SECTION 6 – POLLUTION SOURCES AND CONTROL STRATEGIES

6.1. Introduction

In order to develop an effective water quality master plan, it is essential to identify sources of pollutants in a watershed and then evaluate best management practices (BMPs) that can be utilized to reduce pollutant loads and improve in-stream water quality conditions. Sections 3 through 5 of this plan provide specific information regarding existing water quality concerns in Antelope Creek. From a regulatory perspective, the primary concern is fecal indicator bacteria (*E. coli*), with elevated concentrations occurring during both base flow and wet weather conditions. In addition to identifying measures that may reduce *E. coli* loads to the stream, the project team also considered best management practices (BMPs) that would increase the quality of stormwater runoff by reducing other water quality constituents (*i.e.,* solids, nutrients, metals, etc.).

To develop an understanding of sources of pollutant loading to Antelope Creek and BMPs expected to be effective at reducing these loads, Dr. Robert Pitt conducted Windows Source Loading and Management Model (WinSLAMM) modeling for the Antelope Creek watershed.

This section provides a brief overview of pollutant sources in urban runoff, followed by a summary of stormwater modeling results completed for Antelope Creek, and a discussion of structural and non-structural BMPs that may be effective at reducing pollutant loading and improving water quality in Antelope Creek.

To develop an understanding of sources of pollutant loading to Antelope Creek and BMPs expected to be effective at reducing these loads, Dr. Robert Pitt conducted Windows Source Loading and Management Model (WinSLAMM) modeling for the Antelope Creek watershed. This analysis provided useful information for evaluating pollutant loads from various land uses in the Antelope Creek watershed, as well as alternative management strategies and costs for reducing pollutant loads. The WinSLAMM modeling reports can be obtained upon request from the project team, and include the following detailed reports:

- *Lincoln, Nebraska Standard Land Use Characteristics and Pollutant Sources* (Pitt, 4/2011), which describes land use areas, expected stormwater characteristics, and pollutant sources.
- *Lincoln, Nebraska, Retrofit Stormwater Management Options* (Pitt, 7/2011), which provides descriptions of stormwater control practices, an analysis of results including the most suitable controls, and an appendix containing detailed modeling results for all constituents and land uses.

6.2. Pollutants

The chemical and physical characteristic of stormwater runoff change as urbanization occurs; requiring comprehensive planning and management to reduce adverse effects on receiving waters. As stormwater flows across roads, rooftops, and other surfaces, pollutants are picked up and then discharged to streams and lakes. Numerous studies conducted since the late 1970s show stormwater runoff from urban and industrial areas can be a significant source of pollution (EPA 1983; Driscoll et al. 1990; Pitt et al. 2008). Table 6-1 identifies a variety of pollutants and sources often found in urban settings such as solids, nutrients, pathogens, dissolved oxygen demands, metals, and oils.

The increased frequency, flow rate, duration, and volume of stormwater discharges due to urbanization can result in the scouring of rivers and streams, degrading the physical integrity of aquatic habitats, stream function, and overall water quality (EPA 2009). Impacts are site-specific (and watershed-specific) and vary depending on a host of factors. Although historical focus of stormwater management was either flooding or chemical water quality, more recently, the hydrologic and hydraulic (physical) changes in watersheds associated with urbanization are recognized as significant contributors to receiving water degradation. Whereas only a few runoff events per year may occur prior to development, many runoff events per year may occur after urbanization (Urbonas et al. 1989) for sites that have soils that readily infiltrate rainfall, and in the absence of onsite controls that reduce the frequency of post-development runoff. In the absence of controls, runoff peaks and volumes increase due to urbanization (UDFCD 2010).

Table 6-1. Common Urban Runoff Pollutant Sources

Pollutant Category Source	Solids	Nutrients	Pathogens	Dissolved Oxygen Demands	Metals	Oils	Synthetic Organics
Soil erosion	X	X		X	X		
Cleared vegetation	X	X		X			
Fertilizers		X	X	X			
Human waste	X	X	X	X			
Animal waste	X	X	X	X			
Vehicle fuels and fluids	X			X	X	X	X
Fuel combustion						X	
Vehicle wear	X			X	X		
Industrial and household	X	X		X	X	X	X
Industrial processes	X	X		X	X	X	X
Paints and					X	X	X
Pesticides				X	X	X	X
Stormwater facilities without proper	X	X	X	X	X	X	X

Adapted from: Horner, R.R., J.J. Skupien, E.H. Livingston and H.E. Shaver. 1994. *Fundamentals of Urban Runoff Management: Technical and Intuitional Issues*. Washington, DC: Terrene Institute and EPA.

In the Antelope Creek watershed, the primary source of pollutant loading that can be reduced through implementation of BMPs is expected to be stormwater. Given the complexities of pollutant loading associated with urban land uses, the project sponsors selected a modeling approach based on WinSLAMM to better understand pollutant sources, concentrations, treatment approaches and costs.

6.2.1 WinSLAMM Setup and Scenarios

Lincoln's WinSLAMM model was developed using site specific land-use information from the Antelope Creek watershed collected by the project team. WinSLAMM calculates concentrations, mass discharges, percentage contributions, and control benefits for a broad range of stormwater constituents. The following information and concepts are incorporated into WinSLAMM:

- Soil type (see Section 3.2.1: Physical Setting, for more information)
- Land use area and types
- Local rainfall records
- Development characteristics
- BMPs

The Antelope Creek WinSLAMM modeling effort focused on nine land use categories as seen in Table 6-2. Thirty sites were surveyed within the Antelope Creek watershed to help refine the attributes of the nine land use categories. Attributes of interest included impervious cover types and quantities (many subcategories of impervious area are available in WinSLAMM), landscaping, roofing materials, drainage system information, etc. The surface type in urban areas determines the magnitude of runoff, as well as the amount of pollutants that are conveyed from that area. As an example, pitched roofs are much more efficient in producing runoff than flat roofs. Treated wood, galvanized metals, and other coverings, all affect the concentrations of heavy metals from roofs. Table 6-2 summarizes a few key characteristics of the different land uses in WinSLAMM.

Table 6-2. Typical Land Use Characteristics

Land Use Category	Percent of Roofs that are Directly Connected	Percent Total Directly Connected Impervious Areas (DCIA)	Percent Total Partially Connected Impervious Areas	Percent Total Pervious Areas
Low density residential	12	18	16	66
Med density residential <1960	16	22	20	58
Med density residential 1960-1980	24	18	19	63
Light industry	55	58	27	15
Commercial—strip mall	100	86	0	14
Commercial—shopping center	100	88	0	12
Institutional—school	100	56	0.5	44
Institutional—church	37	44	10	46
Institutional—hospital	80	62	5	33

Source: Pitt 7/2011

6.2.2 WinSLAMM Results – Flow and Pollutant Sources

In *Lincoln, Nebraska Standard Land Use Characteristics and Pollutant Sources* (Pitt, 4/2011), WinSLAMM model results estimating runoff volumes and pollutant loads for various land uses were developed. A summary of these findings is shown in Table 6-3. Results are provided for three general rain event categories: small (<0.5 inches), intermediate (0.5 to 2 inches), and large (>2 inches). See Appendix C of Pitt's April 2011 WinSLAMM report for more detailed results. The results in Table 6-3 are important in terms of identifying the relative contribution of various source areas. Additional discussion based on rain event and source area characteristics follows. Discussions in Section 6.2.2 and 6.2.3 have been established based upon Pitt's WinSLAMM reports completed for the City in 2011.

