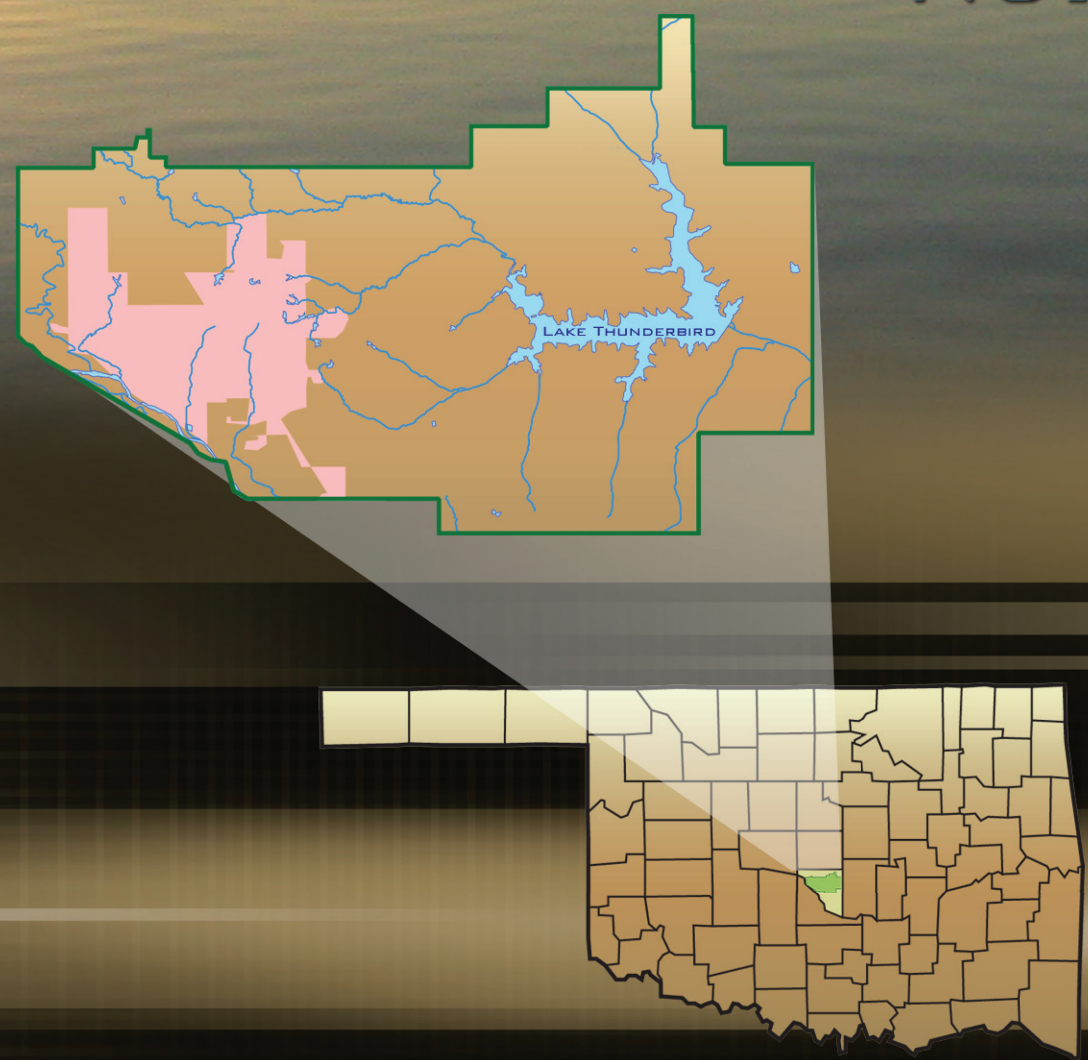
STORM WATER
MASTER PLAN

FINAL REPORT

STORM WATER MASTER PLAN
NORMAN, OKLAHOMA

NORMAN



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STORM WATER MASTER PLAN
NORMAN, OKLAHOMA

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Acronyms and Abbreviations

°F	degrees Fahrenheit
µg/l	micrograms per liter
ac-ft	acre-feet
BMP	best management practice
BNSF	Burlington Northern and Santa Fe Railroad
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
DO	dissolved oxygen
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
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
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

Project Identification Numbers (for flood-related and stream erosion problems identified within Norman, Oklahoma)

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

RCB	reinforced box culvert
RFD	Rapid Floodplain Delineation
ROW	right of way
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
SWMP	Storm Water Master Plan
SWS	sensitive water supply
TMDL	Total Maximum Daily Load
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
WQS	Water Quality Standards

Acknowledgements

This Storm Water Master Plan was developed by the City of Norman's Public Works and Planning Departments with technical and professional assistance from PBS&J, Halff Associates, Inc., and Vieux, Inc. A great number of Norman residents have dedicated their time and effort to provide input and guidance as part of this master planning undertaking. A special thanks go to these individuals listed below.

City of Norman, City Council

Cindy S. Rosenthal	Mayor
Bob Thompson (ended 2009)	Ward 1
Alan Atkins (began 2009)	Ward 1
Tom Kovach	Ward 2
Hal Ezzell	Ward 3
Carol Dillingham	Ward 4
Rachel Butler	Ward 5
James Griffith	Ward 6
Doug Cubberley	Ward 7
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Norman Stormwater Task Force Members

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
Jane Ingels	Greenbelt Commission
Jim Gasaway	Planning Commissioner
Joan Goth	Parks Board Member
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Curtis McCarty	Planning Commission/Home Builders Association President
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Joan Goth	Parks Board
Curtis McCarty	Planning Commission
Joyce Pitchlynn	Tree Board
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Dan Butler	Oklahoma Conservation Commission
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Tom McCaleb	SMC Consulting Engineers
Sarah Peterson	University of Oklahoma
Richard Ryan	University of Oklahoma
Jean Vieux	Vieux and Associates, Inc.

EXECUTIVE SUMMARY

As the county seat of Cleveland County and home of the University of Oklahoma, the City of Norman is a large and diverse community that is proactive on a wide range of issues, including its land and water environments. The City encompasses almost 190 square miles, including almost 30 square miles that has been developed to accommodate its current population of approximately 112,000. As Norman has grown in population and further urbanized many of its watersheds, the resulting impacts on flooding, water quality, and erosion have increased significantly. Of particular concern, Lake Thunderbird's water quality has deteriorated significantly, which is a condition that could directly impact all of Norman's citizens. At the same time, the recreational opportunities offered by the City's waterways have become increasingly apparent and desirable. Given these and other related factors, the City initiated development of a Storm Water Master Plan (SWMP) in late 2005 with its primary goals aimed at reducing flooding dangers, protecting water quality, enhancing the environment, and advancing recreational opportunities. Development of the present SWMP project began in August 2007 and includes all City watersheds. The SWMP incorporates "quality of life" elements for Norman's citizens by outlining measures to manage creek corridors and floodplains in an environmentally sound manner while offering opportunities for increased recreational activities. A Greenway Master Plan is being developed by the City (Halff Associates, Inc. [Halff], 2009) in parallel with the SWMP and is also nearing completion. This greenway plan is being produced in a separate report although opportunities and constraints were shared between the two studies.

The overall approach to development of the SWMP involved the use of existing information and data to the extent possible, building on that base with new information and data, and performing the analyses needed to meet the SWMP goals. Realizing that local public input was a critical component in fulfilling the goals of the SWMP, a Storm Water Task Force was formed to coordinate ongoing project issues and provide guidance on local perspectives. Several meetings with City Council members, the SWMP Task Force, and City staff as well as three public meetings were held to review ongoing study efforts, discuss project progress, and coordinate the SWMP work flow. Additional City Council workshops, public meetings, and numerous other related meetings are being held throughout 2009.

STUDY LEVELS

In order to focus on the primary stream systems and provide detailed evaluations in the areas having the worst problems, analyses associated with watershed/stream assessments, stream flooding, and stream erosion were performed at different "levels" of study detail based on the needs of the City. Generally, Levels 1 and 2 were studied in detail and Levels 3 and 4 were more generally studied. All watersheds in the City were studied in some capacity, but depending on needs some were analyzed in detail while others were considered using more general methods. Exhibit ES-1 identifies the level of study undertaken for respective streams throughout the City. In consideration of the amount of future urbanization projected to occur in the City, data and other useful information were obtained from the Norman 2025 Plan. **In this report, any reference to this plan should be considered to mean the "Norman 2025 Plan and subsequent updates to this comprehensive plan as adopted by the City Council."**

