



Lincoln Urban Pollutant Reduction Strategies

About the Green Infrastructure Technical Assistance Program

Stormwater runoff is a major cause of water pollution in urban areas. When rain falls in undeveloped areas, soil and plants absorb and filter the water. When rain falls on our roofs, streets, and parking lots, however, the water cannot soak into the ground. In most urban areas, stormwater is drained through engineered collection systems and discharged into nearby water bodies. The stormwater carries trash, bacteria, heavy metals, and other pollutants from the urban landscape, polluting the receiving waters. Higher flows also can cause erosion and flooding in urban streams, damaging habitat, property, and infrastructure.

Green infrastructure uses vegetation, soils, and natural processes to manage water and create healthier urban environments. At the scale of a city or county, *green infrastructure* refers to the patchwork of natural areas that provides habitat, flood protection, cleaner air, and cleaner water. At the scale of a neighborhood or site, *green infrastructure* refers to stormwater management systems that mimic nature by soaking up and storing water. Green infrastructure can be a cost-effective approach for improving water quality and helping communities stretch their infrastructure investments further by providing multiple environmental, economic, and community benefits. This multibenefit approach creates sustainable and resilient water infrastructure that supports and revitalizes urban communities.

The U.S. Environmental Protection Agency (EPA) encourages communities to use green infrastructure to help manage stormwater runoff, reduce sewer overflows, and improve water quality. EPA recognizes the value of working collaboratively with communities to support broader adoption of green infrastructure approaches. Technical assistance is a key component to accelerating the implementation of green infrastructure across the nation and aligns with EPA's commitment to provide community focused outreach and support the President's *Priority Agenda Enhancing the Climate Resilience of America's Natural Resources*. Creating more resilient systems will become increasingly important in the face of climate change. As more intense weather events and dwindling water supplies stress the performance of the nation's water infrastructure, green infrastructure offers an approach to increase resiliency and adaptability.

For more information, visit <http://www.epa.gov/greeninfrastructure>.

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Contents

About the Green Infrastructure Technical Assistance Program	ii
1 Introduction	1
1.1 Urban Stormwater Pollutants and Sources	1
1.2 Hydrologic Processes Affecting Urban Waters	2
1.3 Stormwater Management Strategies for Urbanized Areas	3
2 City of Lincoln Pollutant Reduction Strategies.....	5
2.1 Antelope Creek TMDL for Ammonia and E. Coli.....	5
2.2 Antelope Creek Watershed Basin Management Plan	5
2.3 City of Lincoln Code of Ordinances.....	6
2.4 Evaluation of Local Potential Pollutant Sources.....	7
3 Pollution Reduction Strategies From Other Urban Watersheds.....	9
3.1 Pet Waste Management Program in Snohomish County, Washington	9
3.2 Fecal Coliform TMDL Implementation Plan for Four Mile Run, Virginia	11
3.3 Bacteria Reduction Plan for Middle Huron River in Michigan.....	12
3.4 Stormwater Management Practices for Upper Emigration Creek Watershed.....	13
3.5 Bacteria TMDL Implementation Plan for Hoffler Creek Watershed, Virginia.....	14
3.6 Bacteria TMDL Implementation Plan for Virginia Beach Watersheds.....	14
3.7 US EPA Publication on Managing Pet and Wildlife Waste.....	14
4 Summary of Potential Strategies for Addressing Pollutants in Antelope Creek	15
4.1 Summary of Strategies in the Antelope Creek Plan	17
4.2 Prioritization of non-structural strategies for Antelope Creek.....	19
5 References.....	20

Tables

Table 1-1. Common urban stormwater pollutants and sources.....	2
Table 1-2. Structural and non-structural stormwater management practices.....	4
Table 2-1. Summary of Lincoln NE ordinances (reviewed July 2014) addressing pet waste and wildlife management.....	6
Table 3-1. Organisms in dog waste that can cause disease in humans.....	10
Table 4-1. Example management practices screening matrix for hydrologic and pollutant factors.....	15
Table 4-2. Potential screening criteria for structural stormwater management practices.....	16

Table 4-3. Physical, infrastructure, cost, and acceptance factors for stormwater structural practices.....	16
Table 4-4. Structural stormwater practices and hydrologic/treatment processes.	18
Table 4-5. Non-structural practices to address pollutants in Antelope Creek.	18

I Introduction

The City of Lincoln, Nebraska, requested green infrastructure technical assistance from the U.S. Environmental Protection Agency (EPA) to complete several different tasks. The City requested support in developing fact sheets on five different green infrastructure practices. The City also requested support in identifying specific pollutant reduction strategies for an urban watershed. Finally, the City requested support in hold a green infrastructure design charrette for local high school students.

This report documents specific pollutant reduction strategies for an urban watershed in the City of Lincoln, the Antelope Creek watershed. After a discussion of urban stormwater pollutants and sources, the report reviews existing information for the Antelope Creek watershed. The report also discusses pollutant reduction strategies developed for similar urban watersheds across the country, and summarizes potential strategies that can be used in Antelope Creek.

Antelope Creek is on the 303(d) impaired waters list mainly due to the high levels of Escherichia coli (E. coli) measured in the creek. A Total Maximum Daily Load (TMDL) developed in 2007 set a reduction goal of 113 cfu/100mL, which is the amount of E. coli that must be reduced in order for the waterbody to meet water quality standards. The Antelope Creek Watershed Basin Management Plan indicated that at the confluence with Salt Creek E. coli would need to be reduced 93% to meet the TMDL limit.

Under a task order issued by EPA, the project team was charged with reviewing existing materials related to Antelope Creek, primarily the Antelope Creek Watershed Basin Management Plan and any additional City of Lincoln resources, such as the ordinances, to categorize and evaluate any potential sources of pollutants. Special emphasis was to be placed on determining sources for E. coli in the watershed.

The project team was also asked to review TMDLs, implementation plans, and watershed plans in other urban watersheds across the country that address E. coli as a pollutant for examples of strategies that have been developed. For example, the Four Mile Run watershed in northern Virginia was one of the first detailed implementation plans for a fecal coliform TMDL. The project team reviewed Four Mile Run and similar plans to identify potential strategies.

This report documents the project team's summary of potential urban pollutant reduction strategies based on this review. The summary prioritizes strategy recommendations and also identifies non-structural strategies for both existing and new programs. The purpose of this summary is to identify the broad universe of potential strategies available for the watershed.