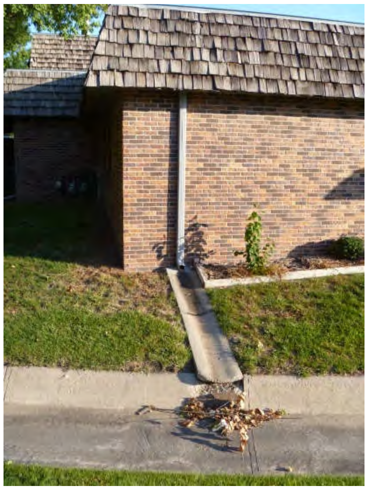
Rain Event Categories

The small rainfall event category generally includes most of the rain and runoff events by number, but produces a small fraction of the annual runoff mass. This category of events is therefore of greatest interest when the number of events is of concern. If stormwater discharges have numeric effluent limits, then the number of runoff events is of the greatest concern, and stormwater control strategies would focus on eliminating as many of the runoff events as practical. By lowering the total number of runoff events, the overall frequency of events discharging stormwater to the stream is lowered. For example, if numeric limits were applied to stormwater discharges, typical numeric standards for bacteria and total recoverable heavy metals would be frequently exceeded. Therefore, runoff volume, bacteria, and heavy metals would be of the greatest interest for removal from the small rain category.

The intermediate rain event category generally includes most of the runoff pollutant discharges by mass; frequently more than 75% of the annual pollutant discharges, by mass. It is therefore desirable to remove as much of the runoff volume as feasible from this rain category. However, site soil and development conditions will typically prevent the elimination of all runoff from this category. Therefore, stormwater treatment will be needed for the constituents of concern for runoff that will be discharged. Flow reduction will always be of interest, but further treatment of stormwater to reduce bacteria, nutrients, and /or heavy metals will also likely be necessary.

The largest rain category includes events that occur less frequently and are generally described as channel-forming; often with significant effects on habitat conditions. These events are the primary focus for drainage design and public safety and rely on basin-wide hydraulic analyses results to determine the most effective stormwater management and drainage options. It is unlikely that pollutant discharges would be of great concern during these large events, as they contribute relatively small fractions of the amortized annual flows, and most treatment methods that could manage these large flows would be costly and inefficient. Thus, these large events are not the primary focus of the Basin Plan, although practices that reduce runoff volumes may still provide some benefit during these larger storms.

Flow Sources



Picture 13: Directly connected impervious areas are common throughout the City

As shown in Table 6-3, most of the flows originate from the directly connected impervious areas (DCIA) such as paved parking lots, roofs, driveways, and streets. However, undeveloped or landscaped areas can contribute large portions of the flows if these areas are very large (such as in the residential areas) and/or if they have “tight” soils, with low infiltration rates. For these areas, the landscaped/undeveloped areas can produce significant flows during large rain events. The goal of most stormwater management programs should therefore be to reduce runoff from the DCIA. However, there are many conditions where large-scale infiltration of stormwater may not be desirable (mainly in areas having severely limited soils that hinder infiltration, shallow groundwater, or other factors that would not adequately mitigate pollutant movement to the groundwater). In most cases, roof runoff, being the least contaminated DCIA source water, should be preferentially infiltrated or used on site for beneficial uses.

In residential areas, the roof runoff comprises about 15% of the total annual runoff amount, mainly because most of the roofs are disconnected (Pitt 4/2011). Streets can comprise the majority of the total flows in residential areas during small to intermediate events. A typical strategy in residential areas would therefore be to apply rain gardens, or otherwise disconnect the roof drainage, for roof runoff control (for currently directly connected roofs). If possible, soil amendments and other strategies to reduce soil compaction to improve infiltration in the landscaped areas can reduce runoff from those areas. Street and driveway runoff are significant flow and pollutant sources. If the area was drained using grass swales, runoff peaks and volumes will be reduced. If drained by conventional curb and gutter, curb-cut bioretention areas could be a retrofit project to significantly reduce runoff (and associated pollutants); particularly for small events. In residential areas having loamy soils that are not compacted and are drained by grass swales, especially if most of the impervious areas are disconnected and drain to pervious areas, no additional or few stormwater controls may be needed. High-density residential areas having larger amounts of impervious areas will normally require additional BMPs.

Runoff from commercial areas primarily originates from paved parking areas, streets, and roofs, unless they are situated in heavy clay soils, where the soils can also be a significant source of runoff. Impervious areas can also be the main sources for many of the pollutants examined, although others such as solids, bacteria and nutrients may be found in higher concentrations in runoff from pervious areas. Commercial areas are often limited on space for development of BMPs that address a single runoff source. A more appropriate approach may be to use a bioretention area that receives runoff from multiple sources such as from roofs and parking areas. Parking areas, islands or the edge of landscaped areas can be retrofitted with infiltration devices for significant runoff volume reductions or for control of critical pollutant source areas such as automobile activity and galvanized metals.

Flows and pollutants in industrial areas originate, primarily, from paved parking and storage areas. Roofs and streets are lesser, but still important sources. Infiltration in these areas is of greater concern as the runoff from industrial areas is more likely to result in groundwater contamination. Critical source area controls (such as media filtration and biofilters using specialized media as part of treatment trains) are often necessary, along with pollution prevention to reduce the exposure of metals, especially galvanized, and other materials. In some industrial areas, stormwater can be used for dust suppression. If the site is relatively large, wet detention ponds could also be located on available land to collect and further treat remaining surface runoff.

Some institutional areas are predominately landscaped, with less directly connected impervious areas and larger landscaped or undeveloped areas for stormwater management. Designing stormwater management features that take advantage of the topography in these areas can result in significant runoff discharge reductions. Most institutional areas in the Antelope Creek drainage basin have large parking areas with long-term parking that could benefit from parking lot islands or perimeter bioretention areas.

