal coliform concentrations, and thus actions must be taken to meet the water quality standard. Where the TMDL has been developed, additional sampling becomes part of the implementation requirements for regulated MS4 discharges such as those from the City of Norman. Significant monitoring and reporting of water quality and implementation of BMPs are expected to result.

Structural and Nonstructural Stormwater Quality Controls. Both structural and nonstructural solutions have been implemented in areas across the United States, ranging from site-specific engineering solutions to watershed solutions. **Structural controls** constitute engineering solutions designed to reduce pollution in surface water runoff primarily through three basic mechanisms: infiltration, filtration, and detention (EPA, 1993). In effect, these systems attempt to counteract the opposite tendencies of decreased infiltration, filtration, and detention which urbanization imposes upon the land. This section discusses the advantages and disadvantages of the major options available, detailing both design and general cost constraints.

The many BMP options offer varying capabilities in terms of type and extent of pollutant removal, size of upland basin appropriate to the structure and general comparisons. These BMPs have been developed for use across the United States and are generally suitable for the Norman area. This section presents comparative information for several structural BMP options. Tables 7-1 through 7-3 provide a considerable amount of information on (1) pollutant removal efficiencies, (2) siting restrictions, and (3) general cost information, where available.

Nonstructural controls include a wide variety of pollution prevention measures. Whereas structural BMPs require the design, installation and maintenance of actual control facilities/infrastructure, nonstructural BMPs rely on the proper management of existing resources and adherence to common-sense materials management practices to maintain water quality. As such, nonstructural controls are generally less expensive to implement and maintain than structural controls. By anticipating potential problems and by acting to limit contaminants at the source, a substantial savings can be realized compared with a program which solely reacts to pollution once it has occurred. The latter approach involves relatively costly containment, mitigation, cleanup and treatment methods while the former involves techniques such as public education, pollutant source reduction, improved development site design, and protection of environmentally critical areas. Ultimately both strategies are necessary as some entry of pollutants into waterways must be anticipated. However, inexpensive preventative methods can enable end-of-the-pipe structural solutions to be both less expensive and more effective.

Buffer Zones/Protection of Existing Vegetation. Vegetation inherently addresses the hydrologic goals of many structural BMPs with minimal cost and maintenance: tree canopies intercept and diminish the erosive force of rainfall; ground cover by plants and organic matter slows runoff velocities, increases infiltration rates, and inhibits contaminants from entering waterways; and root growth holds and protects the soil from channel and gully erosion. Wetlands serve many of the same functions, effectively acting as natural pollution control systems and critical habitat areas. When considered on the large scale of the Lake Thunderbird watershed, proper maintenance of existing vegetative resources becomes an imperative from both cost-effective and pollutant removal standpoints. Through advanced planning, important woodland and wetland areas can be identified and protected. Such strategies have been used nationwide as a highly practical and achievable pollution control measure; significant habitat protection benefits can also be achieved. Table 7-4 presents very general information on the relative costs and benefits of forest and wetland protection.

Buffer zones are nonstructural BMPs that maintain existing or establish new vegetation in critical areas to, among other things, assist in controlling stormwater pollution. They are widely accepted as a means of protecting streambanks, wetlands, and other environmentally important areas. Table 7-4 shows the relative costs and benefits of stream, wetland, and expanded buffers. These zones are often employed in areas which are already unsuitable for development, such as within floodplains or federally protected wetlands. These steeper gradients are more susceptible to erosion, especially with increases in impervious cover in nearby areas following development. Buffer zones in these areas would provide additional protection. Table 7-4 also gives information on limiting the development of steep slopes. Buffer zones may be incorporated into a development plan as an aesthetic amenity, a wildlife habitat area, and a pollution prevention measure. Excellent examples of buffer zone use can be seen in the Woodlands community near Houston, Texas, where pollution control and aesthetic design have been integrally combined.

Site Planning BMPs. A number of water quality benefits may be relatively easily achieved through the use of careful site planning and design in new developments. Table 7-4 presents general considerations for the nonstructural BMPs discussed in this section. Septic limits refer to guidelines on the proper location of onsite disposal systems (OSDS), including septic systems. If improperly sited and/or installed, OSDS are potentially a large source of pollution. Therefore, many municipalities across the U.S. advise against the placement of such systems near streams and other hydrologically problematic areas. Minimization of imperviousness is also a common strategy to avoid many of the negative effects of increases in paved surfaces. Buildings and associated parking areas may be clustered such that open spaces (pervious areas) are maximized and impervious areas are held to a minimum. Reduction of “effective” (hydraulically connected) impervious cover and structural BMPs such as grassed swales, as well as porous and concrete grid pavement, can be logically included in designs minimizing the extent and relative effects of impermeable surfaces (see Table 7-1). These innovative designs build in relatively low maintenance, or no maintenance, water quality features, reducing the need for costly future BMP retrofitting to offset developmental impacts. Time/area disturbance BMPs are those which intelligently sequence the timing of construction "to limit the amount of disturbed area at any given time" and to discourage the disturbance of areas to be used as buffer zones post-development (EPA, 1993).

Public Education Programs. A wide variety of innovative and effective public education campaigns have been developed throughout the United States to combat stormwater pollution. The EPA has compiled several very useful summaries of such programs (EPA, 1993). Table 7-4 presents four basic programs: Urban Housekeeping; Fertilizer Control; Septic Maintenance; and Household Hazardous Waste. Urban housekeeping BMPs seek to educate the public about ways to limit stormwater pollution (e.g., litter and pet waste control) and avoid introduction of harmful substances into waterways. Fertilizer control seeks to educate the public about sensible fertilizer selection and application techniques, minimizing nutrient pollution from more soluble forms of fertilizers. Septic maintenance includes a wide array of strategies on proper septic system upkeep ranging from education of homeowners about operation and maintenance procedures to systematically informing OSDS installers and waste haulers with up-to-date information.

Household hazardous waste programs seek to inform the public about the means of properly disposing of common household toxic substances commonly contributing to stormwater pollution (e.g., waste motor oil, pesticides, paint thinner, etc.) and the availability and selection of non-toxic alternatives. Additional considerations/topics for stormwater public education campaigns include the use of water tolerant, disease-resistant native plant species (e.g., xeriscape strategies, which minimize fertilizer and pesticide use), innovative turf management (e.g., proper use of treated wastewater for golf course irrigation), and education about the connection between stormwater pollution and public infrastructure (e.g., keeping waste materials out of the storm sewer system; some cities have stenciled reminders of the destination of the sewer, such as “Rock Creek”) (EPA, 1993).

Options:

1. Continue meetings between the City Council, SWMP Task Force, City staff, and other stakeholders and move forward with discussions to decide whether the City should investigate new structural and/or nonstructural stormwater controls (BMPs) in new developments to improve existing water quality conditions and help prevent further degradation. The discussions should also include whether the requirement for such controls be different for areas draining into Lake Thunderbird versus those that drain directly to the Canadian River. Use of these controls would serve to comply with the City’s OPDES permit with ODEQ for minimum control measure number five (discussed above) entitled “Post-Construction Management in New Development and Redevelopment.”
2. Generally, implement structural stormwater quality controls in the same manner and locations as stormwater detention and consistent with the ordinance considerations provide below this section. Implement non-structural controls associated with the MS4 (minimum control measures), require SPCs and floodplain dedications, educate the public on limiting fertilizer application, develop a program to educate the public on fertilizer overuse, ensure proper septic system operation and maintenance, and maintain present development density limits in the Lake Thunderbird watershed.
3. Forego any changes to development regulations related to stormwater structural and nonstructural controls and wait for any new requirements under ODEQ’s Lake Thunderbird’s watershed management plan and/or the OPDES MS4 program.

Recommendation Actions: Option 2 – It is recommended that structural stormwater controls be, in general, required in the same manner and locations as required for stormwater detention throughout the city. Further elaboration of how stormwater quality controls could work is provided below in proposed ordinance enhancements. These structural controls can be built in conjunction with stormwater detention facilities in most instances. In most, but not all, cases and due to maintenance costs, public safety, and nuisance (insects, etc.) considerations, the City should encourage the use of dry detention and water quality facilities rather than wet detention/water quality facilities. For nonstructural controls that should be concurrently implemented with structural controls, the City should continue to ensure that the minimum control measures, as part of the OPDES MS4 program, be met. Additionally, the City should require floodplain/SPC dedications, implement a program to educate the public on fertilizer use, develop a program to control the overuse of fertilizers, ensure proper septic system installation and operation, and continue to limit development density (and impervious cover) in the Lake Thunderbird watershed.

Proposed Considerations, including Variances, for Incorporating Stream Planning Corridors (SPCs) and Structural as well as Nonstructural Water Quality Controls into Norman’s Land Development Ordinances

The following generally outlines how SPCs and structural/nonstructural stormwater controls could be incorporated into Norman’s ordinances and subdivision regulations. These recommended ordinance additions are presented to illustrate how the dedications of SPCs and utilization of water quality controls can work in tandem to protect Norman’s stream and lake water quality while allowing some flexibility in compliance for the City and developers. These ordinance items would be in addition to other existing or proposed ordinance requirements. Further, it addresses the possible uses of variances for special or atypical circumstances including the compensatory requirements for those that obtain variances.

- Unless stipulated otherwise herein, these considerations would apply to all developments including, but not limited to, single-family residential, multi-family residential, commercial, industrial, and possible institutional developments.
- Dedicate WQPZs and/or the 100-year full buildout floodplains to the City of Norman by easement or title for streams located in the Lake Thunderbird watershed that have a drainage area greater than 40 acres.
  - Prohibit development or significant land disturbance in the SPCs and/or 100-year full buildout floodplain. Exemptions should include items such as, but not limited to, maintenance activities, greenway trails, road crossings, utilities, and stream stabilization measures.
  - Additional stream-side buffers of 15 ft to be added to each side of waterways for streams with greater than 40 acres that are located in the Lake Thunderbird watershed and also in Suburban Residential and Country Residential areas as defined in the Norman 2025 Plan.
  - If development per lot stormwater fees are ultimately required to help pay for stormwater management costs in the City, these fees will not be charged to developments that dedicate WQPZs and/or full buildout 100-year floodplains to the City by easement or title for streams that drain more than 40 acres and are located in the Lake Thunderbird watershed.
- Require that water quality facilities be constructed to capture and treat runoff from all proposed developments in the City of Norman that exceed one acre (or some other size selected by the City) in size. The runoff “capture and treatment volume” should be set to 0.5 inch of runoff from the development area unless specified otherwise for a special condition.
  - The City should consider allowing very small developments, say less than one acre or some other limit, to pay into a regional detention/water quality program in lieu of building very small water quality structures. The City’s present regional detention program should be broadened to include this water quality fee in lieu process.
  - The City should allow and encourage low impact development techniques such as rain gardens and biofilters to provide a portion or all of their stormwater quality control requirements subject to the developer providing sufficient technical justification for the techniques.
  - For developments that do not dedicate the WQPZs or full buildout 100-year floodplain by virtue of obtaining a variance, the runoff capture and treatment volume for their development area should be increased to 0.7 inch of runoff.
- Require stormwater detention facilities to control post-development peak discharges to pre-development peak discharges for the 2-, 5-, 10-, 25-, 50-, and 100-year events assuming full buildout watershed development.
  - Inlet and outlet structures to provide erosion protection and will be constructed of materials that offer sustainability of the structures.
  - Entity with dedicated funding source made responsible for general maintenance (mowing, trash cleanup, etc.).
  - City to assume responsibility of dams and other structures.
- Allow limited variances for special conditions/situations that would use alternative approaches that could be shown to achieve similar water quality, flood control, and recreational opportunity. In situations where there is a clearly defined riparian corridor of environmental significance and/or flood prone soils, it should be relatively more difficult to obtain such a variance. However, obtaining such variances should be less difficult in situations where a riparian corridor does not exist and the subject waterway flows through an area that has experienced significant past disturbance or change from natural conditions (such as past agricultural activities and/or activities associated with residential, commercial, transportation, or industrial uses).
- Implement nonstructural stormwater quality controls in addition to SPCs, including a program to educate the public on fertilizer use, a program to control the overuse of fertilizers, a procedure to ensure proper

septic system installation and operation, and a continuation of development density (and impervious cover) limitations in the Lake Thunderbird watershed.

- Require the following compliance measures if development or significant land disturbance occurs within the stream banks of a stream in the City:
  - USACE's 404 permitting documentation and proof of permit to be submitted to the City prior to plat approval
  - Riparian stream corridor mitigation will be required (tree replacement, re-vegetation, stream stabilization using bio-engineering techniques, etc.)
  - Inlet and outlet structures will be provided as needed to incorporate erosion protection

7.3 Acquisition of Drainage Easements and Rights-of-Ways

Like many other municipalities, the City of Norman periodically needs access to streams/creeks, man-made channels, ditches, drains, storm sewers, and stormwater detention ponds, for the purposes of construction, maintenance, repair, and overall management of these stormwater systems to aid in their proper function. Unfortunately, investigations carried out in this SWMP project revealed that there is an overwhelming lack of drainage easements or rights-of-way (ROW) along streams, open channels, and stormwater detention ponds in Norman. The location of easements/rights-of-way along streams and stormwater detention facilities are available in the City's GIS system and are shown in the plan (odd numbered) exhibits in Section 6 for Level 1 and 2 study areas. This information clearly shows that most stream reaches and detention facilities have no easements/ROW at all, others have insufficient amounts, and a few have sufficient easements.

Analyses performed during the SWMP effort revealed that the City would need to acquire, or accept as a donation, easements/ROW on well over a thousand properties to gain the rights and access to major streams (assuming bank to bank plus approximately 10 ft beyond each bank) and stormwater detention facilities in its urban area. The number of properties requiring easement/ROW purchases or donations would increase significantly if the City were to obtain the FEMA floodways along these creeks as easement or outright purchase.