1.1 Urban Stormwater Pollutants and Sources

Urbanization increases the variety and amount of pollutants carried into the nation's waters. In urban and suburban areas, much of the land surface is covered by buildings, pavement and compacted landscapes with impaired drainage. These surfaces do not allow rain and snow melt to soak into the ground, which greatly increases the volume and velocity of stormwater runoff. As the runoff flows over the land or impervious surfaces (paved streets, parking lots, and building rooftops), it accumulates debris, chemicals, sediment or other pollutants that could adversely affect water quality (Table 1-1) if the runoff is discharged untreated. High velocity stormwater flows in urban streams can cause significant channel erosion and scour structural habitat components from water bodies. In addition to these habitat-destroying impacts, pollutants from urban runoff include:

- Sediment from channel erosion, construction sites, and bare areas
- Oil, grease and toxic chemicals from motor vehicles

- Pesticides and nutrients from lawns, landscaped areas, and gardens
- Viruses, bacteria and nutrients from pet waste and failing septic systems
- Road salts
- Heavy metals from roof shingles, motor vehicles and other sources
- Thermal pollution from impervious surfaces such as streets and rooftops

These pollutants can harm fish and wildlife populations, kill native vegetation, foul drinking water, and make recreational areas unsafe and unpleasant. Many stormwater discharges are considered point sources of water pollution and require coverage under a Clean Water Act National Pollutant Discharge Elimination System permit. These permits require the implementation of best management practices (BMPs) to control stormwater impacts to surface waters.

Table 1-1. Common urban stormwater pollutants and sources.

Pollutant Control 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 preservatives					X	X	X
Pesticides				X	X	X	X
Stormwater facilities without proper maintenance	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 Institutional Issues*. Washington, DC. Terrene Institute and EPA.

1.2 Hydrologic Processes Affecting Urban Waters

As noted in the previous subsection, urbanization changes the hydrology of developed areas by increasing landscape imperviousness, reducing stormwater infiltration, and increasing runoff volume and velocity. Surface streams receiving the runoff will expand their cross-sectional area downward and laterally to accommodate the increased and “flashier” stormwater flows. The overall impacts include:

- Rapid mobilization and transport of trash and pollutants into surface waters
- Stream channel erosion, and increased water turbidity
- Increased sediment loads in streams, degrading habitat for aquatic biota
- Collapse of stream banks, and possible loss of property
- Trees and shrubs falling into the channel, creating blockages that cause further erosion

- Exposure and possible damage of nearby infrastructure, such as roads, utility pipes, etc.
- Decreased urban stream base flow, due to lower infiltration of precipitation
- Lowered water table elevations, as aquifers are not fully recharged by precipitation

Addressing hydrologic and other urban watershed processes (e.g., pollutant buildup on land surfaces) involves a range of management strategies that target waterbodies and nearby lands, as summarized in the next section.

1.3 Stormwater Management Strategies for Urbanized Areas

Managing stormwater to prevent surface water degradation involves two primary approaches, which can be employed in areas of existing and new development. *Structural stormwater controls* include a range of landscape and drainage system features that detain or retain stormwater, promote stormwater infiltration, increase evapotranspiration, stabilize channels, and remove pollutants through settling processes, physical screening/filtration, adsorption, and other chemical, physical, and biological processes. *Non-structural controls* are largely focused on pollution prevention, and include street sweeping, good housekeeping, materials management, pet waste pickup, litter and trash cleanups, vehicle and equipment maintenance, and infrastructure management initiatives that keep sewer pipes, underground storage tanks, and other assets from impacting waterways. A list of common structural and non-structural controls for urban areas are listed in Table 1-2.

Structural Practices That Remove and/or Treat Pollutants

Ponds, stormwater wetlands, and sediment traps are used to detain or retain stormwater, allowing sediment and other solids to settle out and trapping floatable pollutants (e.g., oil, grease, trash) through preferentially sited outlet devices, screens, or filters. Roof gardens and underground stormwater storage vaults prevent or slow the migration of precipitation to the drainage system, reducing stormwater volumes and velocities.

Rain gardens, infiltration basins, bioretention facilities, bioswales, pervious pavement, and other practices designed to increase the infiltration of precipitation also reduce stormwater flows, and help to recharge groundwater and dry weather base flows in urban streams. Chemical, physical, and biological processes related to pollutant interaction with soil, microbes, and plants can promote the breakdown of hydrocarbons and other compounds, remove nutrients from stormwater through plant uptake, and trap or otherwise immobilize solids.

Drainage system improvements can also improve stormwater quality. Stabilizing ditches and channels – especially with native vegetation – can reduce channel erosion, trap pollutants in sheet runoff, and improve wildlife habitat. Hydrodynamic oil/grit separators, inlet screens, trash traps, and other drainage system products and devices can also help to remove trash, sediment, and pollutants.

Green infrastructure practices can be used to help detain or retain stormwater, promote stormwater infiltration, increase evapotranspiration, stabilize channels, and remove pollutants through settling processes, physical screening/filtration, adsorption, and other chemical, physical, and biological processes.

Table 1-2. Structural and non-structural stormwater management practices.

	Structural Practices	Nonstructural Practices
Urban	Bioretention cells Breakwaters Brush layering Infiltration basins Green roofs Live fascines Marsh creation/restoration Establishment of riparian buffers Riprap Stormwater ponds Sand filters Sediment basins Tree revetments Vegetated gabions Water quality swales Clustered wastewater treatment Systems	Planning for reduction of impervious surfaces (e.g., eliminating or reducing curb and gutter) Management programs for onsite and clustered (decentralized) wastewater treatment systems Educational materials Erosion and sediment control plan Fertilizer management Ordinances Pet waste programs Pollution prevention plans No-wake zones Setbacks Storm drain stenciling Workshops on proper installation of structural practices Zoning overlay districts Preservation of open space Development of greenways in critical areas

Non-Structural Practices to Prevent Stormwater Pollution

The management of land, materials, vehicles, waste, and infrastructure directly influences stormwater quality. Urban areas with exposed soils (e.g., construction sites, poorly landscaped areas) contribute sediment to stormwater, and vegetated lands treated with excessive amounts of fertilizer, herbicides, and pesticides can generate runoff with high concentrations of unwanted chemicals. In addition, poor management of materials that contain or leach pollutants (e.g., road salt, fuels, oils, soluble compounds), vehicles, waste, and urban infrastructure is linked directly to poor stormwater quality.