Table 6-3: Summary of Major Sources of Flows and Pollutants

	Commercial – Strip Mall	Commercial – Shopping Center	Light Industrial	Institutional - Schools	Institutional - Churches	Institutional - Hospitals	Residential – Low Density	Residential – Medium Density (<1960)	Residential – Medium Density (1960 - 1980)
Flows									
Small	Paved parking (56%) Streets (23%) Roofs (21%)	Paved parking (58%) Roofs (22%) Streets (20%)	Park/stor (55%) Streets (20%) Driveways (19%)	Paved parking (52%) Roofs (32%) Streets (11%)	Paved parking (46%) Streets (33%) Roofs (15%)	Paved parking (63%) Roofs (24%) Streets (11%)	Streets (73%) Driveways (15%) Roofs (12%)	Streets (68%) Driveways (16%) Roofs (16%)	Streets (55%) Roofs (28%) Driveways (16%)
Intermediate	Paved parking (50%) Roofs (30%) Streets (19%)	Paved parking (51%) Roofs (32%) Streets (17%)	Park/stor (53%) Streets (18%) Driveways (14%)	Roofs (42%) Paved parking (41%)	Paved parking (44%) Streets (31%) Roofs (13%)	Paved parking (53%) Roofs (33%)	Streets (60%) Landscaping (15%) Driveways (12%) Roofs (11%)	Streets (59%) Driveways (15%) Roofs (14%) Landscaping (11%)	Streets (47%) Roofs (24%) Driveways (15%) Landscaping (14%)
Large	Paved parking (51%) Roofs (28%) Streets (17%)	Paved parking (52%) Roofs (30%) Streets (15%)	Park/stor (49%) Streets (15%) Driveways (14%)	Paved parking (39%) Roofs (37%) Landscaping (11%)	Paved parking (40%) Streets (24%) Landscaping (15%) Roofs (10%)	Paved parking (51%) Roofs (30%) Landscaping (10%)	Landscaping (40%) Streets (38%) Roofs (14%)	Streets (40%) Landscaping (32%) Roofs (16%) Driveways (11%)	Landscaping (37%) Streets (29%) Roofs (16%) Driveways (11%)
Total Suspended Solids									
Small	Paved parking (83%) Roofs (12%)	Paved parking (84%) Roofs (12%)	Park/stor (78%) Streets (11%) Driveways (10%)	Paved parking (48%) Streets (40%)	Streets (78%) Paved parking (18%)	Paved parking (48%) Streets (46%)	Streets (92%)	Streets (92%)	Streets (90%)
Intermediate	Paved parking (83%) Roofs (13%)	Paved parking (84%) Roofs (13%)	Park/stor (74%) Driveways (12%)	Paved parking (53%) Streets (19%) Roofs (14%)	Streets (56%) Paved parking (30%)	Paved parking (59%) Streets (24%)	Streets (86%)	Streets (88%)	Streets (86%)
Large	Paved parking (64%) Roofs (23%)	Paved parking (66%) Roofs (24%)	Park/stor (87%) Driveways (4%)	Paved parking (47%) Landscaping (30%) Roofs (11%)	Paved parking (37%) Streets (26%) Landscaping (25%)	Paved parking (59%) Landscaping (20%) Streets (10%)	Streets (47%) Landscaping (44%)	Streets (53%) Landscaping (35%)	Streets (48%) Landscaping (40%)
Chemical Oxygen Demand									
Small	Paved parking (67%) Roofs (28%)	Paved parking (67%) Roofs (29%)	Park/stor (73%) Streets (15%) Driveways (10%)	Roofs (42%) Paved parking (37%) Streets (17%)	Streets (56%) Paved parking (25%) Roofs (14%)	Paved parking (46%) Roofs (30%) Streets (22%)	Streets (84%) Driveways (11%)	Streets (71%) Driveways (11%)	Streets (77%) Driveways (11%)
Intermediate	Paved parking (63%) Roofs (31%)	Paved parking (63%) Roofs (32%)	Park/stor (69%) Streets (13%) Driveways (10%)	Roofs (53%) Paved parking (29%)	Streets (37%) Paved parking (32%) Roofs (16%) Landscaping (10%)	Roofs (43%) Paved parking (40%) Streets (10%)	Streets (77%) Landscaping (11%)	Streets (79%)	Streets (73%) Landscaping (10%)
Large	Paved parking (44%) Roofs (42%) Streets (11%)	Paved parking (44%) Roofs (44%) Streets (10%)	Park/stor (81%)	Roofs (44%) Paved parking (26%) Landscaping (24%)	Landscaping (32%) Paved parking (28%) Streets (18%) Roofs (14%)	Roofs (40%) Paved parking (38%) Landscaping (15%)	Landscaping (45%) Streets (40%)	Streets (45%) Landscaping (36%)	Landscaping (41%) Streets (37%) Roofs (10%)
Total Phosphorus									
Small	Paved parking (61%) Roofs (31%)	Paved parking (61%) Roofs (33%)	Park/stor (53%) Streets (24%) Driveways (20%)	Paved parking (43%) Roofs (27%) Streets (16%)	Streets (49%) Paved parking (29%) Driveways (12%) Roofs (10%)	Paved parking (54%) Streets (20%) Roofs (20%)	Streets (88%) Driveways (10%)	Streets (87%) Driveways (10%)	Streets (85%) Driveways (10%)
Intermediate	Paved parking (53%) Roofs (31%)	Paved parking (54%) Roofs (33%)	Park/stor (48%) Streets (22%) Driveways (20%)	Landscaping (30%) Paved parking (25%) Roofs (25%)	Landscaping (39%) Streets (22%) Paved parking (22%)	Paved parking (36%) Landscaping (30%) Roofs (22%)	Streets (58%) Landscaping (36%)	Streets (64%) Landscaping (29%)	Streets (58%) Landscaping (34%)

	Commercial – Strip Mall	**Commercial – Shopping Center**	**Light Industrial**	**Institutional - Schools**	**Institutional - Churches**	**Institutional - Hospitals**	**Residential – Low Density**	**Residential – Medium Density (<1960)**	**Residential – Medium Density (1960 - 1980)**
Large	Landscaping (39%) Paved parking (36%) Roofs (25%)	Landscaping (34%) Paved parking (31%) Roofs (28%)	Park/stor (59%) Streets (16%) Driveways (10%) Landscaping (12%)	Landscaping (56%) Paved parking (12%) Roofs (12%)	Landscaping (74%) Paved parking (11%)	Landscaping (62%) Paved parking (20%) Roofs (12%)	Landscaping (81%) Streets (15%)	Landscaping (75%) Streets (20%)	Landscaping (79%) Streets (15%)
Total Kjeldahl Nitrogen									
Small	Paved parking (64%) Roofs (29%)	Paved parking (64%) Roofs (30%)	Park/stor (64%) Driveways (18%) Streets (13%)	Roofs (40%) Paved parking (36%) Streets (19%)	Streets (58%) Paved parking (35%) Roofs (14%)	Paved parking (44%) Roofs (40%) Streets (24%)	Streets (79%) Driveways (14%)	Streets (76%) Driveways (14%)	Streets (69%) Driveways (14%)
Intermediate	Paved parking (58%) Roofs (33%)	Paved parking (58%) Roofs (34%)	Park/stor (56%) Driveways (18%) Streets (10%)	Roofs (46%) Paved parking (25%) Streets (14%) Landscaping (14%)	Streets (35%) Paved parking (25%) Landscaping (18%) Roofs (13%)	Roofs (39%) Paved parking (35%) Landscaping (14%) Streets (11%)	Streets (52%) Landscaping (37%)	Streets (57%) Landscaping (29%)	Streets (49%) Landscaping (34%)
Large	Roofs (38%) Paved parking (34%) Landscaping (19%)	Roofs (41%) Paved parking (35%) Landscaping (16%)	Park/stor (64%) Landscaping (11%) Roofs (10%)	Landscaping (36%) Roofs (30%) Paved parking (18%)	Landscaping (46%) Paved parking (18%) Streets (15%)	Landscaping (37%) Roofs (28%) Paved parking (27%)	Landscaping (78%) Streets (14%)	Landscaping (71%) Streets (18%)	Landscaping (75%) Streets (14%)
Nitrites + nitrates									
Small	Paved parking (48%) Roofs (27%) Streets (25%)	Paved parking (49%) Roofs (29%) Streets (22%)	Park/stor (50%) Streets (24%) Driveways (16%)	Paved parking (43%) Roofs (41%) Streets (12%)	Streets (37%) Paved parking (39%) Roofs (19%)	Paved parking (55%) Roofs (31%) Streets (12%)	Streets (73%) Driveways (12%)	Streets (68%) Roofs (17%) Driveways (13%)	Streets (53%) Roofs (34%) Driveways (13%)
Intermediate	Paved parking (41%) Roofs (37%) Streets (21%)	Paved parking (42%) Roofs (40%) Streets (18%)	Park/stor (50%) Streets (21%) Driveways (14%)	Roofs (52%) Paved parking (33%)	Paved parking (38%) Streets (34%) Landscaping (15%) Roofs (14%)	Paved parking (44%) Roofs (42%) Streets (10%)	Streets (60%) Landscaping (16%) Roofs (14%) Driveways (10%)	Streets (59%) Roofs (17%) Landscaping (12%) Driveways (11%)	Streets (45%) Roofs (28%) Landscaping (14%)
Large	Paved parking (42%) Roofs (36%) Streets (18%)	Paved parking (43%) Roofs (38%) Streets (16%)	Park/stor (55%) Streets (18%) Driveways (12%)	Roofs (46%) Paved parking (31%) Landscaping (11%)	Paved parking (34%) Streets (27%) Landscaping (18%) Roofs (14%)	Paved parking (42%) Roofs (38%) Landscaping (10%)	Landscaping (41%) Streets (36%) Roofs (15%)	Streets (38%) Landscaping (33%) Roofs (19%) Driveways (14%)	Landscaping (38%) Streets (28%) Roofs (25%)
Total Copper									
Small	Paved parking (79%) Roofs (16%)	Paved parking (80%) Roofs (14%)	Park/stor (63%) Roofs (31%)	Paved parking (51%) Streets (28%) Roofs (17%)	Streets (68%) Paved parking (25%)	Paved parking (54%) Streets (33%) Roofs (11%)	Streets (65%) Driveways (17%)	Streets (74%) Driveways (18%)	Streets (53%) Driveways (18%)
Intermediate	Paved parking (77%) Roofs (16%)	Paved parking (78%) Roofs (16%)	Park/stor (52%) Roofs (31%) Streets (10%)	Paved parking (50%) Roofs (28%) Streets (15%)	Streets (50%) Paved parking (37%)	Paved parking (59%) Roofs (20%) Streets (18%)	Streets (74%) Driveways (13%)	Streets (74%) Driveways (13%)	Streets (68%) Driveways (15%) Roofs (10%)
Large	Paved parking (62%) Roofs (25%) Streets (11%)	Paved parking (63%) Roofs (26%) Streets (10%)	Park/stor (58%) Roofs (33%)	Paved parking (52%) Roofs (27%)	Paved parking (45%) Streets (32%) Landscaping (10%)	Paved parking (62%) Roofs (19%) Streets (10%)	Streets (42%) Landscaping (33%) Driveways (13%) Roofs (10%)	Streets (45%) Landscaping (25%) Driveways (14%) Roofs (11%)	Streets (37%) Landscaping (29%) Driveways (14%) Roofs (14%)
Total Lead									
Small	Paved parking (75%) Roofs (22%)	Paved parking (75%) Roofs (23%)	Park/stor (76%) Driveways (16%)	Paved parking (51%) Streets (25%) Roofs (21%)	Streets (66%) Paved parking (26%)	Paved parking (55%) Streets (31%) Roofs (13%)	Streets (75%) Driveways (15%) Roofs (10%)	Streets (73%) Driveways (15%) Roofs (12%)	Streets (65%) Roofs (21%) Driveways (14%)
Intermediate	Paved parking (74%) Roofs (24%)	Paved parking (73%) Roofs (25%)	Park/stor (73%) Driveways (16%)	Paved parking (49%) Roofs (33%) Streets (10%)	Streets (44%) Paved parking (40%)	Paved parking (58%) Roofs (23%) Streets (14%)	Streets (70%) Landscaping (13%) Driveways (10%)	Streets (71%) Driveways (10%)	Streets (65%) Roofs (14%) Landscaping (11%) Driveways (10%)