Typical easement conditions in Norman

Adding to this overall problem, property owners have built structures, fences, and other flow obstructions adjacent to undersized waterways in the floodplain and even the floodway. These obstructions often block flood flows and increase flooding problems along waterways and contribute to the debris that washes into the streams. Additionally, many property owners have made attempts to "fix" problems such as eroding stream banks or beds by dumping various materials (e.g., concrete rubble, logs, wire mesh, cables, tin, etc.) into the waterways. In doing this, these property owners likely did not understand or contemplate the possible negative impacts that their action may cause to other properties along the stream or to the overall stream environment.

Several discussions on the subject of easement/ROW needs have been held with City Council in work session, the SWMP Task Force, the City staff, and other stakeholders (including City Council sessions). Guidance in a general sense was obtained that basically called for a targeted and controlled acquisition of easements and rights-of-way associated with the City's stormwater planning. Easements and/or ROW needed to construct critical stream flood control and/or stream erosion stabilization projects and to allow access to streams needing critical maintenance will be targeted for acquisition with those involving project construction receiving the highest priority. It is hopeful that much of the easement/ROW area will be donated to the City although in some instances purchasing the easement may be required. The City has indicated that those that donate easement/ROW area will be looked on favorably when selecting projects to build around the City. Even though the City has indicated how they would like to proceed as stated above, the subject of obtaining easements and/or rights-of-way as considered during the SWMP is presented below.

7.3.1 Acquisition of Drainage Easements and ROWs - Key Questions, Options, and Recommended Actions

Question 1: Does the City want to obtain (through donations or purchasing) drainage easements and/or rights-of-way in previously urbanized areas in order to possibly construct needed modifications, provide maintenance, and/or carry out inspections on an as-needed basis?

Discussion: This is an issue that has grown in significance and importance since the inception and initiation of the SWMP project. The lack of drainage easements or drainage-related rights-of-way was not fully understood by many until the SWMP investigations brought attention to the related issues. It is in the best interest (health, safety, maintenance of property values, etc.) of the local citizens to have properly functioning drainage systems. As part of the SWMP, there are apparent needs to construct modifications, clean out clogged and eroding stream reaches, and maintain the stream on a regular basis.

When considering the needs identified by the SWMP, it may be best to obtain rights-of-way or special easements in stream reaches where past structures and/or improvements are located or future structures will be located in order for the City to perform the type of repair, reconstruction, inspection, survey, and/or maintenance work needed in such reaches to keep the system operating properly. It must be very clear that these reaches having significant public investment must be easily accessible to protect those investments. In other stream reaches, it may be acceptable to obtain more or less standard easements primarily for access to maintain the waterway such as cleaning, shaping, seeding, stabilizing, or mowing. Another option on certain stream reaches would be to develop a right-of-entry program such that property owners are asked for "single event" access to a stream area on their property for maintenance or stabilization work. The City can opt to only enter if given the right-of-entry approval or possibly enter regardless if the planned work is for the health and safety of the public at large and inaction would significantly endanger other citizens and property. The City may also want to determine whether it has the legal authority to enter private property for stormwater management maintenance or modifications if it would create an unacceptable risk to the health and safety of the public in not taking such action.

Costs of obtaining these rights or properties are also a big consideration especially since preliminary costs to obtain easements (creek area plus 10 ft beyond the top of bank) along all the Level 1 and 2 streams was estimated to exceed $18 million. Again, the City has decided to be much more selective in purchasing easements/ROW as discussed above. Costs to obtain wider easements such as obtaining the entire floodway along the respective creeks might cost significantly more than the figure given above since numerous buildings and other structures would have to be bought along with a much larger property footprint. Relocations of effected homeowners and businesses would also need to be considered. Some property owners might be willing to donate an easement to the City while others might not. Guidance received from the City indicates that approximately 20–30% might donate drainage easements to the City while 80% would want the easements to be purchased. In most all rights-of-way transfers of property, the owners might want to sell the property to the City rather than donate it although there would be exceptions. One exception might be that land owners along a creek needing improvements could come forward as a group and donate easements or rights-of-way in order to move a project up on the City's priority list which could also reduce costs significantly. Finally, it should be recognized that whatever plan is selected, obtaining easements on a citywide scale would be spread out over a long time period such as 10 to 20 years, if not longer.

In looking at the options below, it is assumed that there will be some stormwater management system improvements in the City as a result of the SWMP.

Options:

1. Obtain drainage easements along all streams identified in the SWMP along the Level 1 and 2 stream reaches studied.
2. Obtain drainage easements along only those streams that have a SWMP improvement project implemented or reaches that are judged to have a significant present and/or ongoing maintenance need (likely obtained when the improvement project is constructed or the first maintenance activity is carried out).
3. Obtain a mixture of drainage easements, rights-of-way, rights-of-entry, and reaches of “no action” depending on the situation/conditions. This option possibly offers the best solution as it is very flexible and allows the City to use their funds in the most efficient manner. For instance, rights-of-way could be obtained along reaches where substantial structures/improvements are built or will be built. Drainage easements could be obtained in areas that have a need to significant initial and/or ongoing maintenance. Rights-of-entry could be used in areas that will likely need maintenance every few years and/or only if certain things occurred (e.g., large storms or a buildup of debris over, say, five to ten years). Finally, there might be some reaches that are presently being maintained (e.g., mowed often like a lawn) by property owners and these property owners would like to continue doing so. The City could simply let the maintenance of those reaches stay with the property owner as they are doing a good job and want to continue doing so.

Recommended Actions: Option 3 – Obtain a mixture of drainage easements, rights-of-way, rights-of-entry, and reaches of “no action” depending on the situation/conditions. The preferred approach would be to obtain easements or rights-of-way wherever possible unless there are location-specific problems with this approach. However, and while it is preferred to obtain easements or rights-of-way, obtaining rights-of-entry and/or not obtaining any easement (“no action”) may be the most prudent action in certain instances. When considering the needs in any specific area, it is recommended that rights-of-way or special easements be obtained in stream reaches where past structures and/or improvements are located or future structures will be located. This is needed to allow the City to perform the type of repair, reconstruction, inspection, survey, and/or maintenance work needed in such reaches to keep the system operating properly. It must be very clear that these reaches having significant public investment and therefore, must be easily accessible to protect those investments. In other stream reaches, it may be acceptable to obtain more or less standard easements primarily for access to maintain the waterway such as cleaning, shaping, seeding, stabilizing, or mowing. On stream reaches where one or more property owner are reluctant to provide easements or rights-of-way, the City should consider obtaining a rights-of-entry to targeted properties. In these instances, property owners are asked for “single event” access to a stream area on their property for maintenance or stabilization work. The City can opt to only enter if given the right-of-entry approval or possibly enter regardless if the planned work is for the health and safety of the public at large and inaction would significantly endanger other citizens and property. The City may also want to determine whether it has the legal authority to enter private property for stormwater management maintenance or modifications if it would create an unacceptable risk to the health and safety of the public in not taking such action.

Consideration 2: Does the City want to obtain rights-of-way or easement widths that cover the respective creek channels (bed and banks), possibly going a distance of say 10 ft beyond the bank, or obtain a much larger area such as creek floodway areas.

Discussion: In instances where the City does want to pursue obtaining easements or rights-of-way, then a follow-on question becomes how much to obtain. As mentioned above, two ideas have emerged related to the amount of easement/ROW to obtain if that is the direction the City chooses. As for obtaining the creek (bank to bank plus say

10 ft), this would cost the least and would be a much smaller undertaking compared to obtaining the FEMA floodway. Although many property owners might be reluctant to “give up” some of their property or property rights near the creek, they might prefer this to being bought out in the floodway-based easement buyout which would be required on numerous properties that are located in the floodway. FEMA defines the regulatory floodway as the channel of a river or other water course and the adjacent land areas that must be reserved in order to discharge the base (100-year or 1%) flood without cumulatively increasing the water surface elevation more than a designated height (usually 1 foot).

There are many benefits to obtaining the floodway as easement. One primary benefit would be to remove numerous structures from harms way in the floodway. This would also offer a much larger area for greenbelts and open space along waterways, a SWMP priority. Again, the main drawbacks would be the increased costs, the need to relocate many residents to different homes, and to move businesses to new locations. The benefits would be that the stream corridor would be more respected and returned to a more natural state (within limits) which would add to the “quality of life” in those stream areas and restore some lost environmental qualities.

Options:

1. When obtaining easements or rights-of-way, target the area extending from stream bank to stream bank plus 10 ft on each side.
2. When obtaining easements or rights-of-way, target the area that is encompassed by the FEMA floodway along the respective streams.

Recommended Actions: The City should use a combination of Options 1 and 2 and obtain easements/ROW extending bank to bank plus 10 ft (or a somewhat wider amount depending on specific site circumstances) on each side of Level 1 and 2 creeks while allowing that in a few special locations such as Imhoff Creek, a plan be developed to obtain properties in the FEMA floodway over a longer period of time.

7.4 Enhanced Maintenance of Creeks and Stormwater Detention Facilities

There is no formal maintenance program to maintain the many open waterways in the City. The lack of drainage easements along the City’s streams has played a major role in the lack of maintenance as access and rights are limited. A large number of steam reaches have not been maintained at all, some have had sporadic maintenance by City workers or landowners, and certain ones appear to have been maintained regularly by landowners. The lack of maintenance has caused “log jams” on creeks such as Imhoff Creek where, in the past, fallen trees and debris have clogged the waterway and built a virtual dam across the stream. In the reaches that are unmaintained, the stream corridor does not appear capable of safely carrying storm flows, detracts from the aesthetic appeal of the creek, presents an environmentally damaged setting, and can subject local citizens to unsafe conditions. However, there are some stream reaches that look well maintained as local residents appear to be maintaining the creek near their properties.

As stated above, the lack of easements/ROW and resulting access limitations has historically played a big role in a significant deficiency in stormwater maintenance throughout Norman. Many times property owner associations (POAs) have the responsibility of maintaining the creeks and stormwater detention facilities located in their neighborhoods. This has led to poor maintenance or no maintenance in many of these stormwater areas. There are some instances where POA maintenance appears to be adequate such as in the Hall Park neighborhood. However, the inadequate and inconsistent maintenance has led to numerous problems that the City Council and City staff feel need to be addressed. If the City of Norman wants to upgrade its maintenance, the acquisition of drainage easements or rights-of-way from existing and new developments must be part of the solution. Discussions with City Council members, the SWMP Task Force, the City staff, and other stakeholders documented the need for future maintenance activities in coordination with the acquisition of selective easements and rights-of-way.

Various cities and counties were contacted to obtain general program costs of maintaining various types of streams. These program costs include the manpower and equipment costs required. Typical costs were developed for each type/condition of a stream from this information. The City's GIS data were used to obtain estimates of stream lengths and stormwater detention facility dimensions to provide the quantities of areas requiring maintenance. Estimating general maintenance costs for Levels 1 and 2 streams included delineating three stream types, obtaining lengths of each stream type, estimating unit maintenance costs by type, respectively multiplying stream lengths by unit costs for the three stream types, and totaling all costs for stream maintenance as shown below. Obtaining general maintenance cost estimates for stormwater detention facilities included measuring the perimeter length around each stormwater detention facility area, totaling the perimeter lengths, obtaining the unit maintenance cost, and multiplying the total perimeter length by the unit cost to arrive at the total cost. When added together, the general estimate of annual maintenance costs for streams and stormwater detention facilities totals approximately $1.2 million.

Debris blocking Imhoff Creek

Woody debris in lower Bishop Creek

Stream maintenance is a significant commitment.

7.4.1 Enhanced Maintenance of Creeks and Stormwater Detention Facilities - Key Questions, Options, and Recommended Actions

Consideration 1: Does the City want to incur the costs and significantly increase the maintenance provided in streams and waterways especially the Level 1 and 2 streams studied?

Discussion: Costs associated with maintaining the Level 1 and 2 stream reaches will be significant and should be considered in future actions. Costs for the Level 1 and 2 streams are discussed below.

Level 1 and 2 Streams:

- Type 1: Natural channels with lots of trees, steep banks, difficult access, debris problems, etc. (Example = lower Imhoff Creek or Brookhaven Creek below 36th Avenue SW or Main Street).
- Type 2: Natural channels that are able to be mowed with few trees, easy access, maybe a concrete low flow channel (Example: Imhoff Creek upstream of the articulated block channel lining near Lindsey Street).
- Type 3: Modified channels with lining such as concrete or articulated block – relatively small and easy. (Example = the WPA channels with mortared rock walls and concrete bottom, such as in upper Imhoff Creek and upper Bishop Creek).
- Unit Costs:
  - Type 1: Assume $12,000/mi/yr. ($24,000/mi for years that inspections are conducted). Assumes maintenance performed once every two years on average.
  - Type 2: Assume $8,000/mi/yr. Maintenance every year (once per year).
  - Type 3: Assume $2,000/mi/yr. Maintenance and/or inspection every year. Expectations would be that in most years only inspections would be performed.

- Total length (miles):
  - Type 1: 42.8
  - Type 2: 3.6
  - Type 3: 11.0
- Total Costs:
  - Type 1: $514,000/yr
  - Type 2: $29,000/yr
  - Type 3: $22,000/yr
- Grand Total Costs: $565,000/yr

Consideration 2: Does the City want to significantly increase the maintenance provided for stormwater detention facilities? Does the City want to vary the maintenance based on certain types of detention facilities? Does the City want to share responsibility with property owner associations?

Discussion: Similar to what was discussed above for streams, the costs of maintaining stormwater detention facilities will be a significant annual expense. A general cost estimate for the present system of detention facilities in the City (based on the City's GIS system data) is presented below.

