Section 6
Water Quality and Stream Stability

6.1 Background

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

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

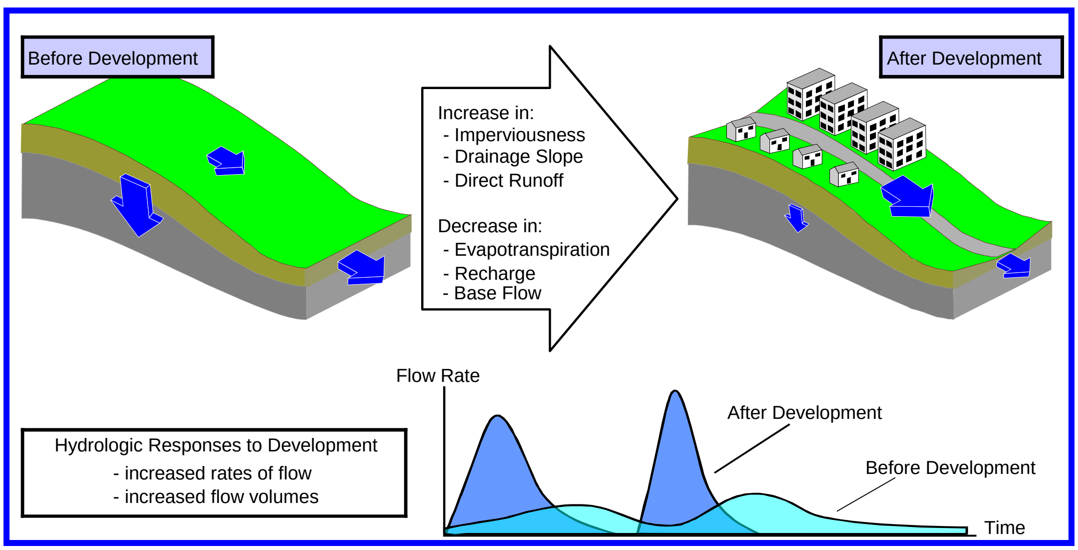


Figure 6-1
Hydrologic Responses to Development (Roesner et al. 2001)

But, as a watershed develops, the land is covered over with impervious surfaces such as roads, parking lots, roofs, driveways, and sidewalks that prevent rainfall from infiltrating into the ground. Even the remaining open ground (pervious surfaces) cannot infiltrate rainfall into the ground as rapidly as it did before development because during construction, the topsoil is removed, compacted, and/or mixed with the underlying less permeable soil. The combined result is that infiltration is greatly reduced or halted by urbanization, and 40 to 90 percent of the rainfall (depending upon land use) is directly converted to stormwater runoff. This causes an increase in stormwater runoff flow rate, volume, and velocity, which increases erosion and sediment deposition. Altering the magnitude, frequency, and duration of stormwater runoff and sediment loads to streams causes impacts to water quality and loss of aquatic life and habitat through a wide variety of geomorphic mechanisms. These mechanisms include changes in channel bed material, increased suspended sediment loads, loss of riparian habitat due to streambank erosion, and changes in the variability of flow and sediment transport characteristics relative to aquatic life cycles.