Urban stormwater programs are required to institute good housekeeping programs that include regular street sweeping and managing problem materials by storing them under a roof or tarpaulin. Pet waste and litter pickup programs, mandated by ordinance or promoted via public education, are common approaches to prevent fecal and trash impacts to urban waters. Keeping vehicles and equipment from leaking fuel, oil, and grease through regular maintenance schedules also helps maintain water quality, as does frequent inspection and repair of sewer piping, storage tanks, and other infrastructure components.

2 City of Lincoln Pollutant Reduction Strategies

The project team reviewed a variety of existing materials from the City of Lincoln related to activities in the Antelope Creek watershed, including the Antelope Creek TMDL for Ammonia and E. Coli, the Antelope Creek Watershed Basin Management Plan, and relevant ordinances of the City of Lincoln. Below is a brief summary of each.

2.1 Antelope Creek TMDL for Ammonia and E. Coli

The *Total Maximum Daily Loads for Antelope Creek*, focusing on total ammonia and E. coli, was produced by the Nebraska Department of Environmental Quality Planning Unit of the state Water Quality Division in June 2007. The document notes that Antelope Creek was included in Category 5 of the 2006 *Nebraska Surface Water Quality Integrated Report* as a waterbody deemed impaired and in need of a TMDL. Data collected during 2002-2005 indicated the primary contact recreation beneficial use, the aquatic life beneficial use, and the agriculture beneficial use were impaired, with the pollutants of concern listed as E. coli bacteria, ammonia, copper, selenium and conductivity, respectively.

The TMDL report noted that approximately 95% of the Antelope Creek watershed was considered urbanized, with the un-urbanized portion being in and around the headwaters region – i.e., upstream of the dam containing Holmes Lake. The report also noted that no TMDLs would be prepared for copper, selenium and conductivity, due to general conclusions that the monitoring data were inconclusive and/or the conditions were likely related to geological conditions and natural background. The 2006 IR notes that Antelope Creek has been characterized as being “quite salty,” with groundwater infiltrating the stream having a total dissolved solids concentration of about 30,000 mg/l. In terms of bacteria and ammonia, the TMDL report noted that natural constituents (e.g., organic matter, wildlife) and sewage were the likely sources for water quality criteria exceedances.

2.2 Antelope Creek Watershed Basin Management Plan

The 2012 *Antelope Creek Watershed Basin Management Plan* produced for the city by a group of consultants assisted by the Lower Platte South Natural Resources District local citizens, and other interested parties provides a comprehensive analysis of the watershed, waterbody conditions, and possible management strategies to address pollutants of concern. Key findings from the plan include:

- E. coli continues to be the pollutant of concern, with recent monitoring for ammonia indicating few problems and levels of selenium, chlorides, and conductivity associated mostly with natural conditions. The plan noted that a 93% reduction in E. coli loading was needed to meet numeric water quality criteria.
- Bacteria sources are probably linked to urban wildlife (e.g., birds, mammals) and pets – and possibly a zoo – rather than to leaking sewer collection pipes. There are no septic systems in the watershed.
- Reducing bacteria loads will be difficult and require a long term systematic approach, due to the relatively ubiquitous and diffuse nature of background level pollutants.
- The most effective pollution control strategies for diffuse sources of E. coli are source controls, stormwater volume reductions, and good housekeeping practices. Source controls include addressing the wildlife and pets associated with E. coli bacteria in the watershed, while structural controls that reduce stormwater volume (e.g., infiltration practices) can help keep bacteria out of the creek during small and moderate storm events. Good housekeeping practices include a variety of non-structural measures that keep pollutants out of the drainage system.

- Control of wildlife bacteria sources should focus on installation of anti-roosting nets and spikes under Antelope Creek bridges, a more robust pet waste pickup program, vegetation management approaches that deter geese from waterbodies, and other animal control practices.
- Stormwater volume controls needed in the Antelope Creek watershed include Infiltration practices such as rain gardens, vegetated drainage swales, and pervious pavement.
- Good housekeeping practices to reduce overall pollutant loading into the stormwater drainage system include sanitary sewer inspections, street sweeping, and in-stream sediment removal.
- Continuation and expansion of public education programs dealing with low/no-phosphorus fertilizers, rain gardens, rain barrels, downspout disconnection, and yard waste pickup can help to reinforce the overall message that stormwater improvement requires a community response.

2.3 City of Lincoln Code of Ordinances

The City of Lincoln has enacted a fairly comprehensive body of *ordinances* that address the full array of issues associated with bacteria loads from wildlife and pets. In general, it is unlawful in Lincoln to harbor wildlife and to allow pet waste to accumulate on – or run off – private property. In addition, pet waste must be removed from public areas. Table 2-1 summarizes key provisions of the ordinances.

Table 2-1. Summary of Lincoln NE ordinances (reviewed July 2014) addressing pet waste and wildlife management.

Ordinance Section & Number	Ordinance Provisions
6.04.020 Unusual and Wild Animals Prohibited.	It shall be unlawful for any person or persons to own, keep, or harbor any unusual or wild animal within the corporate limits of the City of Lincoln.
6.04.050 Sanitary Regulations on Animal Pens.	The owner of any large or small animal or fowl shall keep all pens, enclosures, and shelter structures wherein such animals or fowl are kept in a clean and sanitary condition so as not to give off offensive odors which are a source of discomfort to persons residing in the vicinity thereof. The owner of any large or small animal or fowl shall not allow offal, manure, and waste material of such animal to accumulate or remain in the pens, enclosures, and shelter areas, excluding pasture acreage, upon which such animal or fowl resides or is confined in any manner which is conducive to the breeding or attraction of flies, mosquitoes, or other noxious insects or in any manner which endangers the public health or safety or which creates an unhealthy environment. The maintenance or permitting of any of the foregoing conditions on any such lot or parcel of ground is hereby declared to be a public nuisance. The owner of any large or small animal or fowl shall in a sanitary manner remove or dispose of all offal, manure, and waste material accumulating from such animal or fowl at least once every seven days.
6.08.150 Sanitary Regulations on Confined Dog Areas.	The owner of any dog shall keep any yard, enclosure, shelter structure, or dwelling wherein such dog is kept in a clean and sanitary condition so as not to give off offensive odors which are a source of discomfort to persons residing in the vicinity thereof. The owner of any dog shall not allow offal, manure, and waste material of such dog to accumulate or remain in the yard, pen, enclosure, shelter structure and/or dwelling, upon which such dog resides or is confined in any manner which is conducive to the breeding or attraction of flies, mosquitoes, or other noxious insects or in any manner which endangers the public health or safety or which creates an unhealthy environment. The maintenance or permitting of any of the foregoing conditions on any premises is hereby declared to be a public nuisance. The owner of any dog shall in a sanitary manner remove or dispose of all offal, manure, and waste material accumulating from such dog at least once every five days.