	Commercial – Strip Mall	**Commercial – Shopping Center**	**Light Industrial**	**Institutional - Schools**	**Institutional - Churches**	**Institutional - Hospitals**	**Residential – Low Density**	**Residential – Medium Density (<1960)**	**Residential – Medium Density (1960 - 1980)**
Large	Paved parking (53%) Roofs (40%)	Paved parking (53%) Roofs (42%)	Park/stor (87%)	Paved parking (48%) Roofs (30%) Landscaping (12%)	Paved parking (47%) Streets (21%) Landscaping (17%)	Paved parking (60%) Roofs (23%) Landscaping (10%)	Landscaping (49%) Streets (28%) Roofs (12%) Driveways (11%)	Landscaping (40%) Streets (32%) Roofs (15%) Driveways (12%)	Landscaping (42%) Streets (27%) Roofs (18%) Driveways (11%)
Total Zinc									
Small	Paved parking (68%) Roofs (27%)	Paved parking (68%) Roofs (28%)	Park/stor (76%) Streets (10%)	Paved parking (43%) Roofs (33%) Streets (22%)	Streets (64%) Paved parking (25%) Roofs (10%)	Paved parking (49%) Streets (28%) Roofs (22%)	Streets (80%) Roofs (12%)	Streets (77%) Roofs (14%)	Streets (67%) Roofs (24%)
Intermediate	Paved parking (67%) Roofs (29%)	Paved parking (66%) Roofs (31%)	Park/stor (70%) Roofs (15%)	Roofs (49%) Paved parking (39%)	Streets (45%) Paved parking (37%) Roofs (12%)	Paved parking (48%) Roofs (36%) Streets (13%)	Streets (76%) Roofs (10%)	Streets (76%) Roofs (11%)	Streets (68%) Roofs (18%)
Large	Paved parking (48%) Roofs (46%)	Paved parking (48%) Roofs (47%)	Park/stor (78%) Roofs (15%)	Roofs (47%) Paved parking (41%)	Paved parking (46%) Streets (25%) Roofs (15%)	Paved parking (51%) Roofs (36%)	Streets (43%) Landscaping (33%) Roofs (17%)	Streets (46%) Landscaping (25%) Roofs (20%)	Streets (37%) Landscaping (28%) Roofs (24%)
Fecal Coliform Bacteria									
Small	Paved parking (70%) Streets (25%)	Paved parking (74%) Streets (23%)	Driveways (68%) Streets (25%)	Paved parking (73%) Driveways (16%)	Paved parking (58%) Driveways (21%) Streets (18%)	Paved parking (83%) Driveways (10%)	Driveways (59%) Streets (41%)	Driveways (61%) Streets (38%)	Driveways (66%) Streets (32%)
Intermediate	Paved parking (69%) Streets (23%)	Paved parking (73%) Streets (22%)	Driveways (65%) Streets (24%)	Paved parking (71%) Driveways (15%)	Paved parking (57%) Driveways (21%) Streets (17%)	Paved parking (82%) Driveways (10%)	Driveways (53%) Streets (37%)	Driveways (56%) Streets (34%)	Driveways (59%) Streets (29%)
Large	Paved parking (70%) Streets (21%)	Paved parking (74%) Streets (19%)	Driveways (58%) Streets (21%)	Paved parking (69%) Driveways (12%)	Paved parking (57%) Driveways (18%) Streets (15%)	Paved parking (80%)	Driveways (41%) Streets (28%) Landscaping (21%)	Driveways (44%) Streets (27%) Landscaping (15%)	Driveways (44%) Streets (21%) Landscaping (19%)
E. Coli Bacteria									
Small	Paved parking (70%) Streets (25%)	Paved parking (75%) Streets (23%)	Driveways (58%) Streets (36%)	Paved parking (73%) Driveways (16%)	Paved parking (58%) Driveways (21%) Streets (18%)	Paved parking (83%) Driveways (10%)	Driveways (58%) Streets (41%)	Driveways (61%) Streets (38%)	Driveways (66%) Streets (32%)
Intermediate	Paved parking (70%) Streets (24%)	Paved parking (74%) Streets (22%)	Driveways (55%) Streets (34%)	Paved parking (71%) Driveways (15%)	Paved parking (57%) Driveways (21%) Streets (17%)	Paved parking (82%) Driveways (10%)	Driveways (53%) Streets (37%)	Driveways (56%) Streets (34%)	Driveways (59%) Streets (29%)
Large	Paved parking (71%) Streets (22%)	Paved parking (75%) Streets (20%)	Driveways (49%) Streets (30%) Park/stor (10%)	Paved parking (70%) Driveways (13%)	Paved parking (57%) Driveways (18%) Streets (15%)	Paved parking (81%)	Driveways (43%) Streets (30%) Landscaping (18%)	Driveways (46%) Streets (29%) Landscaping (13%)	Driveways (47%) Streets (23%) Landscaping (16%)

6.2.3 WinSLAMM Results – BMP Removal Effectiveness

After the model was calibrated for conditions in Antelope Creek, 28 stormwater BMP scenarios were evaluated for the nine land use categories throughout the Antelope Creek watershed (Pitt 7/2011). Two different soil conditions were also modeled based on the most prevalent soil conditions in the watershed: clay loam and sandy loam. The BMP modeling scenarios are listed in Table 6-4. Although other management strategies may also be considered, Table 6-4 provides a basic list of practices that can be used to compare general alternatives and costs to reduce stormwater-related pollutant loads in the watershed. Detailed comparisons of alternative control approaches and associated costs are provided in a series of comparative tables and figures within Pitt (7/2011).

