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WRECK POND WATERSHED MICROBIAL SOURCE TRACKING STUDY

Final Report

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WRECK POND WATERSHED
MICROBIAL SOURCE TRACKING STUDY

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The project was conducted by the Monmouth University Urban Coast Institute's Center for Coastal Watershed Management (CCWM) in collaboration with Princeton Hydro, LLC.

The goal of the CCWM is to spearhead the application of science and technology to the effective management of watershed resources in New Jersey's coastal environment. The Center serves as a focal point for the development of leading edge approaches to the solution of problems facing local communities and decision–makers at all levels of government by promoting interdisciplinary studies of coastal watersheds by Monmouth University faculty, students, associates, and colleagues; and fostering collaboration between citizens, watershed and community organizations, governmental agencies, local businesses, the scientific community, and other parties interested in watershed management and restoration.

The mission of the Monmouth University Urban Coast Institute (UCI) is to serve the public interest as a forum for research, education and collaboration that fosters the application of the best available science and policy to support healthy and productive coastal ecosystems and a sustainable and economically vibrant future for coastal communities.

Princeton Hydro (pH) is an ecologically based consulting firm and is recognized as one of the area's leading firms involved in watershed management and restoration.

Dr. Michael Palladino, Associate Professor in the Monmouth University Biology Department, supervised the antibiotic resistance analysis laboratory component of this project. Urban Coast Institute Research Associates who worked on various phases of this project included Suzanne DeLorenzo and Thomas LePage. Undergraduate students from the Monmouth University Marine and Environmental Biology and Policy program also assisted with field and laboratory work associated with this project. Assistance with production of GIS maps was provided by Jaclyn LaMotta and J.P. Bell of Princeton Hydro.

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WRECK POND WATERSHED
MICROBIAL SOURCE TRACKING STUDY

1.0 INTRODUCTION

The Wreck Pond watershed, located in southern Monmouth County, New Jersey, encompasses approximately 8,328 acres (Figure 1). The watershed and includes those portions of Wall Township that drain to Wreck Pond and its tributaries upstream of the discharge point of Old Mill Pond. Smaller portions of the watershed are located in the Borough of Spring Lake Heights, Sea Girt and Spring Lake where water drains to Wreck Pond, Wreck Pond Brook, and the North Branch (also known as Black Creek). Osborne Pond, Albert Pond, and Taylor's Pond are located along Wreck Pond Brook upstream of Old Mill Pond, while Hannabrand Brook, located in Wall Township, discharges to Wreck Pond Brook downstream of Old Mill Pond. At the eastern terminus of Wreck Pond a weir and outfall pipe have been constructed that, during periods of heavy storm associated flow, allows water to be discharged to the Atlantic Ocean in Spring Lake.

Surface water classifications for Wreck Pond and other waterbodies within the watershed are listed in Table 1. All waterbodies in the watershed are classified as freshwater two, nontrout producing waters (NJDEP, 2006).

Land use and land cover in the Wreck Pond watershed is summarized in Table 2 and depicted in Figure 2. Urban uses account for nearly 55% of the watershed area, a majority of which is designated as residential. Agricultural uses are also notable; there are many farm ponds as well as detention ponds for residential housing scattered throughout the watershed. About a third of the watershed can be considered undeveloped. Together forest and wetlands comprise approximately 30% of the watershed area.

Wreck Pond has traditionally been a recreational destination for local residents engaging in activities like fishing, canoeing, kayaking, and bird watching. However, recent studies on Wreck Pond and the component waterbodies within the watershed have identified impairments attributed to fecal coliform contamination. A major environmental problem associated with pathogen contamination in Wreck Pond is the periodic closing of adjacent ocean bathing beaches in Spring Lake and Sea Girt from elevated fecal coliform levels in water and sediment discharged from the pond to the ocean during storm events (NJDEP, 2002; MCPB, 2001). Fecal coliform impairments have been severe enough to result in Wreck Pond Brook being included on the list of fecal coliform impaired stream segments in the New Jersey Water Quality Monitoring and Assessment Report (NJDEP, 2003). Subsequently, to address these impairments, a Total Maximum Daily Load (TMDL) for fecal coliform mandating a 51% reduction in contaminant levels was proposed for Wreck Pond Brook (NJDEP, 2003). A TMDL is based on the assimilative capacity of a waterbody in terms of its ability to conform to applicable water quality standards and support designated uses and quantifies the amount of a pollutant reduction necessary to meet that criteria.

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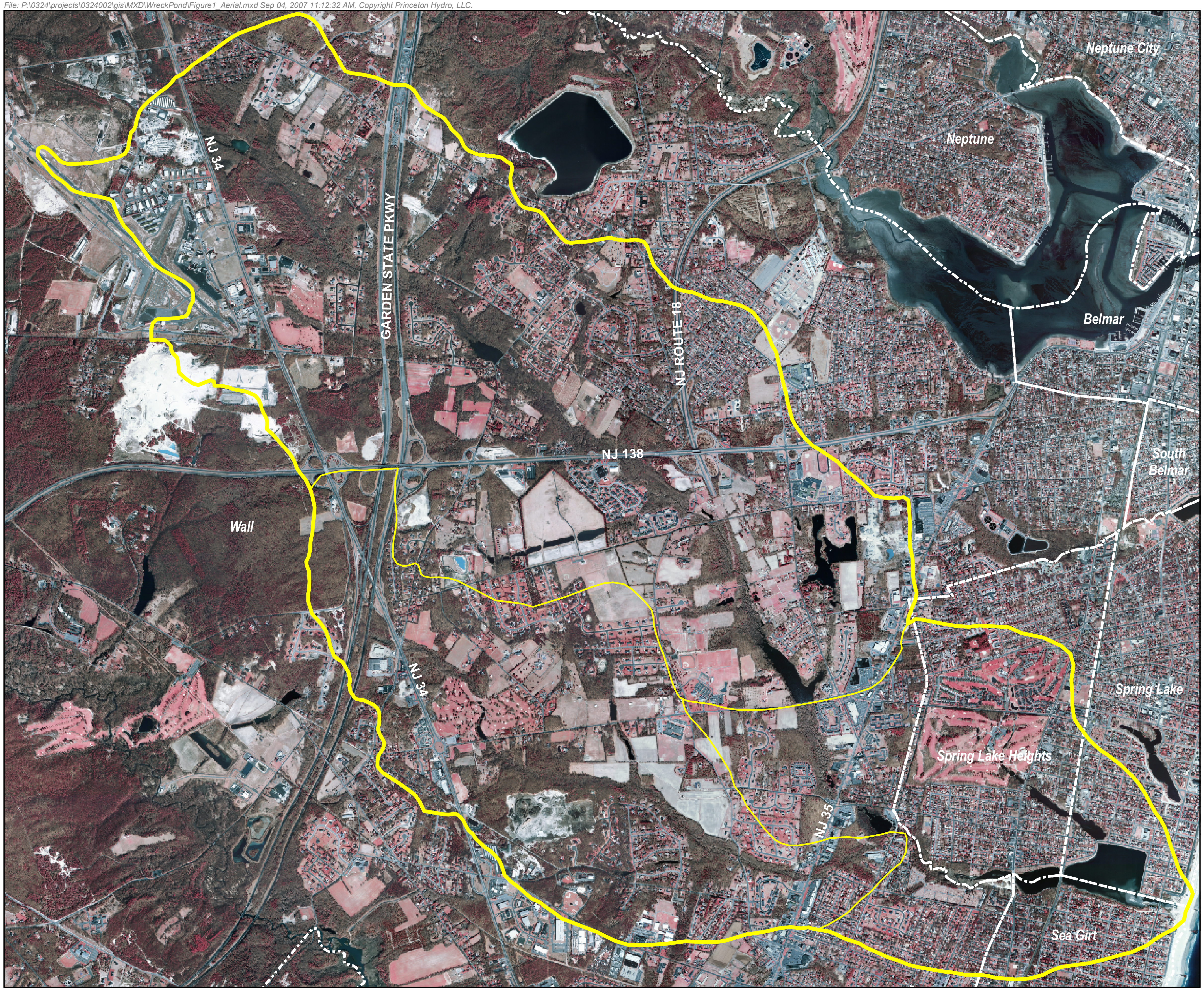

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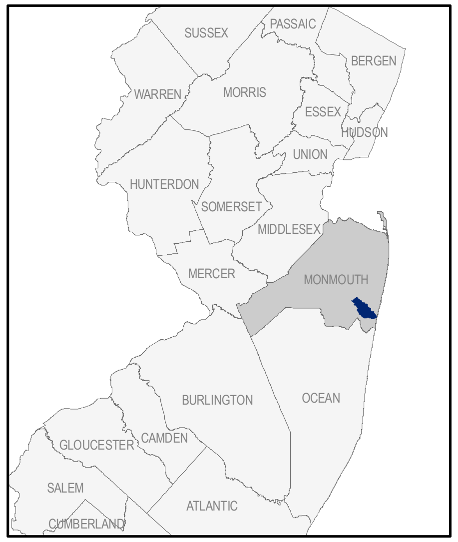
NEW JERSEY COUNTY MAP



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0 1,250 2,500 Feet
1 inch equals 2,500 feet

SOURCES:

1. 2002 Aerial Photographs obtained from the NJ Image Warehouse.
2. Municipal boundaries as obtained from the NJDEP GIS website.
3. Roads data obtained from the NJDOT.

FIGURE 1: 2002 AERIAL PHOTOGRAPH

MONMOUTH UNIVERSITY PATHOGEN STUDY WRECK POND WATERSHED

Legend

Watershed Boundary
Subwatersheds

Table 1. Wreck Pond Watershed Surface Water Classifications

Waterbody	Surface Water Classification
Wreck Pond (Wall) - Entire length	FW2-NT
Wreck Pond Brook	FW2-NT
Black Creek	FW2-NT
Hannabrand Brook	FW2-NT
Old Mill Pond	FW2-NT
Osborne's Pond	FW2-NT
Albert's Pond	FW2-NT
Hurley's Pond	FW2-NT
Unnamed Tributaries	FW2-NT

FW - the general surface water classification applied to fresh waters - all nontidal and tidal waters generally having a salinity, due to natural sources, of less than or equal to 3.5 parts per thousand at mean high tide.

FW1 - those fresh waters, as designated in N.J.A.C. 7:9B-1.15(h) Table 6, that are to be maintained in their natural state of quality (set aside for posterity) and not subjected to any man-made wastewater discharges or increases in runoff from anthropogenic activities. These waters are set aside for posterity because of their clarity, color, scenic setting, other characteristic of aesthetic value, unique ecological significance, exceptional recreational significance, exceptional water supply significance, or exceptional fisheries resource(s).

FW2 - the general surface water classification applied to those fresh waters that are not designated as FW1 or Pinelands Waters.