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

Channel downcutting in Stevens Creek

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

6.2 Regulatory Compliance

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

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

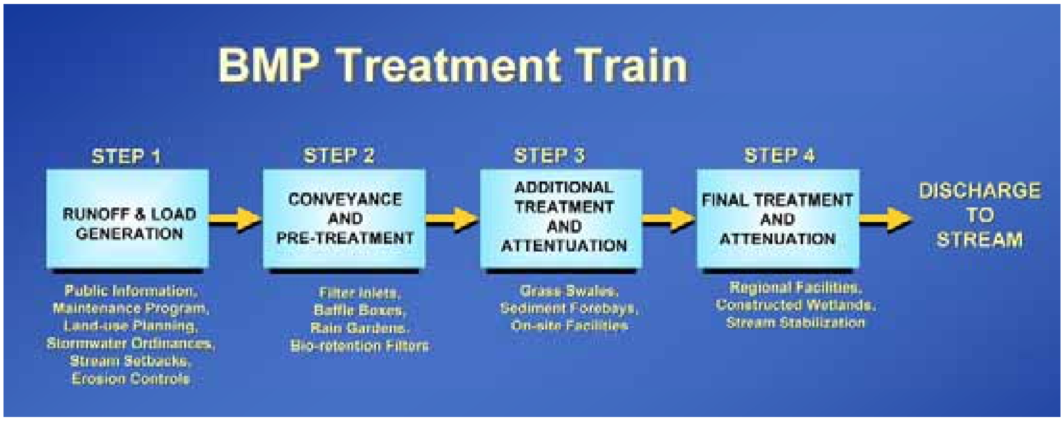


Figure 6-2
BMP Treatment Train

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

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

6.3 Evaluation Approach

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

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

6.4 Biological Assessment

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

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

Mesh net being used in Stevens Creek

6.4.1 Methodology

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

Sorting trays being used in Stevens Creek

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

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

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

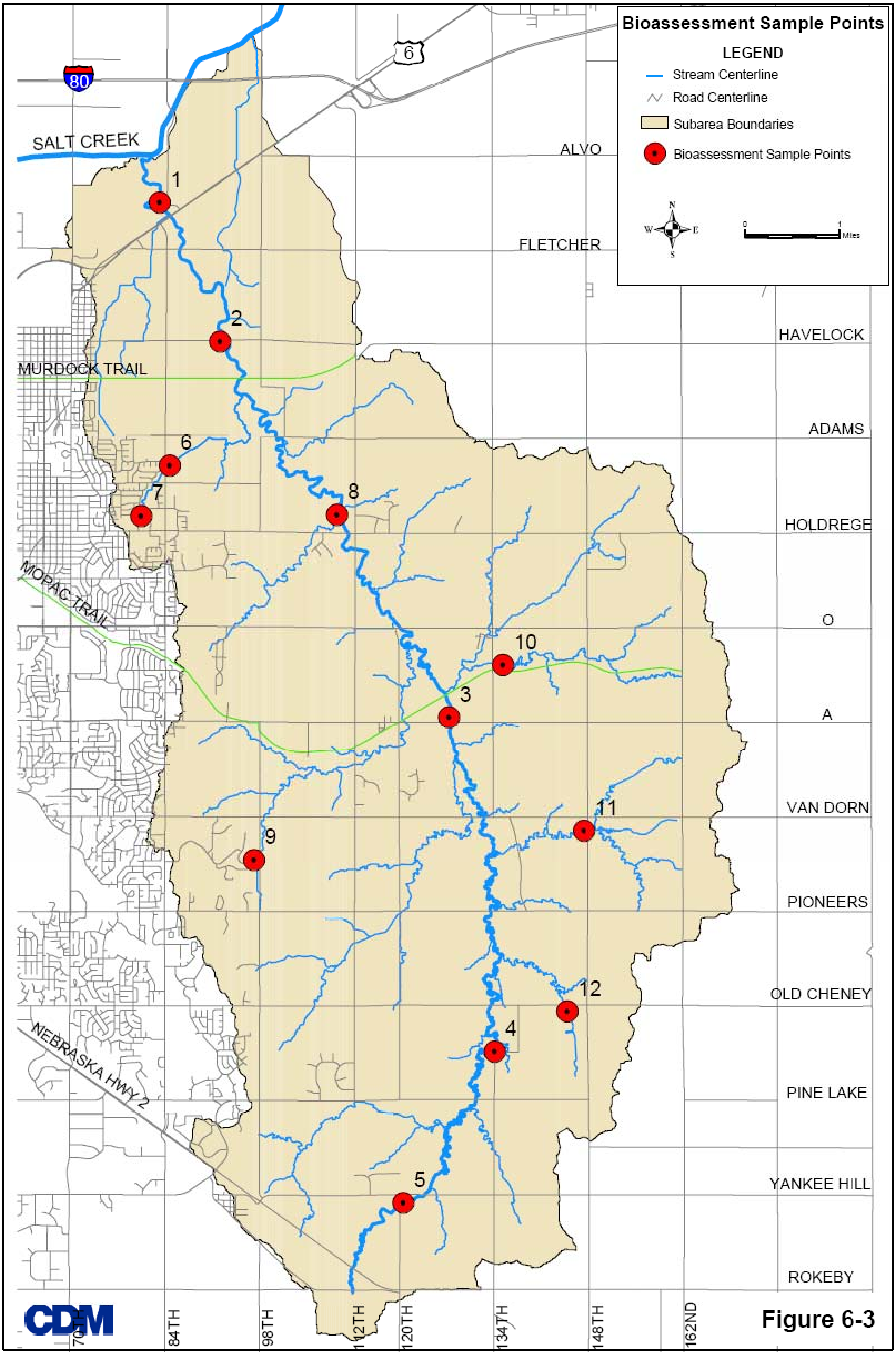

Bioassessment Sample Points
LEGEND
Stream Centerline
Road Centerline
Subarea Boundaries
Bioassessment Sample Points
N
W
E
S
0
1
Miles
80
6
SALT CREEK
ALVO
FLETCHER
HAVELOCK
MURDOCK TRAIL
ADAMS
HOLDREGE
MOPAC TRAIL
O
A
VAN DORN
PIONEERS
OLD CHENEY
PINE LAKE
NEBRASKA HWY 2
YANKEE HILL
ROKEBY
1
2
3
4
5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