WATERSHED AND STREAM ASSESSMENTS

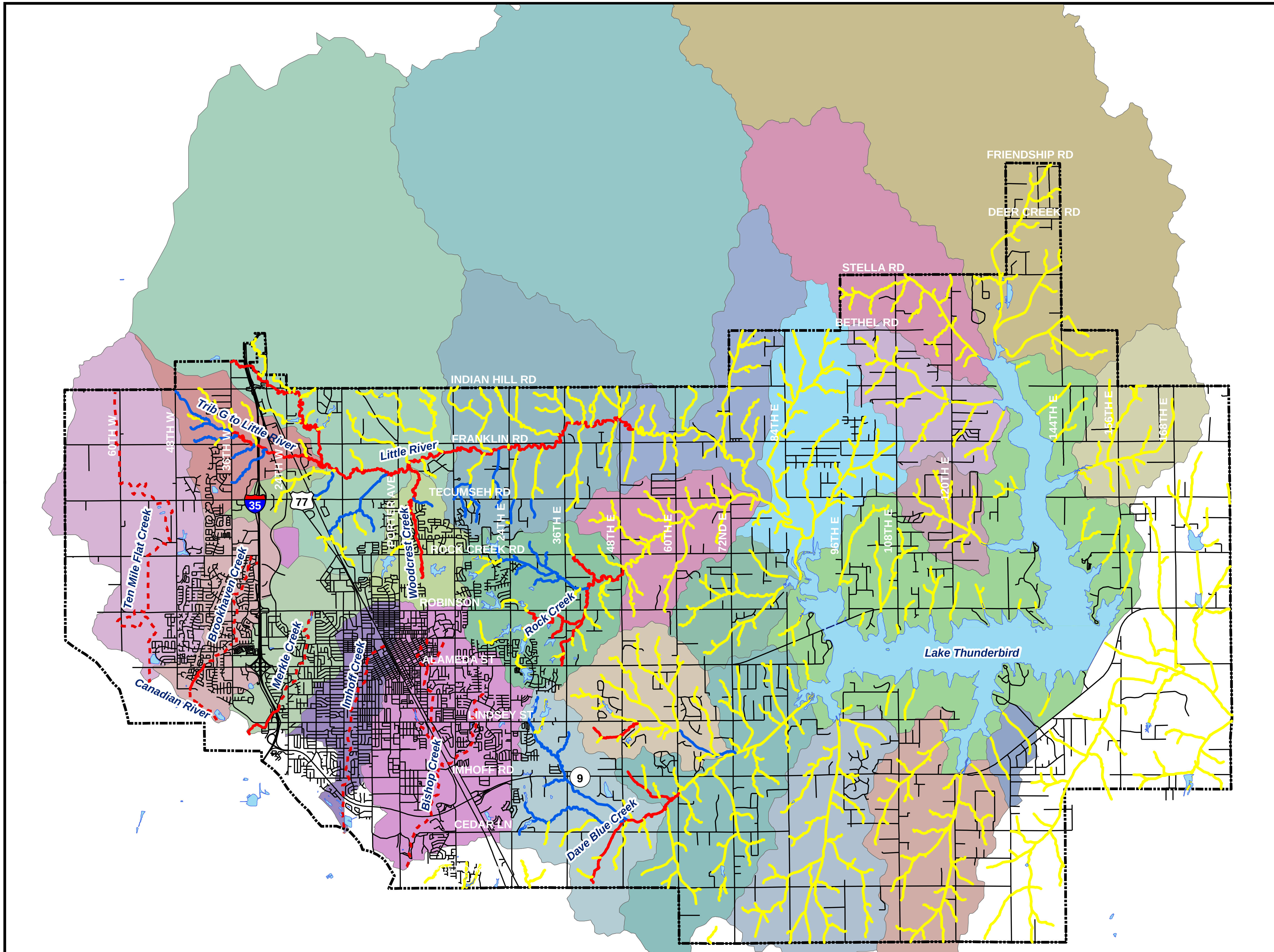
Assessments were developed for 36 watersheds that carry storm water into, through, and/or within the City of Norman. Although most of the watersheds are located in the City of Norman, several also originate north of the City, flow into the Little River, and ultimately discharge into Lake Thunderbird. Exhibit ES-1 outlines boundaries of the 15 major watersheds that were further subdivided into the 36 assessed watersheds by separating out larger tributaries or simply separating the watersheds into upper, middle, and lower divisions. In order to quantify and spatially locate certain physiographic characteristics within a watershed, GIS datasets collected from various sources were analyzed and used to develop watershed-specific tables and presentation maps that outline descriptive information such as land use, hydrologic soil groups, floodplains, and impervious cover. Stream corridor environments were similarly analyzed to identify conditions such as erosion problem areas, channel type, floodplain vegetation, Federal Emergency Management Agency (FEMA) flood zone type, and number of storm water outfalls.

HYDROLOGIC AND HYDRAULIC MODELING

Three complementary hydrologic and hydraulic modeling approaches were used in the development of design flows for the master plan. The most detailed of the three methods utilized 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, utilized a USGS regression equation. The third approach, used in limited cases for site-specific drainage issues, was the Rational Method per the City of Norman design criteria. Hydrologic analyses were performed for 307 square miles of drainage area that includes the City's 190 square miles within its boundaries. Hydraulic analyses and floodplain mapping were developed for almost 400 stream miles, which included 59 miles along detailed (Level 1 and 2) streams and 333 miles along general (Level 3 and 4) streams.

STORM WATER PROBLEMS AND SOLUTIONS

Storm water problem identification and solution development for the detailed study areas were grouped into stream flooding, stream erosion, water quality, and local drainage to assist in understanding the overall magnitude of such problem types in the City. The identification of problems was accomplished through a variety of means including the review and evaluation of items such as: the City's GIS data; past water quality studies; hydrologic and hydraulic modeling and mapping; watershed and stream assessments; input obtained from the City, various committees, and the SWMP Task Force; and input received from the general public as provided through the City staff and during public meetings. Although existing conditions were reviewed and considered, the identification and evaluation of flooding along major streams primarily focused on future (baseline) full buildout watershed conditions that reflect projected development levels in the City's 2025 Plan and subsequent updates to this comprehensive plan as adopted by the City Council. The identification of stream erosion problems was primarily based on existing conditions consistent with the watershed and stream assessments.



Norman Storm Water Master Plan
Exhibit ES-1
Study Areas

City of Norman
201 West Gray, Bldg. A
Norman, OK 73069

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

In developing solutions, considerations were made to incorporate items such as improving and/or protecting stream environmental integrity by using bio-engineering and natural channel design techniques, preserving the historical character of an existing solution type such as the WPA-constructed channels found in the upper Imhoff and Bishop Creek watersheds, improving water quality, and 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 for preserving or enhancing environmental and recreational conditions, the solution development process included the consideration of various possible alternatives or options and review of preliminary findings with City staff as well as the project Task Force to obtain their feedback and guidance.

Due to their “non-point source” nature, the identification of water quality problems and related solutions development were evaluated on a citywide scale consistent with procedures used for similarly sized cities throughout the country. This citywide approach to addressing water quality involves a programmatic approach which is now ongoing through the City’s MS4 Program with the potential for expansion due to Canadian River TMDL concerns as well as the Oklahoma Department of Environmental Quality (ODEQ) Watershed Plan that is being developed for the 256-square-mile basin area draining to Lake Thunderbird which includes a large part of Norman.

In addition to identifying existing water quality problems and related solutions through the City’s MS4 Program, one of several major concerns involves the threat of further water quality degradation throughout Norman’s waterways, especially as it relates to Lake Thunderbird’s water quality, due to future urbanization. The State of Oklahoma has designated 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 recent 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 storm water non-point nutrient and sediment loadings to the lake as well as analyzed the potential effectiveness of management practices 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 chlorophyll-a concentrations currently exceed 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, as well as 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 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) as documented in Sections 5, 6, and 7 of this SWMP report, 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 storm water 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 2007 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 subsequently presented in this executive summary serve to provide an outline of recommended storm water 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.

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.

Fifty-nine problem areas including those characterized by stream flooding, stream erosion and local drainage were identified within the City from the many investigations and evaluations performed. The problems are spread over a large part of the City but all are located along, or west of, 48th Avenue East. Adding to their magnitude, a vast majority of the problems occur on property lacking sufficient drainage easements or rights-of-way requiring that solution costs include the purchase of such easements/rights-of-way. Table ES-1 provides the number of each problem areas in the respective Level 1 and 2 watersheds.

As indicated in Table ES-1, a variety of conceptual solutions were developed for the 59 flood/drainage-related and stream erosion problems. The estimated costs for each solution were developed and totaled by the respective watersheds and for the City as a whole. Approximately 84% of the problems were located in the urban watersheds of Bishop Creek, Brookhaven Creek, Imhoff Creek, Merkle Creek, and Woodcrest Creek with their solution costs amounting to almost 90% of the City's $82.6 million total costs. Stream flooding occurs in several locations in these watersheds with stream erosion also destabilizing the mid and lower reaches of the streams traversing these same watersheds with the exception of Merkle Creek. Certain solutions address overlapping problems, such as stream flooding and stream erosion. The level of protection for most stream flooding solutions varied somewhat although

Table ES-1
Summary of Proposed Storm Water Projects

	Stream Flooding		Stream Stabilization		Local Drainage			
Watershed	No.	Costs	No.	Costs	No.	Costs	Watershed Total Cost	Percent of City Total
Bishop Creek	6	$5,347,808	6	$1,817,248	5	$4,720,055	$11,885,111	14.4
Brookhaven Creek	4	$2,613,904	4	$2,106,735	3	$1,278,962	$5,999,601	7.3
Clear Creek	---	---	---	---	1	$1,794,023	$1,794,023	2.2
Canadian River	---	---	---	---	1	$400,645	$400,645	0.5
Dave Blue Creek	2	$1,786,733	---	---	---	---	$1,786,733	2.2
Imhoff Creek	9	$24,439,559	2	$6,816,509	1	$12,461,087	$43,717,155	53.0
Little River	1	$305,233	1	$123,682	---	---	$428,915	0.5
Tributary G to Little River	1	$992,182	---	---	---	---	$992,182	1.2
Woodcrest Creek	3	$3,167,165	1	$110,965	---	---	$3,278,130	4.0
Merkle Creek	4	$8,856,558	---	---	---	---	$8,856,558	10.7
Rock Creek	3	$3,136,111	---	---	---	---	$3,136,111	3.8
Ten Mile Flat Creek	---	---	---	---	1	$255,326	$255,326	0.3
Citywide Totals	33	$50,645,253	14	$10,975,139	12	$20,910,098	$82,530,490	100.0

improvements associated with channel capacity and roadway bridge openings used projected 100-year baseline (future) peak discharges while roadway culvert openings used projected 50-year peak flows. Exceptions were made 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 (including the Lindsey Street-McGee Drive intersection flooding problem), and a few others.