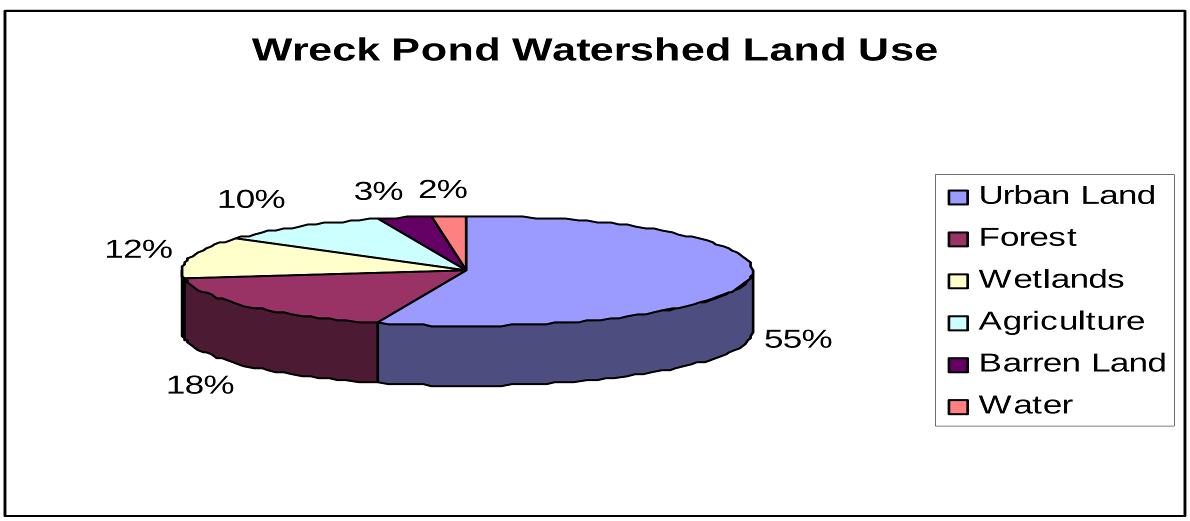
C1 - Category One waters - those waters designated in the tables in N.J.A.C. 7:9B-1.15(c) through (h), for purposes of implementing the antidegradation policies set forth at N.J.A.C. 7:9B-1.5(d), for protection from measurable changes in water quality characteristics because of their clarity, color, scenic setting, other characteristics of aesthetic value, exceptional ecological significance, exceptional recreational significance, exceptional water supply significance, or exceptional fisheries resource(s).

NT - nontrout waters - fresh waters that have not been designated in N.J.A.C. 7:9B-1.15(b) through (h) as trout production or trout maintenance. These waters are generally not suitable for trout because of their physical, chemical, or biological characteristics, but are suitable for a wide variety of other fish species.

TM - trout maintenance - waters designated in N.J.A.C. 7:9B for the support of trout throughout the year

Table 2. Land Use/Land Cover in the Wreck Pond Watershed

Land Use Category	Land Use/ Land Cover (km^2)	Percent Of Watershed
Urban	17.91	54.98%
Forest	6.02	18.49%
Wetlands	3.75	11.52%
Agriculture	3.23	9.91%
Barren Land	0.89	2.73%
Water	0.77	2.37%
Total Area	32.57	100%



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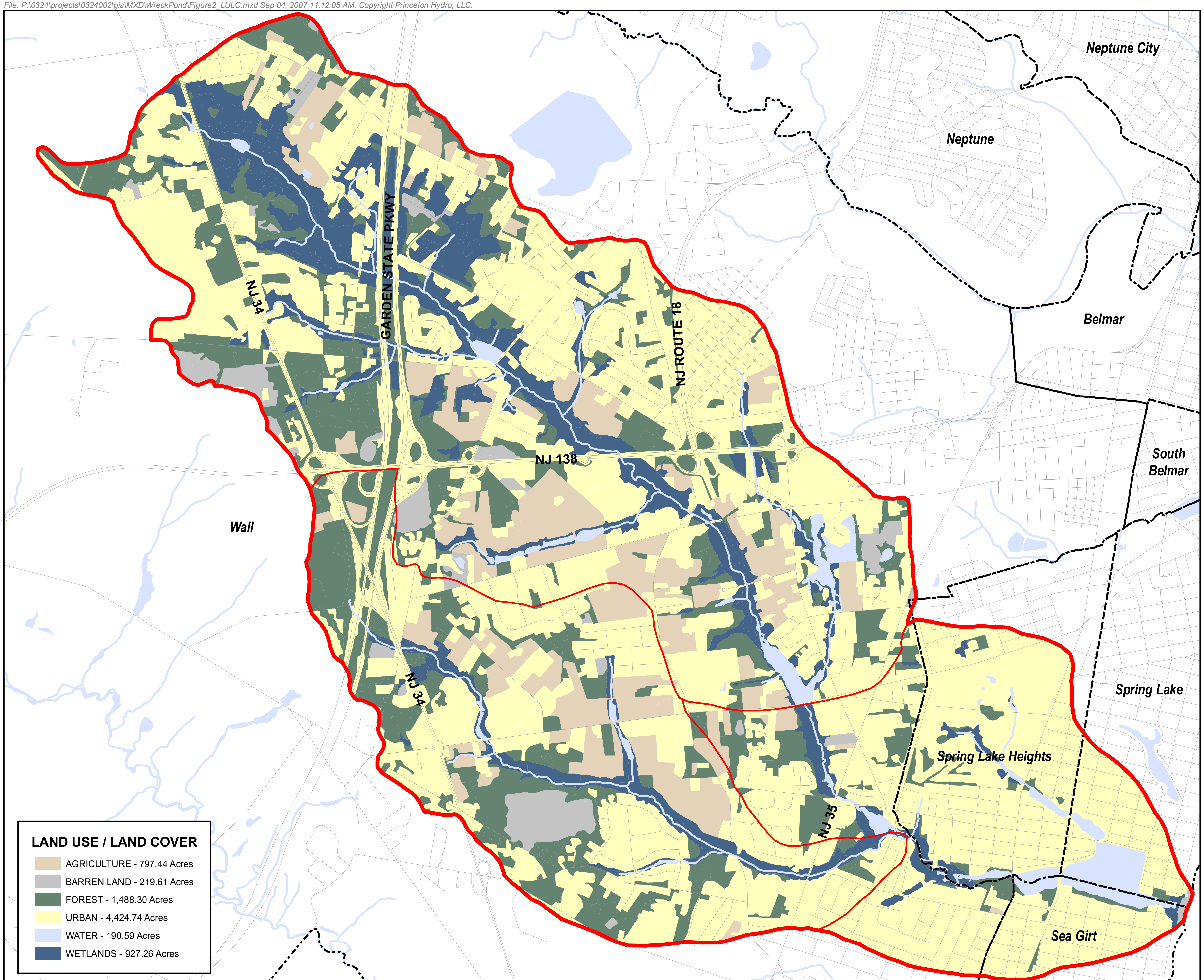
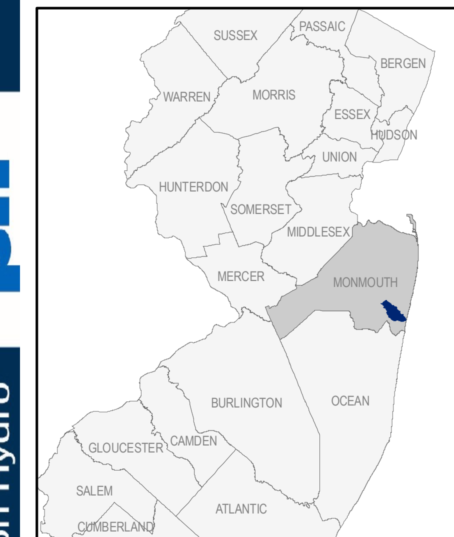


Princeton Hydro

NEW JERSEY COUNTY MAP



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SOURCES:

1. Stream, lakes, municipal boundary and land use data obtained from the NJDEP GIS website.

2. Roads data obtained from the NJDOT.

FIGURE 2: LAND USE / LAND COVER

MONMOUTH UNIVERSITY PATHOGEN STUDY
WRECK POND WATERSHED

Legend

- Watershed Boundary
- Subwatersheds
- Roads
- Lakes
- Streams

2.0 GOALS AND OBJECTIVES OF THE WRECK POND WATERSHED MICROBIAL SOURCE TRACKING STUDY

In order to effectively achieve reductions in pathogen loadings, the actual contribution of bacteria from specific sources and land uses in the watershed need to be identified as part of the stormwater management process. The Wreck Pond Watershed Microbial Source Tracking study was initiated to assist with the regional stormwater management process for the Wreck Pond watershed by:

- Characterizing potential sources of bacterial contaminants contributed to the Wreck Pond watershed using Microbial Source Tracking (MST) methodologies.
- Providing information that assists the regional stormwater management committee with development of drainage area-specific water quality objectives.
- Providing data necessary for the selection of applicable stormwater management measures that result in improved water quality by controlling sources of pollutants (pathogens) that adversely affect beneficial uses of each of the component waterbodies that comprise the Wreck Pond watershed.

3.0 APPROACH

3.1 Microbial Source Tracking Using Antibiotic Resistance Analysis

Microbial Source Tracking (MST) refers to a group of emerging techniques that provide promise for determining the sources of fecal bacteria that contaminate and degrade the quality of aquatic ecosystems. MST uses host-associated characteristics of various microorganisms present in feces and relies on the premise that humans and animals have host-specific or host-adapted strains of *Escherichia coli* and other targeted bacteria (Edge and Schaefer, 2006; Stoeckel, 2005; USEPA, 2005). Three different approaches to MST can be used: phage typing, genetic profiling and antibiotic resistance analysis (ARA).

Phage typing is an MST method based on identifying F+ coliphages, which are viruses that infect *E. coli*. These phages belong to four groups: two groups are associated with human *E. coli* strains, another group is associated with animal strains, and the last group is associated with both humans and animals. A limitation of phage typing is that it can only discriminate between human and nonhuman sources; it does not distinguish among different animal host species (e.g., cows, ducks, cats, raccoons) (USEPA, 2005).

The basic concept behind genetic MST methods is that the strains of *E. coli* living in the intestinal tracts of dogs will have genetic differences compared to the *E. coli* strains inhabiting the intestines of humans or deer or geese, etc. Various techniques developed for the science of molecular genetics are used to detect these differences in bacterial DNA. Some of the more common genetic profiling MST methods are ribotyping, pulsed-field gel electrophoresis (PFGE), and repetitive element sequence-based polymerase chain reaction (rep-PCR). In these approaches, specific fragments of DNA are obtained from a bacterial strain and analyzed to produce patterns for the profile of that particular strain of bacteria. Results are compared to profiles in a library of bacterial strains from known host species (USEPA, 2005).

Antibiotic Resistance Analysis (ARA) is a phenotypic library-based MST technique developed as a method for microbial source tracking based on the assumption that bacteria from the intestines of humans and domestic animals will have different antibiotic profiles. The antibiotic profiles should differ because hosts exposed to different antibiotics or differing amounts of the same or similar antibiotics will develop varying resistance to those antibiotics (Atherholt, 2005: USEPA, 2005).

ARA methodology can target *E. coli*, fecal streptococci or *Enterococcus spp*. An extensive library of antibiotic resistance (AR) profiles of the target pathogen isolated from humans and various other animals forms the basis of ARA research. In building an ARA library, specific, known fecal samples from organisms designated as important based on previous estimates of pollution in a particular watershed are harvested.