Table 6-4. Stormwater BMP Modeling Scenarios

Scenario	Scenario (cont.)
Rain garden (3% of connected roofs only)	Street cleaning daily
Rain garden (15% of connected roofs only)	Street cleaning monthly
Rain garden (3% of all roofs)	Street cleaning weekly
Rain garden (15% of all roofs)	Street cleaning once in spring and fall
Rain barrels (few)	Catchbasin cleaning
Rain barrels	Grass swale drainage
Rain barrels (many)	Wet pond 0.8%
Rain tanks (small)	Wet pond 1.6%
Rain tanks (medium)	Small wet pond and rain tanks
Rain tanks (large)	Small wet pond and rain gardens (15% of all roofs
Porous pavement on driveways	Small wet pond and swales
Curb-cut biofilters 20%	Small wet pond and curb biofilters 40%
Curb-cut biofilters 40%	Small wet pond, rain garden (15% of all roofs) and curb biofilters 40%
Curb-cut biofilters 80%	--

Source: Pitt 7/2011

For runoff volume controls, each land use group had similar most cost-effective controls in areas having clay loam soils and practices providing at least a 25% reduction in runoff volume. Modeling results for stormwater controls for various source areas are listed below. Controls are listed in the following order: The first control listed has the lowest level of maximum control, but the highest unit cost-effectiveness; and the last control listed has the highest level of maximum control, but the lowest unit cost-effectiveness. Therefore, if low to moderate levels of control are suitable, the first control option may be best. However, if maximum control levels are needed, then the last control option listed would be needed. The resulting summary of stormwater control options by source area includes:

- Strip mall and shopping center areas:
  - Porous pavement (in half of the parking areas)
  - Curb-cut biofilters (along 80% of the curbs) for strip malls or biofilters in parking areas (10%of the source area) for shopping centers
  - Biofilters in parking areas (10% of the source area) and curb-cut biofilters (along 40% of the curbs)
- Light industrial areas:
  - Curb-cut biofilters (along 40% of the curbs)
  - Roofs and parking areas half disconnected from the directly connected impervious areas (DCIA)
  - Roofs and parking areas all disconnected from DCIA
- School, church, and hospital institutional areas:
  - Small rain tank (0.10 feet^3 storage per feet^2 of roof area) for schools and churches; rain tank (0.25 feet^3 storage per feet^2 of roof area) for hospitals
  - Roofs and parking areas half disconnected from DCIA

  - Roofs and parking areas all disconnected from DCIA
- Low and medium density residential areas:
  - Curb-cut biofilters (along 20% of the curbs)
  - Curb-cut biofilters (along 40% of the curbs)
  - Curb-cut biofilters (along 80% of the curbs)

For suspended solids, all areas show that wet detention ponds are the most cost-effective control option, irrespective of the conditions. Obviously, other factors may influence the selection of the “best” stormwater control program for an area, beyond least cost for the level of control needed. As an example, wet detention ponds, while being the most cost-effective, are likely very difficult to retrofit into existing areas. However, these analyses indicate that these controls should not be rejected without careful evaluation and searching for potential locations.

Detailed information for all constituents examined (runoff volume, Rv, TSS, TDS, total and filterable phosphorus, nitrates, total and filterable TKN, total and filterable COD, total and filterable copper, total and filterable lead, total and filterable zinc, fecal coliform bacteria, and *E. coli* bacteria) is presented for each land use and soil combination for each set of stormwater controls in the appendices developed by Pitt (7/2011).

6.3. Structural BMPs

The modeling results provided by Pitt (7/2011) can be used to prioritize selection of stormwater BMPs expected to be effective at reducing pollutant loads in Lincoln. Additional factors also influence BMP selection that should be considered early in site development or the retrofitting process. In addition to the BMPs modeled by Pitt (7/2011), other BMP types may also be appropriate. Appendix A provides an overview of several structural BMP types that may be considered for use in the Antelope Creek watershed, including a basic description of site selection factors, general benefits, and limitations. A table is also included for each structural BMP that summarizes their function, typical effectiveness for targeted pollutants, and other considerations. BMPs listed in Appendix A are listed below:

- Grass Buffer
- Grass Swale
- Bioretention (Rain Garden)
- Green Roof
- Extended Detention Basin
- Retention Pond
- Sand Filter Basin
- Constructed Wetland Pond
- Constructed Wetland Channel
- Permeable Pavement Systems
- Underground Practices (when surface BMPs are not feasible)

6.3.1 Selection Criteria

Many different factors should be considered when selecting BMPs for new development or redevelopment projects, based on site-specific conditions. Typically, there is not a single answer to the question of which BMP (or BMPs) should be selected for a site. There are usually multiple solutions, ranging from stand-alone BMPs to treatment trains that combine multiple BMPs, to achieve the stormwater management objectives. When selecting BMPs for a site, selection criteria involve many factors, including:

- Retrofitting and Availability of Land
- Sodium Adsorption Ratio (SAR)
- Clogging of infiltration devices
- Groundwater contamination potential
- Targeted pollutants and BMP processes
- Maintenance and sustainability
- Cost and Performance (discussed further in Section 6.4)

In addition to the criteria listed above, the benefits and limitations listed with each BMP in Appendix A should be deliberated when considering a particular BMP for installation.

Retrofitting and Availability of Land

For the most part, BMPs that are considered in this Basin Plan are those that can be used to retrofit existing developed areas to provide more effective reduction of stormwater pollutant loads. This is one reason that several curb-cut biofilter scenarios were evaluated as part of the WinSLAMM modeling (Pitt 7/2011). For example, curb-cut biofilters can be installed during scheduled repaving and sidewalk repairs that usually occur in many areas every few decades. Rain gardens can be installed by the homeowners with no cost to the City. Street cleaning can be conducted with no change to the land. Redevelopment and new construction periods are the most suitable times for installation for many of these controls in order to have the least interferences with current residents and for the least costs. Table 6.5 outlines the land consumption based on impervious area for a variety of BMPs. Table 6.6 outlines the land requirements and retrofitting potential for an array of BMPs.

Table 6-5. Relative Land Consumption of Stormwater Controls

Stormwater Control Type	Land Consumption (% of Impervious Area of the Watershed)
Retention Basin	2 to 3%
Constructed Wetland	3 to 5%
Infiltration Trench	2 to 3%
Infiltration Basin	2 to 3%
Permeable Pavement	0%
Sand Filters	0 to 3%
Bioretention	5%
Swales	10 to 20%
Grass Buffer	10%

Source: USEPA, 1999

Table 6-6. BMPs Ability to Retrofit and Land Requirements

Controls	Ability to Retrofit	Land Requirements
Roof Runoff Controls		
Rain Gardens	Easy in areas having landscaping	Part of landscaping area
Disconnections	Only suitable if adjacent pervious area is adequate (mild slope and long travel path)	Part of landscaping area
Rain Barrels and Water Tanks	Easy, located close to building, or underground large tanks	Supplements landscaping irrigation, no land requirements
Pavement Controls		
Disconnections	Only suitable if adjacent pervious area is adequate (mild slope and long travel path)	Most large paved areas are not adjacent to suitable large turf areas, except for schools; no additional land requirements, but land is needed.
Biofiltration	Easy if parking lot islands can be rebuilt as bioretention areas; perimeter areas also possible (especially good if existing stormwater drainage system can be used to easily collect overflows)	Part of landscaped islands in parking areas, or along parking area perimeters

Controls	Ability to Retrofit	Land Requirements
Porous Pavement	Very difficult as a retrofit, as it would require complete replacement of pavement system; possible if during re-building effort	Concurrent use of parking area with no reduction in parking spaces
Street Side Drainage Controls		
Grass Swales	Very difficult to retrofit. Suitable if existing swales are to be rebuilt.	Part of street right-of-way
Curb-cut Biofilters	Difficult to retrofit, but much easier than simple swales. Usually built to work with existing drainage system. Can do extensions into parking lanes/shoulders to increase areas.	Part of street right-of-way, but can be major nuisance during construction and may consume street side parking. Can be used to rebuild street edge and improve aesthetics.
Public Works Practices		
Street Cleaning	Very easy, but most effective in areas having smooth streets. If in areas of extensive parking, parking restrictions on days of street cleaning may be needed.	None
Catchbasin Cleaning	Very easy, but requires sumps in catchbasin inlets and hooded outlets for most effective performance. Existing inlets can be replaced with suitable catchbasins	None
Outfall Controls		
Wet Detention Ponds	Usually difficult as land not typically readily available. Can retrofit existing dry detention pond.	Land needed at outfall location, or retrofit existing stormwater control located at outfall location.

Source: Pitt 7/2011

Sodium Adsorption Ratio (SAR)

The sodium adsorption ratio (SAR) can radically degrade the performance of an infiltration device, especially when clays are present in the infiltration layers of a device, and snowmelt containing deicing salts enters the device. Soils with an excess of sodium ions, compared to calcium and magnesium ions, remain in a dispersed condition, and are almost impermeable to rain or applied water. A “dispersed” soil is extremely sticky when wet, tends to crust, and becomes very hard and cloddy when dry. Water infiltration is therefore severely restricted. SAR has been documented causing premature failures of biofiltration devices in northern communities. These failures occur when snowmelt water is allowed to enter a biofilter that has clay in the soil mixture. In order to minimize this failure, do not allow snowmelt water to enter a biofilter unit. As an example, roof runoff likely has little salt and SAR problems seldom occur for roof runoff rain gardens. The largest problem is associated with curb-cut biofilters or parking lot biofilters in areas with snowmelt entering these devices, especially if clay is present in the engineered backfill soil (Pitt 7/ 2011).