Figure 6-3

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

6.4.2 Summary and Recommendations

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

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

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

6.5 Stream Sustainability Analysis

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

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

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

6.5.1 Methodology

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

Watershed Characteristics

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

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

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

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

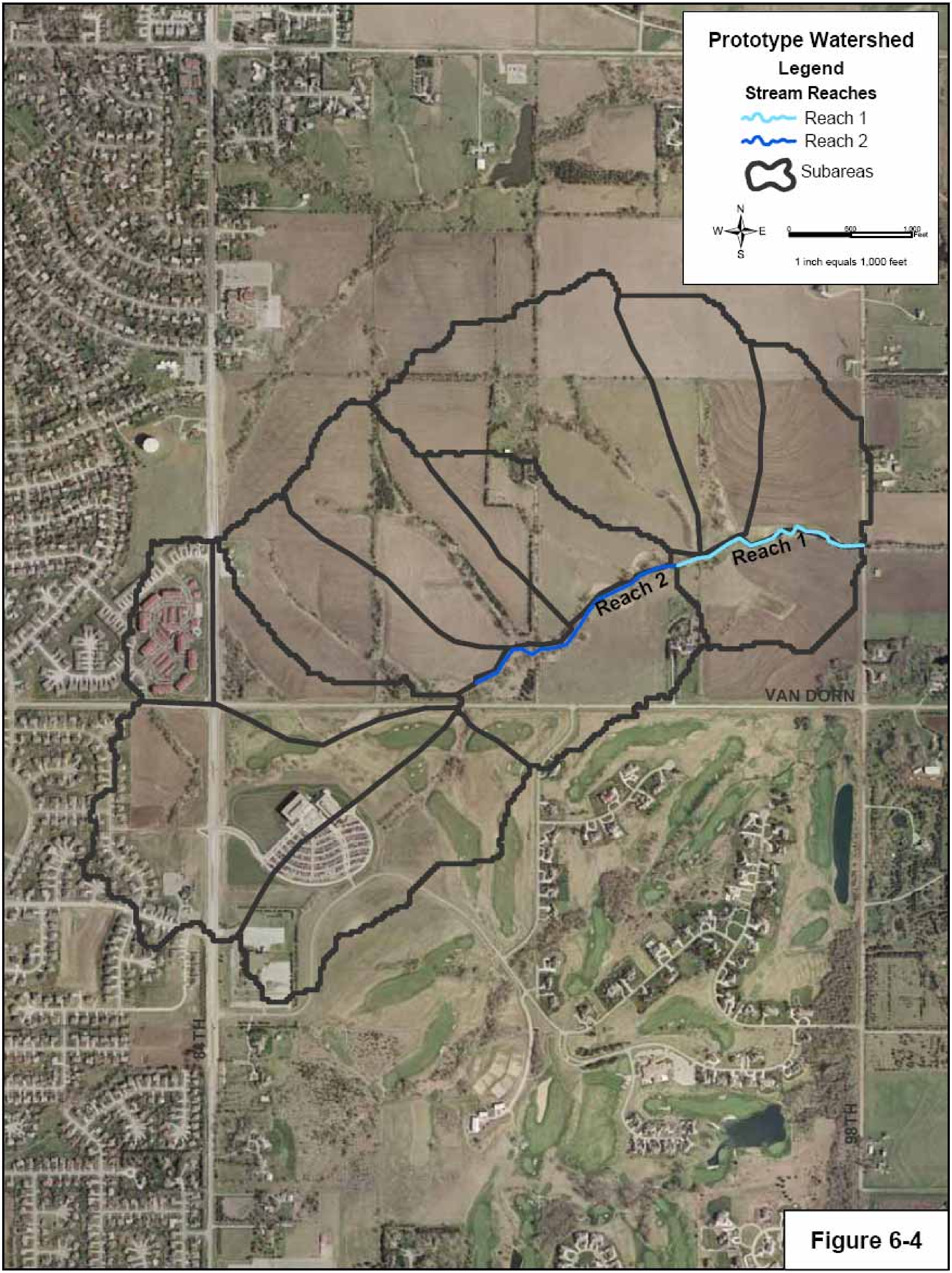

Prototype Watershed
Legend
Stream Reaches
Reach 1
Reach 2
Subareas
N
W
E
S
1 inch equals 1,000 feet
Reach 1
Reach 2
VAN DORN
84TH
98TH