The 59 solutions developed offer resolution and/or mitigation to the problems identified with the following benefits:

- 34 (58% of all solutions) instances of stream flooding mitigation.
  - 26 of the 34 target structure or building flooding.
    - 652 of 830 structures removed from the 100-year baseline floodplain.
  - 29 of the 34 include upgrades to flooded (overtopped) road crossings.
    - 36 out of 36 flood prone road crossings protected to design levels.
  - 12 of the 34 have a structure/parcel buyout component.
    - 62 properties identified as possible buyouts.
- 14 (24% of all solutions) involve stream erosion stabilization.
  - 10,050 ft of eroding streams stabilized.
- 12 (20% of all solutions) represent resolutions of local drainage problems.

Another important aspect of developing solutions for the many problems identified involved prioritization of the solutions. These prioritizations allow for identification of the most critical projects to address the storm water needs in Norman. Further, prioritizations represent an important tool for the City to use along with other information, such as individual project costs, in determining the order that solutions might be implemented or how they might be financed. The prioritization system developed evaluates, scores, and ranks each solution or project in terms of its ability to: solve the problem being considered, provide for public safety, provide sustainability, utilize funding advantages, impart positive impacts on affected neighborhoods and the environment, assist in other important issues like transportation, and present its economic costs versus benefits relationship. Using the evaluation scores, solution (project) rankings were established and organized according to the respective watersheds and ward(s) in which the projects reside as well as within the City as a whole.

KEY ISSUES

During development of the SWMP, several key issues emerged that warranted a considerable amount of attention 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 approaches and ideas about how to resolve these various issues. As reflected in this executive summary and Section 9 of this report, recommendations on these key issues have been made to assist the City in moving forward toward meeting their storm water management goals. However, it is understood that additional discussion will follow to work out the associated details and exceptions/variances. These key issues are:

- incorporating floodplain or “Stream Planning Corridors” dedications in new developments,
- utilizing structural and non-structural water quality controls in new developments including low impact development techniques,
- providing enhanced maintenance of creeks and storm water detention facilities in existing and new developments,
- acquiring drainage easements and rights-of-way in new and existing developments, and
- providing dam safety throughout the City.

FINANCIAL ANALYSES

Financial analyses were performed to meet the funding needs for the programs and activities associated with this SWMP. The funding needs developed primarily include operations and maintenance costs to meet the City’s current MS4 storm water permit requirements, the upcoming expansion of MS4 permit requirements, the storm water capital improvement program costs, trail construction, and the purchase of critical drainage easements/rights-of-way. Guidance on critical financing decisions was obtained from the mayor and City Council, the SWMP Task Force, City staff, and other stakeholders throughout the process. Key analyses investigated the background and legislative history of storm water utilities, revenue requirements, funding potential associated with a storm water utility as well as general obligation (GO) bonding, and utility rate establishment methods. The proposed utility rate structure developed ensures that: a public purpose will be served, a reasonable relationship exists between the amount of service rendered and the amount of charge to be levied, the rates will not be arbitrary, and the rates will be equally and fairly applied.

The amount of revenue required for the proposed storm water management activities and improvements outlined in the SWMP can be broken down into needs for operation and maintenance, cash (or storm water fee) financed capital, debt service, and reserve creation less any non-operating revenues such as interest earnings. In addition to a storm water utility, the City decided to propose funding a portion of the storm water capital improvements with general obligation (GO) bonds in order to more quickly provide needed projects in areas of critical storm water needs. Three rate options were developed to fund the storm water capital improvements using the split between GO bonding and storm water utility rates over a 20-year program as defined by the City. As shown in Table ES-2 and consistent with the CIP costs for proposed solutions, the total 20-year capital improvement program needs in 2008–2009 dollars were estimated to be approximately $83 million. To cover these costs, three options for financing this program were developed with varying amounts of general obligation (GO) bonding and storm water utility user fees.

Table ES-2
Three Rate Options – FY 2008–2009 Dollars (Uninflated)

Line No.	Item	Option 1	Option 2	Option 3
1	Capital Improvement Program (20-Year Period)	$83,000,000	$83,000,000	$83,000,000
2	Funding Source			
3	General Obligation Bonds	$30,000,000	$38,500,000	$40,000,000
4	Storm Water 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	Program Period	20	20	20
7	Capital Improvement Projects per Year Funded by Rates	$2,650,000	$2,225,000	$2,150,000

The total storm water revenue requirements were established by incorporating the costs developed during the SWMP project for pertinent items, specifically the eight items listed in Table ES-3 (excluding items on lines 5, 10, and 11). Table ES-3 shows the storm water 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. As indicated in line 7 of Table ES-3, the capital improvements program is equivalent to line 7 in Table ES-2 with the exception that the ES-3 values have been adjusted for inflation to reflect FY 2011–2012 dollars, which is the middle year in the 5-year planning period.

Establishment of the utility rates in the proposed storm water utility system will be based on impervious cover of the property owners in Norman, which was developed from data provided by the City of Norman. Table ES-4 displays the impervious cover data in five user classes. 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.

Table ES-3
Storm Water Utility Revenue Requirement (FY 2011–2012) Dollars

Line No.	Storm Water 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	$265,000
5	Subtotal	$1,602,880	$1,602,880	$1,602,880
6	Enhanced Maintenance (Trails, Detention Ponds, Creeks)	$1,273,080	$1,273,080	$1,273,080
7	Capital Improvements 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 Rights- 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 ES-4
Impervious Data Analysis Results

All Parcels **User Class**	(A) **Parcel Count**	(B) **Total Area Sq Ft**	(C) **Imp. Area Sq Ft**	(D) **% of Total Impervious Area**	(E) **Avg Impervious Area Sq Ft**	(F) **% of Total 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%**		

The storm water rate, in dollars per square feet (sq ft) of impervious area, was then developed as shown in Table ES-5. The corresponding billing amounts for user classes for each parcel were then determined as shown in Table ES-6 for the first 5-year period and in Table ES-7 for subsequent 5-year periods, assuming Option 1. Table ES-6 also shows the average impervious area and average yearly bill under each of the three options for the three different user classes as well as the University of Oklahoma.

Table ES-5
Storm Water 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

Table ES-6
Average Bill for Each User Class (Based on Mid-Year, 2011–2012, of 2009–2014 Planning Period)

		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 ES-7
Storm Water Rates for the Subsequent 5-Year Planning Periods (Option 1)

	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 rates were being considered, a nationwide survey was performed to help the City ascertain whether it was common to exempt universities from storm water fees. The results indicated that most universities are not exempt from storm water charges. The City eventually decided to bill all impervious surfaces, both universities and other exempt properties, within the City. The survey taken indicated that in cities which claimed that their fees were fully adequate to fund the storm water utility, monthly utility fees averaged $9.95 (in 2008 dollars). This compares quite favorably for the City of Norman's anticipated average fee of approximately $6.74 to $7.29 in FY 2011–2012 dollars. As a final output, a long-range financial plan was developed that mapped the financial health of the storm water utility over the 20-year study period.

Table ES-8 shows various bills in 2011–2012 dollars for various 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 maximum monthly bills of $5.65, $5.28, or $5.22 (probably less depending on each property's actual impervious amount) for Options 1, 2, and 3, respectively. The median single-family impervious square footage is approximately 3,100 square feet and implies a maximum monthly bill of $6.26, $5.85, or $5.78 (probably less depending on each property's actual impervious amount) under Options 1, 2, and 3, respectively.

Table ES-8
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 ($)	Average Monthly Bill ($)	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

RECOMMENDATIONS/IMPLEMENTATION PLAN

Recommendations were developed to cover the range of topics analyzed and evaluated as part of the SWMP development. In certain instances, the recommendations presented should be viewed with the understanding that further meetings, discussions, and considerations will be required. These recommendations covered general items, watershed and stream assessments, hydrologic and hydraulic modeling, drainage criteria manual updates, storm water problems and solutions, key issues, and storm water financing. An overview of the recommendations includes:

Future Meetings and Coordination

- Continue to involve stakeholders in all aspects of the SWMP including implementation.
- Refine storm water 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 further educate citizens about the City's storm water needs, the importance of obtaining adequate funding to meet those needs, and the general support needed to sustain a viable storm water program throughout the City.