The simplest method to minimize degraded performance due to SAR is to not allow snowmelt water to enter a biofilter unit. Another method is to construct a biofilter fill soil without clay. It appears that even a small percentage of clay can present a problem, but little information is currently available on the tolerable clay content of biofilter soils. One helpful improvement to a biofilter unit is the use of an engineered soil mixture of sand and an organic material (such as compost, if nutrient leaching is not an issue or Canadian peat for a more stable material having little nutrient leaching potential) (Pitt 7/2011).

Clogging of Infiltration Devices

The design of infiltration devices must include a review of their clogging potential. As an example, a relatively small and efficient biofilter (in an area having a high native infiltration rate) may capture a large amount of sediment. Having a small surface area, this sediment would accumulate rapidly over the area, possibly reaching a critical clogging load early in its design lifetime. Infiltration and bioretention devices may show significantly reduced infiltration rates after about 2 to 5 lb/ft^2 (10 to 25 kg/m^2) of particulate solids have been loaded (Pitt 7/2011).

Deeply-rooted vegetation and a healthy soil structure can extend the actual life much longer. However, compaction and excessive siltation can significantly reduce the life of the system. If this critical load accumulates relatively slowly (taking approximately 10 or more years to reach this total load) and if healthy vegetation with deep roots is present, the infiltration rate may not significantly degrade due to the plant's activities in incorporating the imported sediment into the soil column. If this critical load accumulates in just a few years or if healthy vegetation is not present, premature failure due to clogging may occur. Therefore, relatively large surface areas may be necessary in locations having large sediment contents in the runoff, or suitable pre-treatment to reduce the sediment load entering the biofilter or infiltration device would be necessary (Pitt 7/2011).

The calculated annual suspended solids loading from an area can be used to determine the clogging potential for a bioretention device having a specific surface area. Examples of these calculations are located within the WinSLAMM report.

Groundwater Contamination Potential

The potential to contaminate groundwater by infiltrating stormwater is dependent on the concentrations of the contaminants in the infiltrating stormwater and how effective those contaminants may travel through the soils and vadose zone to the groundwater. Stormwater from residential areas is not likely contaminated with compounds having significant groundwater contaminating potential (with the exception of high salinity snowmelt waters). In contrast, commercial and industrial areas are likely to have greater concentrations of contaminants of concern that may affect the groundwater adversely. Therefore, pretreatment of the stormwater before infiltration may be necessary, or specially selected media in the biofilter can be used. If the local groundwater is already contaminated, increases in infiltrating water can speed up the movement of that water, moving contaminants towards other areas needing protection. Table 6.7 lists a variety of pollutants along with their potential for contaminating groundwater post-treatment (Pitt 7/2011).

Pitt recommends in his July 2011 report that the groundwater contamination potential of infiltrating stormwater be reduced by:

1) Careful placement of the infiltrating devices. Most residential stormwater is not highly contaminated with the problematic contaminants, except for chlorides associated with snowmelt.
2) Commercial and industrial area stormwater would likely need pretreatment to reduce the potential of groundwater contamination associated with stormwater. The use of specialized media in the biofilter, or external pre-treatment may be needed in these other areas.

Increased amounts of infiltrating stormwater from some controls located near the creek could increase the flow of naturally occurring groundwater pollutants (such as selenium and chlorides) migrating into nearby water bodies. Although selenium appeared to be below the standard during the project sampling, selenium levels should continue to be monitored within Antelope Creek.

Table 6-7. Groundwater Contamination Potential for Stormwater Pollutants Post-Treatment

Compound Class	Compounds	Surface Infiltration and No Pretreatment*	Surface Infiltration with Sedimentation*	Subsurface Injection with Minimal Pretreatment
Nutrients	Nitrates	Low/moderate	Low/moderate	Low/moderate
Pesticides	2,4-D	Low	Low	Low
	y-BHC (lindane)	Moderate	Low	Moderate
	Atrazine	Low	Low	Low
	Chlordane	Moderate	Low	Moderate
	Diazinon	Low	Low	Low
Other organics	VOCs	Low	Low	Low
	1,3-dichlorobenzene	Low	Low	**High**
	Benzo(a) anthracene	Moderate	Low	Moderate
	Bis (2-ethyl-hexyl) phthalate	Moderate	Low	Moderate
	Fluoranthene	Moderate	Moderate	**High**
	Naphthalene	Low	Low	Low
	Phenanthrene	Moderate	Low	Moderate
	Pyrene	Moderate	Moderate	**High**
Pathogens	Enteroviruses	**High**	**High**	**High**
	Shigella	Low/moderate	Low/moderate	**High**
	P. aeruginosa	Low/moderate	Low/moderate	**High**
	Protozoa	Low	Low	**High**
Heavy metals	Cadmium	Low	Low	Low
	Chromium	Low/moderate	Low	Moderate
	Lead	Low	Low	Moderate
	Zinc	Low	Low	**High**
Salts	Chloride	**High**	**High**	**High**

Note: Overall contamination potential (the combination of the subfactors of mobility, abundance, and filterable fraction) is the critical influencing factor in determining whether to use infiltration at a site. The ranking of these three subfactors in assessing contamination potential depends on the type of treatment planned, if any, prior to infiltration.
* Even for those compounds with low contamination potential from surface infiltration, the depth to the groundwater must be considered if it is shallow (1 m or less in a sandy soil). Infiltration may be appropriate in an area with a shallow groundwater table if maintenance is sufficiently frequent to replace contaminated vadose zone soils. (Modified from Pitt, *et al.* 1994)
Source: Pitt 7/2011

Targeted Pollutants and BMP Processes

In addition to site-specific factors that affect BMP selection, it is important to select a BMP, or BMPs, that provide unit treatment processes expected to be effective at removing the pollutants of interest. BMPs have the ability to remove pollutants from runoff through a variety of physical, chemical, and biological processes. The processes associated with a BMP dictate which pollutants the BMP will be effective at controlling. Primary processes include peak attenuation, sedimentation, filtration, straining, adsorption/absorption, biological uptake and hydrologic processes including infiltration and evapotranspiration. Table 6-8 lists processes that are associated with BMPs in this Basin Plan. For many sites, a primary goal of BMPs is to remove gross solids, suspended sediment, and associated particulate fractions of pollutants from runoff. Processes including straining, sedimentation, and infiltration/filtration are effective for addressing these pollutants. When dissolved pollutants are targeted, other processes, including adsorption/absorption and biological uptake, are necessary. These processes are generally sensitive to media composition and contact time, oxidation/reduction potential, pH, and other factors. In addition to pollutant removal capabilities, many BMPs offer channel stability benefits in the form of reduced runoff volume and/or reduced peak flow rates for frequently occurring events. Brief descriptions of several key processes generally categorized according to hydrologic and pollutant removal functions are listed below (UDFCD 2011):

Hydrologic Processes

1. Flow Attenuation: BMPs that capture and slowly release the rain event help to reduce peak discharges. In addition to slowing runoff, volume reduction may also be provided to varying extents by BMPs.
2. Infiltration: BMPs that infiltrate runoff reduce both runoff peaks and surface runoff volumes. The extent to which runoff volumes are reduced depends on a variety of factors such as whether the BMP is equipped with an underdrain and the characteristics and long-term condition of the infiltrating media. Examples of infiltrating BMPs include bioretention and permeable pavements. Water quality treatment processes associated with infiltration can include filtration and sorption.
3. Evapotranspiration: Runoff volumes can be reduced through the combined effects of evaporation and transpiration in vegetated BMPs. Plants extract water from soils in the root zone and transpire it to the atmosphere. Evapotranspiration is the hydrologic process provided by vegetated BMPs, whereas biological uptake may help to reduce pollutants in runoff.