Ordinance Section & Number	Ordinance Provisions
6.08.155 Disposal of Dog Waste.	Any person having custody or control of any dog shall have the responsibility for disposing of dog feces or manure of the dog in a sanitary manner. The provisions of this section shall not apply to law enforcement officers while using the dog to perform law enforcement functions or rescue activity. It shall be unlawful for any person having custody or control of any dog to place, deposit, discard, or dispose of feces or manure on public property or private property of another unless placed in approved garbage or refuse containers on public property or with the consent of the owner of the private property.
8.26.010 Noxious or Offensive Use of Building or Premises.	No building or premises in any part of the city or within three miles of the corporate limits thereof shall be used for any trade, industry, or purpose that is noxious or offensive by reason of the emission of odor, dust, smoke, gas, fumes, noise, water, spray, or other substance or residue, or that is detrimental to the public health, safety, or welfare, and the use of such building or premises for such purpose is hereby declared to constitute a public nuisance.
8.26.020 Deposit and Accumulation of Offensive Substances Prohibited.	Whether within the city or within three miles of the corporate limits thereof, it shall be unlawful for any person to deposit or to permit the accumulation of any foul, decaying, or putrescent substances or other offensive matter in or upon any lot, street, or public way, or in or upon any public or private place, to permit the overflow of any foul liquids or the escape of any gas to such an extent that the same, or any of them, shall become, or are likely to become, hazardous to health, or that the same shall by reason of offensive odors, become a source of discomfort to persons living or passing in the vicinity thereof or otherwise unreasonably interfere with the public health, safety, or welfare; and such conditions and things, as aforesaid, and each and all of them are hereby declared to be a public nuisance.
12.08.180 Animals Running at Large.	It shall be unlawful for any person to allow or permit any dog or other animal to run at large in any park, or to enter any of the lakes, ponds, fountains, or streams therein. For the purposes of this section, the term "at large" is defined to mean not under the control of a person either by leash, cord, chain, or confinement within a vehicle or pen or other similar enclosure. Notwithstanding the foregoing, the Director of the Parks and Recreation Department may designate certain areas to allow dogs to run at large.
17.58.020 Discharge of Untreated Wastewater; Unlawful.	It shall be unlawful to discharge to any natural outlet within the city or within three miles of the corporate limits thereof, or in any area under the jurisdiction of the city, any wastewater, industrial wastes, or other polluted waters, except where suitable treatment has been provided in accordance with subsequent provisions of this chapter.

2.4 Evaluation of Local Potential Pollutant Sources

While E. coli, ammonia, copper, selenium, chlorides, and conductivity are all mentioned as pollutants of concern for Antelope Creek, studies reviewed by the project team indicate that only E. coli represents a documented present or potential threat to beneficial uses of the waterbody. Data regarding the other pollutants are incomplete, inclusive, or indicative of natural background conditions.

Based on a review of the Antelope Creek TMDL, the watershed plan, water quality data in those documents, and the types of land uses in the drainage area, wildlife and pet waste are the most likely sources of E. coli in the creek. The lack of significant dry weather flows containing elevated bacteria concentrations – as confirmed by field observations described in the watershed plan – and the water

monitoring data correlations between rainfall events and high waterbody bacteria concentrations clearly indicate urban runoff pollutant sources, rather than wastewater collection pipe leakage.

Microbial source tracking such as Quantitative Microbial Risk Assessment (QMRA) could help to tease out more precisely the proportion of bacteria linked to dogs, cats, pigeons, geese, ducks, raccoons, muskrats, mice, and so on, but this information – while helpful – is not necessary to begin work on the problem. Field observations conducted during the development of the watershed plan documented the presence of bird droppings under the 29 Antelope Creek roadway bridges, and habitat conditions favorable to a variety of native small mammals were noted. Due to the almost complete buildout of the watershed and lack of significant cover, it is unlikely that a significant population of deer reside in the area.

Besides wildlife, domesticated pets that defecate outdoors – mostly dogs and cats – are common in the type of residential settings found in the watershed, and the presence of pets was documented in the watershed plan. The planning team also documented observations of pet owners failing to pick up pet waste during walks. While no pet census or estimate of pet populations appears to be available for the Antelope Creek watershed, the Humane Society of the U.S. estimates that 47 percent of households nationwide have at least one dog, with a lesser percentage owning one or more cats. Moreover, up to a third or more of households with a dog own more than one. Other studies have found slightly lower dog ownership percentages.

Based on watershed population (48,500), household size (2.7 people), and average dog ownership percentage ranges (35% to 45%, with about one-third owning more than one dog), there are probably around 10,000 dogs in the Antelope Creek watershed and a similar number of cats. If the average dog (32 pounds) produces 0.6 pounds of fecal waste per day, the watershed's dog population alone could be generating approximately three tons of waste per day.

Given that most parkland and publicly owned open space (i.e., dog walk areas) in the watershed lies along the Antelope Creek mainstem and tributaries, and that the entire watershed has a storm drain system, it is likely that most dog waste is deposited close to the stream or near a storm drain inlet. Note that these figures do not include cat waste.

3 Pollution Reduction Strategies From Other Urban Watersheds

This section contains brief, bulleted summaries of key pollutant reduction strategies from other urban watersheds. The primary focus of the programs listed below is bacteria reduction, but other strategies are listed for controlling a range of common urban pollutants, e.g., sediment, nutrients, metals, etc.).