Stormwater Detention Facilities:

- Number of detention facilities from City's GIS system = 286
- Total perimeter length around the facilities = 61.4 miles
- Unit Cost per mile: $10,000. Maintenance every year (once per year).
- Total Cost: $614,000

Total Costs for Streams and Stormwater Detention Facilities = $1,179,000 (use $1,200,000)

Recommended Actions for Considerations 1 and 2: A City stream maintenance program, with maintenance schedules as recommended above, should be ramped up over a few years consistent with the acquisition of easements, rights-of-way, rights-of-way, rights-of-entry, and reaches of "no action" depending on the situation/conditions. Maintenance should focus in those stream reaches and/or detention facility areas where capital improvements are constructed in order to protect those investments as well as in areas where serious problems have been identified, such as lower Imhoff Creek, lower Brookhaven Creek, and stream erosion sites along Bishop Creek and its tributaries.

The City should also consider outsourcing some, or all, of the maintenance activities if it is advantageous especially while a City's program is ramping up. The City should also focus on detention facilities in which dam maintenance becomes a safety issue as discussed below.

7.5 Dam Safety

A key issue that became a concern during the SWMP project involves dam safety. It is obvious from viewing aerial photos of Norman and viewing the City's drainage systems (see Exhibit 4-4) that the City has a great number of dams of significant height with homes and business located in low lying areas downstream of the dams. Many of these dams impound a significant pool of water and/or have the potential to temporarily store large volumes of stormwater during flood events. These conditions pose a dam break public safety concern for those that live, work, drive, recreate, and generally occupy the floodplain area downstream of these impoundment structures. Generally speaking, as the height of a dam increases, risks, danger and public safety become more of a concern.

The Oklahoma National Dam Inventory identified approximately 20 dams in the Norman area as shown in Figure 7-1. Most all of these dams were reported to have been built in the 1960s, which makes them 38 to 48 years old. These 20 dams identified in the national inventory are the more substantial dams and came under the jurisdictional authority of the Oklahoma Water Resources Board pursuant to the enactment of Title 82 of Oklahoma Statutes. Consequently, all of the old (i.e., already in existence) jurisdictional dams in Oklahoma were inventoried and inspected by the USACE in the late 1970s as mandated by The National Dam Inspection Act, Public Law 92-367, 8 August 1972 under the “Phase One Inspection of the National Dam Safety Program.”

Two key issues require consideration.

7.5.1 Dam Safety - Key Questions, Options, and Recommended Actions

Consideration 1: Should the City investigate and identify, to the extent possible, the responsible parties for the inspection, maintenance, and overall safety of the dams that are judged to be a potential safety hazard?

Discussion: Although OWRB oversees dam safety in Oklahoma, it is unclear whether there is a program in place to systematically evaluate the dam sites in Norman. A dam safety concern involves the apparent limited maintenance of many of the dams located in the City, as well as the associated principal spillways, the emergency spillways, and the upstream ponding areas in general. In many instances, it is not known who is responsible for the inspection and maintenance of most of these dams that pose a public safety concern in various areas throughout the City. According to the City and in most instances, property owner associations (POAs) have inherited the responsibility for dam inspection and maintenance. The City could undertake one or more investigative projects to determine ownership of the many dams, say 6 ft or higher, located in the City. The dams with the greatest height, unmaintained condition, and/or most downstream development should receive the highest priority during any such investigations. Once ownership is established, the effort should also include gathering information about the dam and its ponding area such as design drawings, inspection reports, maintenance records, and any other pertinent information.

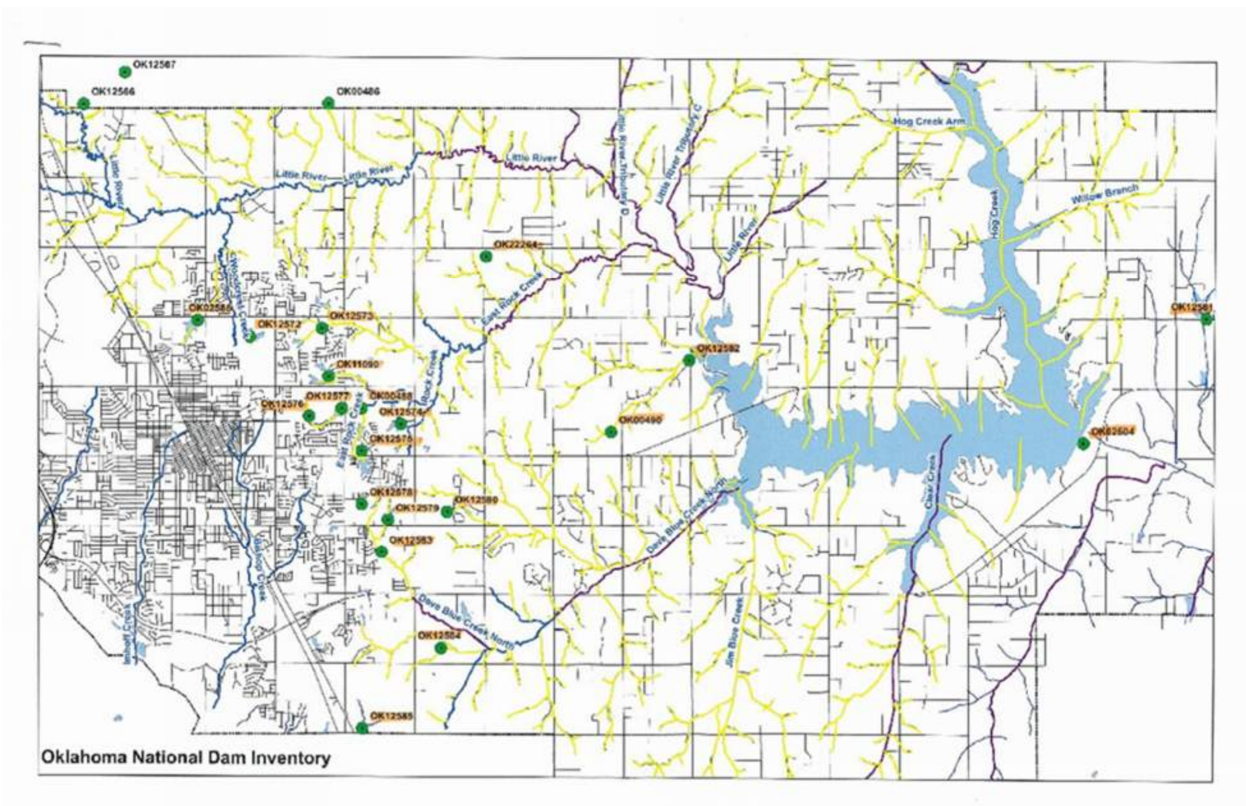


Figure 7-1: Oklahoma National Dam Inventory

Option 1: Undertake one or more investigative projects to determine dam ownership and responsible party for maintenance of the structure and its appurtenances. Collect all available pertinent information about each investigated structure.

Option 2: Forego undertaking any investigative projects.

Recommended Actions: Select Option 1 and undertake the investigative projects beginning with the dams judged to have the greatest public safety risk. An inventory and prioritization method will have to be developed at the beginning of the investigative work.

Consideration 2: Does the City want to take over ownership, liability, and maintenance from POAs or other owners to insure that dams are made safe and properly maintained?

Discussion: The City's GIS data indicate that there are almost 290 stormwater detention facilities, retention ponds, or other waterbodies in the City. Many of these are likely small and inconsequential from a dam safety standpoint but many warrant public safety concerns.

Recommended Actions: The City should meet with OWRB and obtain their input and insight concerning the dams in Norman and their hazard potential. Considering discussions with City staff and other stakeholders, it is recommended that the City take over the inspection and maintenance for all dams that pose safety concerns or, at least, those that pose the greatest hazards. Further, the POAs should maintain the general mowing and small scale maintenance responsibilities while the City undertakes the more critical dam safety, inspection, and maintenance responsibilities.

It is recommended that the City determine the prevailing conditions for any dam and its appurtenances through an initial investigation prior to taking on any additional responsibilities. Should the City take over inspection, maintenance, and upgrading responsibilities for the structures, it should first be determined what actions they or the present owners might have to take to bring any structures into state dam safety compliance. Such actions could include determining whether the dam structures require modifications to strengthen them against failure or breach. Another important aspect is whether any of the dams need an emergency action plan which is developed to reduce the risk to lives and property that can result from dam failure.

Downstream side of unmaintained dam

8.0 Financial Analyses

2025 Financial Analysis Updates

As stated in the introduction, the dollar amounts in this section were not updated through the AIM Norman Process. However, since the 2009 Stormwater Master Plan was updated, there have been two different Stormwater Utility Fee (SWU) campaigns. Both resulted in a rejection of the SWU by the voters but provided valuable insight for future potential campaigns and how the public responded to different types of stormwater utilities. The relative vote share for the 2019 vote was much more in favor of the SWU than the 2016 vote. Further, the overall response from public input into the AIM Norman process suggests that providing stormwater funding that is targeted at the priorities of each watershed in Norman is a high value for the Norman Citizens.

Subsection 8.1.1 was updated with some of the findings from the 2018 Stormwater Citizen Committee Reports and what those reports recommended to City Council. The reports generated from this effort are valuable information regarding citizen's understanding of the stormwater challenges in Norman. Future campaigns to secure funding for stormwater maintenance and stormwater quality controls is highly recommended, but future campaigns should take into account the lessons learned from the 2016 and 2019 campaigns.

The hard numbers that are included in the following sections are (unless specifically noted) financial amounts determined based on 2007-2009 economic conditions. The costs of services and construction has risen with (at times, dramatic) inflation rates in years since this data was developed. This report does not remove those numbers as they may provide a qualitative understanding of the reasoning behind different SWU rate structures. However, the financial numbers (specifically those in Section 8.3) should not be used as a qualitative measure of stormwater costs in Norman for 2025 and beyond. Additional future financial studies should be used to estimate future costs and SWU rate structures.

For reference, a general Consumer Price Index (CPI) inflation adjustment was applied to compare what a single dollar in 2009 equals in 2024 dollars (US Bureau of Labor Statistics). The table below shows the comparison. This demonstrates that generally, any non-construction related costs that were identified in 2009 can be assumed to be 43% more costly (all else equal) than they were when the 2009 costs were calculated. Similarly, construction related costs are generally 85% more costly.

Table 8-1. Inflation Dollar Comparison

	2008 Cost (December)	2024 Cost (December)
General CPI	$1	$1.43
Construction Inflation	$1	$1.85

8.1 Introduction

The City of Norman solicited input regarding a stormwater utility fee (SWU) through a series of Stormwater Task Force and general public meetings held during 2007 and 2008. City and PBS&J staff have developed a comprehensive stormwater master plan as the basis for the creation of the stormwater utility. The stormwater master plan estimates; 1) the operations and maintenance costs to meet the City’s current Phase II permit requirements; 2) the upcoming expansion of Phase II requirements; and 3) capital program costs.

This section provides a stormwater utility background, rate considerations, revenue requirements and the resulting stormwater rates.

8.1.1 Background - The Stormwater Utility Concept

Historically, funding stormwater management programs has been problematic for most local governments. Today hundreds of local governments have discovered a viable option: the stormwater utility.

A stormwater utility operates much like other utilities — water, sewer, or power, for example — that are funded by service fees and administered separately from the general fund, thereby providing a dedicated and stable source of funds that are raised through charges based on a user's contribution to local stormwater runoff. An EPA study identified three major advantages of stormwater utilities over funds generated through property tax revenues: (1) increased stability and predictability; (2) greater equity; and (3) it allows for incentives for on-site stormwater management (Doll et al., 1998). Experts estimate that there are more than 800 stormwater utilities in communities throughout the country. These stormwater utilities serve cities with populations ranging from under 12,000 (Auburndale, Florida) to over 3.5 million (Los Angeles, California) (Black & Veatch Management Consulting, 2007). By contrast, there are thousands of water, sewer, and irrigation districts in the country that work under a similar framework.

While few people enjoy paying more fees, the utility approach is often seen as more equitable to rate payers. PBS&J's experience with stormwater utilities has shown that they are capable of generating substantial revenues for local stormwater management programs at relatively nominal charges.

A sound stormwater utility rate structure is developed around two major themes. The first is the "user pay" concept — the parties that have the most stormwater runoff and receive the most benefits from the stormwater utility pay their proportionate share. The second is that the utility is structured so that it can be administered fairly and cost-effectively.

In Norman, there have been two Stormwater Utility Campaigns. One was in 2016 and the other in 2019. In preparation for the 2019 Stormwater Utility (SWU) vote, a Stormwater Citizen's Committee was formed. This Committee was tasked with developing a long-range stormwater program funding proposal. Based on their research, they concluded that a reasonable, but modest, program of services should be as follows in Table below.

Table 8-2. 2018 Stormwater Citizen Committee Funding Conclusion

Program Elements	Pre-SWU Annual Funding	Post-SWU Annual Funding
Stormwater Quality	$1,194,832.00	$2,403,423.75
Infrastructure Maintenance & Operations	$1,994,516.60	$5,033,942.57
Grand Total	$3,189,348.60	$7,437,366.32

Along with developing the long-range stormwater funding proposal, the Committee also provided detailed information on how the funds generated from this SWU would be used. These categories were split between "Basic Maintenance" and "Stormwater Quality." Under the "Basic Maintenance" category, the proposed funding included personnel costs, supplies & service costs, equipment costs, and building maintenance costs. It also included Emergency Neighborhood Repairs & Materials, Maintenance Access Point Construction, and Enhanced Maintenance Program for Neighborhoods & HOAs.

Under the "Stormwater Quality" category, the proposed funds would cover the Stormwater Program Minimum Control Measures (MCMs) that have been outlined in the Stormwater Management Plan. This Stormwater Management Plan describes in detail the tasks that are to be completed during the 5-year permit cycle for the ODEQ stormwater management permit. These MCMs include the following categories: Public Education & Outreach, Public Participation & Involvement, Illicit Discharge Detection & Elimination, Construction Stormwater Runoff Control, Post-Construction Stormwater Management, and Municipal Good Housekeeping (Ex. inspection of municipal maintenance yards, BMPs are used to address spills and leaks, streeting sweeping costs, etc.). The proposed funds would also cover the tasks associated with the Lake Thunderbird TMDL such as public education, monitoring, and implementation of structural controls.