None of the MST methods described above, including the ARA methods outlined in this report, is completely satisfactory. The genetic approaches generally give the most reliable results, but are also the most expensive. Antibiotic resistance and genetic profiling methods are both library-dependent, requiring a reference library or database of hundreds or even thousands of different bacteria strains collected from host species in the region under investigation. With both these approaches, it is fairly common to either find no match or to find too many matches (i.e., pattern overlap). Because of this, matches are not always completely clear and must be cross-referenced with other types of information or data.

Nonetheless, although MST/ARA methodology is not an exact science, MST/ARA provides a survey of many samples rather than intensive analysis of one strain. When combined with statistical analysis it provides a coherent picture of the whole watershed. Therefore, this methodology greatly expands the ability to better identify sources of fecal related contamination and water quality impairments. This makes the methodology particularly useful in prescribing remedial actions that specifically address these sources when developing watershed based pollutant load reduction plans.

A library of antibiotic resistance (AR) profiles from *E. coli* isolated from humans and various other animals forms the basis of the MST work for this project. Monmouth University developed an AR profile library during research projects conducted in Monmouth County from 2000-2003. The library of AR profiles for *E. coli* was developed from isolates from twenty species of organisms from coastal watersheds in the region. The organisms included in this database were selected because of their potential contribution to bacterial loadings in Monmouth County coastal watersheds.

Feces from between 3 and 12 individuals of each species were collected and processed according to our established ARA procedures outlined below. This resulted in the creation of a searchable library (database) with AR profiles for over 5000 fecal *E. coli* isolates from the organisms targeted for study.

The resulting library of AR profiles was grouped into five categories (Table 3): humans, pets, farm animals, avifauna (birds), and non-avifauna (wild mammals). The AR profiles were categorized in this manner because: (1) the number of replicate fecal samples for some types of animals was limited; and (2) environmental factors can cause pattern overlap which results when AR profiles of multiple host species are similar. In addition, categorizing AR profiles into these groupings was essential for making accurate determinations of the relative contribution of each source group to water quality problems at specific sampling sites.

Table 3. Organisms Designated for Study in the Monmouth Coastal Watersheds Region

Category	**Species Included**
Humans	Humans only
Pets	Domestic and stray cats, domestic dogs
Farm Animals	Horses, pigs, cattle, chickens
Avifauna	Canada geese, gulls, mallard ducks, black ducks, brant, canvasback ducks
Non-avifauna	Raccoons, muskrats, skunks, opossum, deer, rats, mice

In our ARA work, *E. coli* isolated from fecal samples were grown, individually, in the presence of twelve antibiotics (Table 4). Antibiotics were selected primarily because of their widespread applications in animals and humans, as well as their diverse mode of action and molecular target (Kaspar, 1990). All antibiotics were purchased from Sigma-Aldrich, St. Louis, MO and antibiotic plates used for ARA were less than 3 weeks old.

Fresh fecal samples or anal swabs from domestic animals, livestock, wild animals, and avifauna were collected into sterile Whirl-Pak bags. In order to develop resistance patterns for humans in the watershed, grab samples of sewage treatment plant influent were collected in sterile 500 ml Nalgene bottles. Samples were kept in a cooler with ice and delivered to the lab for processing and ARA testing within 6 hours after collection. In the laboratory, fecal and influent samples were processed according to established guidelines for culturing fecal *E. coli* in wastewater samples (APHA, 1998) as follows:

Approximately 100-500 mg of the fecal or influent sample were suspended in 10-50 ml of multiple antibiotic resistance (MAR) saline (8.5 g NaCl, 0.3 g KH_2PO_4, and 0.6 g Na_2HPO_4 per liter at pH 7.3) and vortexed until the sample was thoroughly mixed. The salinity of MAR saline (8 ppt) approximates the salinity of brackish estuarine waters. After allowing particulate material to settle to the bottom of the culture tube, approximately 3-25 ml (depending on the fecal sample) of the mixture was filtered though a 0.45 µm pore-size GN-6 filter (Gelman Laboratory, Ann Arbor, MI). Using sterile forceps, the filter was transferred to a 15 × 60 mm culture plate containing mTEC agar. Plates were incubated at 35°C ± 0.5ºC for 2 hours, then sealed in a Whirl-Pak® bag and placed on a rack in a 44.5°C ± 0.2ºC water bath for 22-24 hours.

Following isolation, clones of *E. coli* isolated from fecal samples for each target species were subjected to ARA testing according to our established guidelines and procedures adapted from Parveen *et al.* (1997) and Wiggins *et al.* (1999) which are outlined below.

Table 4. Antibiotics Used in ARA Testing and Mode of Action

Antibiotic	Mechanism of Action	Specificity	Applications
Ampicillin	Bacteriocidal, kills *E. coli* by inhibiting cell wall synthesis	*E. coli*, Gram -	Humans, not permitted for use in food animals
Amoxicillin	Bacteriocidal, inhibits cell wall synthesis, one of 1st penicillins along with ampicillin	Gram -	Humans,
Chlortetracycline (Aureomycin)	Bacteriostatic, broad spectrum tetracycline class, inhibit protein synthesis	Gram + and -	Humans, food animals – poultry, cattle, swine
Kanamycin	Bacteriocidal, inhibits protein synthesis by blocking translocation, binds to 70S subunit	Gram -	Humans, not allowed for use in food animals
Nalidixic Acid	Bacteriostatic, inhibits DNA synthesis by inhibiting DNA gyrase	Gram + and -	Humans, not allowed for use in food animals
Neomycin	Bacteriocidal, inhibits protein synthesis (aminoglycoside – amino sugars linked by glycoside bonds, strep in this family but rapid R developed)	Gram -	Humans (topical ointment), food animals – poultry, cattle, swine
Oxytetracycline (Terramycin)	Bacteriostatic, broad spectrum tetracycline class, inhibit protein synthesis	Gram + and -	Humans, food animals – poultry, cattle, swine
Penicillin G	Bacteriocidal, inhibits cell wall synthesis, natural penicillin	Gram +	Humans, food animals – poultry, cattle, swine
Streptomycin Sulfate	Bacteriocidal, aminoglycoside, inhibits protein synthesis by binding to 30S ribosomal subunit	Gram -	Humans, not allowed for use in food animals
Sulfathiazole	Bacteriostatic, inhibits folate synthesis	Gram + and -	Humans, not allowed for use in food animals
Tetracyline	Bacteriostatic, inhibits protein synthesis by preventing binding of aminoacyl tRNA to A site	Gram + and Gram -	Human
Vancomycin	Bacteriocidal, inhibits cell wall synthesis	Gram + (Staph)	Humans, treatment of cardiac staph infections

Lactose-fermenting (blue) colonies from mTEC agar plates were picked with sterile micropipette tips and used to inoculate individual wells of a 96-well plate containing 200 µl aliquots of Trypticase Soy (T-Soy) broth. Whenever possible, 48 independent isolates were used. Multiwell plates were incubated in an environmental chamber at 35°C overnight.

T-Soy agar antibiotic plates (105 × 15 mm) were prepared by adding the desired amount of antibiotic to T-Soy agar cooled to 50°C:

ampicillin (40µg/ml)	nalidixic acid (25µg/ml)	streptomycin sulfate (15µg/ml)
amoxicillin (15µg/ml)	neomycin (50µg/ml)	sulfathiazole (750µg/ml)
chlortetracycline (25µg/ml)	oxytetracycline (25µg/ml)	tetracycline (25µg/ml)
kanamycin (25µg/ml)	penicillin G (75U/ml)	vancomycin (10µg/ml)

Using a 48-prong stainless steel replica plater, *E. coli* isolates were replica plated from multiwell plates onto two control plates, one of T-Soy agar and one of T-Soy agar containing 100 µg/ml of 4-methylumbelliferyl-β-D-glucuronide (MUG; Sigma), and each of the 12 T-Soy agar antibiotic plates.

Controls for antibiotic activity were used. All plates were streaked with cells from a fresh overnight culture of *E. coli* (American Type Culture Collection 9637 or JM109 *E. coli*) as a negative control (sensitive to all antibiotics except penicillin G and vancomycin) and *Pseudomonas aeruginosa* (85W1703; Ward's, Rochester, NY) as a positive control (resistant to all antibiotics except sulfathiazole, neomycin, and tetracycline). Plates were incubated in an environmental chamber at 35°C overnight.

MUG fluorescence was used to assay β-D-glucuronidase activity, which is typical of the *Enterobacteriaceae*. MUG activity and detergent resistance, i.e. growth of blue colonies on modified mTEC agar, was considered diagnostic for *E. coli*. MUG-positive *E. coli* isolates on T-Soy agar/MUG plates were verified by fluorescence under long-wave UV light. MUG-negative isolates were not scored. To further verify the presence of gram-negative bacteria, fecal isolates were periodically subjected to Gram-staining with *E. coli* and *P. aeruginosa* as controls.

Upon completion of sample processing, isolates were scored as antibiotic resistant if colony diameter and growth on an antibiotic plate was indistinguishable from growth on T-Soy, and T-Soy + MUG plates. Any colonies showing more than 15% reduction in size were scored as sensitive.

Scores were tallied on standardized ARA scoring sheets that were developed for our studies. Once scored, ARA patterns were identified. ARA indices (number of antibiotics to which isolates were resistant ÷ total number of antibiotics tested) from individual organisms of a given species were recorded in Excel files and catalogued in a searchable database for use in comparing patterns obtained from water and sediment samples collected in local watersheds to our library of AR profiles.

ARA patterns for each animal in the database were compared to the entire database to determine the average rate for correct classification (ARCC). The ARCC was calculated to determine the percentage of correctly and incorrectly classified isolates. This measure allows us to examine the feasibility of using the database to accurately identify the source of an unknown sample. Generally, ARCCs below 25% represent random classification and thus are inaccurate for identifying sources of fecal isolates.

As shown in Table 5, ARCCs for the four major categories of organisms studied were above the 25% level of random classification generally accepted for ARA analysis. In particular, the ARCC for humans was high (93.1%) suggesting that ARA analysis is a more specific tool for identifying human sources of fecal pollution than for determining specific animals sources of fecal pollution. ARCCs for other categories of animal species showed slightly lower values, which is not surprising given the number of pattern overlaps between species. Nonetheless, ARCCs for pets, farm animals, and wild animals were higher than 25%; therefore, the current ARA database does have sufficient specificity for categorizing unknown sources of fecal pollution as originating from humans, pets, farm animals, or wild animals.

Table 5. Average Rate of Correct Classification (ARCC) of Fecal *E. coli* Isolates by ARA

Source	Number of Isolates	ARCC (%)
Humans	475	93.1%
Pets	722	64.6%
Farm Animals	1215	81.1%
Wild Animals		
-Avifauna	1331	74.4%
-Non-avifauna	536	78.9%

3.2 Field Methods

3.2.1 Sampling Station Selection

Sampling stations were established throughout the Wreck Pond watershed based on a number of considerations:

- Monmouth County Department of Health sampling stations experiencing elevated fecal coliform levels (MCHD, 2003).
- Sampling stations from the NJDEP Ambient Biological Monitoring (AMNET) Network (NJDEP, 2003).
- Sampling stations from Sublists 1-5 in the New Jersey 2002 Integrated Water Quality Monitoring and Assessment Report (NJDEP, 2003).
- Stations previously sampled by the project partners.