3.1 Pet Waste Management Program in Snohomish County, Washington

Like many coastal counties, Snohomish County water quality analysts are concerned about high bacteria inputs to valuable shellfish and recreational waters. The Snohomish County Surface Water Management agency in 2006 conducted an intensive series of surveys and research projects designed to identify effective approaches for reducing bacteria concentrations in county waterbodies. Some of the key findings included:

- Pet feces contain a wide range of microorganisms, such as *Anacyclostoma sp.*, *Toxocara canis* eggs, *Giardia lamblia* cysts, *Cryptosporidium parvum* cysts, *Campylobacter jejuni* bacteria, and *Escherichia coli*. These microbes – which can survive for up to six months and more outside the animal host – can cause severe human illness (see Table 3-1).
- The level of bacterial contamination of surface waters in the county rises in tandem with the number of dogs per acre in the affected watersheds. Approximately 37.4% of all Washington state households have dogs, with dog-owning households averaging 1.5 dogs per home.
- The estimated pet population of Snohomish County was 126,141 dogs and 206,773 cats – a total of nearly 333,000 animals. The total dog population was estimated to produce 2.7 times more fecal waste than the total cat population, with dogs producing as much waste as 32,000 people.
- Most of the existing pet waste management programs focus on managing waste in public areas, such as parks, sidewalks, parkways, and so on. However, a survey of dog owners indicated that nearly 90 percent of the animals defecated in yards, with only 10 percent of the events occurring on walks.
- Since the vast majority of feces deposition occurred in yards, the program developed by the county focused on yards, and was designed to be a behavior change program, not an education program.
- Focus group sessions with local residents found that messages targeting safe kids, safe pets, clean yards, and clean shoes were more effective than the conventional educational messages regarding poop pickup, which focused on regulations or disposal requirements/methods. Secondary messages such as “dog waste is not fertilizer” and “dog waste is raw sewage” were also found to be effective.
- Messages were delivered directly to the target audience by brochure, signage, advertisements, and veterinarians.

Table 3-1. Organisms in dog waste that can cause disease in humans.

Organism	Common Name	Survival	Human Disease
<i>Escherichia coli</i>	<i>E. coli</i> , Fecal coliform bacteria	Months. 3 days at 140°F required to kill organism	Bloody diarrhea, severe cramps, blood clots in the kidney (hemolytic uremic syndrome or HUS), leading to kidney failure.
<i>Toxocaracanis</i>	Roundworms	4 years in soil	VLM (visceral larva migrans) or toxocariasis, an infection caused by certain parasites, leading to enlargement of the liver (hepatomegaly), inflammation of the middle muscular layer of the heart wall (myocarditis), inflammation of the kidneys (nephritis), inflammation of the lungs (pneumonitis), and blindness. Usually in children.
<i>Salmonella spp.</i>	none	Up to 6 months in ruminant feces.	Usually, mild inflammation of the lining membrane of the stomach and the intestines (gastroenteritis) within 6-48 hours.
<i>Cryptosporidium parvum</i>	None	At least 6 months. Susceptible to drying	Self-limiting inflammation of the lining membrane of the stomach and the intestines (gastroenteritis), protracted in susceptible individuals. CDC reports 300,000 cases annually, 90% of waterborne origin.
<i>Giardia duodenalis</i> <i>lamblia</i> (<i>Giardia intestinalis</i>)	<i>Giardia</i> , Giardiasis	Months in water. Resistant to drying, chlorine, and temperature extremes	Diarrhea, cramps, gas (flatulence), nausea, an excess of fat in stools (steatorrhea). Can be protracted and debilitating. CDC estimates 2 million cases in U.S., 90% of waterborne origin.
<i>Campylobacter spp.</i>	None	Rapidly killed by heat, drying, and freezing	Mild to severe, bloody diarrhea.
<i>Yersinia enterocolitica</i>	none	Unknown	Mild inflammation of the lining membrane of the stomach and the intestines (gastroenteritis).
<i>Leptospira interrogans</i>	Leptospirosis	Weeks to months in soil or water	Usually mild fever but complications can be serious, including inflammation of the liver (hepatitis), interference with normal production and discharge of bile (jaundice), inflammation of the membranes that envelop the brain and spinal cord (meningitis), and kidney failure. Life threatening, but uncommon. There has been a recent increase in the numbers of dogs with leptospires.
<i>Baylisascaris procyonis</i> (<i>g. Toxocara</i>)	Roundworms	Eggs can survive in moist soil for years	Severe neurological form of VLM (visceral larva migrans, see above), especially in young children.
<i>Ancylostoma spp.</i>	Hookworms	Several days. No known effective chemical or pesticide treatment	Spreading lesions and severe itching (pruritis). In rare instances can cause symptoms like VLM (see above). Puppies are a significant source of infection. Prompt removal of dog and cat feces greatly reduces risk of infection.

Source: Washington Department of Ecology

3.2 Fecal Coliform TMDL Implementation Plan for Four Mile Run, Virginia

Four Mile Run traverses the highly urbanized area in Northern Virginia just southwest of Washington DC. A TMDL was developed to address high fecal coliform and E. Coli levels in Four Mile Run, and a companion document described an [implementation plan](#) for the bacteria control measures outlined in the TMDL (NVRC, 2004). Below are the highlights of the TMDL implementation plan.

Non-Structural and Indirect Mitigation Measures:

- **Sanitary Sewer Maintenance:** Routine Inspection and Maintenance of the system and a Sewer Rehabilitation Program.
- **Inappropriate (Illicit) Discharge Controls:** City Ordinances that disallow discharges other than stormwater to the municipal separate storm sewer system (MS4); pilot programs to investigate, detect and eliminate inappropriate discharges; dry weather screening process; storm sewer line inspections; city-wide plans that may include mapping outfalls.
- **Septic System Maintenance:** pump out every 5 years and inspect regularly; correct septic system or connect the home to a MS4 if a septic system is found to be failing.
- **Proper Pet Waste Disposal:** use of dog parks; pet waste pick-up laws; pickup bags and receptacles.
- **General Outreach:** proper dog walking outreach and education programs; storm drain inlet markers; Earth Day environmentally related activities; water quality ads at local movie theatres; presentations/workshops at schools; educational door hangers, brochures, newsletters; volunteer activities (e.g. stream monitoring).
- **Directed Outreach (focus solely on behavior changes):** specific ads/website pages that focus on pet waste, car washing, fertilizer, leaking oil from cars, etc.
- **Signage:** posting signs for stream crossings, activity limiting (e.g. fishable-consumable, swimmable, catch and release, etc.), no littering, no dogs off leash, no car washing, no drinking water.