Along with "Basic Maintenance" and "Stormwater Quality," there was a "Stormwater Utility Management Services" category that would also be covered by the additional funding if a stormwater utility was passed. This includes GIS services, fleet maintenance, finance, and other city services associated with administering the program.

For more information on the recommendations from the 2018 Stormwater Citizen Committee, please refer to Appendix N for their completed report.

8.1.2 Rate Structure Considerations

A fundamental concept of any utility is the capacity of the service delivered by that utility to be bought in measurable, discrete units of services, i.e., kilowatt-hours in electric utilities, phone service in minutes of connect time, water in hundred cubic feet or thousands of gallons, etc. In each case, buyers pay for what they consume. This concept is founded on the intuitively appealing notion that one pays proportionate to the cost or burden one puts on the system. How much one pays for stormwater services might better be related to the amount of “stormwater management” services consumed, which can be reasonably and accurately estimated. Also, it follows that billing by “consumption” rather than by value of property could be the basis of a more equitable charge philosophy.

The unit of measurement for stormwater service is most often based on impervious surface area. This is supported by research performed by PBS&J and detailed in a white paper titled *Results from National and University Specific Stormwater Surveys* shown in Appendix K. Many utilities establish a base-billing unit, commonly referred to as an equivalent runoff, or residential unit (ERU), or an equivalent stormwater unit (ESU). Some utilities establish tiered flat rates where parcels are billed depending on where they fall in the tier structure. Other topics for discussion when establishing rate structures include using fixed rates for overhead costs, assessing additional surcharges to areas with more complex stormwater requirements, and the need to meet federal requirements.

Paramount to the establishment of stormwater utility rates is obtaining buy-in from the community. It is recommended that public education is started at least a year before any fee program or change is put into place. If people understand what is being done and think it is fair, they will support and become part of the outreach process and pass the word along.

There is not one type of stormwater utility rate-setting strategy that fits the needs of all communities. Being equitable across the board, having a solid basis for measuring service, and establishing a solid administration structure are the keys to success.

8.1.3 Stormwater Legislation

Legislation in most states indicates that reasonable stormwater utility fees will be upheld if legally challenged. The stormwater utility rate should be designed to defray the costs of the service provided by the municipality (Bloom v. Ft. Collins, 784 P. 2d 304, 308, 1989). While it is not necessary for there to be mathematical symmetry (Sandy Springs Water Co. v. Department of Health and Envtl. Control, 324, S.C. 177, 181, 478 S.E. 2d, 60, 62, 1996), an equitable relationship between the amounts of stormwater generated by a given property, the benefit received by the rate-payer, and the corresponding fee is normally required.

Generally, case law suggests that a rate will be deemed valid where the:

1. Revenue generated provides benefits for the payers, primarily even, if not exclusively
2. Revenue is only used for the projects for which they were generated
3. Revenue generated does not exceed the costs of the projects
4. The rate in uniformly applied among similarly situated (from a runoff view point) residents (*C.R. Campbell Constr. Co Inc. v. Charleston, 481 S. E.2d 437, 438, 1997*).

Furthermore, benefits do not need to be either direct or quantifiable; intangible benefits such as an improved overall state of public health may be counted (*Kentucky River Auth. v. County of Danville*, 932 S.W.2d 374, 377, Ky. Appl., 1996). Any property that is part of the watershed may be considered to have benefited from surface drainage improvement, through improvements of health, comfort, convenience, and enhanced property values (*Kentucky River Auth. v. County of Danville*, 932 S.W.2d, 377, Ky. Appl., 1996).

The key to determining just exactly who benefits from a community's stormwater management is the concept of "burden." Virtually all property has the potential to generate stormwater runoff, and hence the aggregate runoff must be managed in an organized and systematic manner if owners are to enjoy the use of their property with some degree of reliability. The burden of managing the accumulating stormwater falls to the community. Stormwater systems and facilities must be constructed and maintained to reduce the undesired impacts of accumulated runoff.

While most communities split the responsibility of managing the burden of runoff between the parcel owner (developer) and the community (hydrologic drainage design criteria), the responsibility for managing stormwater runoff that exceeds on-site design requirements is clearly the responsibility of the community. The amount of runoff generated by a parcel and sent to a stormwater system represents its proportionate share of the burden of creating and maintaining the stormwater system. Therefore, the costs of the stormwater management program are a tangible, aggregate measure of the management of the burden of runoff generated by each parcel.

All rate structures are ultimately constrained by the legal context they must operate within. Several of the most fundamental points that directly impact the design of a rate structure are highlighted below:

- Public Purpose – All components of the rate structure must work to affect a clear public purpose.
- Rational Nexus/Special Benefit – There must be a reasonable relationship between the amount of service rendered and the amount of charge levied.
- Not Arbitrary – Each component of the structure must have a purpose and should be the result of logically based consideration of fact. Specifically, the structure should not be inconsistent with basic tenants of stormwater engineering science. It is also recommended that normal procedural and statistical rigor be well documented in the construction of the fundamental structure in the determination of all categories, classes and groups, and in the calibration of arithmetic parameters.
- Uniform/Equal Application of the Law – All parcel/customers equally situated must be equally treated, and exemptions, where used, must be awarded to all similarly situated customers.

A sound stormwater utility rate structure is developed around two major themes. The first is the "user pay" concept, and the second involves the balance between simplicity and equity. The key is to strike a balance so that enough factors are considered so as to be fair, but so that the structure is simple enough to be explained easily and to be administered cost-effectively.

8.2 Impervious Surface Analysis

The City provided impervious data for each parcel from its GIS database and Vieux reviewed this data for accuracy and completeness. PBS&J categorized the parcel data into five user classes as shown in Table 8-3. Column A shows there are 39,851 parcels within the study area for a total of almost 292 million square feet of impervious surface as shown in Column C. Column D shows that the single-family user class accounts for 32% percent of the total impervious area. Column E shows the average impervious area for each user class and Column F shows the percent of individual user class total area that is impervious.

Table 8-3: Impervious Data Analysis Results

All Parcels	(A)	(B)	(C)	(D)	(E)	(F)
User Class	Parcel Count	Total Area Sq Ft	Imp. Area Sq Ft	% of Total Impervious Area	Avg Impervious Area (Sq Ft)	% of User Class Area that is Impervious
Single Family	26,078	636,195,726	94,245,445	32%	3,614	15%
Multi-family	6,626	193,751,640	42,293,081	15%	6,383	22%
Comm/Indust/Office	2,314	222,531,361	59,935,187	21%	25,901	27%
Agriculture	4,616	3,854,345,991	72,687,230	25%	15,747	2%
University of Oklahoma	199	76,314,671	15,637,104	5%	78,578	20%
Miscellaneous	18	17,709,556	6,827,420	2%	379,301	39%
Total	**39,851**	**5,000,848,945**	**291,625,467**	**100%**		

Table 8-1 shows data for all parcels within the City, including exempt parcels. The City Council decided to include all impervious parcels as billable parcels after first assessing the impact to rates if exempt parcels (including the University of Oklahoma, churches, schools, Indian land, county, state and federal land, and non-profit land) were excluded. This is further discussed in Section 8.3. The City chose a conservative approach, reflecting the economic environment of FY 2008–2009, by assuming no impervious surface growth for the 20-year study period.

While the data provided by the City shows that the average single-family residence has approximately 3,600 square feet of impervious area, the median impervious square footage is approximately 3,100 square feet. The various single-family square-footage deciles are tabulated below. The information provides a range showing how many single-family properties have impervious cover amounts less than or equal to the respective amount shown. For instance, the data indicate that 50% of the single-family properties in Norman have 3,100 square feet or less of impervious area and 30% of the single-family properties have 2,500 square feet or less of impervious cover.

Single-Family Impervious Cover (sq ft)	% Single-Family Properties Less Than or Equal to
2,500	30%
2,800	40%
3,100	50%
3,400	60%
3,800	70%
4,100	80%

8.3 Stormwater Revenue Requirement

8.3.1 Revenue Requirement Definition

The stormwater revenue requirement is defined as the revenue required to pay for operation and maintenance, cash (or stormwater fee) financed capital, debt service and reserve creation less any non-operating revenues such as interest earnings.

8.3.2 Revenue Requirement Discussion

The stormwater revenue requirement is broken into eight main cost components as shown on Table 8-3 (lines 5, 10, and 11 not counted). The revenue requirement for each option is developed using the mid-year of a 5-year planning period to establish one user fee for the period of FY 2009–2010 to FY 2013–2014. The mid-year used in all of the following tables is FY 2011–2012 (except Table 8-4, which is in FY 2008–2009 dollars) and inflation is applied to all of the operations, maintenance, and capital numbers shown in Table 8-2. A brief description for each category of expenses follows:

1. Operation and maintenance: These expenses include general street sweeping and stormwater system maintenance provided by the streets department. Other items covered under O&M are (but not limited to) office supplies, asphalt materials, minor tools, training, and temporary positions.
2. Shared city services: These costs are similar to those included in the City's water and wastewater user fees. They recover the costs of departments such as finance and City administration whose staff and services support the utility but are not directly charged to the utility.
3. Minimum control measures: These are the costs associated with compliance to the City's current stormwater permit and are more fully described in Section 5 and 6 as well as Appendix H of the report. These costs increase dramatically in FY 2012-2013 to cover the costs of the City's upcoming expanded Phase II permit.
4. Reserve funding: All utilities need a moderate amount of reserves for unforeseen operational or capital events. The revenue requirement includes funding for an operating reserve, rate stabilization reserve, and capital reserves. Reserves are slowly built up over time to minimize impacts on rates.
5. Enhanced maintenance: The City has millions of dollars in deferred trail, detention pond and creek maintenance. During the course of the master plan as annual program was defined and an annual average budget established at $1.2 million before inflation.
6. Trial construction: As part of the City's overall master planning process, a separate Greenway Master Plan (Halff, 2009) was prepared. Many communities have successfully established a dual purpose stormwater/trail program that incorporates stormwater and flooding concerns with recreation. An annual amount of $1 million before inflation has been incorporated for such a plan over 20 years.
7. Easements and Right-of-Way acquisition: As part of the master planning process it was determined that the City has acquired only a fraction of easements and/or right-of-ways to operate and maintain their stormwater facilities. This is discussed in more detail in Section 7. Two hundred fifty thousand dollars per year before inflation is incorporated into the stormwater revenue requirement to assist the City in this program.
8. Cash Financed (Pay-go) Capital Projects: The master plan has identified $83 million in capital improvement projects. As discussed in Section 8.2, the capital program is partially funded through general obligation bonds and stormwater fees (pay-go). Line number 7 in Table 8-2 shows the stormwater fee funded capital program under each of the three different options which are defined in Section 8.3.5 below.

8.3.3 Inflationary and Interest Assumptions

The expenses shown in Table 8-4 are adjusted for inflation using the inflationary factors shown in Table 8-5.

Table 8-4: Stormwater Utility Revenue Requirement (FY 2011–2012 Dollars)

Line No.	Stormwater Revenue Requirement, FY 2011-2012	Option 1	Option 2	Option 3
1	Operation and Maintenance	$459,799	$459,799	$459,799
2	Shared City Services	$129,465	$129,465	$129,465
3	Minimum Control Measures	$748,616	$748,616	$748,616
4	Reserve Funding	$265,000	$265,000	$265,00
5	Subtotal	$1,602,880	$1,602,880	$1,602,880
6	Enhanced Maintenance (Trails, Detention Ponds, Creek)	$1,273,080	$1,273,080	$1,273,880
7	Capital Improvement Program	$2,866,240	$2,406,560	$2,325,440
8	Trail Construction	$1,081,600	$1,081,600	$1,081,600
9	Easements and Right of Way	$265,225	$265,225	$265,225
10	Less Interest on Cash Accounts	$(25,758)	$(25,758)	$(25,758)
11	Total Revenue Requirement	$7,063,267	$6,603,587	$6,522,467

Table 8-5: Inflationary and Interest Assumptions

Budget Component	Rate	Use
Interest Earnings	3.0%	Cash Balances
Salary Inflation	4.0%	Salaries and Shared City Services
General Inflation	3.0%	O&M, Enhanced Maintenance, Easements and ROW
Construction Inflation	4.0%	Capital Projects, Trail Construction
MCM* Inflation	5.0%	Used for First 5 Years, General Inflation Used Thereafter

8.3.4 General Obligation Bond Financing

The City decided to partially fund stormwater capital improvement with general obligation (GO) bonds instead of revenue bonds due to the following:

1. The City feels property tax revenue (used to repay GO bond debt) is more secure and thus would result in a lower expected interest rate for GO bonds.
2. The impact of increased property taxes is, for most property owners, absorbed within the homeowner's mortgage payment. Relative to the overall mortgage payment, the increase does not "feel" as large as it would in a stormwater fee that appears as a separate line item on the utility bill.
3. The separate vote that would be required to authorize GO bonds would give more of a feel of transparency to the process of approving the projects. If the projects are just a part of the stormwater rate structure that is voted upon, voters may feel as if they had less of a say in the issuance of the debt backed by the utility revenue stream.

Once the GO bonds are authorized, the City would issue the bonds via a competitive sale as is mandated by Oklahoma state law and would determine whether it would be advantages to issue the debt all at once, or to schedule several sales to match cash flow needs of the capital projects (in general, it is less costly to combine the bond sales to achieve economies of scale in the fixed costs of issuing bonds regardless of the amount of the bond issue). The City would prepare documents and agenda items for the City Council to set a date of bidding on the bonds, and then award the bid to the lowest bidder based on the true interest cost method. A few weeks later the City would close the sale, deliver the bond specimen and receive the proceeds to pay for the projects.