Stations selected based on these considerations are listed in Table 6 and depicted in Figure 3.

Table 6. Sampling Station Locations for the Wreck Pond Watershed

WRECK POND WATERSHED STATIONS	STATION NAME	STATION LOCATION
Station 1	Wreck Pond West of Oceanfront Floodgate	Salt pond area west of ocean floodgate south of the municipal parking lot adjacent to Brown Avenue Latitude: 40°08.317' N; Longitude: 74°01.641'W
Station 2	Wreck Pond at Second Avenue	Wreck Pond shoreline at the intersection of Second Avenue and Ocean Road Latitude: 40°08.524' N; Longitude: 74°01.782'W
Station 3	Wreck Pond	Northern shore of Wreck Pond south of Ocean Road crossing Latitude: 40°08.588' N; Longitude: 74°02.059'W
Station 4	Black Creek (N. Branch) at Ocean Road	Eastern shore of Black Creek at the intersection of Ocean Road and Fourth Avenue Latitude: 40°08.603' N; Longitude: 74°02.010'W
Station 5	Black Creek (N. Branch) East of Route 71	Stream channel of Black Creek east of Route 71 across from the Spring Lake Golf Club Latitude: 40°08.827' N; Longitude: 74°02.455'W
Station 6	Wreck Pond Brook West of Route 71	Southern shore of Wreck Pond Brook west of Route 71 adjacent to Jimmy Byrne property Latitude: 40°08.428' N; Longitude: 74°02.579'W
Station 7	Wreck Pond Brook at Old Mill Road	Northern shore of Wreck Pond Brook east of Old Mill Road at the intersection of Old Mill Road and Butternut Road Latitude: 40°08.609' N; Longitude: 74°03.189'W
Station 8	Old Mill Pond	Northeast shore of Old Mill Pond at the Old Mill Inn restaurant boat ramp Latitude: 40°08.699' N; Longitude: 74°03.261'W
Station 9	Osborn Pond	Osborn Pond at foot of Mill Pond Court Latitude: 40°09.350' N; Longitude: 74°03.572'W
Station 10	Albert Pond	Albert Pond at intersection of Oxford Lane and private road Latitude: 40°09.719' N; Longitude: 74°03.516'W
Station 11	Wreck Pond Brook at Allenwood Road	Stream channel east of Allenwood Road crossing just downstream from Hurley Pond Latitude: 40°10.652' N; Longitude: 74°05.421'W
Station 12	Hannabrand Brook At Allaire Road	Eastern stream bank of Hannabrand Brook on south side of Allaire Road across from Bel-Aire County Golf Course Latitude: 40°09.032' N; Longitude: 74°05.483'W

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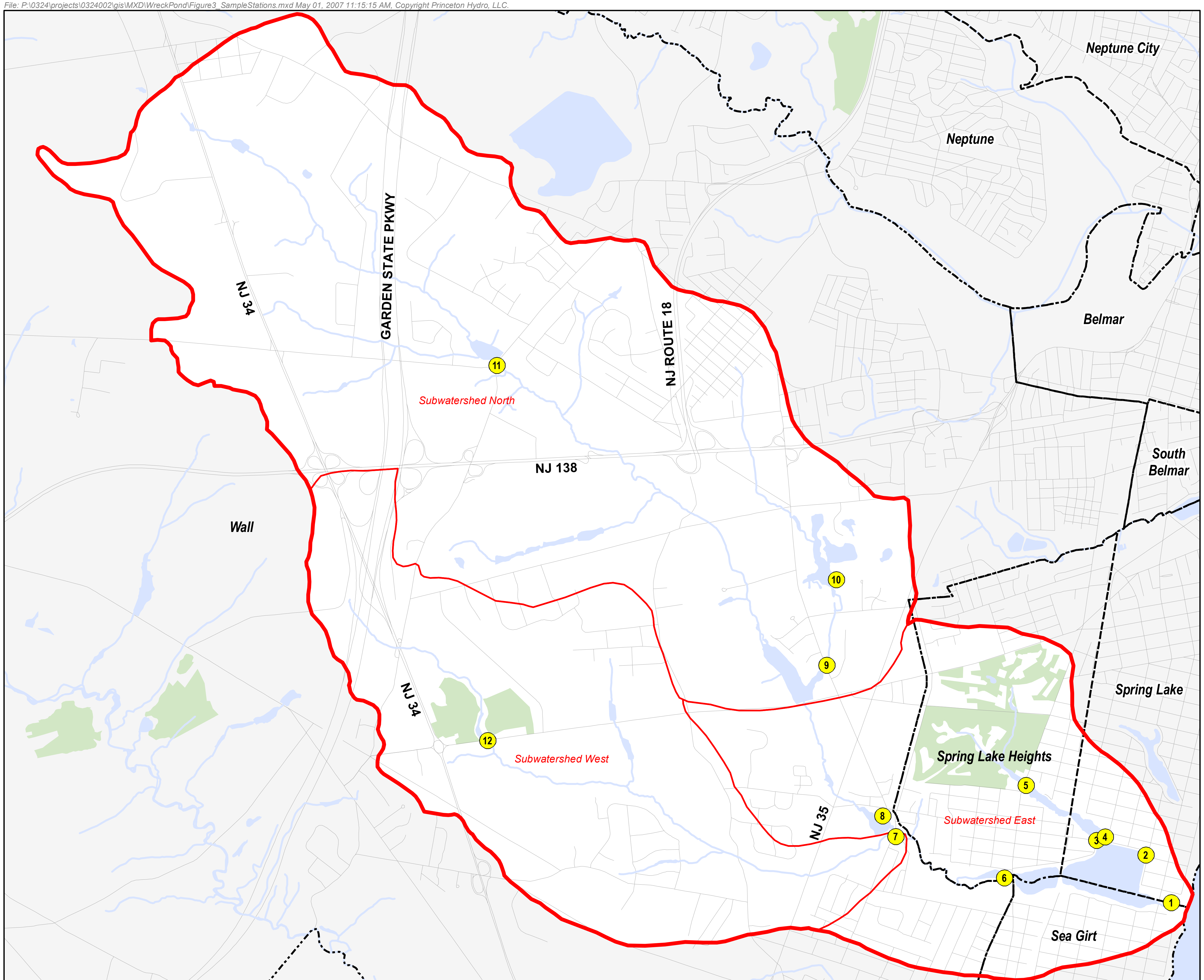

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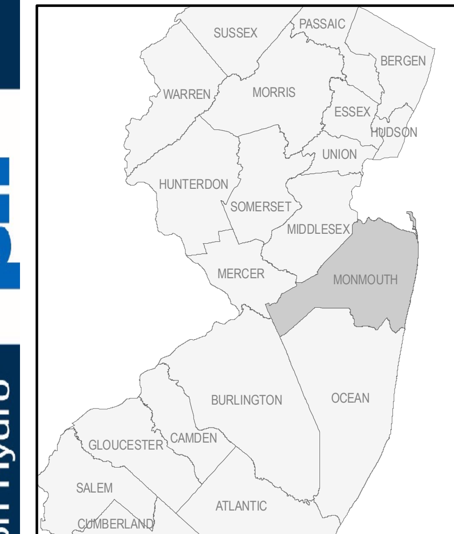
NEW JERSEY COUNTY MAP



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0 1,250 2,500 Feet

1 inch equals 2,500 feet

SOURCES:

1. Streams, lakes and municipal boundary data as obtained from the NJDEP GIS website.

2. Roads data obtained from the NJDOT.

FIGURE 3: SAMPLE STATIONS

MONMOUTH UNIVERSITY PATHOGEN STUDY WRECK POND WATERSHED

Legend

- Sample Station
- Watersheds
- Subwatersheds
- Roads
- Streams
- Lakes
- Golf Courses

3.2.2 Sampling Schedule

Sampling events were conducted in the Wreck Pond watershed on the following dates:

- June 16, 2005
- June 27, 2005
- July 13, 2005
- July 25, 2005
- August 9, 2005
- August 23, 2005
- September 15, 2005
- September 29, 2005

3.2.3 Water Sampling Procedures

Surface Water Quality Measurements –

Surface water quality measurements made at each sampling station included the following parameters: water temperature, salinity, dissolved oxygen, pH, water transparency, and depth. These data, with the exception of water transparency, were acquired by using a YSI 600XL datasonde with a cable connection to a hand-held display unit, which was calibrated in the laboratory prior to each sampling event. Water transparency was determined with a secchi disk.

It should be noted that the intended use of these ancillary data was to assist in the ARA analysis, in particular in interpreting any anomalies in water quality conditions that may have bearing on the ARA results.

Water Sample Collection –

Surface water samples were collected at each sampling station using sterile 50 ml conical tubes. At each station, two 50-ml surface water samples were acquired from the upper meter of the water column. Each water sample container was labeled with the date, time of collection, and station number. Samples were then placed in a cooler with ice for transport to the Monmouth University laboratory within 5 hours of collection so that they could be processed within 6 hours of collection.

Sediment Sample Collection –

At each site where water depths were less than one meter a sediment sample from the surficial sediment layer (top 2-3 cm) was collected. The samples were collected using a sterile spatula and the sediment was placed in a sterile 50 ml conical tube. Each sediment sample container was labeled with the date, time of collection, and station number. The container of sediment was then placed in a cooler with ice for transport to the Monmouth University laboratory within 5 hours of collection so that the sample could be processed within 6 hours of collection.

Antibiotic Resistance Analysis of Water and Sediment Samples –

Surface water and sediment samples collected for ARA analysis were delivered to the Monmouth University lab and processed according to USEPA Method 1603: *E. coli* in Water by Membrane Filtration Using Modified Membrane-Thermotolerant *E. coli* Agar (Modified mTEC) (USEPA, 2002) and then subjected to ARA testing according to the procedures adapted from Parveen *et al*. (1997) and Wiggins *et al*. (1999) outlined above.

Upon completion of the sample processing, *E. coli* isolates from these samples were also scored as antibiotic resistant or sensitive and scores were tallied using the standardized ARA scoring sheets developed for our MST studies. Once scored, AR profiles from the water and sediment samples were identified. AR indices (number of antibiotics to which isolates were resistant ÷ total number of antibiotics tested) for these samples were recorded in Excel files and catalogued in a searchable database for use in comparing profiles obtained from water and sediment samples collected in the watershed to the AR profiles in the fecal source library.