Structural Mitigation Measures

- **Stormwater Treatment:** installation of structural BMPs such as stormwater management ponds, sand filters, and hydrodynamic facilities, enhanced stormwater ponds, stormwater wetlands, and bioretention facilities; Stormwater management program or City Ordinance that includes BMP requirements.
- **Street and Storm Drain Infrastructure:** street sweeping, catch basin cleaning, storm drain maintenance/mapping/digitization.
- **Stream Corridor Restoration:** DNA fingerprinting/source tracking; restoration of stream beds, banks, and riparian areas; spot repairs of stream segments; daylighting (allowing UV radiation from the sun to reach the stream) of stream segments; invasive species removal.
- **Stormwater Reduction and Reuse:** rain barrels/cisterns; green roof construction; infiltration systems (e.g. permeable paving, bioretention basins, etc.), other site specific drainage designs that control runoff rate, volume, frequency, and quality; green building programs.
- **UV Disinfection:** UV disinfection systems for stormwater.
- **Ozone Treatment:** ozone treatment technology.
- **Flocculant Treatment:** alum injection systems and other flocculant technology.

3.3 Bacteria Reduction Plan for Middle Huron River in Michigan

The Middle Huron River flows through southeastern Michigan. Many surface waters in the middle Huron do not meet these designated uses due to a number of water quality and water quantity issues, including high levels of sediment entering the river system, destruction of native aquatic and terrestrial habitat, river flow fluctuations, and pollutant loads of metals and other toxins, bacteria, and excess nutrients. Nutrient enrichment of the middle Huron system is of particular concern, driving annual algal blooms in the river's reservoirs.

Among other initiatives, a plan for reducing bacteria loads in the river was developed to identify practices that improve water quality. Pollution prevention strategies identified in the *Bacteria Reduction Implementation Plan for the Middle Huron River Watershed* (Middle Huron Partners and Stormwater Advisory Group, 2011) included:

- **Septic system inspection program** for identifying and correcting failing septic systems and providing specific requirements for residential property transfer such as an inspection by certified inspectors, report submitted to the environmental/health department, and for the seller to receive a letter back from the department. [Middle Huron, page 19/31.]
- **Illicit discharge elimination program** to remove non-storm discharges to storm sewers. Collect sampling records, video, and dye-test data and store in a database to help monitor discharges. Inspection of storm sewers annually by closed circuit T.V. Dry weather sampling including checking manholes, if a flow is detected than samples are taken and data is compiled over several years for a dry weather screening report.
- **Recreational vehicle (RV) disposal education:** educate RV owners about proper waste disposal and develop plans that prohibit certain activity (e.g. parking overnight in certain parking lots) to prevent illicit discharges.
- **Storm drain/catch basin marking** to create public awareness of the danger of dumping into these drains. Markers should be placed and replaced every few years, when markers begin to fade or fall off and new drains should have a warning engraved into the frame.
- **Information and education mass media campaign/public education program** to provide awareness about septic system maintenance.
- **Information and public education through the internet** as an ongoing program (with minimal cost) which also receives feedback from visitors of the page.
- **Pump station overflow plan** to reduce pump station flooding.
- **Farmer education program:** N/A in an urban setting.
- **Pets:** pet waste education program, providing doggie bags in parks, and pooper scooper ordinance to educate the public on the impact of pet waste and reduce pet waste from entering the storm sewer.
- **Operation Goose Down:** program to decrease Giant Canada goose populations and eliminate year-round goose habitat, which result in reduced goose droppings that contain E. coli that can pollute waterways. Using pond buffer plantings, replacing turf with shrubs and trees, and interfering with feeding and nesting are some possible BMPs.
- **Community partners for clean streams:** through presentations, print material, and signed agreements to use BMPS and abide by good housekeeping measures, these programs provide education on methods to discourage geese and waterfowl habitat.
- **Native landscaping ordinance development:** reduce green grass cover and encourage tall prairie species to displace foraging geese by creating an unfavorable environment for them.

- **Update stormwater management standards:** incorporate standards that reduce nuisance geese habitat at stormwater ponds through the installation of shoreline buffer plantings or other means.
- **Park goose control:** hire contractors to collect eggs from nests and trap molting geese and move them to locations in the wild. Dogs can also be used to disturb the geese.
- **Comprehensive plan:** a tool that can help preserve open land and protect tributary watersheds by discouraging residential development outside of sewer, water and road infrastructure, preventing sprawl development.
- **Wetlands protection program:** local regulation and incentives to protect wetlands on 1/5 of an acre or larger since damaged and destroyed small wetlands cannot provide the services of filtering and cleaning pollutants in stormwater.
- **Other ordinance development:** protect open space, reduce parking and road requirements to increase pervious surface, and increase natural features buffer areas.
- **Flood control structures:** redesign flood control structures to improve water quality treatment.

3.4 Stormwater Management Practices for Upper Emigration Creek Watershed

Upper Emigration Creek flows through Salt Lake County, Utah. Residential development in the canyons and foothills surrounding Salt Lake City is growing at a rapid pace. Urban development typically degrades water quality. In Emigration Canyon, residential development is replacing land formerly used for grazing and recreation. Practices described in a [TMDL for Upper Emigration Creek Watershed](#) to address degradation linked to residential development identified by the watershed protection team included (Utah DEQ, 2011):

- **Improve/increase streamside vegetated buffers.** Usually buffers must be 35 feet wide on average to be eligible for any state or federal cost share money.
- **Analysis of septic systems** to identify and correct failing systems. Educate the public on septic tank pump-outs as well as a septic system repair/replacement program and the use of alternative waste treatment systems.
- **Control urban wash-off from parking lots and roads**
- **Street sweeping**
- **Drainage ditch bank stabilization**
- **Drainage structure maintenance**
- **Enforcement of storm sewer discharge ordinance**
- **BMP inspections:** e.g. ponds, dry ponds, infiltration ponds, stormwater treatment devices.
- **Stormwater BMPs:** incorporation of low impact development.
- **Streamside fencing**
- **Pet litter control programs**
- **Outreach/education programs:** functions as ‘first line of defense’ to reduce/eliminate bacteria washed from surfaces. Includes municipal incentives to encourage proper irrigation and landscaping and public education of homeowners over proper pet waste disposal.

The team noted that follow-up monitoring is essential to evaluate the effectiveness of the pollution control strategies. Dye tests were identified as a possible method of determining whether or not effluent from failing septic systems is contributing to the bacterial contamination of the waterbody.