Figure 6-4

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

Computer Modeling

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

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

Precipitation Data

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

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

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

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

Model Parameters

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

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

Table 6-2
Subarea Land Surface Characteristics

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

6.5.2 Watershed Management Scenarios

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

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

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

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

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

6.5.3 Modeling Results

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

Flow Frequency Curves

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

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

Table 6-3
Peak Flow Rates

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

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

Flow Duration Curves

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

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

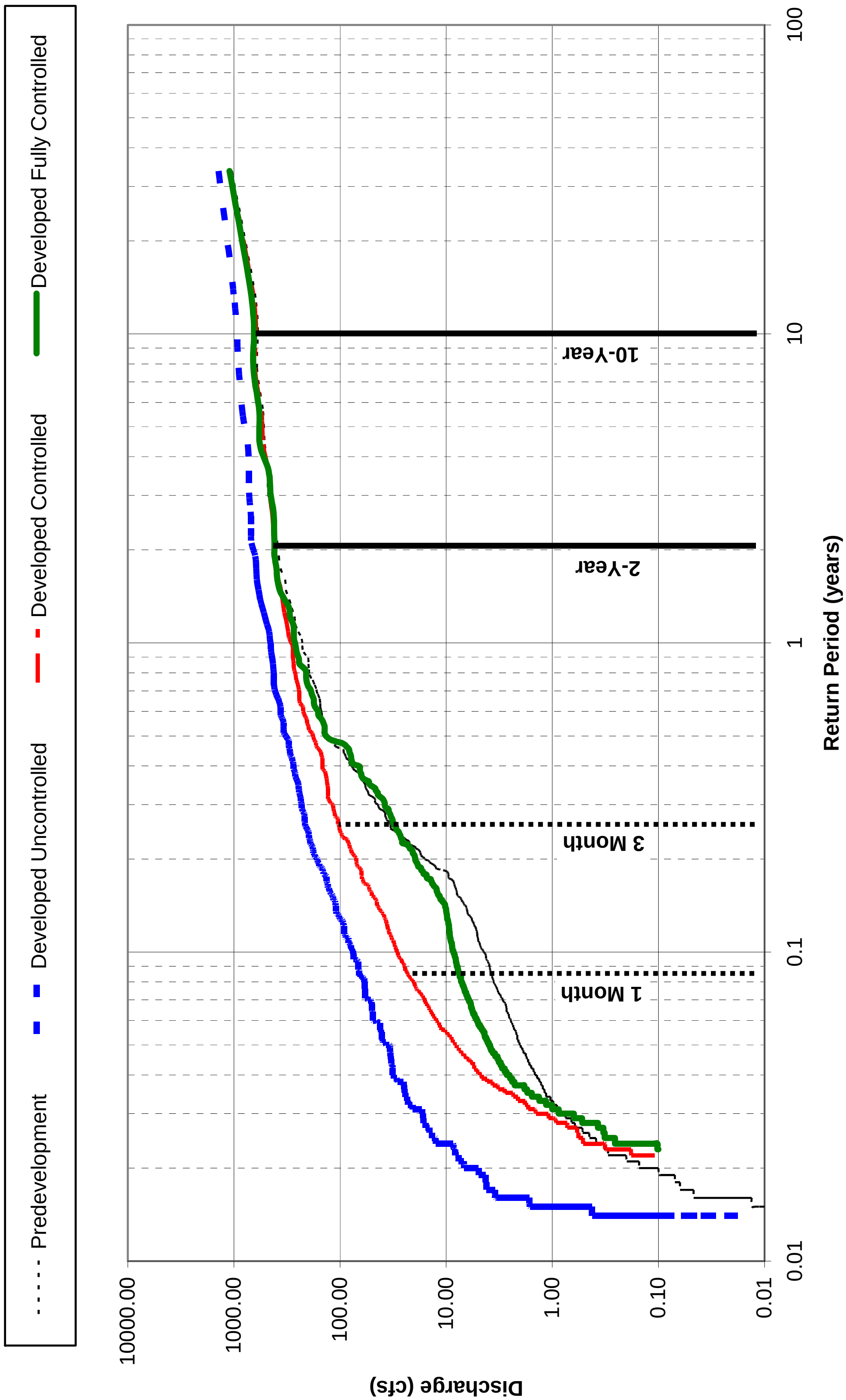


Figure 6-5
Reach 1 - Flow Frequency Curve

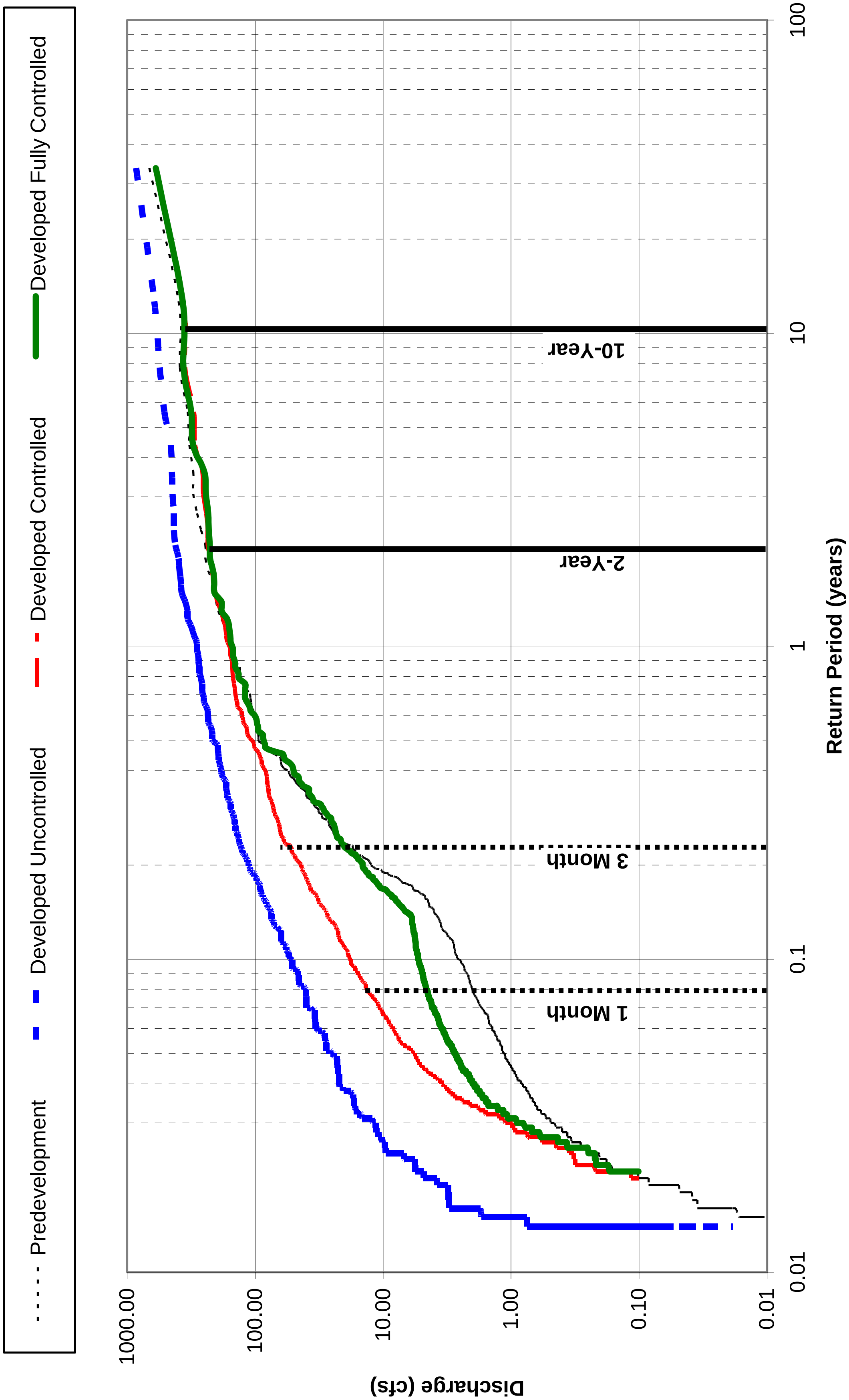


Figure 6-6
Reach 2 - Flow Frequency Curve

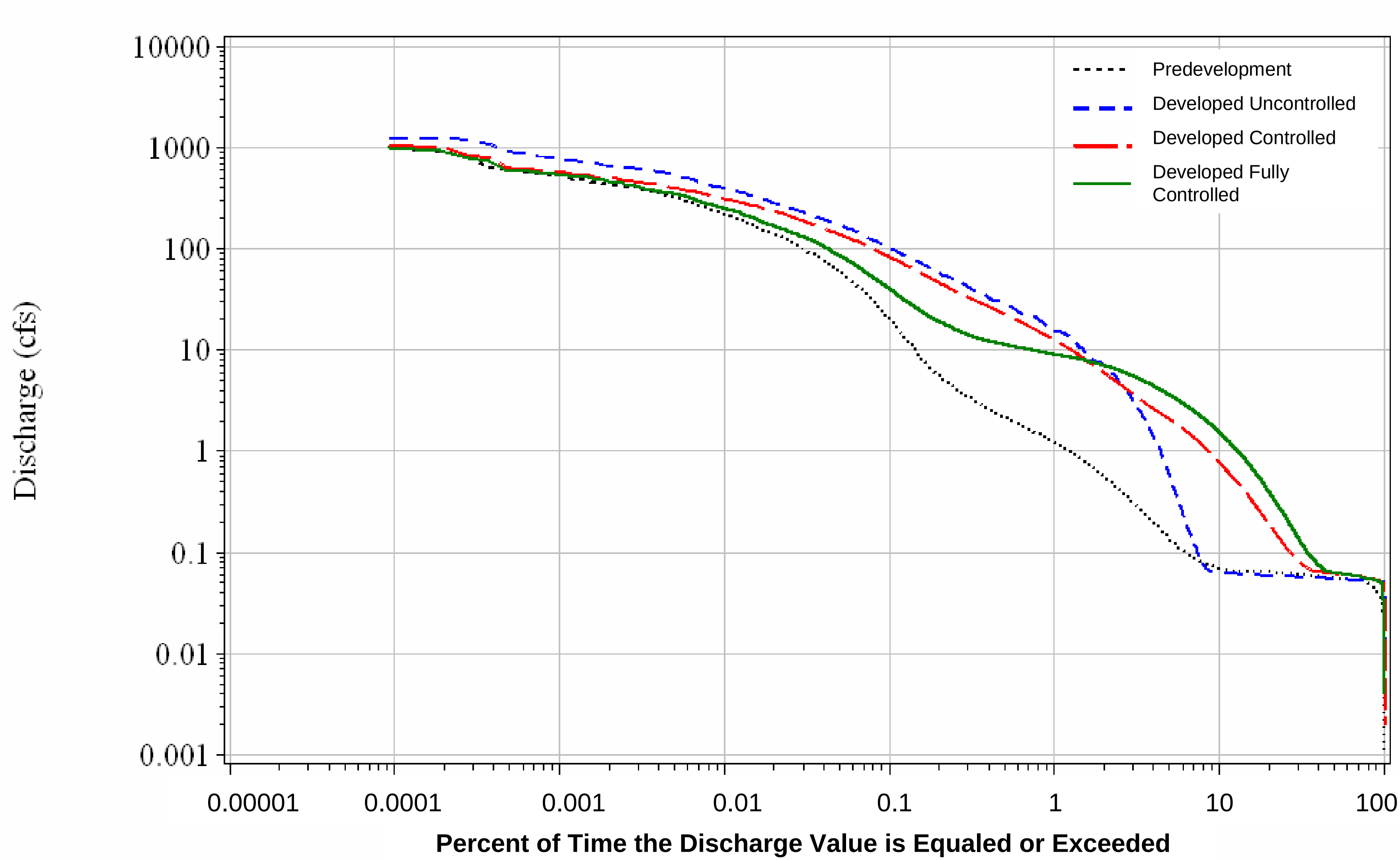


Figure 6-7