The net assessed property valuation in Norman was $616,042,224 in 2007 (assessments are made at 12% of the estimated market value of the property). The City normally assumes the average house in Norman is $100,000 (the median home value in Norman is about $112,000). As a very rough rule of thumb, $10 million worth of capital projects costs a median homeowner in Norman about $1 a month in increased property taxes. A $40 million stormwater project, financed with 20-year general obligation bonds, would raise property tax about $4.21 per month on average. Very little of property tax bill revenue in Norman goes to the City since property taxes in Oklahoma cannot be used by cities to pay for operations – only GO bond debt service. Most of the property tax revenue goes to school districts, county and libraries.

The one shortcoming of using GO bonds versus revenue bonds is that exempt properties do not receive property tax bills. With a few exceptions for "payments in lieu of taxes," exempt properties (such as the University of Oklahoma) DO NOT share in the cost of retiring City of Norman GO bond indebtedness. This is one of the "pros" for financing utility costs with utility user fees instead of GO bonds. However a special formula can be added to the stormwater user fee bill for exempt properties to recover their proportionate share of the capital projects financed by GO bonds.

8.3.5 Three Revenue Requirement Options

The City asked to have three rate options developed thus creating three different revenue requirements. The revenue requirement changes in each option due to the amount of stormwater fee based capital financing — also known as pay-go or cash financed capital. As shown in Table 8-6, the total 20-year capital improvement program in 2009 dollars is $83 million. The means of financing this program is also shown in Table 8-4. In Option 1, The City plans to raise $30 million through general obligation (GO) bonds, which leaves $53 million over 20 years to be financed through stormwater user fees. Table 8-4 also shows the amount of bond financing and cash financing under options 2 and 3.

Under option 1, line 7 shows the average yearly cash financed capital expenditure is approximately $2.65 million in 2009 dollars.

Table 8-4 shows the stormwater revenue requirement assumed for the first 5-year period – FY 2009–2010 through FY 2013–2014 under the three rate options. The City chose to implement one rate for the next 5 years and therefore FY 2011–2012 — the midyear in this 5-year period — is used to set rates for this 5-year period. Note that line 7 in Table 8-4 — the capital improvement program — is equivalent to line 7 in Table 8-6; however, it has been adjusted for inflation to reflect FY 2011–2012 dollars, which is the mid-point of the 5-year planning period.

Table 8-6: Three Rate Options – FY 2008–2009 Dollars (Uninflated)

Line No.	Item	Option 1	Option 2	Option 3
1	Capital Improvement Program (20-year Period)	$83,000,00	$83,000,000	$83,000,000
2	Funding Source			
3	General Obligation Bonds	$30,000,000	$38,500,000	$40,000,000
4	Stormwater User Rates (pay-go) Financing	$53,000,000	$44,500,000	$43,000,000
5	Total	$83,000,000	$83,000,000	$83,000,000
6	Study Period	20	20	20
7	Capital Improvement Projects per Year Funded by Rates	$2,650,000	$2,225,000	$2,150,000

8.4 Stormwater Rates

8.4.1 Rate Calculation

The stormwater rate, in dollars per square feet of impervious area, is calculated as follows;

$$\frac{\text{Revenue Requirement (\$)}}{\text{Impervious Area (sq ft)}}$$

Each user classes cost burden is proportional to its impervious area. The stormwater rate is a flat rate across all user classes.

The corresponding bill for each parcel is calculated as:

Stormwater Bill ($) = Stormwater Rate ($/sq ft) x Parcel Impervious Area (sq ft)

8.4.2 Stormwater Rates

Table 8-7 shows the calculation of stormwater rates for each of the three options for the first 5-year period (FY 2009– 2010 to FY 2013–2014). The City is required to go to a vote of the people in order to create their stormwater utility and set rates. The City chose to implement a stormwater rate for a 5-year period. This means that each 5 years the City would go out to the electorate to establish the rates for the next 5 years.

Table 8-7: Stormwater Rate Calculation for FY 2009-2010 through 2013-2014

	Option 1	Option 2	Option 3
Revenue Requirement	$7,063,267	$6,603,587	$6,522,467
Total Impervious Sq Ft	291,625,467	291,625,467	291,625,467
Yearly Rate ($/Sq Ft)	$0.024	$0.023	$0.022
Monthly Rate ($/Sq Ft)	$0.0018	$0.0017	$0.0017

8.4.3 Average Bills

Table 8-8 shows the average impervious area and average yearly bill under each of the three options for the three different user classes and the University of Oklahoma.

Table 8-8: Average Bill for Each User Class

		Option 1		Option 2		Option 3	
User Class	Average Impervious Surface (Sq Ft)	Average Yearly Bill ($)	Average Monthly Bill ($)	Average Yearly Bill ($)	Average Monthly Bill ($)	Average Yearly Bill ($)	Average Monthly Bill ($)
Single Family	3,614	87.53	7.29	81.84	6.82	80.83	6.74
Multi-family	6,383	154.60	12.88	144.54	12.04	142.76	11.90
Commercial/Industrial/ Office	25,901	627.33	52.28	586.50	48.88	579.30	48.27
Agriculture	15,747	381.40	31.78	356.58	29.71	352.20	29.35
University of Oklahoma	78,578	1,903.19	158.60	1,779.33	148.28	1,757.47	146.46

Table 8-9 shows various bills for each impervious cover deciles (i.e., groups of equal frequency). As indicated, approximately 40% of single-family customers have 2,800 square feet of impervious surface or less, which would result in 40% of Norman’s single-family property owners receiving monthly bills of $5.65, $5.28, or $5.22 or less for Options 1, 2, and 3, respectively. The median single-family impervious square footage is approximately 3,100 square feet and implies a monthly bill of $6.26, $5.85, or $5.78 under Options 1, 2, and 3, respectively.

Table 8-9: Bill for Various Impervious Surface Deciles

		Option 1		Option 2		Option 3	
Single-Family Impervious Surface (sq ft)	Decile – % Properties ≤ sq ft Given	Average Yearly Bill ($)	Average Monthly Bill ($)	Average Yearly Bill ($)	Average Monthl y Bill ($)	Average Yearly Bill ($)	Average Monthly Bill ($)
2,500	30	60.55	5.05	56.61	4.72	55.91	4.66
2,800	40	67.82	5.65	63.40	5.28	62.62	5.22
3,100	50	75.08	6.26	70.20	5.85	69.33	5.78
3,400	60	82.35	6.86	76.90	6.42	76.04	6.34
3,800	70	92.04	7.67	86.05	7.17	84.99	7.08
4,400	80	106.57	8.88	99.63	8.30	98.41	8.20

Table 8-10 shows how the average yearly single-family stormwater bill breaks down for each of the different revenue requirement components under Option 1 as presented in Table 8-8. Table 8-10 shows that one of the largest drivers of the stormwater bill is the capital improvement program.

Table 8-10: Stormwater Bill Components

Line No.	**Yearly Rate**	
1	Operation and Maintenance	$5.70
2	Shared City Services	$1.60
3	Minimum Control Measures	$9.28
4	Reserve Funding	$3.28
5	Base Rate	$19.86
6	Enhanced Maintenance (Trails, Detention Ponds, Creek)	$15.78
7	Capital Improvement Program	$35.52
8	Trail Construction	$13.40
9	Easements and Right of Way	$3.29
10	Total Rate	$87.53
11	**Monthly Rate**	
12	Operation and Maintenance	$0.47
13	Shared City Services	$0.13
14	Minimum Control Measures	$0.77
15	Reserve Funding	$0.27
16	Base Rate	$1.66
17	Enhanced Maintenance (Trails, Detention Ponds, Creek)	$1.31
18	Capital Improvement Program	$2.96
19	Trail Construction	$1.12
20	Easements and Right of Way	$0.27
21	Total Rate	$7.29

8.4.4 Rate Discussion - All Impervious Parcels are Charged for Stormwater Service

The stormwater rates shown in Table 8-7 are based on charging all impervious parcels within the City. During 2008, the Norman community and City Council reviewed stormwater rate scenarios in which exempt parcels were not billed for stormwater service. Table 8-11 shows the various exempt parcel data provided by the City.

Table 8-11: Exempt Parcel Data

Exempt Type	Impervious Area (SQ Ft)
Church	4,773,247
City	4,073,940
County	871,160
Indian	1,181,350
Non-Profit	2,989,044
University of Oklahoma	15,637,104
School Land	7,033,443
State	6,865,783
Unknown	1,099,635
USA – Federal	11,498,621
Total	56,023,327

The City Council reviewed three scenarios in which the University of Oklahoma and other exempt parcels were excluded from stormwater charges. Table 8-10 shows a summary of the three stormwater rate scenarios reviewed by the City Council and the Norman community. PBS&J performed a nationwide survey to help the City ascertain whether it was common to exempt universities from stormwater fees. The results were summarized in a white paper titled Results from National and University Specific Stormwater Surveys. The results, shown in Appendix K, indicate that most universities are not exempt from stormwater charges. PBS&J also presented preliminary rate and sample bill results for each of the three scenarios. The details are provided in another white paper titled Creation of a Stormwater Utility and Associated User Charges presented by PBS&J to the Norman City Council and shown in Appendix L. The information in this Appendix may be somewhat outdated as this white paper was completed months earner and may not reflect changes. The City eventually decided to bill all impervious surfaces, both universities and other exempt properties, within the City.

Table 8-12: Stormwater Billing Scenarios

	Billed for Stormwater?		
Exempt Type	Scenario 1	Scenario 2	Scenario 3
University of Oklahoma	No	Yes	No
Other Exempt Parcels	Yes	No	No

8.4.5 Stormwater Rate Comparison with Other Stormwater Utilities

PBS&J conducted a survey to assess stormwater fees in Cities with large universities such as Norman. Page 5 of Appendix K shows the results of the research. The average stormwater fee, in Cities which claimed that their fees were fully adequate to fund the stormwater utility, averaged $9.95 (in 2008 dollars). This compares quite favorably for the City of Norman's anticipated fee in the range of $6.74 (Option 3) to $7.29 (Option 1) in FY 2011–2012 dollars as shown in Table 8-8.

8.5 Stormwater Capacity Fees (New Development Fees)

Most water and wastewater utilities also include new development fees as an integral component of their capital funding plans, in part because state and federal assistance for system construction has become more limited. As much of the utility capital cost burden has shifted to the local level, concerns about equity between current and future system users have become heightened as communities are faced with significant costs for system rehabilitation and replacement, along with additional capacity needs. Development fees are often assessed either to avoid charging existing users for extra capacity costs or to compensate (via reduced future utility bill increases) the existing users for the costs they have previously incurred to provide this capacity.

State enabling acts and case law provide broad guidelines related to development fee calculation and implementation. It is then up to the local community to select specific approaches that are consistent with both the constitutional standards and local circumstances and objectives.

Assessing new development can take several forms. The first is to assess a capacity fee. The second is to require new development to build their own in-tract facilities and contribute them to the City for ongoing operations and maintenance. The third is to require new development to contribute to or build regional facilities. And finally, a combination of the first three alternatives can be used.

During the course of the study much discussion centered on new development fees versus contributed stormwater facilities. It is recommended that new development build their own in-tract stormwater detention and water quality facilities and contribute to regional facilities in certain applicable instances. It is also recommended that the City continue to consider the possibility of charging developers a per-lot capacity fee to offset downstream stormwater impacts.

8.6 Long-Range Financial Plan (Under Option 1 Revenue Requirement)

The long-rang financial plan models the financial health of the stormwater utility over the 20-year study period. The plan models the yearly ending cash balance in each of the reserves. The long-range financial plan uses the revenue requirement from the mid-year in each 5-year period to establish rates (revenue). The mid-year revenue requirement, for Option 1, is shown in Column C in each of Tables 8-12 through 8-15. These tables also show the projected stormwater expenses used in developing the 20-year long-range financial plan. In other words, the revenue is fixed at the mid-year amount while the expenses vary from year to year. This is the reason for the rise and fall of the operating reserve as shown in Figure 8-1.