Pollutant Removal/Treatment Processes

1. Sedimentation: Gravitational separation of particulates from urban runoff, or sedimentation, is a key treatment process by BMPs that capture and slowly release runoff. Settling velocities are a function of characteristics such as particle size, shape, density, fluid density, and viscosity. Smaller particles under 60 microns in size (fine silts and clays) (Stahre and Urbonas, 1990) can account for approximately 80% of the metals in stormwater attached or adsorbed along with other contaminants, and can require long periods of time to settle out of suspension. Extended detention allows smaller particles to agglomerate into larger ones (Randall et al, 1982), and for some of the dissolved and liquid state pollutants to adsorb to suspended particles, thus removing a larger proportion of them through sedimentation. Sedimentation is the primary pollutant removal mechanism for many treatment BMPs including extended detention basins, retention ponds, and constructed wetland basins.
2. Straining: Straining is physical removal or retention of particulates from runoff as it passes through a BMP. For example, grass swales and grass buffers provide straining of sediment and coarse solids in runoff. Straining can be characterized as coarse filtration.
3. Filtration: Filtration removes particles as water flows through media, such as engineered soils. A wide variety of physical and chemical mechanisms may occur along with filtration, depending on the filter media. Metcalf and Eddy (2003) describe processes associated with filtration as including straining, sedimentation, impaction, interception, adhesion, flocculation, chemical adsorption, physical adsorption, and biological growth. Filtration is a primary treatment process provided by infiltration BMPs. Particulates are removed at the ground surface and upper soil horizon by filtration, while soluble constituents can be absorbed into the soil, at least in part, as the runoff infiltrates into the ground. Site-specific soil characteristics, such as permeability, cation exchange potential, and depth to groundwater or bedrock are important characteristics to consider for filtration (and infiltration) BMPs. Examples of filtering BMPs include bioretention and permeable pavements with a sand filter layer.
4. Adsorption/Absorption: In the context of BMPs, sorption processes describe the interaction of waterborne constituents with surrounding materials (*e.g.,* soil, water). Absorption is the incorporation of a substance in one state into another of a different state (*e.g.,* liquids being absorbed by a solid). Adsorption is the physical adherence or bonding of ions and molecules onto the surface of another molecule. Many factors such as pH, temperature and ionic state affect the chemical equilibrium in BMPs and the extent to which these processes provide pollutant removal. Sorption processes often play primary roles in BMPs such as constructed wetland basins, retention ponds, and bioretention systems. Opportunities may exist to optimize performance of BMPs through the use of engineered media or chemical addition to enhance sorption processes.
5. Biological Uptake: Biological uptake and storage processes include the assimilation of organic and inorganic constituents by plants and microbes. Plants and microbes require soluble and dissolved constituents such as nutrients and minerals for growth. These constituents are ingested or taken up from the water column or growing medium (soil) and concentrated through bacterial action, phytoplankton growth, and other biochemical processes. In some instances, plants can be harvested to remove the constituents permanently.

In addition, certain biological activities can reduce toxicity of some pollutants and/or possible adverse effects on higher aquatic species. Unfortunately, not much is understood yet about how biological uptake or activity interacts with stormwater during the relatively brief periods it is in contact with the biological media in most BMPs, with the possible exception of retention ponds between rainfall events (Hartigan, 1989). Bioretention, constructed wetlands, and retention ponds are all examples of BMPs that provide biological uptake.

It is critical to recognize that for BMPs to function effectively, meet performance expectations, and provide for public safety, BMPs must be:

1. Designed according to City of Lincoln criteria, taking into account site-specific conditions (*e.g.,* high groundwater, expansive clays and long-term availability of water).
2. Constructed as designed. This is important for all BMPs, but appears to be particularly critical for permeable pavements, rain gardens and infiltration-oriented facilities.
3. Properly maintained to function as designed. Although all BMPs require maintenance, infiltration-oriented facilities are particularly susceptible to clogging without proper maintenance. Underground facilities can be vulnerable to maintenance neglect because maintenance needs are not evident from the surface without special tools and procedures for access. Maintenance is not only essential for proper functioning, but also for aesthetic and safety reasons. Inspection of facilities is an important step in identifying and planning for needed maintenance (UDFCD 2010).

Table 6-8. Primary, Secondary, and Incidental Treatment Processes Provided by BMPs

BMP	**Hydrologic Processes**			**Treatment Processes**				
	Peak	Volume		Physical			Chemical	Biological
	Flow Attenuation	Infiltration	Evapo-transpiration	Sedimentation	Filtration	Straining	Adsorption/ Absorption	Biological Uptake
Grass Swale	I	S	I	S	S	P	S	S
Grass Buffer	I	S	I	S	S	P	S	S
Constructed Wetland Channel	I	N/A	P	P	S	P	S	P
Green Roof	P	S	P	N/A	P	N/A	I	P
Permeable Pavement Systems	P	P	N/A	S	P	N/A	N/A	N/A
Bioretention	P	P	S	P	P	S	S[1]	P
Extended Detention Basin	P	I	I	P	N/A	S	S	I
Constructed Wetland Pond	P	I	P	P	S	S	P	P
Retention Pond	P	I	P	P	N/A	N/A	P	S
Underground BMPs	Variable	N/A	N/A	Variable	Variable	Variable	Variable	N/A

Notes: P = Primary; S = Secondary, I = Incidental; N/A = Not Applicable

[1] Depending on media

Source: UDFCD, 2010

Maintenance and Sustainability

Maintenance should be considered early in the planning and design phase. Even when BMPs are thoughtfully designed and properly installed, they can become eyesores, cease to function and breed mosquitoes if not properly maintained. BMPs can be more effectively maintained when they are designed to allow easy access for inspection and maintenance. Other factors that increase maintenance ease are property ownership, easements, visibility from easily accessible points, slope, vehicle access, and other factors. For example, fully consider how and with what equipment BMPs will be maintained in the future. If the City is not assuming upkeep responsibilities, clear, legally-binding written agreements assigning maintenance responsibilities should be completed. The City may also require right of access to perform emergency repairs/maintenance should it become necessary (UDFCD 2010).

Sustainability of BMPs is based on a variety of considerations related to how the BMP will perform over time. For example, vegetation choices for BMPs determine the extent of supplemental irrigation required. Choosing native or drought-tolerant plants and seed mixes helps to minimize irrigation requirements following plant establishment. Other sustainability considerations include watershed conditions. For example, in watersheds with ongoing development clogging of infiltration BMPs is a concern. In such cases, a decision must be made regarding either how to protect and maintain infiltration BMPs, or whether to allow use of infiltration practices under these conditions. Various types of porous pavement require frequent maintenance to preserve their function and if clogged, would be difficult to repair (UDFCD 2010). According to WinSLAMM results, many stormwater controls are predicted to have decreased performance when maintenance is not performed or delayed.

Cost and Structural BMP Performance

Costs are a fundamental consideration for BMP selection, but often the evaluation of costs during planning and design phases of a project focuses narrowly on up-front, capital costs. A more holistic evaluation of life-cycle costs including operation, maintenance and rehabilitation is prudent. From a municipal perspective, cost considerations are even broader, involving costs associated with off-site infrastructure, channel stabilization and/or rehabilitation, and protection of community resources from effects of runoff from urban areas. Generally, the components of the whole life cost for a constructed facility include construction, engineering and permitting, contingency, land acquisition, routine operation and maintenance, and major rehabilitation costs minus salvage value. In addition, the cost of administering a stormwater management program could also be included as a long-term cost for BMPs. Whole life costs (also known as life cycle costs) refer to all costs that occur during the economic life of a project. In addition to the cost estimates developed as part of the WinSLAMM modeling effort in Lincoln, several other resources are available that provide costing tools, including the UDFCD BMP-REALCOST tool (www.udfcd.org) and the Water Environmental Research Foundation (WERF) Whole Life Cycle Cost tool (www.werf.org).