Key Issues

- Stream Planning Corridors and 100-year full buildout floodplain dedications as well as structural and non-structural storm water quality controls.
  - 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.
    - 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.
    - Require additional stream-side buffers of 15 feet 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.
  - 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. 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.
    - 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. The City's present regional detention program should be broadened to include this water quality fee in lieu process.
    - Allow and encourage low impact development techniques such as rain gardens and biofilters to provide a portion or all of their storm water quality control requirements subject to the developer providing sufficient technical justification for the techniques.
    - For developments that do not dedicate the SPC 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.
  - Allow limited variances for special conditions/situations that would utilize 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 storm water 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 present 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.), and
    - Inlet and outlet structures will be provided as needed to incorporate erosion protection.
  - Continually assess water quality conditions in Lake Thunderbird and update or modify activities and controls to protect this important water supply.

- Acquisition of drainage easements and rights-of-way along streams and detention facility areas.
  - Develop a plan and begin to obtain drainage easements and/or rights-of-way (as needed) in Level 1 and 2 streams and for storm water 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 feet on each side of the stream channel. This can include those areas where storm water CIP projects have been identified if the maintenance need justifies obtaining the easements in advance of designing and constructing the proposed CIP project.
- Enhanced maintenance of creeks and storm water detention facilities.
  - 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-way, rights-of-entry, and reaches of "no action," depending on the situation/conditions. 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 in which dam maintenance may become a safety issue.
- Dam safety issues.
  - 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.
  - 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.
  - 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.

Policy, Ordinances, and Criteria

- Use watershed full buildout peak discharges for new developments and make necessary changes to City policy, the subdivision regulations, and drainage criteria manual.
- Retain the low density development policies outlined in the Norman 2025 plan for the Ten Mile Flat Creek watershed and the areas generally east of the urban core draining to Lake Thunderbird.
- Update the City's Drainage Criteria Manual in all aspects, including the rainfall and runoff methods established in the SWMP as well as a reassessment of the adequacy of the fee-in-lieu of on-site detention criteria.
- Develop a Storm Water Quality Criteria Manual with SWMP findings and recommendations.
- Develop an Erosion Control Manual aimed at preventing erosion problems associated with construction.

General Storm Water Quantity and Quality Management

- To facilitate SWMP improvements implementation, develop a CIP program with staff dedicated to managing the associated design and construction activities. This staff can balance their cyclic work load by using consulting firms and other professionals.
- 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.
- Monitor and document conditions associated with the problems identified in the SWMP until CIP improvements solve or mitigate them.
- Incorporate any new problems and possible solutions on a continuing basis.
- Review and update solution prioritizations every few years.
- Continually explore ways to integrate solutions to address multiple problem types and incorporate greenway opportunities.
- Develop collaborative agency partnerships to assist in project funding and cooperation.
- Maintain awareness and knowledge of all water quality monitoring being carried out in watersheds that originate in, or flow through, the City of Norman.
- Meet with the cities of Moore and Oklahoma City to explore ways to improve water quality and preserve Lake Thunderbird's water quality.
- 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 as well as the MS4 program as compliance activities associated with these three programs will impact water quality in Norman for the foreseeable future.
- Assure compliance with requirements of the City's MS4 OPDES storm water permit, the recently developed Canadian River Bacteria TMDL, and the ODEQ Lake Thunderbird Watershed Management Plan development.

Hydrologic and Hydraulic Modeling

- Update hydrologic and hydraulic models consistent with up-to-date priorities using the data, methods, and findings of the SWMP.

- Develop a hydrologic and hydraulic model management system using an internal City server or a web server to improve user access to the models, facilitate City maintenance and distribution of the models, and to track legitimate updates.
- Submit Letters of Map Revision (LOMRs) to FEMA for the Level 1 streams studied during the SWMP development. When other streams are studied or updated in detail, those studies/updates should be submitted as FEMA LOMRs at that time.

Funding

- Establish long-range funding sources for storm water management such as general obligation bonding and the establishment of a storm water utility.
  - Develop and carry out a strategic work plan for a citizen vote on the proposed storm water 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.
  - Develop and carry out a strategic work plan for a citizen vote on the proposed general obligation bond program as described in Section 8.

SUMMARY STATEMENT

With the results of this SWMP as a solid foundation, the City of Norman will be able to:

- Satisfy their regulatory requirements including the mandated OPDES MS4 storm water quality permitting program.
- Meet the challenges facing the community, including identifying problems and solutions associated with stream flooding, stream erosion, local drainage problems, and water quality.
- Enhance recreational opportunities and protect the environment.
- Obtain input from all stakeholders, receive public input, provide public education on important issues, and maintain public support into the future.

1.0 INTRODUCTION

1.1 GOALS

Located in Central Oklahoma, the City of Norman is the county seat of Cleveland County and home of the University of Oklahoma. Norman is a progressive community that is proactive on a wide range of issues that include its land and water environments. As Norman has grown in population and further urbanized many of its watersheds, the resulting impacts on flooding, water quality, and erosion have increased significantly, including the considerable degradation of the water quality in Lake Thunderbird and many of its contributing streams. At the same time, the recreational opportunities offered by the City's waterways have become increasingly apparent. Given these and other related factors, the City began developing the framework for a Storm Water Master Plan (SWMP) in late 2005 with its primary goals aimed at guarding its citizens from flooding dangers, protecting its water quality, enhancing its environment, and advancing its recreational opportunities. This effort began with developing a comprehensive scope of work, continued with completion of a wide range of storm water investigations, and has progressed to completion of this report. This SWMP advances Norman's future storm water planning with the knowledge that such planning must continue indefinitely. As requested by the City, this SWMP includes all watersheds in the City while addressing the many storm water issues. The SWMP also incorporates "quality of life" elements for Norman's citizens by outlining measures to manage creek corridors and floodplains in an environmentally sound manner and to provide for increased recreational opportunities.

Norman's Municipal Complex

1.2 GENERAL STUDY AREA CHARACTERISTICS

With mean daily temperatures that range from 37 degrees Fahrenheit (°F) in January to 82°F in July and an annual rainfall of near 35 inches, Norman has grown to a population of approximately 112,000. The City area is large and diverse with an area of almost 190 square miles characterized by a variety of conditions generally ranging from urban land uses along both sides of the IH 35 highway corridor to rural areas on the City's western edge and eastern areas. The local land character can be described as gently rolling hills with native prairie grasses, scrub oak, and scattered hardwood trees. The topography varies from flat in the Ten Mile Flat prairie area along the City's western edge and in some upland areas to gently rolling hills in the central and eastern cross timbers portions of the city. As shown in Exhibit ES-1, the northern part of the City drains into Little River, which flows easterly into Lake Thunderbird along with numerous smaller streams in the City's large rural eastern side. Lake Thunderbird's 256-square-mile watershed receives storm water runoff from the cities of Norman, Moore, Del City, and Oklahoma City as well as some unincorporated areas. Norman contributes about 50 percent of the lake's drainage area. The City's urban core area primarily drains in a southerly direction into the Canadian River that runs along a portion of the City's southern boundary. Many of the urban streams in the City experience flooding and erosion due to their urban land use and intense localized thunderstorms that occur in spring, summer, and early fall.

Lake Thunderbird sunset

1.3 APPROACH

The overall approach to developing the SWMP involved using existing information and data to the extent possible, building on that base with new information and data, and performing the analyses needed to meet the SWMP goals. The SWMP project began in August 2007 following the contract signing date in July 2007. From the beginning, obtaining local public input was a critical component in fulfilling the goals of the SWMP. Soon after the project began and in order to coordinate ongoing project issues and provide guidance on local perspectives, a Storm Water Task Force was formed. This SWMP Task Force met with the consultant team and City staff on numerous occasions to review ongoing study efforts, including the methods used and results developed, generally offer suggestions, and coordinate the SWMP work flow.

Three public meetings were also held to present progress and findings as well as receive input directly from the public. Additionally, "one on one" meetings with the City Council members respectively representing each City ward and the mayor were held in August 2008 to present the special investigations and findings specific to each ward. In this manner, the Council members were able to more fully investigate and provide input on the issues and opportunities related to their respective ward as well as the City as a whole. Four meetings were also held with the Greenbelt Commission to receive their input and perspectives as well as review the City's Greenway Master Plan (Halff, 2009) being developed and its relationship to the SWMP. Finally, regular conference calls were held every 2 or 3 weeks on average throughout the project to insure proper coordination between the consultant team, the City staff, and the SWMP Task Force. Plans to present the findings and recommendations associated with the SWMP in an early 2009 Task Force and public meetings are presently being made.

Public input obtained

The analyses associated with watershed/stream assessments, stream flooding, and stream erosion were performed at different "levels" or intensities based on the needs of the City as discussed below. However and as discussed further in Sections 5 and 6, water quality was studied using a different method as its characterization is generally viewed as an overall citywide condition associated with urban development activities. In order to focus on the primary stream systems and provide detail analyses in the areas having 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.

Level 1 (detailed) – Level 1 streams, including their respective watersheds, represent those streams in which new detailed studies were conducted for hydrology, hydraulics, and floodplain mapping. New hydrologic and hydraulic models were developed for these streams utilizing the new 2007 City topography and aerial coverage incorporated and attached hereto as a critical element in the SWMP, field surveying 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 developed using City GIS files to obtain land use (or zoning), impervious cover, floodplain, soil, and other watershed data. Watershed and stream assessments were developed utilized extensive field reconnaissance visits and the City's 2007 aerial and topographic data to document stream channel and overbank flow conditions as well as 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.