Table 8-13: Stormwater Expenses for FY 14/15 through FY 18/19

	(A)	(B)	(C)	(D)	(E)
	FY 14/15	FY 15/16	FY 16/17	FY 17/18	FY 18/19
Operation and Maintenance	$504,922	$520,941	$537,475	$554,541	$572,156
Shared City Services	$145,631	$151,456	$157,514	$163,815	$170,367
Minimum Control Measures	$1,962,724	$2,021,606	$2,082,254	$2,144,722	$2,209,063
Reserve Funding	$265,000	$265,000	$265,000	$265,000	$215,000
Subtotal	$2,878,277	$2,959,003	$3,042,243	$3,128,077	$3,166,587
Enhanced Maintenance (Trails, Detention Ponds, Creek)	$1,391,129	$1,432,863	$1,475,849	$1,520,124	$1,565,728
Capital Improvement Program	$3,224,130	$3,353,095	$3,487,219	$3,626,708	$3,771,776
Trail Construction	$1,216,653	$1,265,319	$1,315,932	$1,368,569	$1,423,312
Easements and Right of Way	$289,819	$298,513	$07,468	$316,693	$326,193
Less Interest on Cash Accounts	$(346)	$(20,402)	$(31,797)	$(33,936)	$(26,195)
Total Revenue Requirement	**$8,999,662**	**$9,288,391**	**$9,596,914**	**$9,926,235**	**$10,227,401**

Table 8-14: Stormwater Expenses for FY 19/20 through 23/24

	(A)	(B)	(C)	(D)	(E)
	FY 19/20	FY 20/21	FY 21/22	FY 22/23	FY 23/24
Operation and Maintenance	$590,340	$609,109	$628,484	$648,484	$669,131
Shared City Services	$177,182	$184,269	$191,640	$199,306	$207,278
Minimum Control Measures	$2,275,335	$2,343,595	$2,413,903	$2,486,320	$2,560,910
Reserve Funding	$15,000	$15,000	$15,000	$15,000	$15,000
Subtotal	$3,057,857	$3,151,974	$3,249,027	$3,349,110	$3,452,318
Enhanced Maintenance (Trails, Detention Ponds, Creek)	$1,612,700	$1,661,081	$1,710,913	$1,762,240	$1,815,108
Capital Improvement Program	$3,922,647	$4,079,553	$4,242,735	$4,412,445	$4,588,943
Trail Construction	$1,480,244	$1,539,454	$1,601,032	$1,665,074	$1,731,676
Easements and Right of Way	$335,979	$346,058	$356,440	$367,133	$378,147
Less Interest on Cash Accounts	$(7,919)	$(30,274)	$(42,238)	$(43,100)	$(32,112)
Total Revenue Requirement	**$10,401,508**	**$10,747,846**	**$11,117,910**	**$11,512,903**	**$11,934,080**

Table 8-15: Stormwater Expenses for FY 24/25 through 28/29

	(A)	(B)	(C)	(D)	(E)
	FY 24/25	FY 25/26	FY 26/27	FY 27/28	FY 28/29
Operation and Maintenance	$690,444	$712,446	$735,160	$758,609	$782,817
Shared City Services	$215,569	$224,192	$233,159	$242,486	$252,185
Minimum Control Measures	$2,637,737	$2,716,869	$2,798,375	$2,882,327	$2,968,796
Reserve Funding	$15,000	$5,000	$5,000	$5,000	$5,000
Subtotal	$3,558,750	$3,658,507	$3,771,695	$3,888,421	$4,008,798
Enhanced Maintenance (Trails, Detention Ponds, Creek)	$1,869,561	$1,925,648	$1,983,417	$2,042,920	$2,104,207
Capital Improvement Program	$4,772,500	$4,963,400	$5,161,936	$5,368,414	$5,583,150
Trail Construction	$1,800,944	$1,872,981	$1,947,900	$2,025,817	$2,106,849
Easements and Right of Way	$389,492	$401,177	$413,212	$425,608	$438,377
Less Interest on Cash Accounts	$(8,489)	$(34,946)	$(49,283)	$(50,357)	$(37,272)
Total Revenue Requirement	**$12,382,757**	**$12,786,767**	**$13,228,877**	**$13,700,822**	**$14,204,110**

The City requested a 20-year long-range plan to assess the long term impacts of near term financing and capital investment decisions. Table 8-16 shows the resulting stormwater rates, under Option 1, for each 5-year planning period. The resulting rates are approximate since it is difficult to pinpoint inflation so far in the future. Inflation has ranged from over 6% to just over 1% in the past 15 years. Hence, the City may need to adjust operation and maintenance expenses. As the City further assesses and refines its stormwater capital improvement program it may also choose to adjust its capital program. The City may also have more impervious surface area in the future. All of these factors will affect the rates shown in Table 8-16.

Table 8-16: Stormwater Rates for the Subsequent 5-Year Planning Periods

	5-Year Planning Period		
	FY 14/15 to 18/19	FY 19/20 to 23/24	FY 24/25 to 28/29
Revenue Requirement	$9,596,914	$11,117,910	$13,228,877
Total Impervious Sq Ft	291,625,467	291,625,467	291,625,467
Yearly Rate ($/Sq Ft)	$0.0329	$0.0381	$0.0454
Monthly Rate ($/Sq Ft)	$0.0027	$0.0032	$0.0038
Average Yearly Single Family Bill	$118.93	$137.78	$163.94
Average Monthly Single Family Bill	$9.91	$11.48	$13.66

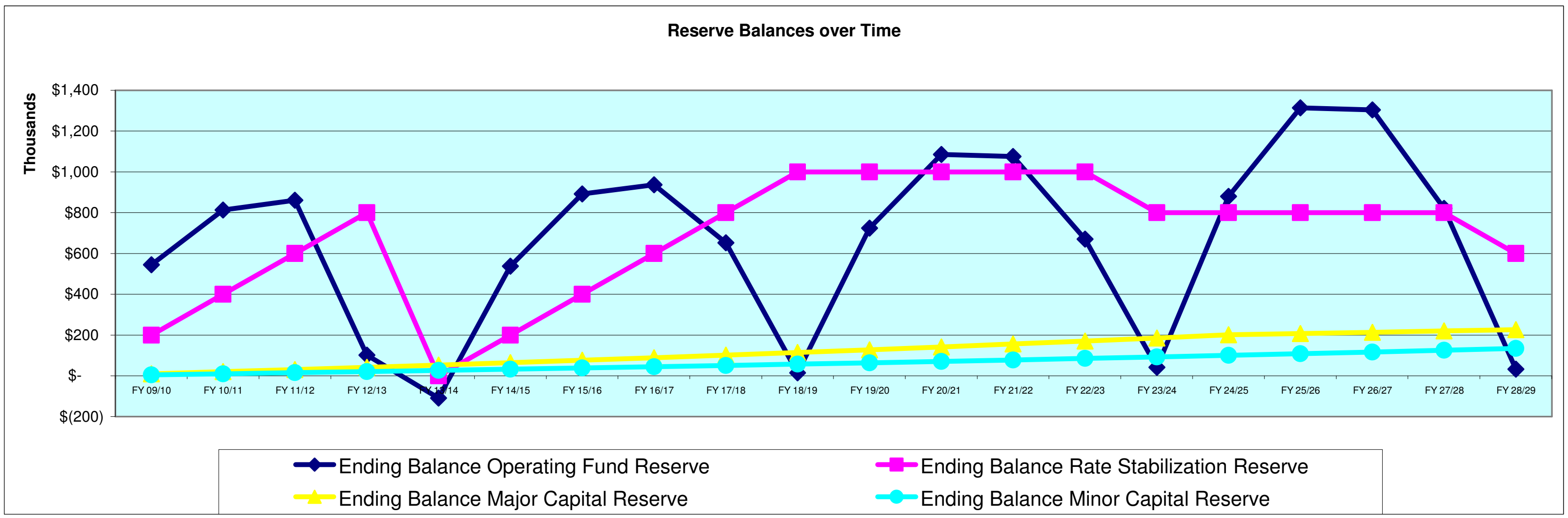
As shown by analyzing the operating reserve in Figure 8-1, the operating reserve balance rises and falls due to the City's decision to set rates for 5-year periods. For the first 2 or 3 years the operating reserve increases, since the stormwater rate is slightly above the rate needed to fully cover expenses. However in the later half of the 5-year period, the operating reserve decreases since the rate is insufficient to cover all expenses.

For the first 5-year period (FY 2009–2010 to FY 2013–2014), the rate stabilization reserve increases until FY 2012–2013. The large decrease in FY 2013–2014 is due to a transfer from the rate stabilization reserve to the operating reserve to cover shortfalls in revenue. This is a necessary depletion of the rate stabilization reserve in order to cover shortfalls in revenue during the first 5 years. In the subsequent three 5-year periods, smaller transfers from the rate stabilization reserve may be required.

Figure 8-1
Long-Range Financial Plan

Reserve	FY 09/10	FY 10/11	FY 11/12	FY 12/13	FY 13/14	FY 14/15	FY 15/16	FY 16/17	FY 17/18	FY 18/19
Ending Balance Operating Fund Reserve	$545,208	$812,416	$861,030	$101,358	$(109,299)	$537,607	$891,856	$936,815	$651,662	$14,530
Ending Balance Rate Stabilization Reserve	$200,000	$400,000	$600,000	$800,000	–	$200,000	$400,000	$600,000	$800,000	$1,000,000
Ending Balance Major Capital Reserve	$10,000	$20,300	$30,909	$41,836	$53,091	$64,684	$76,625	$88,923	$101,591	$114,639
Ending Balance Minor Capital Reserve	$5,000	$10,148	$15,452	$20,916	$26,543	$32,340	$38,310	$44,459	$50,793	$57,314
Total All Reserves	$760,208	$1,242,864	$1,507,392	$964,110	$(29,665)	$834,630	$1,406,790	$1,670,197	$1,604,046	$1,186,483

Reserve	FY 19/20	FY 20/21	FY 21/22	FY 22/23	FY 23/24	FY 24/25	FY 25/26	FY 26/27	FY 27/28	FY 28/29
Ending Balance Operating Fund Reserve	$723,449	$1,084,942	$1,075,253	$669,418	$41,218	$880,086	$1,313,653	$1,303,779	$820,591	$32,704
Ending Balance Rate Stabilization Reserve	$1,000,000	$1,000,000	$1,000,000	$1,000,000	$800,000	$800,000	$800,000	$800,000	$800,000	$600,000
Ending Balance Major Capital Reserve	$128,078	$141,920	$156,178	$170,863	$185,989	$201,569	$207,616	$213,844	$220,260	$226,867
Ending Balance Minor Capital Reserve	$64,034	$70,955	$78,084	$85,426	$92,989	$100,779	$108,802	$117,066	$125,578	$134,345
Total All Reserves	$1,915,561	$2,297,818	$2,309,514	$1,925,707	$1,120,196	$1,982,433	$2,430,071	$2,434,690	$1,966,428	$993,917



9.0 Recommendations and Implementation Plan

2025 Recommendations and Implementation Plan Updates

The revised recommendations contained in this section are a significant portion of the updates to this SWMP. The 2009 SWMP recommendations laid the groundwork for a robust stormwater management system, addressing critical aspects such as flood mitigation, water quality, and community engagement. Many of these recommendations remain relevant and are reaffirmed in the 2025 update. Recommendations have been removed or modified if they have been implemented or partially implemented, respectively. In addition, new recommendations have been introduced to help create a comprehensive, future-focused approach that will support Norman's growth while protecting and preserving our surface water resources. Many of these added recommendations are supported with additional context in the preceding sections of this report.

One of the changes with the 2025 update was revising the stormwater master plan goals. As recommendations were created for this update, it was imperative to have recommendations that reflect the overall goals. For this section, there is a "**GOALS ADDRESSED**" section for each recommendation that tells which of the SWMP goal(s) are being addressed. For reference, the list of goals is below:

- GOAL 1: Protect the runoff water quality contributing to Lake Thunderbird and the Canadian River to preserve the natural and beneficial uses of these waterbodies.

- GOAL 2: Provide an understanding of the flood risk to citizens in our community and continue to implement and enhance the capital improvement program to help reduce flooding risks.

- GOAL 3: Enhance and preserve the ecological character of the unurbanized areas of Norman through stormwater management efforts.

- GOAL 4: Restore and rehabilitate riparian areas in the urbanized areas of Norman while expanding recreational access and opportunities that support ecological health of these areas.

- GOAL 5: Continue to prioritize community awareness and education regarding stormwater quality, City infrastructure, flood risk, and individual responsibilities to preserve and maintain both natural and manmade stormwater resources.

- GOAL 6: Prioritize stormwater projects using a transparent process that includes collaboration with all stakeholders.

2009 Recommendations and Implementation Plan Introduction

The previous eight report sections presented the investigations undertaken and the resultant findings that make up the primary framework for Norman's SWMP. This section expands on several of the key findings to formalize recommendations and provide an "Implementation Plan" (see Section 9.11 below) for future actions that will help improve stormwater management in Norman. By necessity, stormwater management will always be an ongoing activity at the City and the recommendations made in this report will provide the direction needed to move beyond the SWMP in the future. Some of these recommendations would be best implemented by City staff while others may require the City to obtain assistance from consultants and/or other professionals. Again, these recommendations align with many of the SWMP investigations completed since future actions will be a natural outgrowth of these investigations.

9.1 General Recommendations

- Continue to involve all stakeholders in all aspects of the SWMP, including implementation.
- Refine stormwater and watershed protection goals and needs in the future based on continued public involvement and new studies.
- Develop a formal public outreach campaign or program to continue educating citizens about the City's stormwater needs, the importance of obtaining adequate funding to meet those needs, and the general support needed to sustain a viable stormwater program at the City level. Some of these primary needs include reliable funding mechanisms such as GO bonding and a stormwater utility, MS4 permit compliance requirements, a stormwater CIP program, basic operations and maintenance of the stormwater system, enhanced maintenance to keep streams clear of debris and trash, enhanced maintenance of detention facilities, acquisition of easements and rights-of-way, and dam safety.

GOALS ADDRESSED: 1, 2, 3, 4, 5, 6

9.2 Watershed and Stream Assessments (Section 3)

- Incorporate all of the digital and reference data developed during the SWMP project into the City's GIS and other records. This includes the GIS map overlay system developed to display geo-reference field photo locations taken at strategic creek locations during reconnaissance with the link to view the photos by clicking on the location symbol. Establish a process to systematically update this data and information.
- Update the photo library and GIS layers with new photos of critical areas in the future during maintenance inspections or other field work.
- Inspect and monitor the stream erosion areas identified on a regular schedule (e.g., every 1 or 2 years) until streams are stabilized with adequate improvements.
- Assess the Little River, Rock Creek, and Dave Blue Creek corridors in more detail if significant and contiguous stream access can be obtained.

GOALS ADDRESSED: 1, 3, 4

9.3 Hydrologic Modeling for Level 2 and Other Streams (Section 4)

- Develop modeling for Level 2 (initially) and Level 3 streams that is consistent with the Level 1 modeling performed for the master plan, which used the most up-to-date data and methods. Advances in modeling technology (new versions of HEC-HMS or HEC-RAS) should be integrated as appropriate.
- Continually update modeling needs and change priorities to fit those needs.
- Update drainage area delineations based on the City's 2007 topographic data including resolution of all watershed boundary discrepancies. Update both the GIS layer with the watershed boundaries and the areas in the hydrologic models.
  Update all Level 2 hydrologic models to use HEC-HMS (many are still HEC-1). Also update all HEC-HMS models to version 3.3 (current version at this time) or to the latest version in the future (this should not have any impact on the results of our modeling, which was done with version 3.1.0).
- Update models to include consistent design storm rainfalls (totals and distributions) based on the USGS WRI 99-4232 and the Frequency Storm rainfall distribution (storm centering at 50%).
- Use a standard procedure for design rainfall areal reductions in all modeling of watersheds greater than 9.6 square miles. No areal reduction should be used for smaller watersheds.
- Use standard procedures (NRCS curve numbers) for rainfall loss rate development in all modeling. This includes both the derivation and application of the parameters.
- Use standard procedures for the development of unit hydrograph lag times and update the lag times in the Level 2 and other models as needed.