6.4. Non-Structural BMPs

Source controls, or non-structural BMPs, reduce the source of the pollutant rather than treating the pollutant through a structural BMP. Source controls are usually low-cost and are typically the responsibility of the resident or property owner to implement (*i.e.,* Low/No-phosphorus fertilizers and picking up pet waste). BMPs that achieve stormwater runoff volume reduction ultimately reduce the volume of surface water reaching Antelope Creek, thus reducing the pollutant load. Infiltration BMPs treat stormwater runoff and capture pollutants prior to reaching Antelope Creek. Recommendations for programmatic changes are discussed separately in SECTION 8 - MANAGEMENT PRACTICES–RECOMMENDED PROJECTS/PROGRAMS. Table 6-9 below reinforces the idea that source controls are an effective way for reducing bacteria loading to streams (Pitt, 2007).

Source controls, or non-structural BMPs, reduce the source of the pollutant rather than treating the pollutant through a structural BMP.

Table 6-9. Overview of Bacteria Control Measures and Expected Cost and Effectiveness

Control Measure	Control Effectiveness	Costs
Litter control	Low	Low/Moderate
Bird control on river bridges	Moderate (to 50%)	Low/Moderate
Catchbasin cleaning	Low (<10%)	Moderate/High
Street cleaning	Low/Moderate (to 20%)	Very high
Dog feces control programs	Moderate (to 35%)	Very low
Inappropriate discharge detection and elimination program	High (if present)	Moderate/High
Runoff treatment and disinfection	Can be very high (>99%)	Very high

6.5. Conclusion

Upon review and analysis of all of the data presented in the previous chapters, the following conclusions were made and used to develop the Plan recommendations summarized below and detailed in the following chapters:

1. Based on the cumulative data sets now available, Antelope Creek attains water quality standards for ammonia and copper.

2. Antelope Creek does not attain *E. coli* standards established by NDEQ (126 cfu/100 mL) for the stream during both dry and wet weather conditions. The *E. coli* recreation season geometric mean concentration at AC-9 during the 2004 sampling under the NDEQ rotating basin monitoring program was 3,433 cfu/100 mL. The *E. coli* geometric mean at AC-9 during the 2009 sampling by NDEQ was 620 cfu/100 mL. The *E. coli* geometric mean at AC-9 during the 2010-2011 sampling by EA was 1,511 cfu/100 mL.

Due to the diffuse nature of the sources of E. coli, meeting the standard could be difficult and costly, and will most likely require a long-term, systematic approach.

3. Dry weather sampling of stormwater outfalls to the stream did not show illicit sanitary connections to the storm drainage system; therefore, *E. coli* in the watershed is expected to be associated with diffuse, transient sources such as urban wildlife (*e.g.,* pigeons, raccoons) and potentially domestic pets (background level). Because of the relatively ubiquitous and diffuse nature of such background level pollutants, it is impractical to treat or remove all sources of *E. coli* in the watershed. Nonetheless, from a regulatory perspective, it is important for the City to proactively implement measures that may help to incrementally reduce *E. coli* loads to the stream.
4. Additional investigation into potential sources of *E. coli* in Antelope Creek through MST is not recommended. Although MST could provide additional information on the potential sources of *E. coli* in Antelope Creek, neither the EPA nor the NDEQ currently recognize differentiating between bacteria source organisms (human vs. wildlife for example) in applying Water Quality Standards. Therefore MST would likely not change the existing TMDL nor be considered in the evaluation of attainment of the beneficial use.
5. The level of background bacteria naturally occurring within the watershed is unknown.
6. Due to the diffuse nature of the sources of *E. coli*, meeting the standard could be difficult and costly, and will most likely require a long-term, systematic approach.
7. Antelope Creek does not attain water quality standards for several constituents believed to be associated with naturally occurring conditions in the watershed. Specifically, groundwater inflows to the stream are expected to provide the source of chloride, conductivity and selenium in the lower portion of Antelope Creek. These regulatory issues are best addressed through development of site-specific standards based on naturally occurring conditions and are not addressed as part of this watershed plan.
8. With the exceptions of *E. coli*, conductivity, chloride and selenium, Antelope Creek currently attains all other stream standards assigned to the stream by NDEQ.
9. Nuisance algae are present in various portions of the stream, particularly during warm weather. This is likely due to a combination of physical and chemical factors such as shallow flow depth, low flow velocities and stagnant areas, sunlight (limited tree canopy), and nutrients. Phosphorus, which is often a limiting factor for algal growth, is not particularly elevated in the limited stream samples collected from Antelope Creek to date (compared to typical urban streams); therefore, it is likely that the physical characteristics of the stream and flow regime also play a significant role related to nuisance algae. Hydraulic characteristics of the stream channel above the labyrinth weir create a stagnant area where sediment deposition occurs.
10. The stormwater quality management chapter of the City of Lincoln's Storm Drainage Criteria Manual was last updated in 2004, with significant reliance on 1992 criteria from the Urban Drainage and Flood Control District in Denver.

6.6. Recommendations

Due to the diffuse nature of the pollutant sources within the Antelope Creek watershed and the magnitude of the problem, a plan must be developed and implemented to work towards water quality goals. The Project team recommends;

"Together, the City, Lincoln citizens, and the LPSNRD should work proactively to reduce *E. coli* loads to the stream and implement strategies to reduce overall stormwater pollutant loads to Antelope Creek"

This recommendation was developed with the overall goal of eventually removing Antelope Creek from the 303(d) impaired waters list. To achieve this goal, a variety of control strategies to reduce pollutant loading to Antelope

Creek will need to be implemented. The control strategies can include a combination of structural and non-structural stormwater BMPs encompassing both source controls and water treatment technologies. Below are general Plan recommendations that were used to develop the specific recommended strategies and projects presented in SECTION 8 - MANAGEMENT PRACTICES–RECOMMENDED PROJECTS/PROGRAMS and the implementation strategy detailed in SECTION 10 - IMPLEMENTATION.

1. Enforce existing City ordinances to control pollutant sources within the Antelope Creek watershed such as pet waste pickup and sediment control.
2. Consider developing new City ordinances to control sources of the pollutants of concern.
3. Develop and implement wildlife control practices in the Antelope Creek watershed to discourage bird use of areas near the creek, such as on bridges and creek tunnels.
4. Continue and expand preventative maintenance and cleaning activities such as sanitary sewer inspections, street sweeping, and, in-stream sediment removal to minimize future pollutant sources.
5. Continue and expand pollution source control and runoff quantity reduction programs such as public education programs, Low/No-phosphorus fertilizer program, and the rain garden/rain barrel programs.
6. Develop and implement additional pollution source and runoff volume control programs such as downspout disconnection program and yard waste pickup programs.
7. Implement structural stormwater BMPs that treat frequently occurring rainfall events and reduce surface runoff volumes. The BMPs should be designed to target the 90% rainfall event (1.25 inches) or less if possible. Such stormwater BMPs could be implemented on new development projects, with opportunities for retrofits and demonstration projects also pursued by the City, as budgetary constraints allow.
8. Evaluate the feasibility of altering release patterns from Holmes Lake to determine whether more frequent “flushing flows” would be a benefit to water quality in Antelope Creek.
9. Evaluate channel modifications throughout Antelope Creek to minimize sedimentation areas and reduce nuisance algae blooms.
10. Evaluate Lincoln’s Storm Drainage Criteria Manual to ensure consistency with the 2010 version of the Urban Drainage and Flood Control District manual, or another comparable national manual.
11. Consider concentration of resources into a priority sub-basin. A concentration of resources, such as developing several projects in a smaller sub-basin, would allow the City to more closely evaluate BMP performance. Focusing on a sub-basin is a more practical approach for a diffuse pollution source and is typical of EPA approved water quality plans.

The general recommendations listed above were used to develop the specific Plan recommendations detailed in SECTION 8 - MANAGEMENT PRACTICES–RECOMMENDED PROJECTS/PROGRAMS. The Antelope Creek Watershed Management Plan Implementation Plan is provided in SECTION 10 - IMPLEMENTATION, along with Plan evaluation criteria and milestones to provide the City and LPSNRD with a road map to achieve the overall goal of removing Antelope Creek from the 303(d) impaired waters list.

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