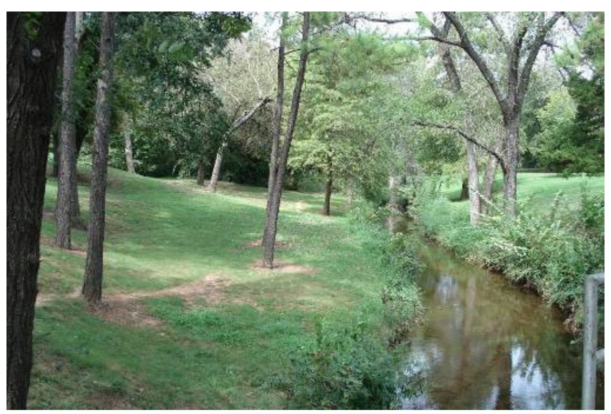
Level 2 (detailed) – Level 2 streams, including their respective watersheds, represent those streams in which hydrologic and hydraulic models from past FEMA studies or study updates were utilized. Similar to the Level 1 streams, the City's 2007 topographic and aerial base maps were used in floodplain 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 utilized extensive field reconnaissance visits and the City's 2007 aerial and topographic data to document stream channel and overbank flow conditions as well as 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, new hydrologic and hydraulic models were developed for these streams utilized the new 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 utilized 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.

As mentioned at the beginning of this section, an important goal of the SWMP was to investigate ways to provide enhanced recreational opportunities by integrating greenbelt planning with storm water solutions. A Greenway Master Plan has been conducted by the City in parallel with the SWMP and is also nearing completion. It was determined that the best way to integrate storm water 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 storm water and greenway projects in these overlapping locations.



Utilize greenbelt opportunities

1.4 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 utilized 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 storm water 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) as well as those receiving more general analyses (Level 3 and 4 steams).

Section 5: Storm Water Problems. Storm water 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: Storm Water 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 storm water goals. These key issues include Stream Planning Corridors, structural and/or non-structural controls for storm water, 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 storm water 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.

2.0 DATA SOURCES AND COLLECTION

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 utilize 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 utilize the best available data and information relating to storm water 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, as well as 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).
- 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).
- 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).
- Easements and rights-of-way from the City of Norman.
- FEMA 2008 Flood Insurance Study Update (FEMA, 2008).
- Various Letter of Map Revision (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 storm water 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.

- Storm Water 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).

3.0 WATERSHED AND STREAM ASSESSMENTS

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 storm water in the City. The management of storm water runoff is critical to protecting the health and safety of local citizens while also preserving the environment and ensuring that the City is developed in a sustainable manner. By utilizing the results of these assessments to identify and correct existing storm water 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 storm water 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 provide a description of the conditions in each watershed with respect to the factors that are important in determining runoff generation and magnitude as well as the nature or quality of that runoff. The watershed and stream assessments provided important information for the identification of storm water related problems in the City (Section 5), the development of solutions for these problems (Section 6), as well as the future allocation of resources and planning needed to minimize and manage the impacts of storm water 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 also 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 storm water 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 storm water 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 (map pocket) outlines the boundaries of these 36 watersheds as well as their numerous small contributing subareas. In addition to providing a means of determining and spatially locating the characteristics of watersheds that contribute storm water 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 storm water 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 as well as the floodway, where the respective data are available. An example of the watershed-specific statistical overview is provided in Table 3-1 for Bishop Creek.

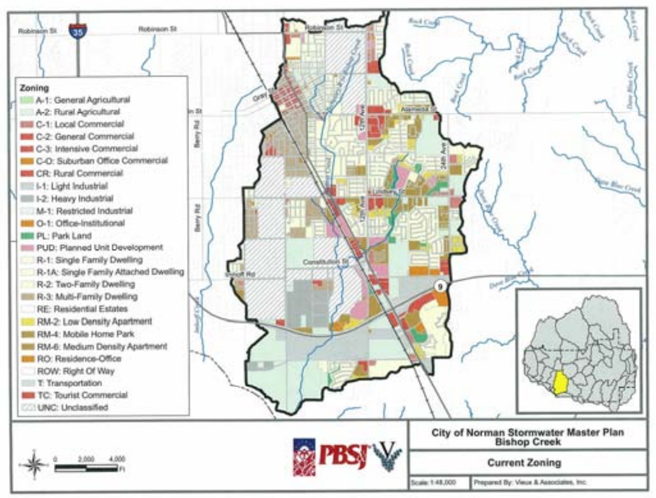


Figure 3-1: Current Zoning, Bishop Creek Watershed

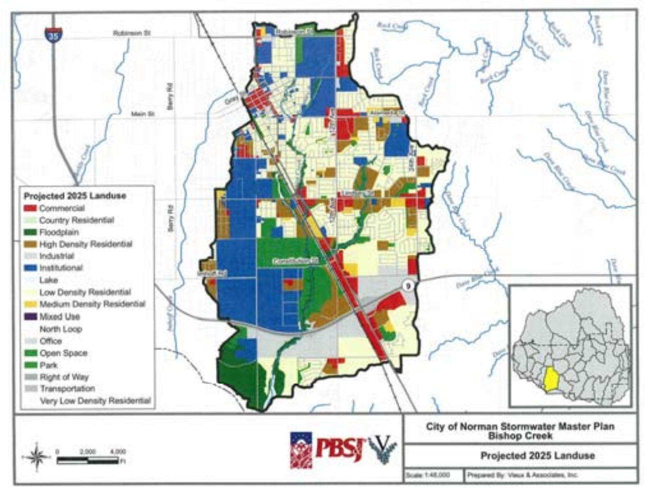


Figure 3-3: Projected 2025 Land Use, Bishop Creek Watershed

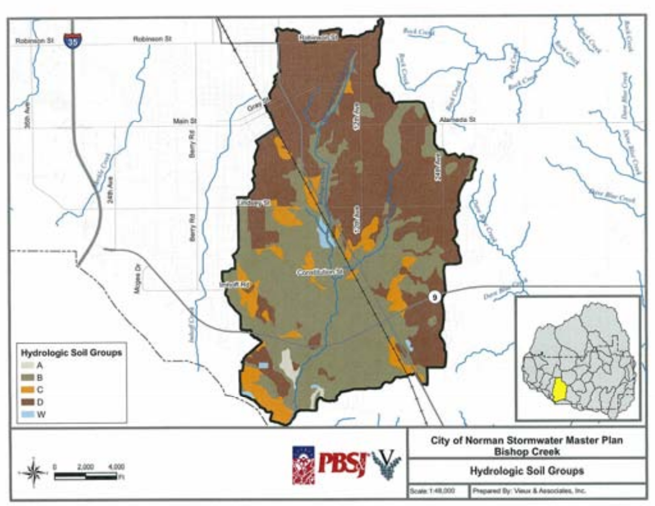


Figure 3-2: Hydrologic Soil Groups, Bishop Creek Watershed

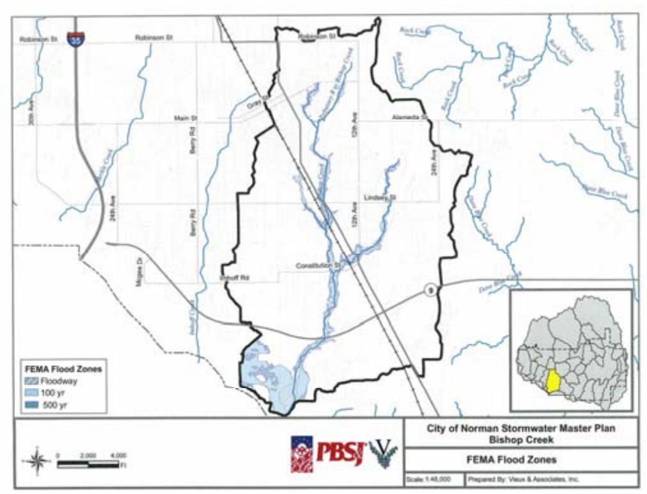


Figure 3-4: FEMA Flood Zones, Bishop Creek Watershed

Table 3-1
Basin Statistics, Bishop Creek Watershed

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 below. Discussions outlining the methods used follow the basic work procedures employed which included obtaining, developing, and/or evaluating data for watersheds and their component subareas as well as the primary streams and their component reaches that traverse the watersheds and subareas. 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 storm water 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; Storm Water 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 storm water 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 storm water 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 groups,
- 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 as well as 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; and
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; and
- 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; and
- 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 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

Exhibit 3-3: Stream Reach Level Assessment Form

Reach Level Assessment **RCH**

Survey Reach ID: BC-1	Wrtshd/Subshd: Bishop Creek	Date: 11/8/2007	Assessed by: PM/GG
Start Time: 8 :10 AM/PM LMK: _____ Lat___°_____'_____" Long ___°_____'_____" Description:	*End* Time:___:____AM/PM LMK: _____ Lat___°_____'_____" Long ___°_____'_____" Description:	GPS ID:	

Rain in last 24 hours ☐ Heavy rain ☐ Steady rain ☒ None ☐ Intermittent ☐ Trace

Present conditions ☐ Heavy rain ☐ Steady rain ☐ Intermittent ☒ Clear ☐ Trace ☐ Overcast ☐ Partly cloudy

Surrounding land use: ☐ Industrial ☐ Commercial ☐ Urban/Residential ☐ Suburban/Res ☒ Forested ☐ Institutional ☐ Golf course ☐ Park ☒ Crop ☐ Pasture ☐ Other:

Average Conditions (*check applicable*)

Base Flow as % Channel Width ☐ 0-25% ☐ 50%-75% ☒ 25-50 % ☐ 75-100%

Dominant Substrate
☐ Silt/clay (fine or slick) ☐ Cobble (2.5 –10")
☒ Sand (gritty) ☐ Boulder (>10")
☒ Gravel (0.1-2.5") ☐ Bed rock

Water Clarity ☒ Clear ☐ Turbid *(suspended matter)*
☐ Stained *(clear, naturally colored)* ☐ Opaque *(milky)*
☐ Other *(chemicals, dyes)*

Aquatic Plants in Stream Attached: ☒ none ☐ some ☐ lots
Floating: ☒ none ☐ some ☐ lots

Wildlife in or Around Stream (Evidence of)
☐ Fish ☐ Beaver ☐ Deer
☐ Snails ☒ Other:

Stream Shading (water surface)
☒ Mostly shaded (≥75% coverage)
☐ Halfway (≥50%)
☐ Partially shaded (≥25%)
☐ Unshaded (< 25%)

Channel Dynamics
☒ Downcutting ☐ Bed scour
☐ Widening ☐ Bank failure
☐ Headcutting ☐ Bank scour
☐ Aggrading ☐ Slope failure
☐ Sed. deposition ☐ Channelized
☐ Unknown

Channel Dimensions (*Facing downstream*)
Height: LT bank 10-15 (ft)
RT bank 10-15 (ft)
Width: Bottom 30-40 (ft)
Top 60 (ft)

Reach Sketch and Site Impact Tracking

Simple planar sketch of survey reach. Track locations and IDs for all site impacts within the survey reach (OT, ER, IB,SC, UT, TR, MI) as well as any additional features deemed appropriate. Indicate direction of flow

Reach Accessibility

Good: Open area in public ownership, sufficient room to stockpile materials, easy stream channel access for heavy equipment using existing roads or trails.	Fair: Forested or developed area adjacent to stream. Access requires tree removal or impact to landscaped areas. Stockpile areas small or distant from stream.	Difficult. Must cross wetland, steep slope, or sensitive areas to get to stream. Few areas to stockpile available and/or located a great distance from stream. Specialized heavy equipment required.
5 4	3 2	1

(Selected: 4)

Notes: *(biggest problem you see in survey reach)*

Reported to authorities ☐ Yes ☒ No

Overall Stream Condition

	Optimal	Suboptimal	Marginal	Poor
In-stream Habitat *(May modify criteria based on appropriate habitat regime)*	Greater than 70% of substrate favorable for epifaunal colonization and fish cover; mix of snags, submerged logs, undercut banks, cobble or other stable habitat and at stage to allow full colonization potential (i.e., logs/snags that are not new fall and not transient).	40-70% mix of stable habitat; well-suited for full colonization potential; adequate habitat for maintenance of populations; presence of additional substrate in the form of newfall, but not yet prepared for colonization (may rate at high end of scale).	20-40% mix of stable habitat; habitat availability less than desirable; substrate frequently disturbed or removed.	Less than 20% stable habitat; lack of habitat is obvious; substrate unstable or lacking.
17	20 19 18 17 16	15 14 13 12 11	10 9 8 7 6	5 4 3 2 1 0
Vegetative Protection *(score each bank, determine sides by facing downstream)*	More than 90% of the streambank surfaces and immediate riparian zone covered by native vegetation, including trees, understory shrubs, or nonwoody macrophytes; vegetative disruption through grazing or mowing minimal or not evident; almost all plants allowed to grow naturally.	70-90% of the streambank surfaces covered by native vegetation, but one class of plants is not well-represented; disruption evident but not affecting full plant growth potential to any great extent; more than one-half of the potential plant stubble height remaining.	50-70% of the streambank surfaces covered by vegetation; disruption obvious; patches of bare soil or closely cropped vegetation common; less than one-half of the potential plant stubble height remaining.	Less than 50% of the streambank surfaces covered by vegetation; disruption of streambank vegetation is very high; vegetation has been removed to 5 centimeters or less in average stubble height.
9	Left Bank 10 9	8 7 6	5 4 3	2 1 0
9	Right Bank 10 9	8 7 6	5 4 3	2 1 0
Bank Erosion (facing downstream)	Banks stable; evidence of erosion or bank failure absent or minimal; little potential for future problems. <5% of bank affected.	Grade and width stable; isolated areas of bank failure/erosion; likely caused by a pipe outfall, local scour, impaired riparian vegetation or adjacent use.	Past downcutting evident, active stream widening, banks actively eroding at a moderate rate; no threat to property or infrastructure	Active downcutting; tall banks on both sides of the stream eroding at a fast rate; erosion contributing significant amount of sediment to stream; obvious threat to property or infrastructure.
8	Left Bank 10 9	8 7 6	5 4 3	2 1 0
8	Right Bank 10 9	8 7 6	5 4 3	2 1 0
Floodplain Connection	High flows (greater than bankfull) able to enter floodplain. Stream not deeply entrenched.	High flows (greater than bankfull) able to enter floodplain. Stream not deeply entrenched.	High flows (greater than bankfull) **not** able to enter floodplain. Stream deeply entrenched.	High flows (greater than bankfull) **not** able to enter floodplain. Stream deeply entrenched.
9	20 19 18 17 16	15 14 13 12 11	10 9 8 7 6	5 4 3 2 1 0

Overall Buffer and Floodplain Condition

	Optimal	Suboptimal	Marginal	Poor
Vegetated Buffer Width	Width of buffer zone >50 feet; human activities (i.e., parking lots, roadbeds, clear-cuts, lawns, crops) have not impacted zone.	Width of buffer zone 25-50 feet; human activities have impacted zone only minimally.	Width of buffer zone 10-25 feet; human activities have impacted zone a great deal.	Width of buffer zone <10 feet: little or no riparian vegetation due to human activities.
9	Left Bank 10 9	8 7 6	5 4 3	2 1 0
9	Right Bank 10 9	8 7 6	5 4 3	2 1 0
Floodplain Vegetation	Predominant floodplain vegetation type is mature forest	Predominant floodplain vegetation type is young forest	Predominant floodplain vegetation type is shrub or old field	Predominant floodplain vegetation type is turf or crop land
18	20 19 18 17 16	15 14 13 12 11	10 9 8 7 6	5 4 3 2 1 0
Floodplain Habitat	Even mix of wetland and non-wetland habitats, evidence of standing/ponded water	Even mix of wetland and non-wetland habitats, no evidence of standing/ponded water	Either all wetland or all non-wetland habitat, evidence of standing/ponded water	Either all wetland or all non-wetland habitat, no evidence of standing/ponded water
5	20 19 18 17 16	15 14 13 12 11	10 9 8 7 6	5 4 3 2 1 0
Floodplain Encroach-ment	No evidence of floodplain encroachment in the form of fill material, land development, or manmade structures	Minor floodplain encroachment in the form of fill material, land development, or manmade structures, but not effecting floodplain function	Moderate floodplain encroachment in the form of filling, land development, or manmade structures, some effect on floodplain function	Significant floodplain encroachment (i.e. fill material, land development, or man-made structures). Significant effect on floodplain function
18	20 19 18 17 16	15 14 13 12 11	10 9 8 7 6	5 4 3 2 1 0

Sub Total In-stream: 60/80 + Buffer/Floodplain: 59/80 = **Total** Survey Reach 119/160

- 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.