- Establish standard procedures for hydrograph routing that consider floodplain storage such as the Modified Puls Method. This should be implemented wherever corresponding HEC-RAS models are available.
- Incorporate regional detention facilities into the hydrologic models if an ongoing maintenance program is established (thereby assuring their proper function) and the facilities measurably reduce downstream discharges.

GOALS ADDRESSED: 6

9.4 Hydraulic Modeling for Level 2 and Other Streams (Section 4)

- Develop modeling for Level 2 (initially) and Level 3 streams that is consistent with Level 1 modeling (as modified with future advancements) which used the most up-to-date data and methods.
- Continually update modeling needs and change priorities to fit those needs.
- Update flows based on any modifications to the hydrologic models.
- Create updated cross sections based on the City's 2007 topographic data that are fully georeferenced. This will ensure that the latest topography is used and will greatly facilitate accurate floodplain mapping. At a minimum, a georeferenced cross section layer containing all of the cross sections (some locations may have to be estimated if new cross sections are not generated) for each Level 2 model should be created. Fully georeferenced cross section will greatly facilitate floodplain mapping, model updates and the use of the models for development purposes.
- Update roughness coefficients along the streams and in the adjacent overbank areas to better match current existing conditions.
- Review and update bridge/culvert modeling as needed. Structures in models that were converted from HEC-2 should receive special attention.
- Revise the junction modeling for the Brookhaven Creek model. The junctions in the HEC-RAS model received from the City were improperly converted from a previous HEC-2 model yielding slightly conservative water surface elevations.

GOALS ADDRESSED: 6

9.5 Criteria Manual Updates

- 2025 Updates: The comprehensive effort to update the Engineering Design Criteria in 2023 met many of the recommendations in this section. Section 6000 and 7000 of the 2023 EDC includes erosion control and water quality control criteria and standards. Additional changes to the EDC include providing a requirement and incentive system for new developments to treat a Water Quality Volume (WQV) before runoff exits the site.
- The Engineering Design Criteria should be reevaluated every two years to recommend any changes that are needed to uphold Norman's commitment to stormwater management.

9.6 Model Management

- The City of Norman has invested a significant amount in the development of hydrologic and hydraulic models a part of the SWMP. Since the master plan will not directly result in an update of the FEMA floodplains, it will be incumbent upon the City to maintain available and up-to-date copies of these models if they are to be of use to the community as a whole. There are varying levels of solution that can be implemented in order to facilitate the management and distribution of models and supporting data. The following recommendations outline a basic approach that would provide for easy access to the models by City staff and a procedure for tracking updates to these models.
  - Develop an Arc Hydro-compliant stream network and subbasin geodatabase and provide hyperlinks to an associated directory structure built to contain the models for each watershed. Basic tools to

store and access the models through these hyperlinks could be adapted from recent systems developed by other entities. There are a variety of options that could be built-on to such an existing system to allow the city to track access to the models, enforce standards, document model changes, etc.).
    - Internal Option – Deploy on an internal server that will allow City staff to store, access and distribute models as needed.
    - External Option – Deploy on a web server and allow the engineering community to access the system and download models for selected stream reaches or watersheds.
  - Include a “metadata” file (can be a simple text or XML file) to document the origin and history/evolution of each hydrologic and hydraulic model.

9.7 FEMA LOMRs

- Submit Letters of Map Revision (LOMRs) to FEMA for the Level 1 streams studied during the SWMP. If other streams are studied or updated, those updates should be submitted as FEMA LOMRs at that time.
- Incorporate regional detention facilities into the hydrologic models if an ongoing maintenance program is established (thereby assuring their proper function) and the facilities measurably reduce downstream discharges.

GOAL(S) ADDRESSED: 2

9.8 Stormwater Problems and Solutions (Sections 5 and 6)

- Stream flooding, stream erosion, and local drainage.
  - Continue to monitor and document conditions associated with the problems identified in the SWMP until CIP improvements solve or mitigate them.
  - Review and update solutions prioritization on an annual, two, or five year cycle.
  - Incorporate any new problems and possible solutions on a continuing basis.
  - Continue to explore ways to integrate solutions to address multiple problem types and incorporate greenway opportunities.
  - Continue to develop collaborative agency partnerships to assist in project funding and cooperation.
  - Use stream equilibrium and other geomorphological principals for stream erosion project designs.
  - Any update to the SWMP in the Little River corridor needs to be performed in concert with a roadway planning study as the numerous creek crossings and roadway lengths across the wide Littler River floodplain warrant special consideration in this area.
- Water quality.
  - Maintain awareness and knowledge of all water quality monitoring being carried out in watersheds that originate in, or flow through, the City of Norman.
  - Continue to develop collaborative agency partnerships to assist in project funding and cooperation.
  - Assure compliance with requirements of the MS4 Program and the City’s MS4 OPDES stormwater permit.
  - Continue to prioritize and provide funding for the tasks outlined in the 2016 Lake Thunderbird TMDL Compliance and Monitoring Plan
  - Comply with recently developed Canadian River Bacteria TMDL requirements as the City may be required to participate in a coordinated monitoring program or develop their own to document the effectiveness of their selected BMPs and to demonstrate progress toward attainment of water quality standards. Reporting requirements include documentation of actions taken by the permittee that affect MS4 stormwater discharges to Bishop Creek and the Canadian River.
  - Increase monitoring of erosion controls at construction sites to assure compliance with regulations.

- See items for Stream Planning Corridors as well as structural and nonstructural stormwater controls in Section 9.9 below.

- Capital Improvements Program.
  - Continue developing the Stormwater Program staff under the direction of the Director of Public Works to manage the SWMP CIP program and associated projects.
  - Assuming that funding is available, complete construction the identified CIP projects over a 20- to 25-year period.

GOAL(S) ADDRESSED: 1, 2, 3, 4, 6

9.9 Key Issues (Section 7)

- 2025 Update: The items in this section of the original 2009 Master Plan were duplicated in the "Implementation Plan" Section. Please refer to that updated section of this document for updated implementation recommendations for the key issues facing Norman.

9.10 Stormwater Financing (Section 8)

- Establish long-range funding options for stormwater such as those presented in Section 8.
- Educate the public on the need to have adequate funding or stormwater management as described under the general recommendations.

2025 AIM Norman Updated Recommendations

Engineering Design Criteria

- The current EDC should be regularly compared to City goals and lessons learned. A two-year cycle of scheduled and budgeted review of the 2023 EDC is recommended to facilitate this process.
- Continually reevaluate the recommended stormwater control measures (SCM) and criteria presented in the EDC section 7000.
- It is recommended that “sustainable development” incentives be considered and initiated so that stormwater best management practices (BMPs) will be promoted through meaningful credits to property owners participating in increasing population density in the “Current Development Area.” The “Site Design Credits” and “Sustainable Development Incentives” aspects of the EDC should be more fully processed given the City’s stormwater management budget.
- Incentives should promote sustainable and affordable developments to the maximum extent practicable (MEP). MEP guidelines should be developed as a consistent document throughout the City. Refer to section 7.2 for more details on this recommendation.

GOALS ADDRESSED: 1, 2, 3, 4

Community Rating System

- The Community Rating System (CRS) is a voluntary program that rewards communities for implementing floodplain management practices that exceed the minimum requirements of the National Flood Insurance Program (NFIP). Norman participates in this program and currently has a rating of 6, which corresponds to a 20% discount on flood insurance premiums for Norman residents. Communities can continue to improve their CRS score by implementing additional creditable activities. Discussed below are a few ways Norman could improve their score.
  - Implementation of a flood warning system is recommended to provide advance notice of impending flooding. A flood warning system can help identify flooding threats, disseminate information to residents as a warning or advisory, signal the need for emergency services, and promote public

understanding of flood risks. This would give residents and authorities time to take proactive measures to ensure their own safety and minimize damage to their homes, businesses, and personal property. An example of what the flood warning system could entail are rain gauges, stream gauges, and detention gauges on an automated system that send updates in real time to the city's Public Works Department, Fire Department, and Police Department.
    - It is recommended to complete an inventory of stormwater conveyance system across Norman. Maintaining an inventory of the stormwater infrastructure will help prevent costly emergency repairs and will give insight to the overall condition of the system.

GOALS ADDRESSED: 2, 4, 5, 6

Norman's Water Quality Protection Zone (WQPZ)

- The Water Quality Protection Zone (WQPZ) Ordinance should be updated to reflect lessons learned from the implementation of the ordinance since 2011. Language should be modified to reinforce the importance of maintaining the WQPZ area in natural state (restrict clearing) during construction. WQPZ width should not be allowed to be reduced to an "alternative width" in the 2045 Reserve Area identified in the Comprehensive Land Use Plan Character Area Map.

GOALS ADDRESSED: 1, 3, 4

Low Impact Development Incentivization

- Low Impact Development (LID) has the capability to enhance stormwater management and protect the environment. LIDs can also increase community wellbeing by creating green spaces. For Norman, it is recommended to create an LID incentivization program to encourage the development of LIDs. Below lists out potential ways Norman can incentivize LIDs.
    - Create an exchange where participants receive expense credits to go towards for stormwater and other city service costs if they meet or exceed current stormwater requirements. The exchange of credits will be monitored by City staff and can be used for stormwater, permit, connection, and other City fees.
    - Create an annual developer and/or builder stormwater award with monetary or credits provided to the winner. The awards could be offered by the City and BASCO (or similar organization).
    - Create an expedited permitting process for projects that exceed current stormwater standards.
    - Examine the possibility of overlaying districts tied to tier-based requirements based on proximity to water bodies for standards that can be provided with some of the incentives noted. Refer to section 7.2 for more details on this recommendation.
- Create a grant program or cost share with focus on retrofits of stormwater infrastructure in the current urbanized areas in Norman.
    - It is recommended that the City provide technical assistance and training to neighborhoods to properly maintain their stormwater infrastructure once build-out is complete.

GOALS ADDRESSED: 1, 2, 3, 4, 5

Construction Site Inspections

- Implementing a pre-development meeting with the developer is recommended. This will provide the opportunity for the City to explain what the developer will need to comply with during construction. Developing an informational packet to provide to developers that lists out what they will need to comply with during construction is recommended.
- Inspectors play a key role in ensuring that construction sites implement proper erosion and stormwater management. It is recommended to hire more staff to help with inspections at construction sites.

- It is recommended to implement requirements for contractors to have a dedicated “compliance officer” to enforce permit requirements at all times during construction.
- City staff, elected officials and citizens should actively support the stormwater quality inspectors and enforcement procedures to reduce impairment of the waterbodies in Norman.

GOALS ADDRESSED: 1, 2, 3, 4, 5

Total Maximum Daily Load (TMDL) Monitoring Stations

- Install additional TMDL monitoring stations to establish baseline water quality data for streams that may be affected by additional development allowed by the Comprehensive Land Use Plan or upcoming major transportation projects.

GOALS ADDRESSED: 1, 3

Tree Cover Protection

- Establish a forest cover preservation goal for post-construction, aiming to retain a significant percentage of existing cross-timber forest, such as preserving 60% of beneficial tree cover within the WQPZ post-construction. This may be implemented as a Water Quality Volume credit for developments that attain this goal post-construction.

GOALS ADDRESSED: 1, 3

Geomorphology & Sediment Transfer Study

- Complete a watershed sediment transport study for the entire city to help determine how much sediment is being moved downstream from potential disturbed earth upstream. Apply the results of the study to the city and use it to find what BMPs are most applicable to maintain a normal level of sediment transfer. This will help inform the city of where material is moving, where there is excess, and what needs to be controlled as it leaves development sites.

GOALS ADDRESSED: 1, 3, 4

Accessory Structures

- To reduce the impact of increased impervious coverage in areas where stormwater management is an existing issue, require implementation of stormwater Best Management Practices when accessory structures are permitted.
- Develop a plan to repair or retrofit, thereby improve stormwater infrastructure as Core Norman incrementally redevelops.

GOALS ADDRESSED: 1, 3, 4

Additional Recommended Studies

Norman should prioritize additional studies to address data gaps, emerging challenges, and long-term planning needs. The following list of studies are recommended to equip the city with the insights necessary for more effective stormwater management.

- Flood Warning System (in progress)
- Stormwater Infrastructure Inventory (in progress)
- Low Impact Development (LID) Optimization Study
    - Include 2009 OWRB Garber-Wellington Aquifer Recharge Study in LID Optimization Study

- Rain-On-Mesh Hydrologic and Hydraulic Modeling where appropriate to identify pluvial flooding issues in the urbanized areas
- Update regulatory floodplain mapping for the city
    - Specifically Merkle Creek Subbasin to include effects of airport detention

9.11 Implementation Plan

2025 Implementation Plan Updated Introduction

2025 Implementation Plan Update: The City of Norman has successfully implemented several of the items that were included in the 2009 Implementation Plan. The items below have been revised to reflect such cases with a ***[bracketed]*** statement at the beginning of the item. Note also that a Stormwater Policy Manual (Appendix O) has been developed for use by the Stormwater Program to implement essential stormwater maintenance and runoff quality control activities throughout the City. Additional plans that are focused on implementation of this program are the 2016 Lake Thunderbird TMDL Compliance and Monitoring Plan and the regularly updated Stormwater Management Plan that coincides with the MS4 permitting updates. These plans have all been developed since 2009 and are valuable tools for the City to continue achieving the goals that have been presented in this Stormwater Master Plan Update.

Logistical implementation of the recommendations in this SWMP Update must be coordinated through Norman's standard regulatory process. The implementation pathways that have been used in the past include the Zoning Code, Engineering Design Criteria, Subdivision Regulations, and individual ordinances. The recommendations included in this report may be included in one or more of those regulatory pathways as determined by City Staff.