Data Analysis –

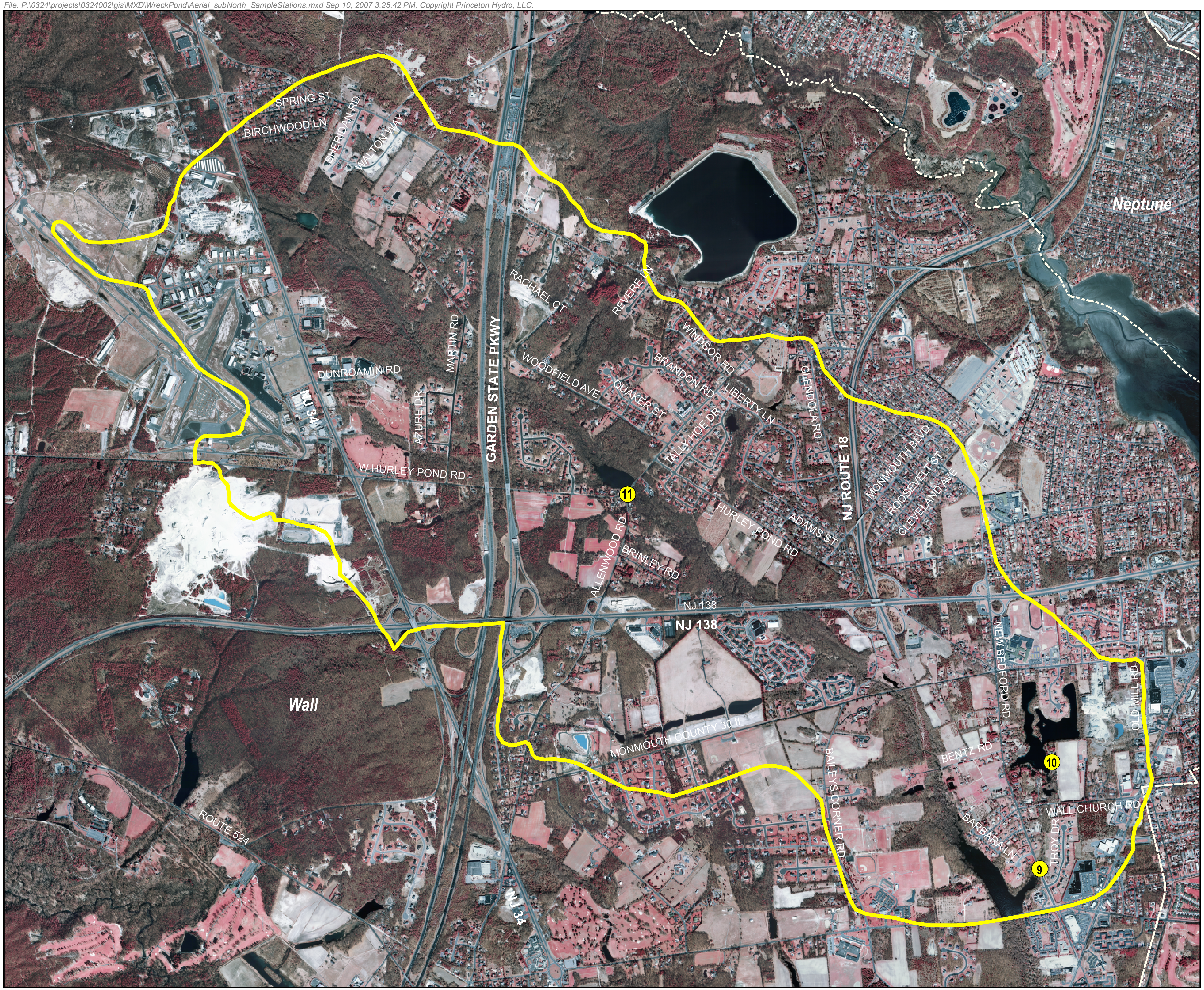
Because each water sample produces up to 48 *E. coli* isolates, large numbers of comparisons are needed to compare each to the 562 database types in the fecal source library, i.e. a calculation of 26976 correlation coefficients. After consultation with software program designers to determine a suitable method for processing the large amount of statistical information generated for each sample, SYSTAT 11 software was selected (SYSTAT Software Inc.) to handle these data. SYSTAT 11 provides robust statistical analysis capabilities that provide meaningful results to large and complex data sets.

Once analyzed, these data were used to develop profiles of the various sources of fecal contamination in the Wreck Pond watershed.

4.0 RESULTS OF THE WRECK POND WATERSHED MICROBIAL SOURCE TRACKING STUDY

Results of the Wreck Pond Watershed Microbial Source Tracking Study are presented in the following section. Each sampling site is described along with a summary of ambient water quality conditions at the time of sampling and a profile of sources of *E. coli* identified in surface water and sediment samples (detailed ambient water quality data and source profile data for surface water and sediment samples are found in Appendix A – C, respectively). Aerial maps and land use/land cover maps depicting sampling site locations within each subwatershed in the Wreck Pond watershed have also been provided. When coupled with the information discussed in Section 5.0 (Summary and Recommendations), these results will allow municipalities in the watershed to geographically identify potential land based sources of pathogen loadings based on predominant land use and source category and select appropriate areas to begin implementing the recommendations to control nonpoint sources of bacteria in the watershed.

File: P:\0324\projects\0324002\gis\MXD\WreckPond\Aerial_subNorth_SampleStations.mxd Sep 10, 2007 3:25:42 PM, Copyright Princeton Hydro, LLC.



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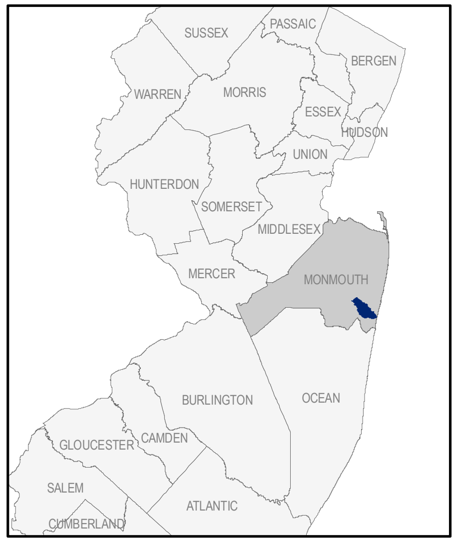
NEW JERSEY COUNTY MAP



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0 750 1,500 Feet

1 inch equals 2,000 feet

SOURCES:

1. New Jersey 2002 High Resolution Orthophotography obtained from the New Jersey Image Warehouse.

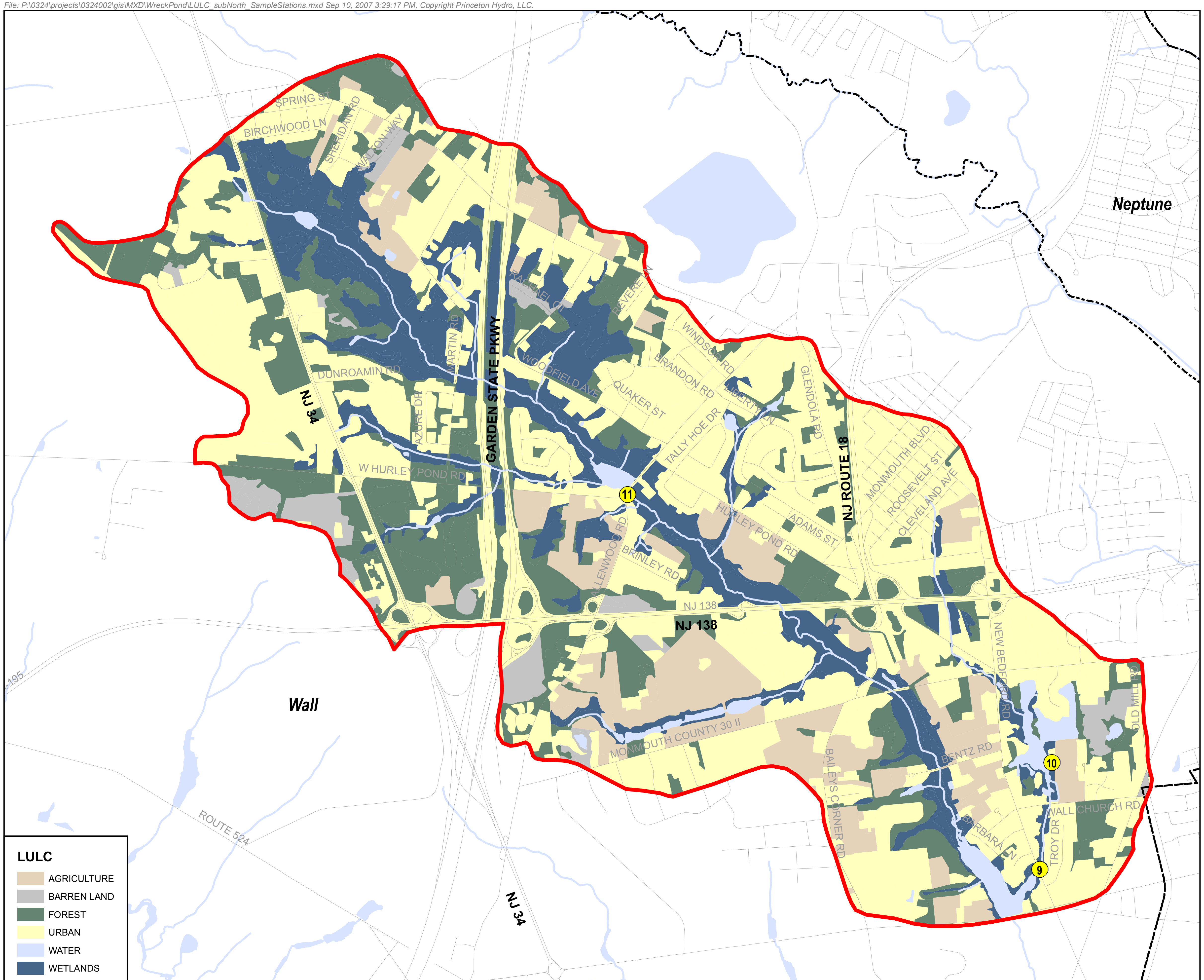
AERIAL PHOTOGRAPHY: SUBWATERSHED NORTH SAMPLE STATIONS

MONMOUTH UNIVERSITY PATHOGEN STUDY WRECK POND WATERSHED

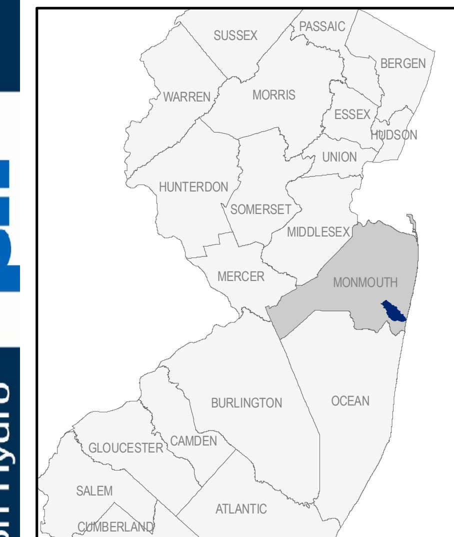
Legend

Subwatershed North Boundary

Sample Station



NEW JERSEY COUNTY MAP



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SOURCES:

1. Streams, lakes, municipal boundary data, and land use / land cover as obtained from the NJDEP GIS website.

2. Roads data obtained from the NJDOT.

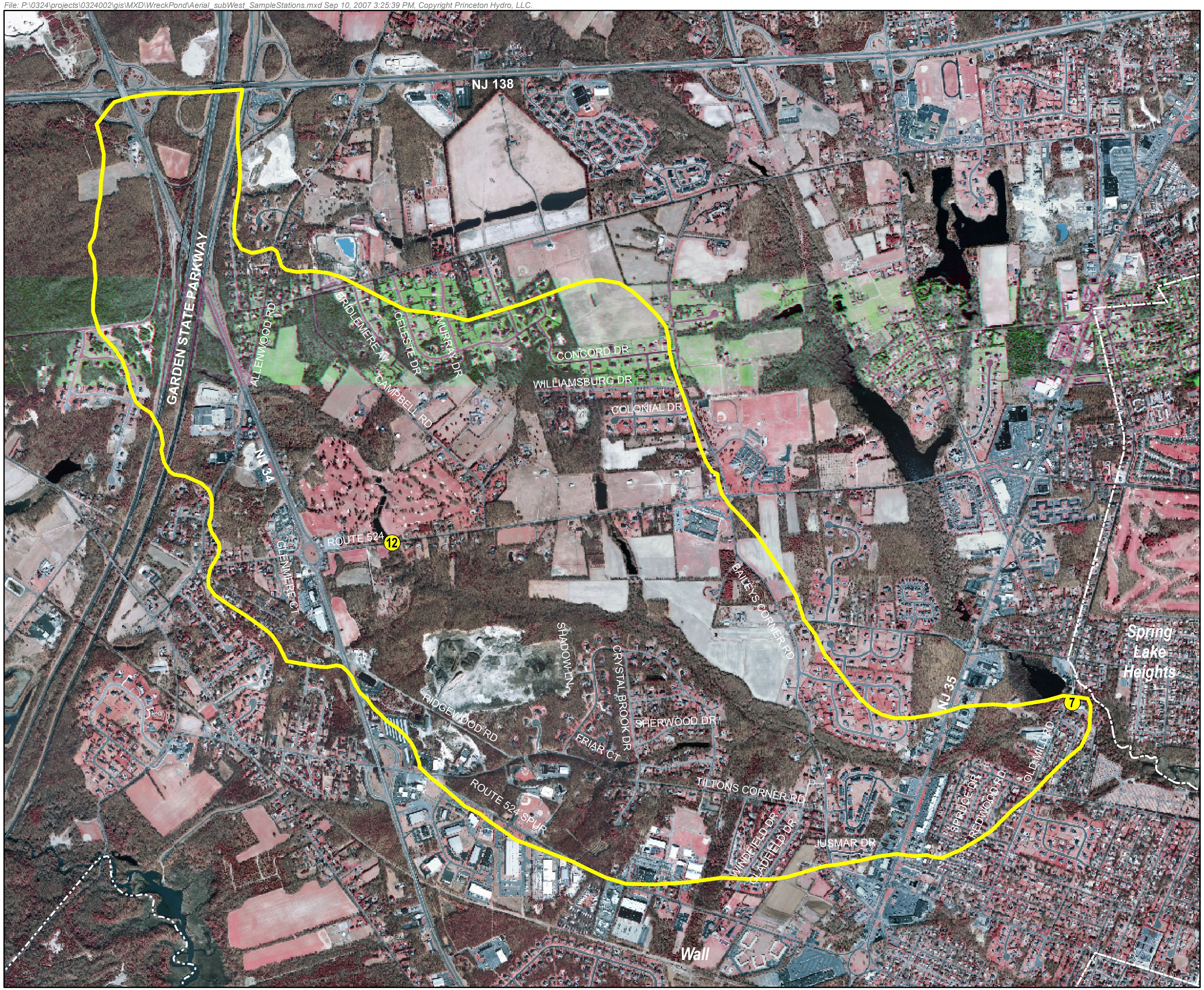
LAND USE / LAND COVER: SUBWATERSHED NORTH SAMPLE STATIONS

MONMOUTH UNIVERSITY PATHOGEN STUDY WRECK POND WATERSHED

Legend

- Subwatershed North Boundary
- Sample Station
- Roads
- Lakes
- Streams

File: P:\0324\projects\0324002\gis\MXD\WreckPond\Aerial_subWest_SampleStations.mxd Sep 10, 2007 3:25:39 PM, Copyright Princeton Hydro, LLC.



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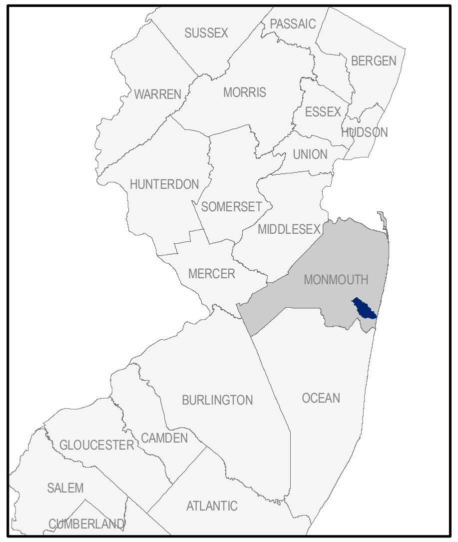
NEW JERSEY COUNTY MAP



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SOURCES:

1. New Jersey 2002 High Resolution Orthophotography obtained from the New Jersey Image Warehouse.

AERIAL PHOTOGRAPHY: SUBWATERSHED WEST SAMPLE STATIONS

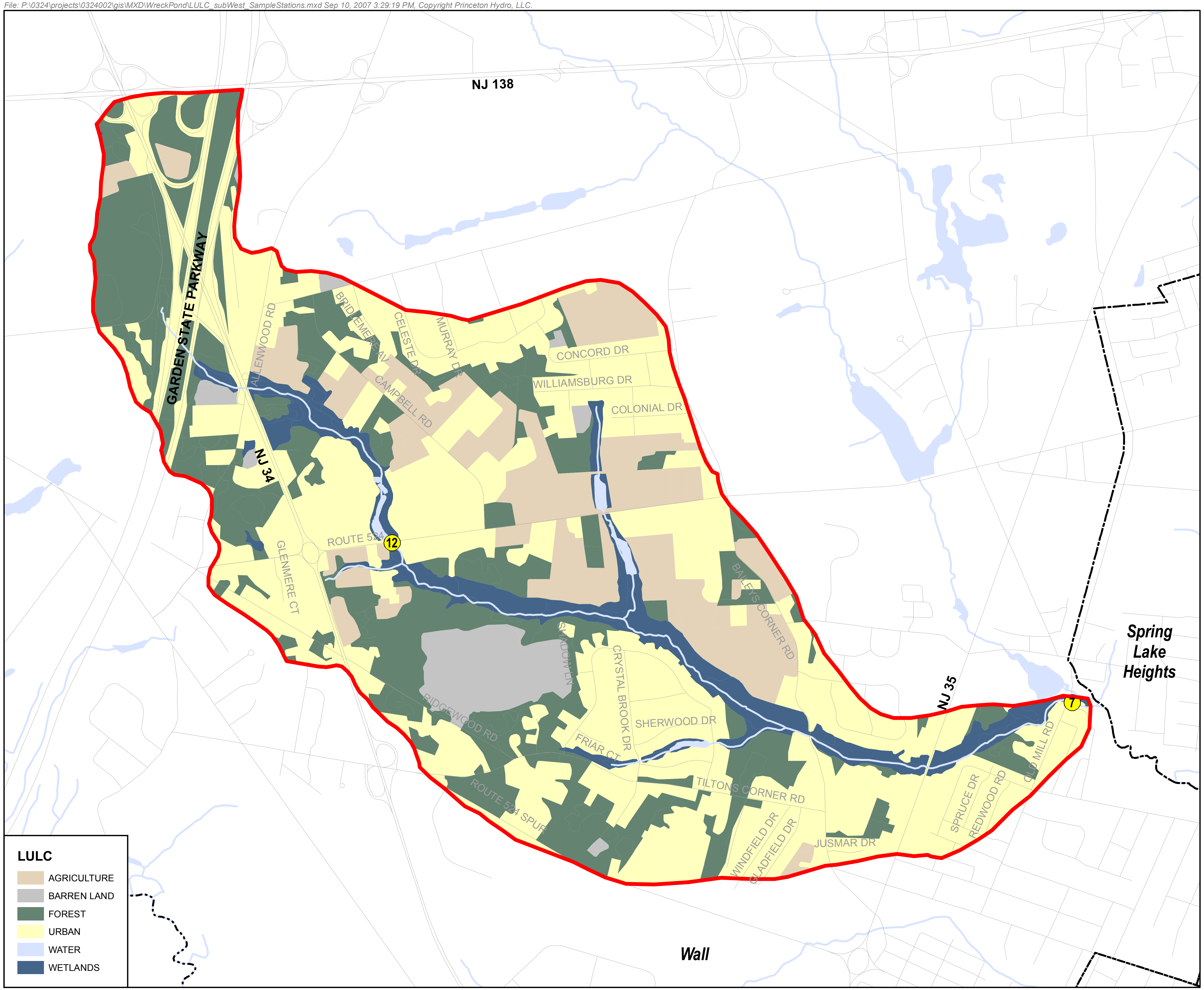
MONMOUTH UNIVERSITY PATHOGEN STUDY WRECK POND WATERSHED

Legend

Subwatershed West Boundary

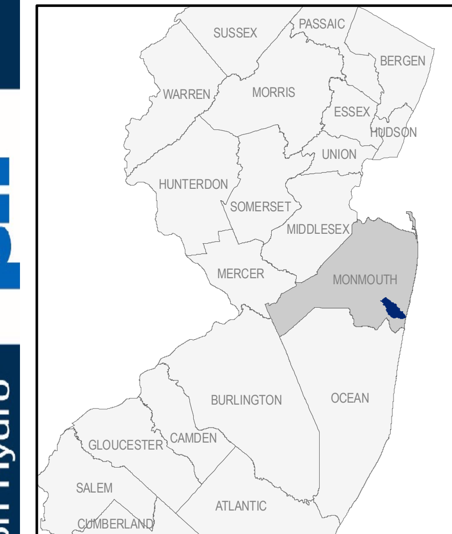
Sample Station

File: P:\0324\projects\0324002\gis\MXD\WreckPond\LULC_subWest_SampleStations.mxd Sep 10, 2007 3:29:19 PM, Copyright Princeton Hydro, LLC.