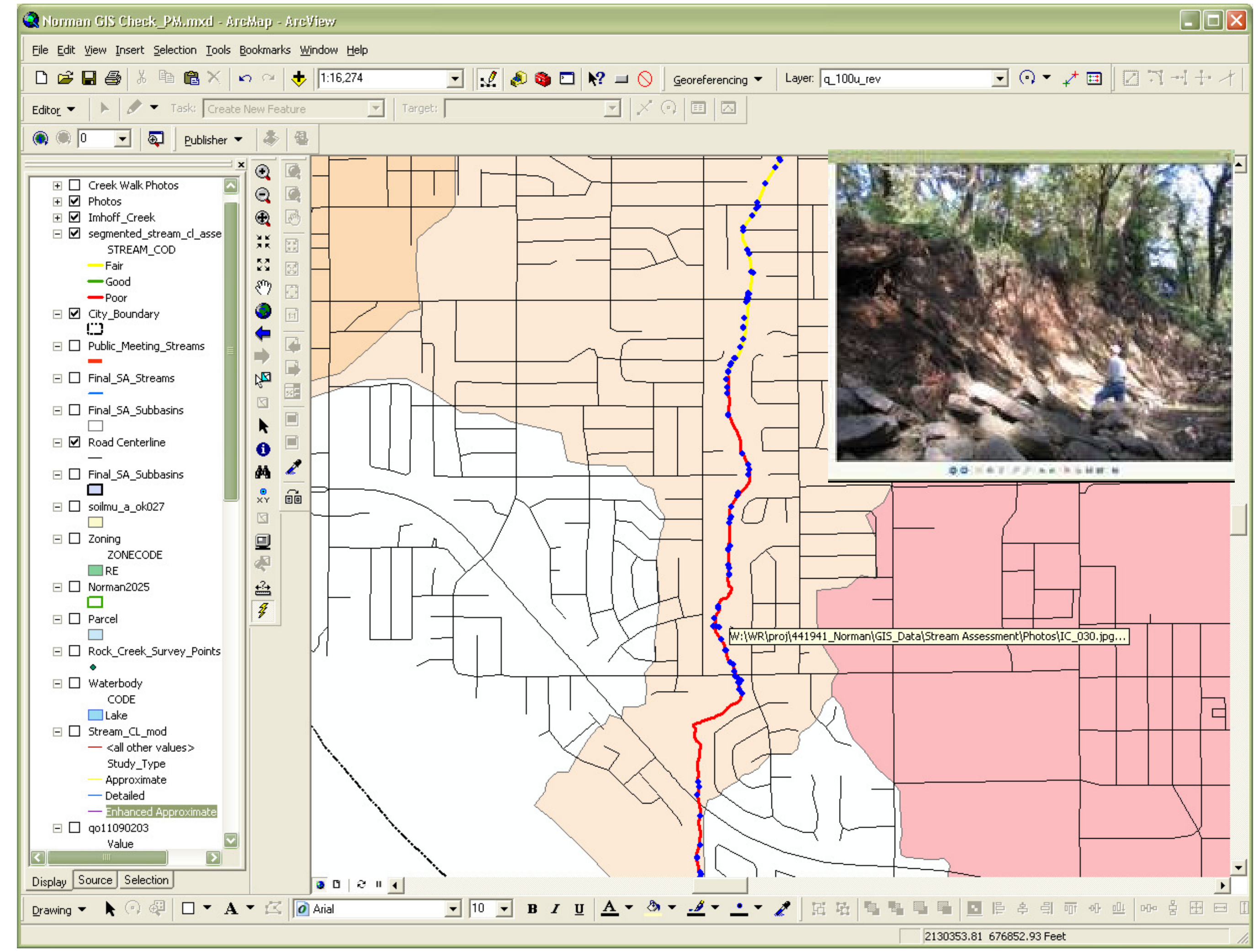


Exhibit 3-4
Desktop Display of Georeferenced Creek Reconnaissance Photo Locations

Table 3-2: Stream Reach Level Assessment Scoring

Reach ID	Sub Total: In-stream	Buffer/ Floodplain	Total Survey Reach	Reach ID	Sub Total: In-stream	Buffer/ Floodplain	Total Survey Reach
Bishop Creek				**Tributary G to Little River**			
BC-1	60	59	119	TGLR-1	61	57	118
BC-2	48	45	93	TGLR-2	47	42	89
BC-3	29	38	67	TGLR-7	54	56	110
BC-4	47	36	83	**Woodcrest Creek – Little River**			
BC-5	55	53	108	WC-1	41	64	105
BC-6	58	50	108	WC-4	48	55	103
BC-7	51	51	102	WC-5	49	43	92
BC-8	56	49	105	WC-6	46	38	84
Tributary A to Bishop Creek				WC-7	46	61	107
TABC-1	54	33	87	**Merkle Creek**			
TABC-2	47	41	88	MC-1	50	59	109
TABC-3	45	31	76	MC-2	44	54	98
Tributary B to Bishop Creek				MC-3	58	54	112
TBBC-1	60	43	103	MC-4	57	45	102
TBBC-2	54	45	99	MC-5	46	36	82
Tributary C to Bishop Creek				MC-6	66	40	106
TCBC-1	45	47	92	MC-7	68	37	105
Brookhaven Creek				MC-8	60	35	95
BHC-1	61	68	129	MC-9	67	40	107
BHC-2	28	33	61	MC-10	70	45	115
BHC-3	37	27	64	**Rock Creek**			
BHC-4	44	34	78	RC-22	43	59	102
BHC-5	60	52	112	RC-25	42	61	103
BHC-6	50	18	68	RC-26	51	59	110
Tributary A to Brookhaven Creek				RC-34	60	58	118
TABHC-1	41	20	61	**Tributary A to Rock Creek**			
Tributary B to Brookhaven Creek				RC-40	68	60	128
TBBHC-1	45	16	61	**Tributary B to Rock Creek**			
Imhoff Creek				RC-32	72	69	141
IC-1	53	54	107	**Tributary C to Rock Creek**			
IC-2	41	28	69	RC-29	51	55	106
IC-3	31	25	56	RC-30	57	60	117
IC-4	55	26	81	**Tributary D to Rock Creek**			
IC-5	52	30	82	RC-47	45	56	101
IC-6	52	29	81	RC-48	55	58	113
Little River				**Ten Mile Flat Creek**			
LR-45	35	56	91	TMFC-1	55	50	105
LR-48	42	59	101	TMFC-2	71	59	130
LR-53	39	57	96	TMFC-3	71	63	134
LR-64	43	54	97	TMFC-4	72	51	123
LR-65	45	55	100	TMFC-5	71	51	122
LR-68	63	54	117	TMFC-6	71	52	123
LR-69	68	55	123				

4.0 HYDROLOGIC AND HYDRAULIC ANALYSES

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 utilized 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.

4.1.1.1.1 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 utilizes 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.

4.1.1.1.2 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.

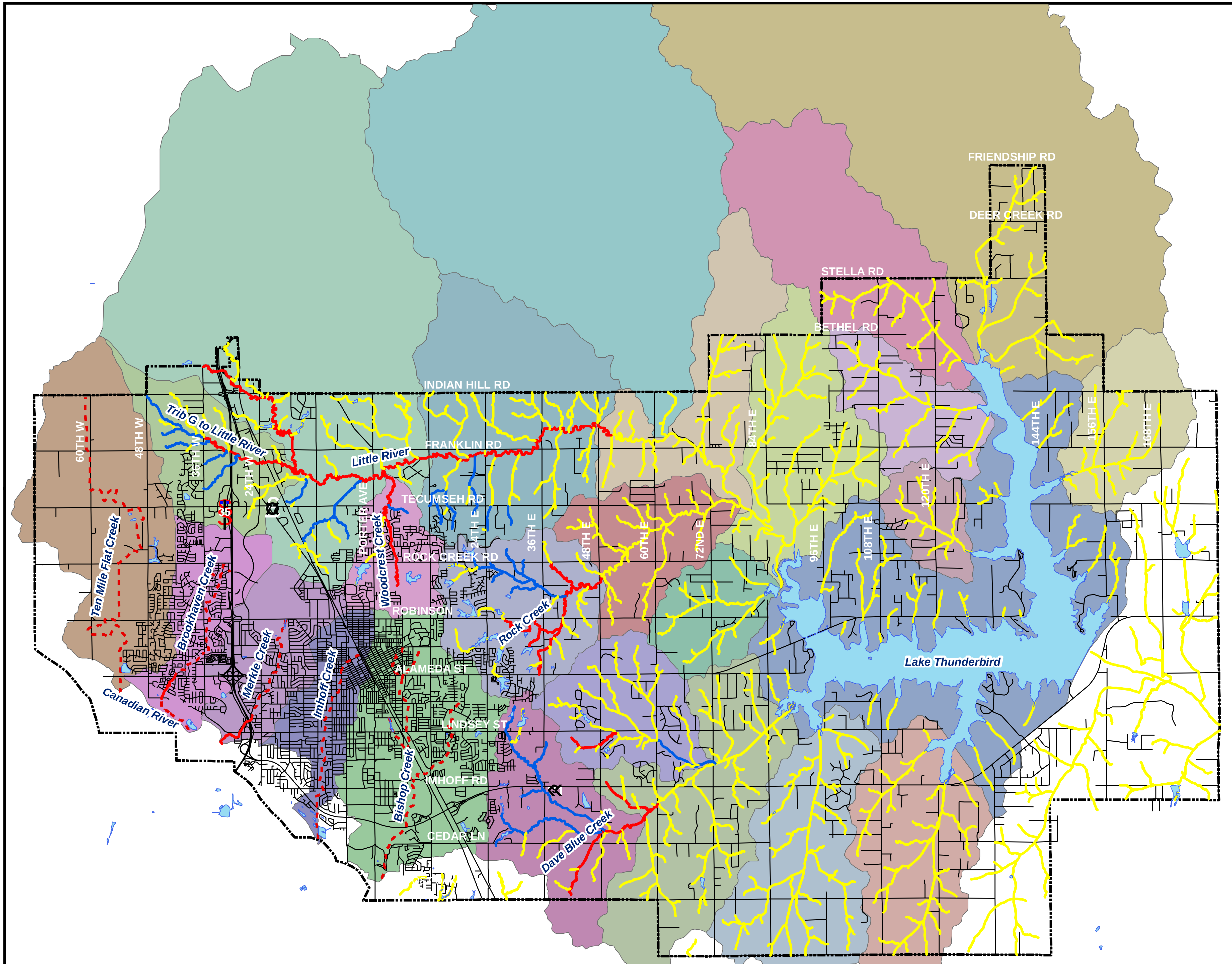
Table 4-1
Summary of Hydrologic Models for Levels 1 and 2 Watersheds

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

PBS&J



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

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 Rainfall Depths for Design Events

	Total Rainfall (inches) Frequency (Return Period)													
	USGS WRI 99-4232**							TP-40 / HYDRO-35***						
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
5-min								0.48	0.56	0.62	0.72	0.79	0.86	1.01
10-min								0.84	0.99	1.11	1.27	1.41	1.54	1.83
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
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-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
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
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
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
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
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

* 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).

4.1.1.1.3 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 utilized 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.

4.1.1.1.4 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 utilizes 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.