Reach 1 – Flow Duration Frequency Curves

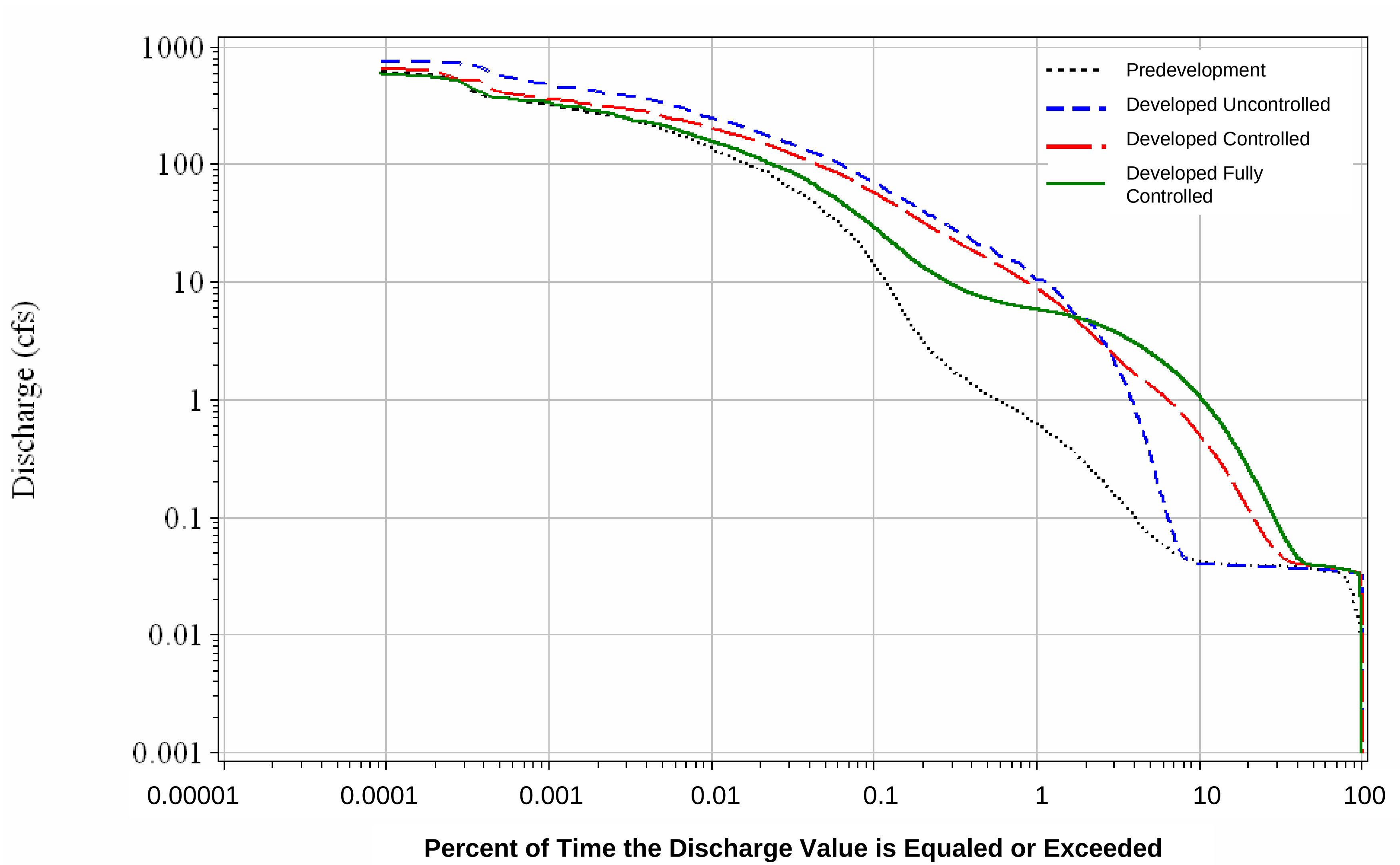


Figure 6-8
Reach 2 – Flow Duration Frequency Curves

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

Shear Stress Curves

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

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

Long-Term Cumulative Excess Shear Stress

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

**Table 6-4
Cumulative Excess Shear Stress**

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

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

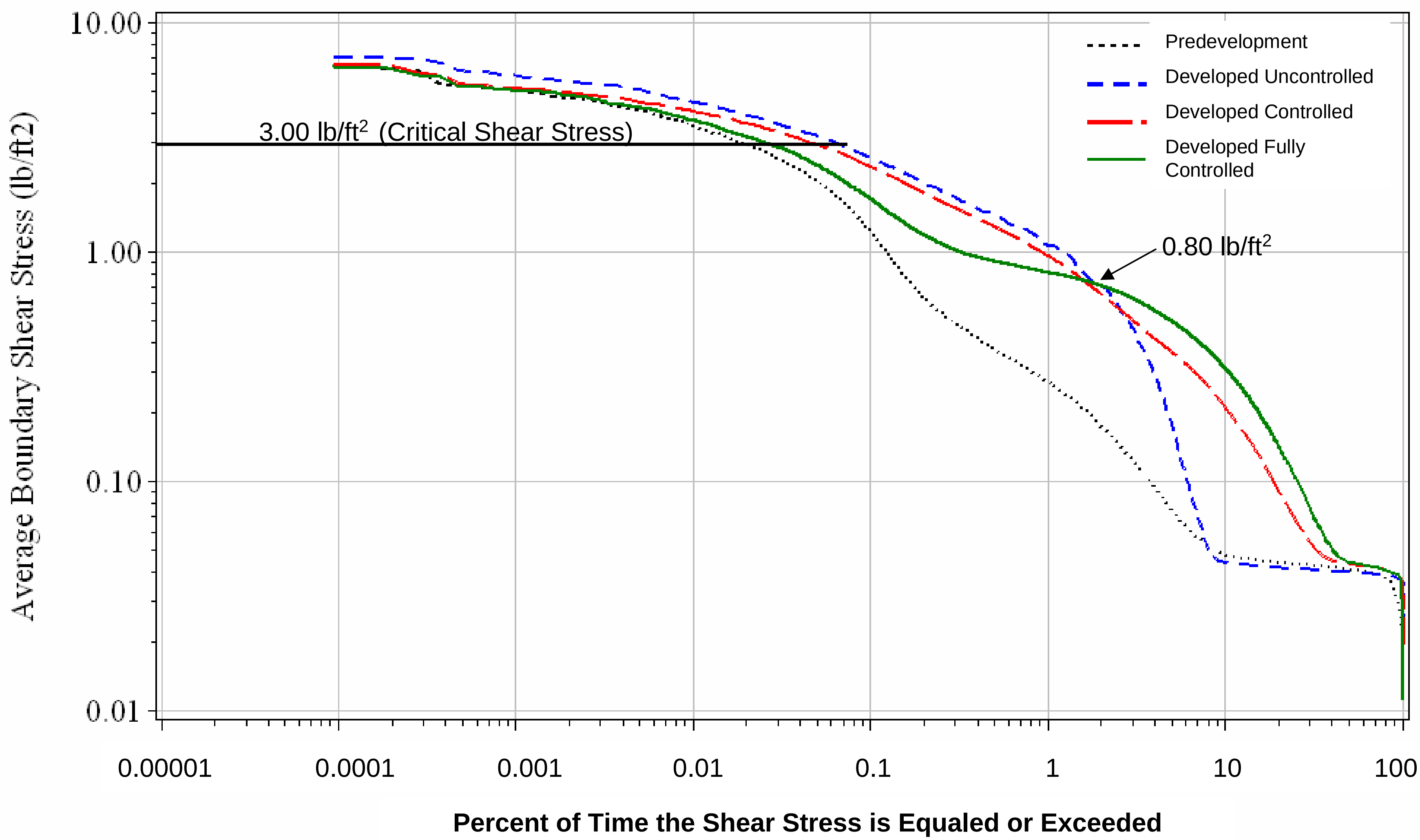


Figure 6-9

Reach 1 – Shear Stress Duration Curves

Critical Shear Stress = 3 lb/ft^2

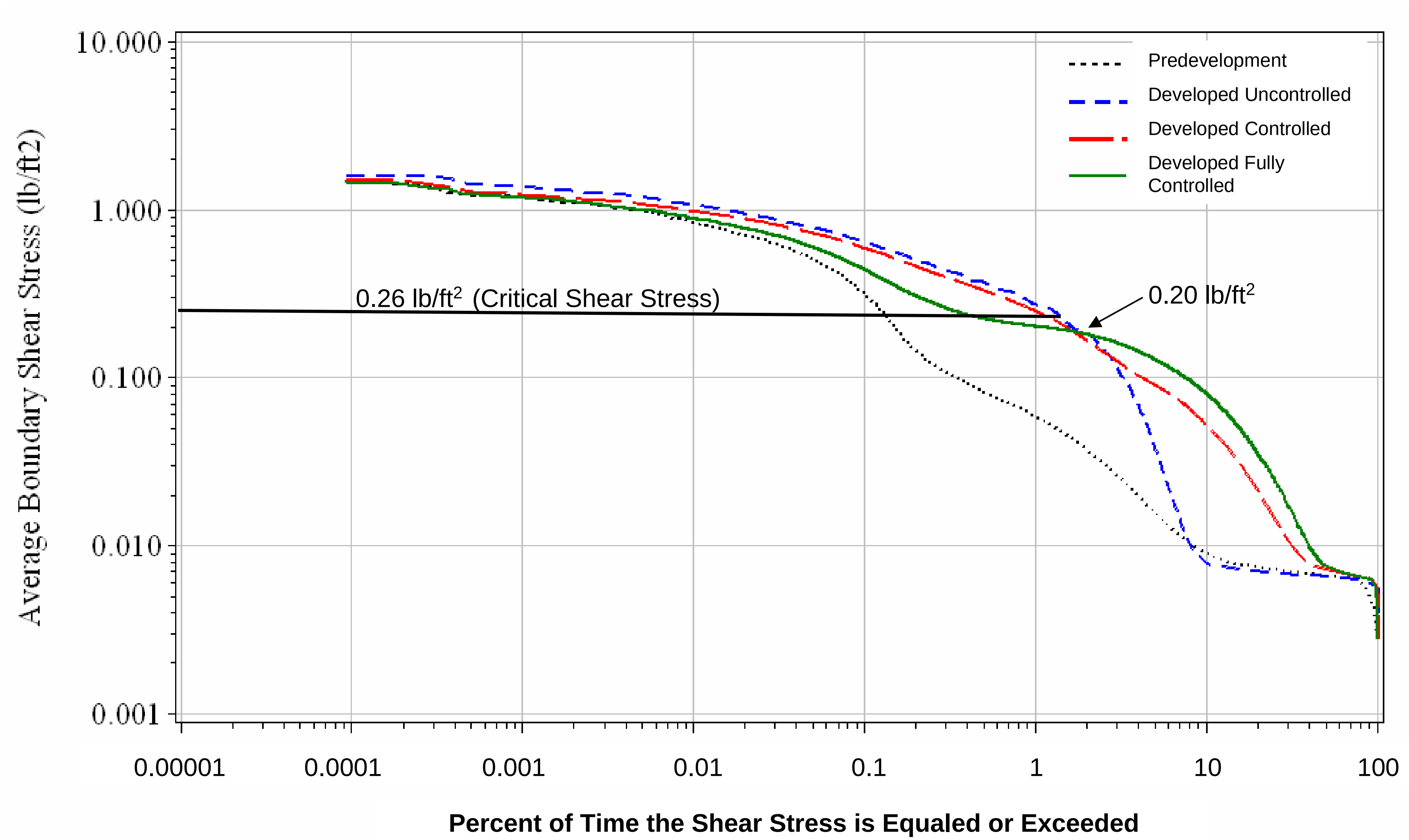


Figure 6-10
Reach 2 – Shear Stress Duration Curves
Critical Shear Stress = 0.26 lb/ft^2