3.5 Bacteria TMDL Implementation Plan for Hoffler Creek Watershed, Virginia

The Hoffler Creek watershed is located in the tidal region of Virginia, within the Cities of Suffolk and Portsmouth, and empties into the James River at the Hampton Roads Harbor. A segment of Hoffler Creek near Norfolk was first listed as bacteria impaired on Virginia's 2008 303(d) Total Maximum Daily Load Priority List due to exceedances of the state's recreational criteria for Enterococcus. The estuarine bacteria-impaired segment of Hoffler Creek is located along the southern shore of Hampton Roads Harbor (James River), and encompasses the entirety of Hoffler Creek. A *TMDL implementation plan* for the creek (The Louis Berger Group, 2012) included a few relevant recommendations, based on studies that found bacteria loads were linked mostly to pets (71.9%) and wildlife (24.6%). Primary control methods included:

- A pet waste education program, implemented through the Hoffler Creek Wildlife Foundation and Preserve, homeowner associations, and city staff.
- Public awareness signage, including "no dumping" metal storm drain markers, pet waste clean up signs, and pet waste disposal containers.

3.6 Bacteria TMDL Implementation Plan for Virginia Beach Watersheds

Another brief description of appropriate management practices for control of bacteria loadings comes from an adjacent area in coastal Virginia. The Hampton Roads Planning District Commission and Virginia Department of Environmental Quality in 2010 developed a TMDL implementation plan for two watersheds with significant pet and wildlife issues, *Back Bay* and *North Landing* (Hampton Roads Planning District Commission, 2009). The primary recommendations were:

- Pet waste clean-up ordinance
- Scoop the poop education program
- Watershed markers
- Habitat enhancement

3.7 US EPA Publication on Managing Pet and Wildlife Waste

Finally, the US EPA publication on *Managing Pet and Wildlife Waste to Prevent Contamination of Drinking Water* (2001) notes that pet waste can comprise a significant (20 percent or more) fraction of the bacteria in surface waters, can threaten human health due to the presence of disease-causing pathogens, and can be controlled through known management methods that focus on clean up and disposal. Recommendations for managing pet and wildlife waste include:

- Behavior change programs that encourage/require cleaning up and disposing of pet waste.
- Designation of special dog parks, where drainage is routed to special vegetated areas for containment and treatment.
- Prohibiting pets in areas near streams, ponds, and lakes.
- Reducing the attractiveness of yards and other areas to wildlife by prohibiting feeding, removing trash, reducing palatable plant species, managing grass and vegetation to deter problem species (e.g., Canada geese), and using beaver and muskrat controls near the drainage system.

4 Summary of Potential Strategies for Addressing Pollutants in Antelope Creek

The past several decades of work to improve urban stormwater quality has resulted in a wide range of non-structural pollution prevention measures and structural management practices that address a full range of pollutants, habitat threats, and sources of waterbody degradation (see Section 2 of this document). This section summarizes pollutant reduction strategies listed in the Antelope Creek watershed plan, which upon review appear to have been evaluated in a manner consistent with good stormwater management practices. It should be noted that the strategies listed in the plan address E. coli and other pollutants that, while perhaps posing future threats to water quality, are not listed as current causes of impairment. This section also lists specific practices focused on the E. coli impairment to Antelope Creek, in Section 3.

In determining which management practices may be appropriate for the various pollutant parameters, it is helpful to consider the relative effectiveness of the practices to address specific pollutants. Table 4-1 provides basic information on which practices address a range of hydrologic and pollutant factors.

Table 4-1. Example management practices screening matrix for hydrologic and pollutant factors.

Structural Practice	Hydrologic Factor				Pollutant Factor				
	Interception	Infiltration	Evaporation	Reduced Leak Flow	Total Susp. Solids	Nutrients	Fecal Coliform	Metals	Temperature
Bioretention	H	M	M	M	H	H	H	H	H
Conventional dry detention	L	L	M	H	L	L	H	M	M
Extended dry detention	L	L	M	H	M	M	H	M	L
Grass swale	M	M	L	L	M	L	L	H	M
Green roof	H	L	H	M	L	L	L	L	H
Infiltration trench	L	H	L	M	H	H	H	H	H
Larking lot underground storage	M	M	L	H	H	H	M	H	H
Permeable pavement	M	M	M	M	M	L	M	L	M
Sand filter	L	L	L	L	H	H	M	H	H
Stormwater wetland	H	L	M	H	H	H	H	H	M
Vegetated filter strip with level spreader	M	M	L	L	M	M	L	M	M
Water quality swale	M	M	M	M	H	H	L	H	H
Wet Pond	L	L	H	H	H	H	H	H	L

L Low, poor, or no influence

M Moderate influence

H High influence, good

Tables 4-2 and 4-3 list additional screening criteria for structural stormwater practices, as summarized by US EPA in the 2008 document entitled *TMDLs to Stormwater Permits Handbook (Draft)*, by the Office of Wetlands, Oceans and Watersheds.

Table 4-2. Potential screening criteria for structural stormwater management practices.

Screening criteria	Description
Volume reduction/source controls	Consider the role volume plays in contributing to elevated pollutant loads. Determine the extent to which rate and volume of flow can be retained or reduced on-site.
Location of the management practice within the critical area/watershed landscape	Check to see if the candidate management practice can help implement the load reductions that were identified in one of the critical areas of the watershed.
Estimated load reductions	Using the information you collected during desktop and field scoping, document whether the anticipated load reduction is low, medium or high.
Legal and regulatory requirements	Identify legal or regulatory requirements for projects, and determine whether any pose significant constraints.
Property ownership	Determine the number of property owners that need to agree to installation or implementation of the management practice(s). It is often easier to obtain easements on lands in the public ownership.
Site access	Consider whether you will be able to physically access the site and identify a contact to obtain permission if private property must be traversed to access the site. Consider whether maintenance equipment (e.g., front-end loaders, vacuum trucks) will be able to reach the site safely. Designs and cost estimates might require adjustment if a structural control requires hand-cleaning because of maintenance access constraints.
Added benefits	In addition to their intended design, management practices can also provide secondary benefits by controlling other pollutants, depending on how the pollutants are generated or transported. For example, practices that reduce erosion and sediment delivery often reduce phosphorus losses because phosphorus is strongly absorbed to silt and clay particles.
Unintended effects	In some cases, management practices that are used to control one pollutant could inadvertently increase the generation, transport, or delivery of another pollutant.