2009 Implementation Plan Introduction

An implementation plan is presented here that provides the actions that the City of Norman can take to advance the work that was performed to develop the City’s Stormwater Master Plan. In some instances, it may overlap or repeat certain aspects of the recommendations provided above, but that is to be expected as these implementation actions reflect the work that was performed and the recommendations. These implementation items focus on the immediate future covering the next few months and years although some items may unfold for many years to come.

The successful implementation of the stormwater master plan and the associated future actions needed to implement the plan will rely heavily on additional public input and support. Additional meetings with stakeholders, including or such as the Stormwater Task Force, will help greatly in determining the specifics of educating and involving the public about future stormwater master plan activities. Without the support of the public and approval of the funding needed, implementation of the master plan will be severely limited.

In listing these key implementation actions below, it is assumed that funding, such as the stormwater utility and general obligation bonding described in this SWMP report (Section 8), will eventually become available to allow the City to pursue the actions. Additionally, the implementation actions can be taken out of the order given below as the ultimate order of these actions will depend on many events that have yet to occur.

General

1. Maintain funding of a formal outreach program as it is critical to continue educating citizens about the City’s stormwater needs, the importance of obtaining adequate funding to meet those needs, and the general support needed to sustain a viable stormwater program at the City level. Some of these primary needs include reliable funding mechanisms such as GO bonding and a stormwater utility, MS4 permit compliance requirements, a stormwater CIP program, basic operations and maintenance of the stormwater system, enhanced maintenance to keep streams clear of debris and trash, enhanced

maintenance of detention facilities, acquisition of easements and rights-of-way, and dam safety. This outreach program has been funded as part of Norman's Public Works Stormwater Program and the Utilities department Division of Environmental Resilience & Sustainability.

Financing

2. Develop and carry out a strategic work plan for a citizen vote on the proposed stormwater utility as described in Section 8. The City must also decide whether establishment of the master account file and other key billing logistics will be worked out before or after the citizen vote (assuming it passes). Regardless, preliminary discussions on billing and administration requirements should begin.

3. Develop and carry out a strategic work plan for a citizen vote on the proposed general obligation bond program as described in Section 8.

Data Management

4. Incorporate all of the digital and reference data developed during the SWMP project into the City's GIS and other records. This includes the GIS map overlay system developed to display geo-reference field photo locations taken at strategic creek locations during reconnaissance with the link to view the photos by clicking on the location symbol. Establish a process to systematically update this data and information.

Criteria Manuals

5. Set a regularly scheduled update to the City's Drainage Criteria Manual with SWMP findings and recommendations.
6. ***[This item has been implemented at time of 2025 update. Refer to 2023 EDC Section 7000.]***
   Develop a Stormwater Quality Criteria Manual with SWMP findings and recommendations.
7. ***[This item has been implemented at time of 2025 update. Refer to 2023 EDC Section 6000.]***
   Develop an Erosion Control Manual aimed at preventing erosion problems associated with construction.

Hydrology and Hydraulic Analyses

8. Following detailed recommendations in Section 9, develop detailed modeling for Level 2 (existing models used, some becoming outdated) and Level 3 (future detailed) streams consistent with the detailed Level 1 modeling performed for the master plan, which used the most up-to-date topographic and other data as well as hydrologic/hydraulic modeling methods. Advances in modeling technology (new versions of HEC-HMS or HEC-RAS) should be integrated as appropriate. This should be done prior to, or at the beginning of, developing designs for CIP projects.
9. Institute a stormwater hydrologic and hydraulic model management system to maintain and facilitate distribution of the latest models to users. This system should be network and/or internet based to minimize the overall effort.
10. ***[Ten Mile Flat Creek and Brookhaven Creek FEMA Maps have been updated since 2009. Additional Level 1 streams should be updated by LOMR including Merkle Creek, Imhoff Creek, Bishop Creek, and Woodcrest Creek. Note that Woodcrest Creek is referred to as "Rock Creek" in the FEMA Maps, and Rock Creek is referred to as "East Rock Creek."]***
    Submit Letters of Map Revision (LOMRs) to FEMA for the Level 1 streams studied during the SWMP. If other streams are studied or updated, those updates should be submitted as FEMA LOMRs at that time.

Water Quality

11. ***[Implementation Plan Items 11 and 12 have been superseded by the Lake Thunderbird TMDL Compliance and Monitoring Plan as well as the Stormwater Management Plan/ MS4 Permit Annual Reports. Coordinating agencies such as the Lake Thunderbird Watershed Alliance have been established to foster collaboration between these municipalities.]***
    Meet with the cities of Moore and Oklahoma City to explore ways to improve water quality and preserve Lake Thunderbird's water quality.

12. ***[See Note above for 2025 update. Continue to coordinate with ODEQ to anticipate potential future TMDL requirements for Canadian River and Bishop Creek to mitigate concerns before a TMDL is required.]***
    Meet with the Oklahoma Department of Environmental Quality (ODEQ) and get updates on the Lake Thunderbird Watershed Management Plan development and the Canadian River TMDL status. Assign a City coordinator to follow the progress and status of these two programs and the MS4 program as compliance activities associated with these three programs will impact water quality in Norman for the foreseeable future.
13. ***[Refer to the WQPZ Ordinance in the City's Municipal Code for current implementation of this item. Additional recommendations are to prohibit "alternative width" reduction of WQPZ within the 2045 Development Reserve Character Area Map in the AIM Norman Land Use Plan Report.]***
    Continue to dedicate Stream Planning Corridors (SPCs) and/or the 100-year full buildout floodplains to the City of Norman by easement or title for streams located in the Lake Thunderbird watershed that have a drainage area greater than 40 acres.
    a. Prohibit development or significant land disturbance in the SPCs and/or 100-year full buildout floodplain. Exemptions should include items such as, but not limited to, maintenance activities, greenway trails, road crossings, utilities, and stream stabilization measures.
    b. Require additional stream-side buffers of 15 ft to each side of steams with drainage areas greater than 40 acres that are located in the Lake Thunderbird watershed and also in Suburban Residential and Country Residential areas as defined in the Norman 2025 Plan including subsequent updates to the comprehensive plan as adopted by the City Council.

14. ***[A Water Quality Volume (WQV) calculation procedure has been included in Section 7000 of the 2023 EDC Update. The City should amend the 2023 EDC to require this WQV be implemented according to the zones outlined in Section 7.2 of this SWMP Update. These zones will require a higher WQV for developments that would have a greater direct impact on runoff water quality entering Lake Thunderbird. The minimum required WQV should be calculated using a baseline of 0.5-inches of the initial precipitation for the zone that impacts Lake Thunderbird the least, and 1.5-inches for the areas that impact the lake the most.]***

    Require that water quality facilities be constructed to capture and treat runoff from all proposed developments in the City of Norman that exceed 1 acre (or some other size selected by the City) in size.

    a. Encourage low impact development techniques such as rain gardens and biofilters to provide a portion or all of their stormwater quality control requirements subject to the developer providing sufficient technical justification for the techniques.
    b. Allow very small developments less than 1 acre in size or some other size limit to pay into a regional detention/water quality program in lieu of building very small water quality structures.
15. Do not allow variances for the water quality treatment unless there are unique conditions/situations that would use alternative approaches that could be definitively shown to achieve similar water quality, flood control, and recreational opportunities. In situations where there is a clearly defined riparian corridor of environmental significance and/or flood prone soils, it should be significantly more difficult to obtain such a variance. In situations where a riparian corridor does not exist and the subject waterway flows through an area that has experienced significant past disturbance or change from natural conditions (such as past agricultural activities and/or activities associated with residential, commercial, transportation, or industrial uses), restoration of structural water quality measures should be prioritized over preservation of the previously modified stream banks.
16. ***[Nonstructural stormwater BMPs are being implemented throughout Norman through the MS4 Permit compliance plan (2024 Stormwater Management Plan) and the 2016 Lake Thunderbird TMDL Compliance and Monitoring Plan. A fertilizer ordinance has been adopted by the City to reduce the discharge of unnecessary and harmful nutrients into the waterways. Implementation of these plans and enforcement of these nonstructural stormwater quality control measures should continue to be***

supported by all City staff and City Council.]
Implement nonstructural stormwater quality controls in addition to WQPZs, including a program to educate the public on fertilizer use, a program to control the overuse of fertilizers, a procedure to ensure proper septic system installation and operation, and a continuation of development density (and impervious cover) limitations in the Lake Thunderbird watershed.

17. ***[The WQPZ Ordinance should be referenced in addition to these requirements for any disturbance within the stream banks of an existing stream.]***
    Require the following compliance measures if development or significant land disturbance occurs within the stream banks of a stream in the City:
    a. USACE's 404 permitting documentation and proof of permit to be submitted to the City prior to plat approval,
    b. Riparian stream corridor mitigation will be required (tree replacement, re-vegetation, stream stabilization using bio-engineering techniques, etc.), and
    c. Inlet and outlet structures will be provided as needed to incorporate erosion protection.
18. ***[See note on 16 regarding fertilizer ordinance.]***
    Establish an education outreach program for, and voluntary compliance with, fertilizer application controls in City areas located in the Lake Thunderbird watershed.

CIP/Easements/Maintenance

19. ***[The geomorphological study recommended by this 2025 Update would include the following implementation plan item.]***
    Establish an ongoing program activity to inspect and monitor the stream erosion areas identified on a regular schedule (e.g., every 1 or 2 years) until streams are stabilized with adequate improvements.
20. Develop a plan and begin to obtain drainage easements and/or rights-of-way (as needed) in Level 1 and 2 streams and for stormwater detention facilities where access is needed for continuous/routine maintenance activities. For streams, the amount of easement or right-of-way would be as needed based on specific site conditions but, in general, would include a width of stream extending bank to bank plus 10 ft on each side of the stream channel. This can include those areas where stormwater CIP projects have been identified if the maintenance need justifies obtaining the easements in advance of designing and constructing the proposed CIP project.
21. Develop an analysis outlining the "pros and cons" of obtaining the FEMA floodway as drainage easement or right-of-way along various reaches of Imhoff Creek as part of a long-term solution to flooding and limited access along this creek.
22. A citywide stream maintenance program should be implemented over the next 2 or 3 years consistent with the acquisition of easements, rights-of-way, rights-of-entry, and reaches of "no action," depending on the situation/conditions. Obtaining easements and rights-of-way is the preferred method of gaining routine access to the city's streams. Maintenance should focus on those stream reaches and/or detention facility areas where capital improvements are constructed in order to protect those investments. The City should also consider outsourcing some, or all, of the maintenance activities if it is advantageous, especially while a City's program is ramping up. The City should also focus on detention facilities where dam maintenance may become a safety issue.
23. As funds permit, preliminary designs along with refined construction cost estimates should be developed for the top priority projects.
24. ***[As of the 2025 Update, the Public Works Department includes a dedicated Stormwater Program and the Utilities Department includes a Division of Environmental Resilience & Sustainability. These divisions should continue to be funded and prioritized.]***
    Consider developing program staff under the direction of the Director of Public Works to manage the SWMP CIP program and associated projects. These staff can be part of an existing group or make up a new group at the City. If the amount of work is variable, cyclic, or heavy at times, it is recommended that staffing levels target the steady work flow and have consultants assist during times of high work flow.

25. ***[A stormwater project "Action Plan" (updated in August 2018) has been included in Appendix O. This Action Plan should be regularly updated with the revised CIP scoring model and updated costs. A Stormwater General Obligation funding vote will require these stormwater projects to be identified in an actionable list.]***
    The CIP projects have been identified, described (functionality/character/costs), and prioritized. In order of their priority, a list should be developed outlining the specific projects (and therefore the total budget outlay) that would be funded through general obligation bonds versus those that would be funded through a stormwater utility over a 20-year period.
26. Develop a future roadway improvement plan for Franklin Road east of Interstate Highway 35 that includes a significant drainage or flood prevention study element as this roadway and many of its intersecting roadways are significantly flood prone for several miles of roadway length.

Dams

[As of this 2025 Update, the Oklahoma Water Resources Board (OWRB) has identified the dams that are under its jurisdiction throughout the City. The City continues to be responsible for monitoring the condition of these dams and their impact on downstream development and infrastructure. Specifically, the City should consider changes in Land Use planning on how an upstream dam's hazard classification has been documented. Changes in downstream land use could change the hazard classification of a dam, and that change should be coordinated with OWRB to identify action steps that must be taken to confirm the dam is property inspected and that there is a proper emergency action plan in place. Generally, the items in this section should be coordinated with the OWRB to determine the legal and appropriate steps forward to protect the Norman citizens and overall infrastructure from aging dam facilities in the City.]

27. The City should investigate and identify, to the extent possible, the responsible parties for the inspection, maintenance, and overall safety of dams that are judged to be a potential safety hazard. This work should be undertaken beginning with the dams judged to have the greatest public safety risk. An inventory and prioritization method should be developed at the beginning of the investigative work.
28. While stopping short of taking over dam ownership, liability, and routine maintenance from Property Owner Associations (POAs) or other owners, on a case by case basis the City should take over the inspection and maintenance of dams that pose significant safety concerns. POAs should maintain the general/routine mowing and small scale maintenance responsibilities while the City undertakes the more critical inspection and maintenance responsibilities.
29. For any dam for which the City considers taking over certain inspection and maintenance responsibilities, it is recommended that the City first study and determine the prevailing conditions for such dam and its appurtenances. Should the City take over inspection, maintenance, and upgrade responsibilities for the structures, it should first be determined what actions they or the present owners might have to take to bring such structures into state dam safety compliance. Such actions could include determining whether the dam structures, including emergency spillways, require modifications to strengthen them against failure or breach. Another important aspect is whether any of the dams need an emergency action plan to reduce the risk to lives and property that can result from dam failure.

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