6.6 Evaluation Results

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

6.6.1 Major Conclusions

The major conclusions are summarized below:

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

6.6.2 Recommendations

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

Nonstructural BMPs

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

Stream Buffers

The primary ecological stressor identified during the biological assessment was the potential loss of stream riparian habitat due to channel encroachment during development. The City's floodplain standards for new growth areas include a stream buffer ordinance that provides a minimum setback distance from the stream that must be preserved in its natural conditions. This would include streams draining 150 acres or more and streams draining less than 150 acres with a defined bed and bank. As development occurs in the watershed, it will be critical that this ordinance be strictly enforced to preserve the aquatic habitat within the natural streams.

Erosion and Sediment Control

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

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

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

Land Development Planning

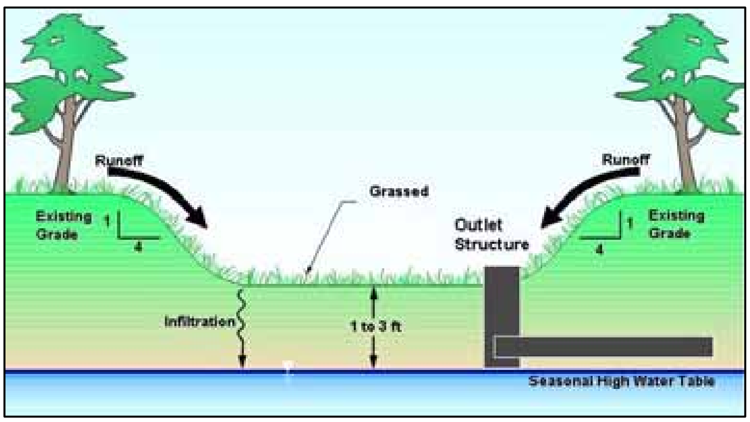
One of the most effective nonstructural BMPs that can be used to preserve the water quality of runoff after development is land development planning. Land use planning tools such as subdivision regulations, zoning ordinances, and master planning can be used to ensure consistent watershed management practices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

Structural BMPs

One of the major conclusions from the stream sustainability analysis is to install stormwater facilities that control the WQCV to provide long-term stream stability and pollutant removal benefits. This will require the implementation of structural BMPs to address the smaller more frequent rainstorms that carry the majority of pollutants and are believed to cause the greatest amount of erosion and sediment deposition. Structural BMPs can be implemented using a regional or site-specific approach, each having its own advantages and disadvantages. These two implementation methods are discussed in Section 6.7. The following types of structural BMPs are recommended for the Stevens Creek Watershed.

Extended Dry Detention Basins

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

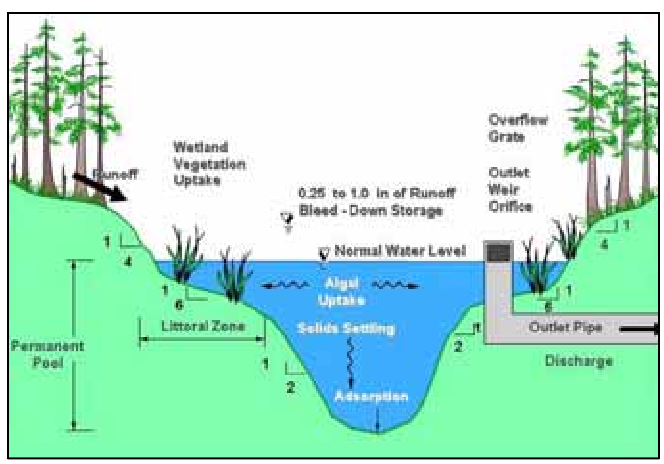


Example Extended Dry Detention Pond

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

Extended Wet Detention Basins

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

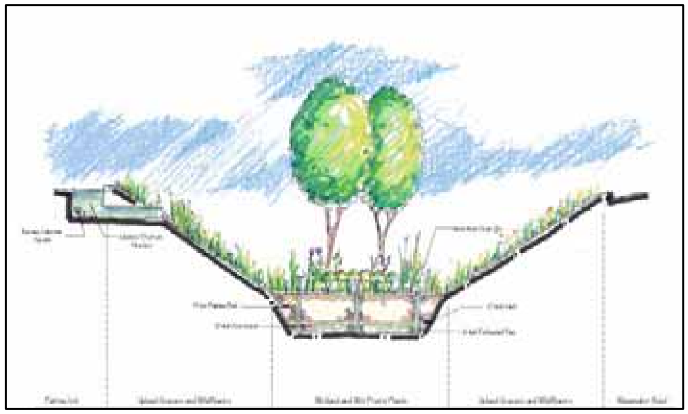


Example Extended Wet Detention Basin

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

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

Vegetated Swales



Example Vegetated Swale (Rendering by Patti Banks Associates)