Table 4-3. Physical, infrastructure, cost, and acceptance factors for stormwater structural practices.

Screening criteria	Description
Physical factors	There are many physical factors that can determine whether you will be able to install management practices. Look for constraints such as steep slopes, wetlands, high water tables, and poorly drained areas. Also look for opportunities such as open space, existing management practices that can be upgraded, outfalls where management practices could be added, and well-drained areas.
Infrastructure	Look for sites that have few utilities, road crossings, buried cables, pipelines, parking areas, or other significant physical constraints that could preclude installation or cause safety hazards.
Costs	The appropriateness of a management practice for a site can be affected by economic feasibility considerations that encompass short- and long-term costs. Short-term costs include installation costs, while long-term costs include continued O&M.
Social acceptance	Consider how nearby landowners will perceive the management practice. Will it cause nuisances such as localized ponding of water or vector control problems? Can these issues be addressed in the siting and design of the practice? How can nearby residents be involved in selecting and designing the practice to address their concerns? The optimal method for evaluating site feasibility for both riparian and upland management practices is through a site visit.

4.1 Summary of Strategies in the Antelope Creek Plan

As noted previously, the *Antelope Creek Watershed Basin Management Plan* contains a defined set of reasonable structural and non-structural strategies to improve water quality. Most of the practices target bacteria loads and “flashy” stormwater flows, but some consider sediment and nutrient inputs. Below is a summary of the recommendations in the plan. The project team has grouped recommended pollutant reduction strategies into high priority, medium priority, and lower priority categories, based on their relative effectiveness in reducing E. coli bacteria, cost, and ease of implementation.

High priority recommendations

- Enforce existing City ordinances to control pollutant sources within the Antelope Creek watershed such as pet waste pickup and sediment control.
- 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 culverts.
- 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.
- 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.

Medium priority recommendations

- Develop and implement additional pollution source and runoff volume control programs such as downspout disconnection program and yard waste pickup programs.
- 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.
- Consider developing new City ordinances to control sources of the pollutants of concern.

Lower priority recommendations

- 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.
- Evaluate channel modifications throughout Antelope Creek to minimize sedimentation areas and reduce nuisance algae blooms.
- 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.
- 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.

The watershed plan also contains an excellent table that summarizes the hydrologic and treatment processes of key structural management practices for improving stormwater quality (Table 4-4). Note that most of these are intended to improve stormwater infiltration, which would have an ancillary benefit of keeping transported E. coli bacteria out of the drainage system and Antelope Creek – at least during small to moderate storms.

Table 4-4. Structural stormwater practices and hydrologic/treatment processes.

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.

Non-structural management practices included in the watershed plan include primary source control approaches for directly reducing bacteria inputs, i.e., by eliminating wildlife harborage, bird roosting areas, and better managing pet waste. Table 4-5 lists these non-structural practices, and indicates their relative effectiveness and cost.

Table 4-5. Non-structural practices to address pollutants in Antelope Creek.

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 program	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

4.2 Prioritization of non-structural strategies for Antelope Creek

The watershed plan identifies a number of existing and new programs that can be leveraged to improve stormwater quality, listed below:

Existing Programs

- **Pet Waste Ordinances/Disposal Cans:** signs explaining the importance of picking up pet waste; containers for disposing of pet waste; bill stuffers, letters, news articles, etc. to inform residents about the water quality benefits of picking up pet waste and possible enforcement actions.
- **Lincoln Children's Zoo:** create water quality management plan; expand on-site water quality BMPs.
- **Long Grass Maintenance Area Expansion:** encourage filtration of pollutants, promote shallow sheet flow, discourage geese gathering, establish native grass species and expand buffer zones to all applicable drainage ways.
- **Sanitary Sewer Line Inspection Program:** preventative maintenance program that involves internal inspection of sanitary sewer systems using a T.V. camera mounted on a sled and pulled by an electric winch.
- **Dry Weather Storm Drainage Screening Program:** visual monitoring and sampling.
- **Targeted Rain Garden Program:** cost-share programs/incentivizing.
- **Targeted Rain Barrel Program:** build-your-own rain barrel classes and workshops; cost-share programs.
- **LPSNRD Cost-share Program:** cost-share programs to assist landowners with the implementation of BMPs. Currently funds up to 50% of total project costs up to a max of \$10,000 for selected projects using eligible practices.
- **Low/No-Phosphorus Fertilizers Program:** establish a low/no-phosphorus fertilizer program that educates and encourages the community to use these types of fertilizers; make soil testing available for low/no cost to residents.
- **Snow and Ice Management:** avoid piling up snow; orient snow dump sites such that snowmelt is directed through an appropriate BMP before entering a waterway.
- **Cost Share Program for the Antelope Park sub basin:** 75% cost share program for rain gardens, depaving, deep rooting lawn seeding, redirecting runoff up to a maximum of \$2,000 for residents that live in the sub drainage area encompassing Antelope Park.

New Programs

- **Urban Wildlife Management:** retrofit bridges and overpasses to reduce feeding, watering, roosting, and nesting of birds; perform a wildlife assessment study to determine species present in the watershed and find ways to limit habitat of nuisance species that may be contributing to the pollutant load.
- **Rooftop and Parking Lot Disconnection Incentive Programs:** disconnections from impervious surfaces; incentive programs to disconnect downspouts and roof drains from spilling onto impervious surfaces; identify locations in Basin Plan where parking lot drainage to storm drain inlets could be disconnected and directed to stormwater BMPs; use pervious pavement.
- **Quantitative Microbial Risk Assessment (QMRA):** conduct a QMRA to increase knowledge on specific types of bacteria present and further understand the risks to human health associated with those types.

- **Antelope Creek Water Quality Partnership:** have an active group of stakeholders available to support implementation of BMPs in the watershed and encourage others in the watershed to utilize stormwater controls as part of any planned development or redevelopment project.
- **Operation and Maintenance Plan for Sediment Removal:** establish a plan; mechanically or hydraulically remove sediment; coordinate with the USACE to provide occasional flushing flows.
- **Urban Soil Quality Restoration:** establish a program that provides education and incentives for residents to reduce soil compaction, increase pore space, improve organic matter content, and reestablish soil dwelling populations of microbes, worms, insects, etc.
- **Paired Watershed Study:** monitor the effectiveness of small scale structural and non-structural BMPs through water quality monitoring of where the BMPs are implemented and an adjacent watershed of similar size.

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