Princeton Hydro

NEW JERSEY COUNTY MAP



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0 750 1,500 Feet
1 inch equals 1,500 feet

SOURCES:

1. Streams, lakes, municipal boundary data, and land use / land cover as obtained from the NJDEP GIS website.

2. Roads data obtained from the NJDOT.

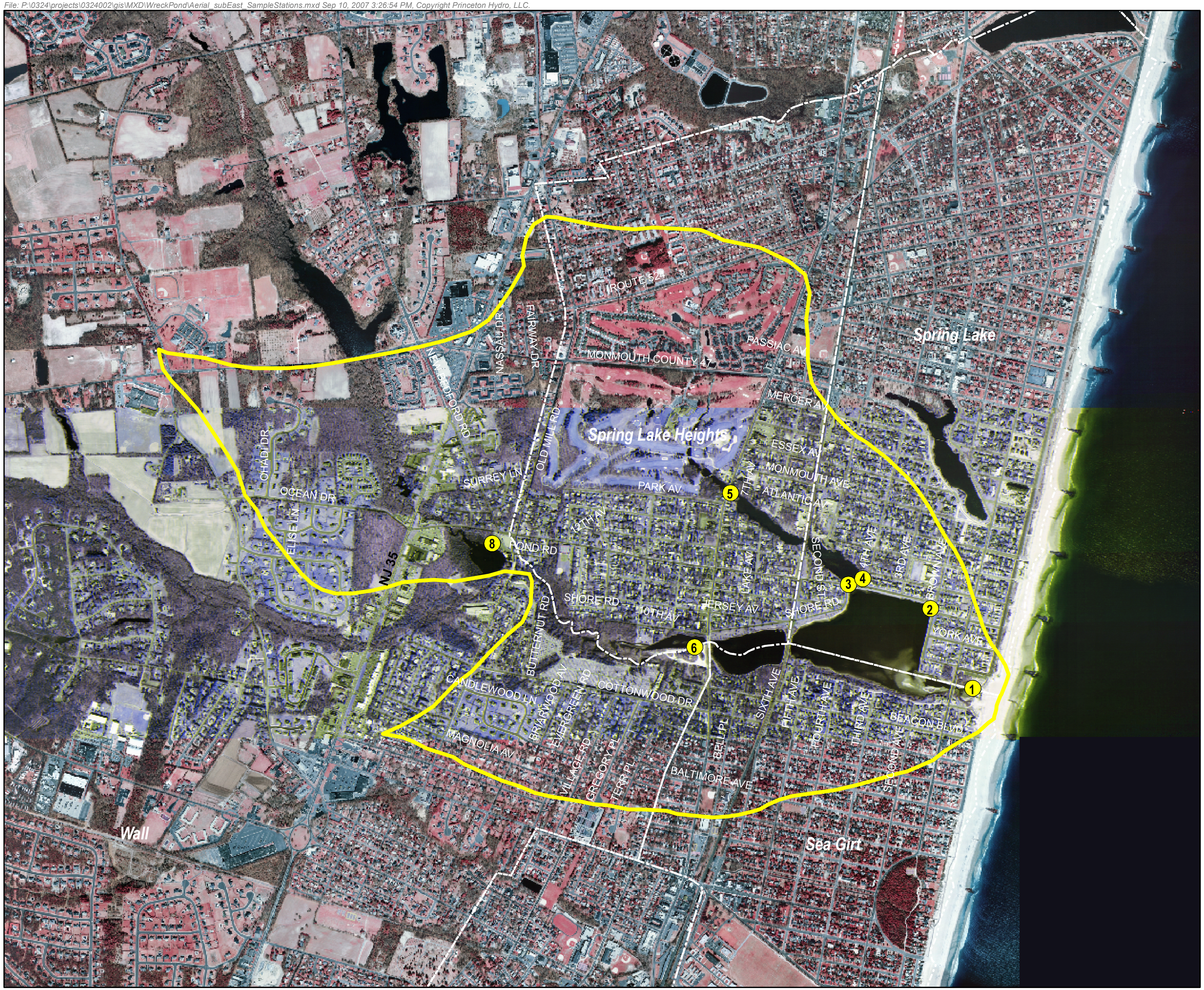
LAND USE / LAND COVER: SUBWATERSHED WEST SAMPLE STATIONS

MONMOUTH UNIVERSITY
PATHOGEN STUDY
WRECK POND WATERSHED

Legend

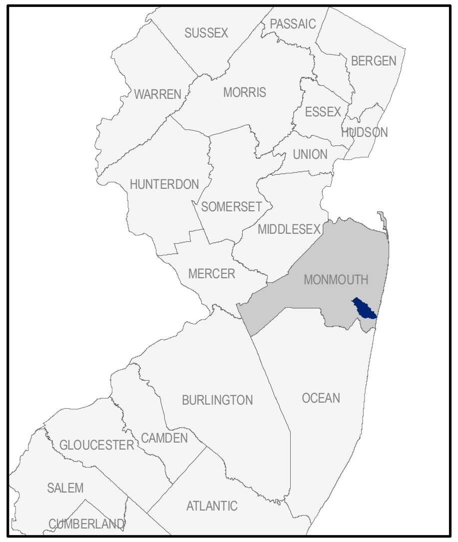
- Subwatershed West Boundary
- Sample Station
- Roads
- Lakes
- Streams

File: P:\0324\projects\0324002\gis\MXD\WreckPond\Aerial_subEast_SampleStations.mxd Sep 10, 2007 3:26:54 PM, Copyright Princeton Hydro, LLC.



Princeton Hydro

NEW JERSEY COUNTY MAP



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SOURCES:

1. New Jersey 2002 High Resolution Orthophotography obtained from the New Jersey Image Warehouse.

AERIAL PHOTOGRAPHY: SUBWATERSHED EAST SAMPLE STATIONS

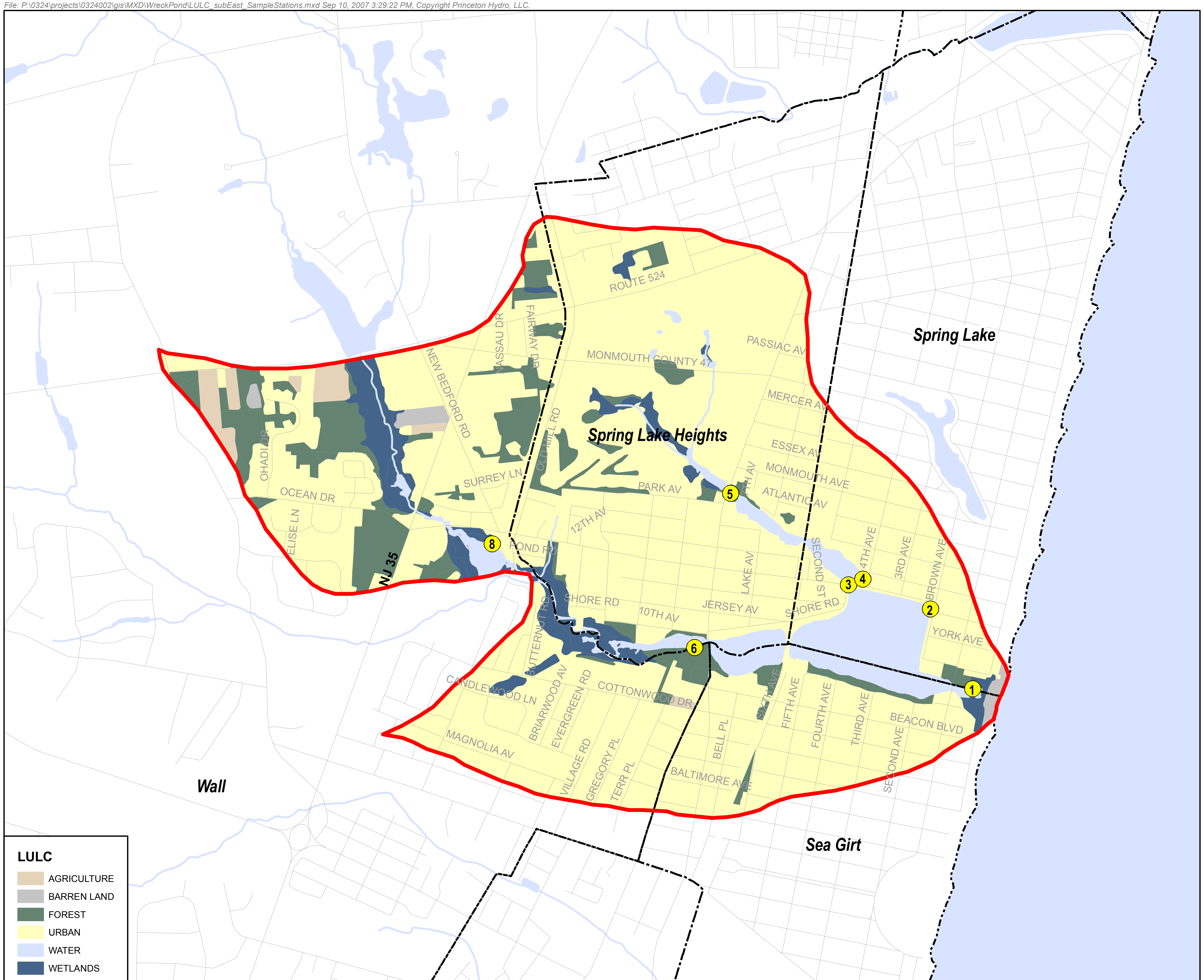
MONMOUTH UNIVERSITY PATHOGEN STUDY WRECK POND WATERSHED

Legend

Subwatershed East Boundary

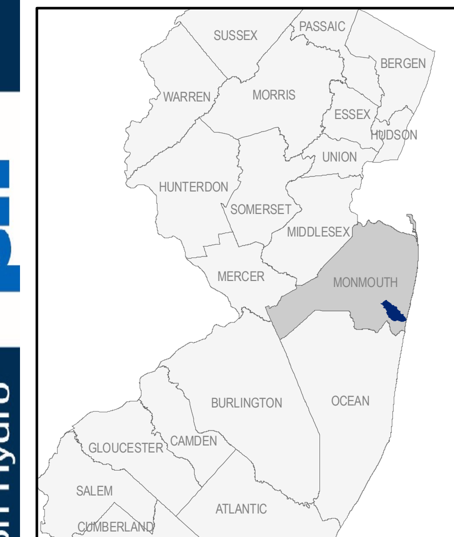
Sample Station

File: P:\0324\projects\0324002\gis\MXD\WreckPond\LULC_subEast_SampleStations.mxd Sep 10, 2007 3:29:22 PM, Copyright Princeton Hydro, LLC.



Princeton Hydro

NEW JERSEY COUNTY MAP



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SOURCES:

1. Streams, lakes, municipal boundary data, and land use / land cover as obtained from the NJDEP GIS website.

2. Roads data obtained from the NJDOT.

LAND USE / LAND COVER: SUBWATERSHED EAST SAMPLE STATIONS

MONMOUTH UNIVERSITY PATHOGEN STUDY WRECK POND WATERSHED

Legend

- Subwatershed East Boundary
- Sample Station
- Roads
- Lakes
- Streams

Station 1: Wreck Pond

Station Location:

Salt pond area west of the ocean floodgate

Site Description:

Station 1 was located at the eastern terminus of Wreck Pond west of a weir structure constructed to discharge water into the Atlantic Ocean during heavy storms. The area is characteristic of a shallow estuarine environment. The area is bordered by sandy, vegetated open space and sand dunes. Route 71 crosses Wreck Pond west of the site and land use in the area is residential.