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

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

Constructed Wetlands

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

Stream Stabilization

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

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

6.7 Implementation Methods

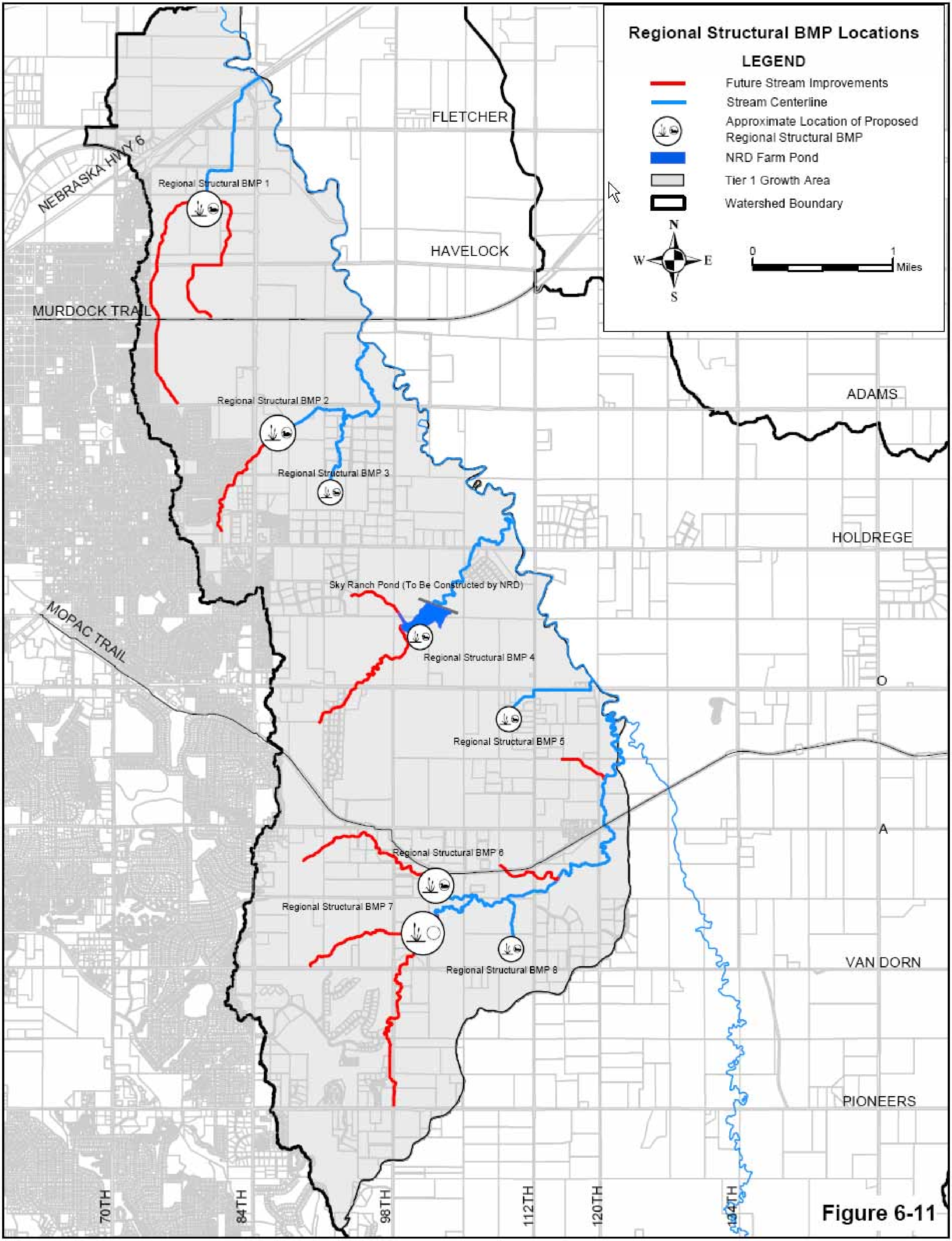
As summarized above, the key to preserving water quality and providing long stream stability is to install stormwater facilities that control the full range of hydrologic conditions, including not only the 2-, 10-, 100-year storm events, but also the smaller rainstorms. The structural BMPs described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

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

6.7.1 Method 1 – Regional Structural BMPs

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

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



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

Figure 6-11

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

Conceptual Cost Estimate

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

Table 6-5
Method 1: Conceptual Cost Estimate

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

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

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

6.7.2 Method 2 –Site-Specific Structural BMPs

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

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

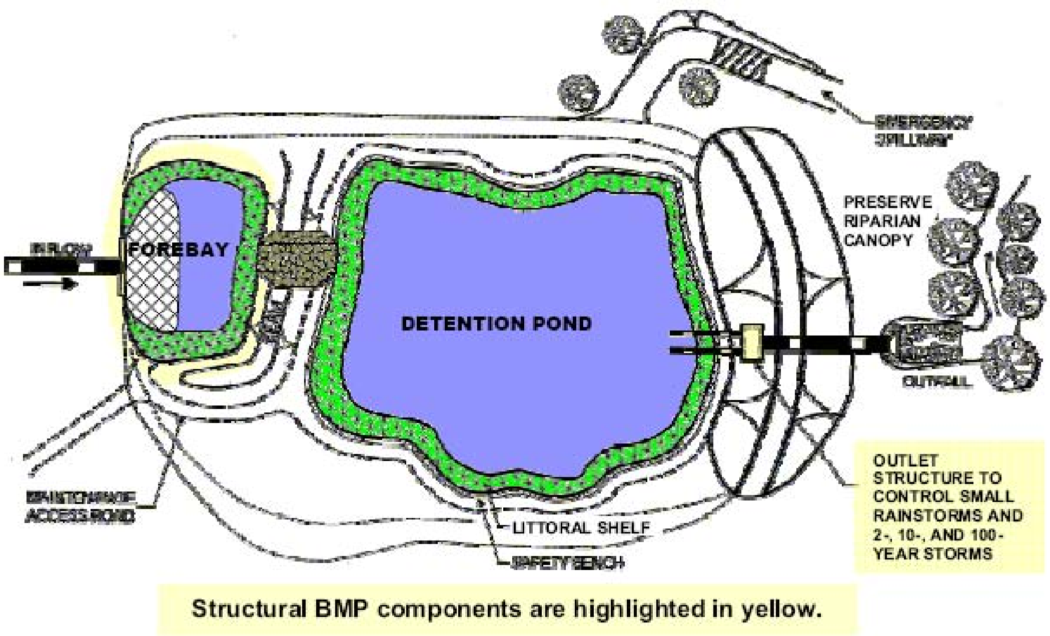


Figure 6-12
Integrated Detention Pond and Structural BMP

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

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

Table 6-6
Method 2: Conceptual Cost Estimate

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

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

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

6.7.3 Comparison Evaluation

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

Table 6-7
Method 1 - Regional Structural BMPs

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

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

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

6.7.4 Recommendations

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

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

Alternative Design Approaches

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

Potential Cost Share Program

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

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

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

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

Maintenance Plan

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

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

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