4.1.1.1.5 Lag Time Calculations

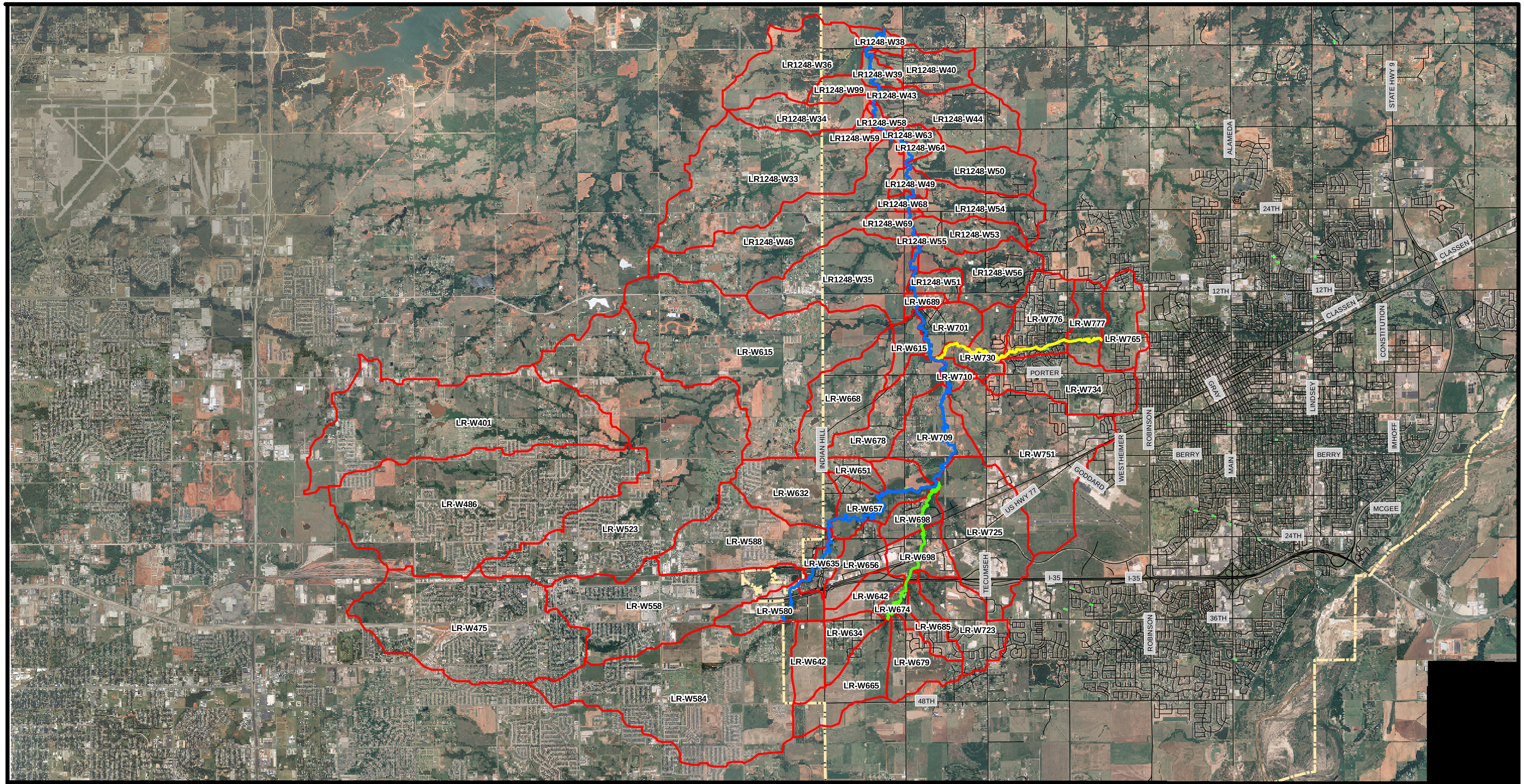
The lag times used for the NRCS (SCS) unit hydrograph transforms in the Level 1 HEC-HMS models were calculated based on the procedure outlined in TR-55 (Soil Conservation Service, 1986). This procedure separates the longest representative flow path in a particular subbasin into three different types 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

Table 4-4
Variations in Subbasin Size for Study 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



0 4,050 8,100 16,200 Feet

Aerial Photography: 2006
Coordinate System: Oklahoma State Plane, South Zone
Horizontal Datum: NAD 1983
Vertical Datum: NAVD 1988

Legend

- Little River
- Tributary G to Little River
- Woodcrest
- Watershed Boundary
- City Boundary

PBSJ

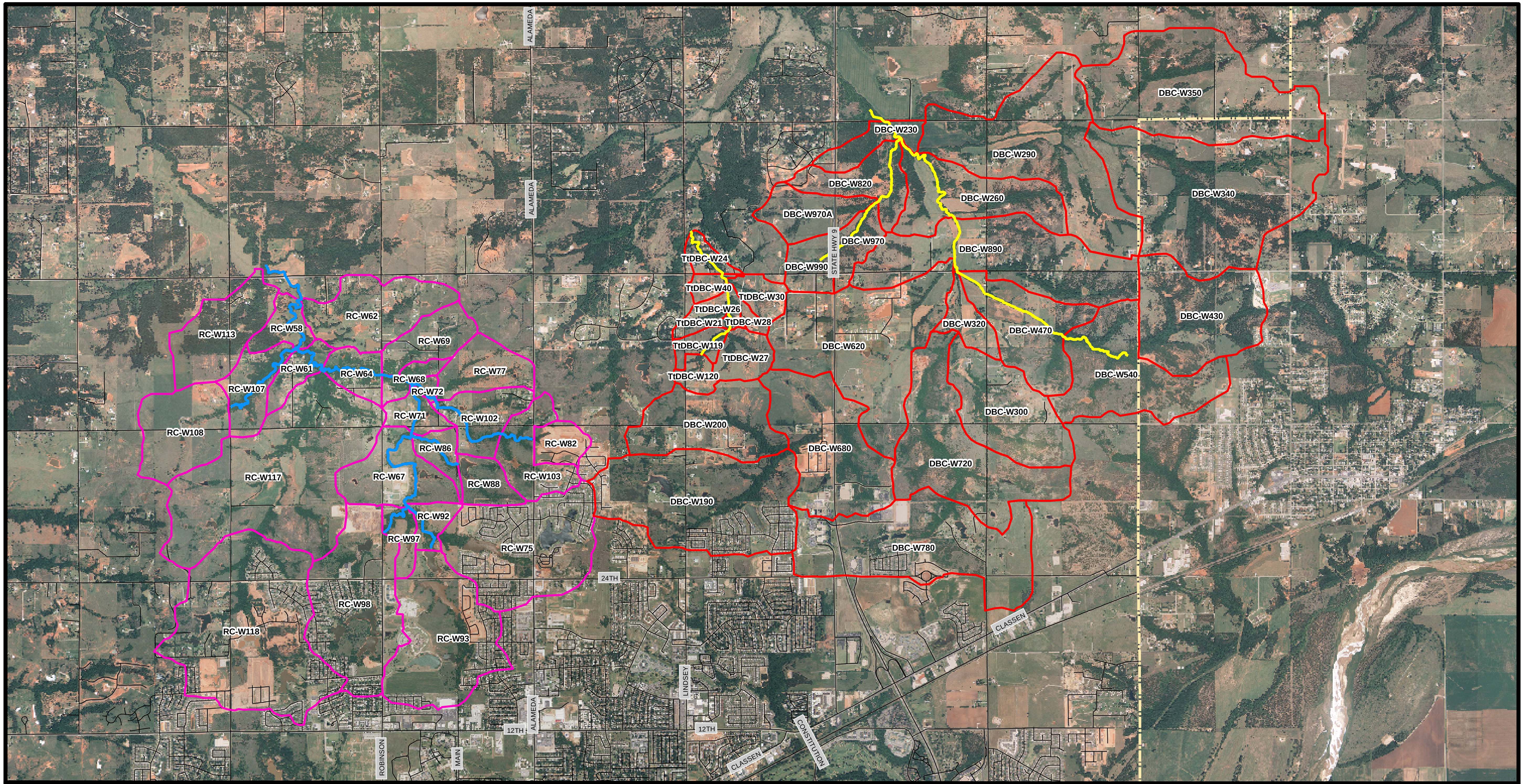
Storm Water Master Plan

Figure 4-1

Little River Mainstem, Tributary G to Little River and Woodcrest Wastersheds

Job No.: 044194100 | Date: 12-19-08 | 1 inch equals 6,500 feet

File: W:/WR/proj/441941_Norman/Report/Figures/DrainageAreaFigures/



0 2,000 4,000 8,000 Feet

Aerial Photography: 2006
Coordinate System: Oklahoma State Plane, South Zone
Horizontal Datum: NAD 1983
Vertical Datum: NAVD 1988

Legend

- Rock Creek and Tributaries
- Dave Blue Creek and Tributaries
- Dave Blue Creek Watershed
- Rock Creek Watershed
- City Boundary

PBSJ

Storm Water Master Plan

Figure 4-2

Dave Blue Creek and Rock Creek Watersheds

Job No.: 044194100	Date: 12-19-08	1 inch equals 3,500 feet
File: W:/WR/proj/441941_Norman/Report/Figures/DrainageAreaFigures/		