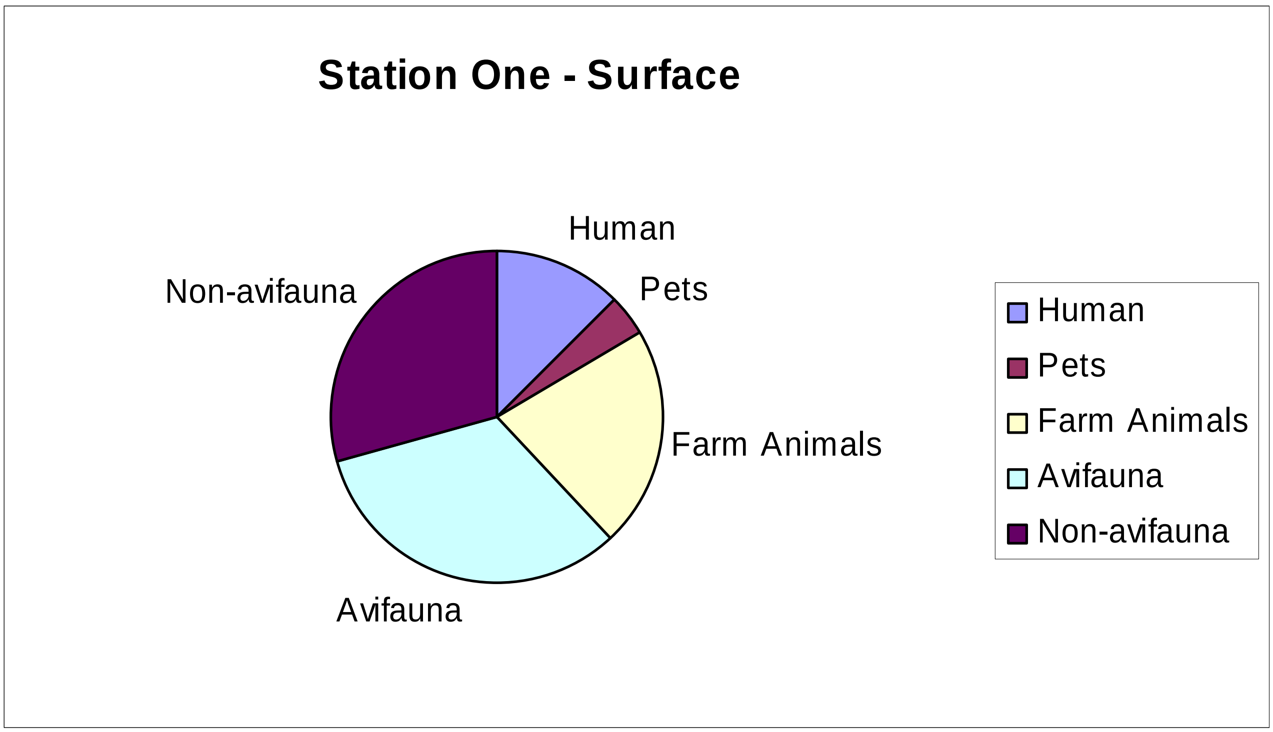
Ambient Water Quality:

Water depth at Station 1 was generally less than a quarter of a meter and water transparency was to the bottom. The water temperature at Station 1 ranged from 17.1 to 26.8^{o}C throughout the sampling sessions. Salinity at this station ranged from 12.3 to 29.6 ppt depending on the tidal stage. Dissolved oxygen ranged from 4.8 to 8.8 mg/l with lowest levels recorded in September. The pH at Station 1 ranged from 7.6 to 8.5.

Surface Water Source Profile:

Mixed pollution sources are seen for all dates at this station. Human, farm animal, and avifauna contributions peaked in mid June while non-avifauna peaked in mid July. Large peaks for avifauna were also recorded in late August and September.

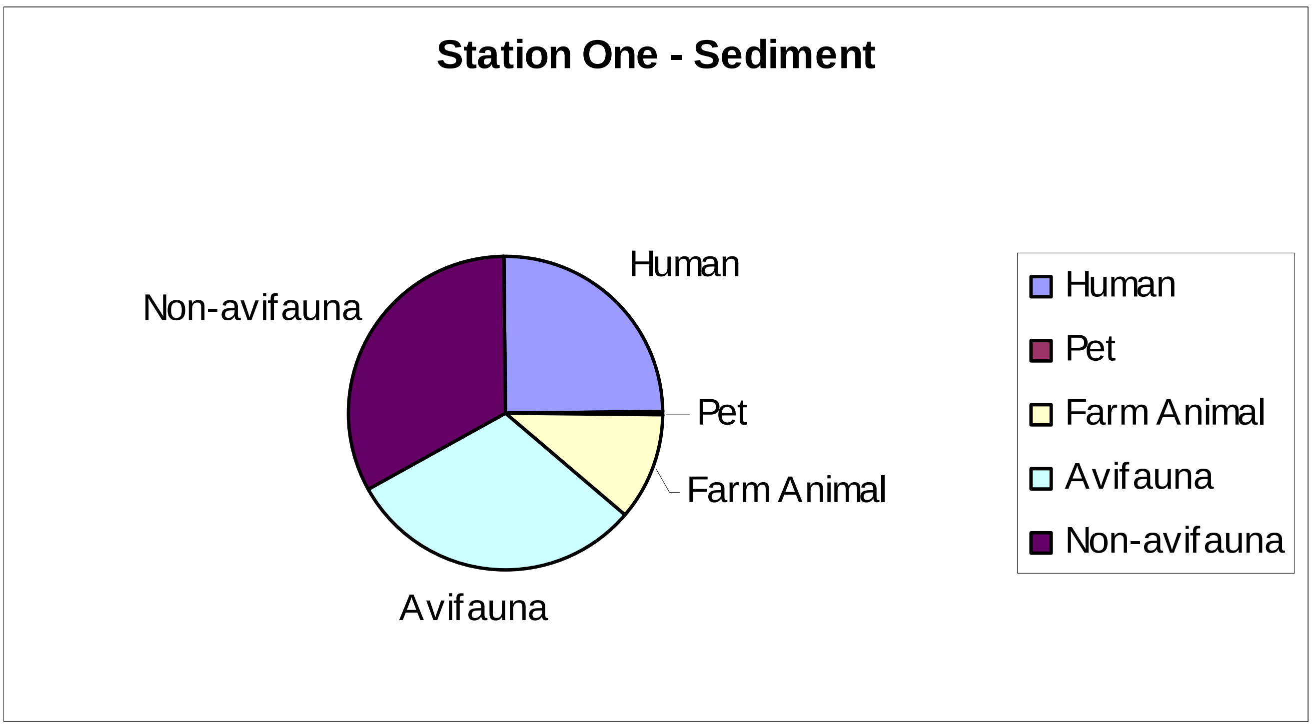
Surface Water Source Summary By Source Category
Based on Mean Relative Abundance – All Sampling Events



Sediment Source Profile:

Sediment contamination was evident throughout the study period and fecal loadings rose to a broad maximum in mid July before declining marginally. Human sources peaked, then declined, at the end of July then peaked again in early August. Farm animal contributions peaked at the end of June. Wild animal contributions peaked in mid July.

Sediment Source Summary by Category
Based on Mean Relative Abundance – All Sampling Events



Station 2: Wreck Pond

Station Location:

Wreck Pond at the intersection of Second Avenue and Ocean Road

Site Description:

Station 2 was located in the northeastern corner of Wreck Pond adjacent to a large outfall pipe that drains water from Spring Lake, a waterbody located approximately five miles to the north. The shoreline of the pond is supported by bulkhesds and the outfall is surrounded by riprap. A narrow grass buffer surrounds the pond. Development in the area is residential.

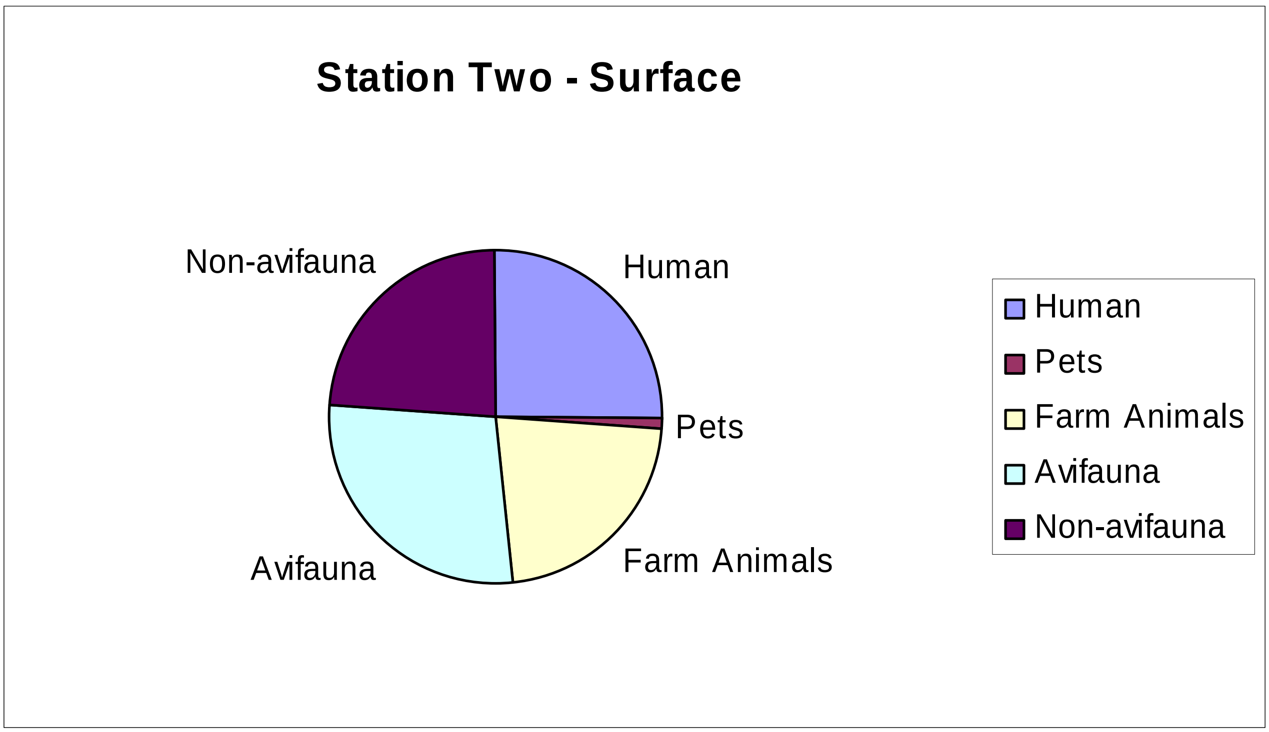
Ambient Water Quality:

Water depth at Station 2 was less than a quarter of a meter and water transparency was to the bottom. The water temperature at Station 2 ranged from 21.0 to 26.1^{o}C throughout the sampling sessions. Salinity at this station ranged from 7.4 to 24.9 ppt depending on the tidal stage. Dissolved oxygen ranged from 3.9 to 9.7 mg/l with lowest levels recorded in June and September. The pH at Station 2 ranged from 7.1 to 8.1.

Surface Water Source Profile:

Fecal loadings at Station 2 showed human, farm animal, avifauna, and non-avifauna as major contributors with little contribution from pets. Human and farm animal sources declined from mid June to mid July then peaked again at increased levels in mid September.

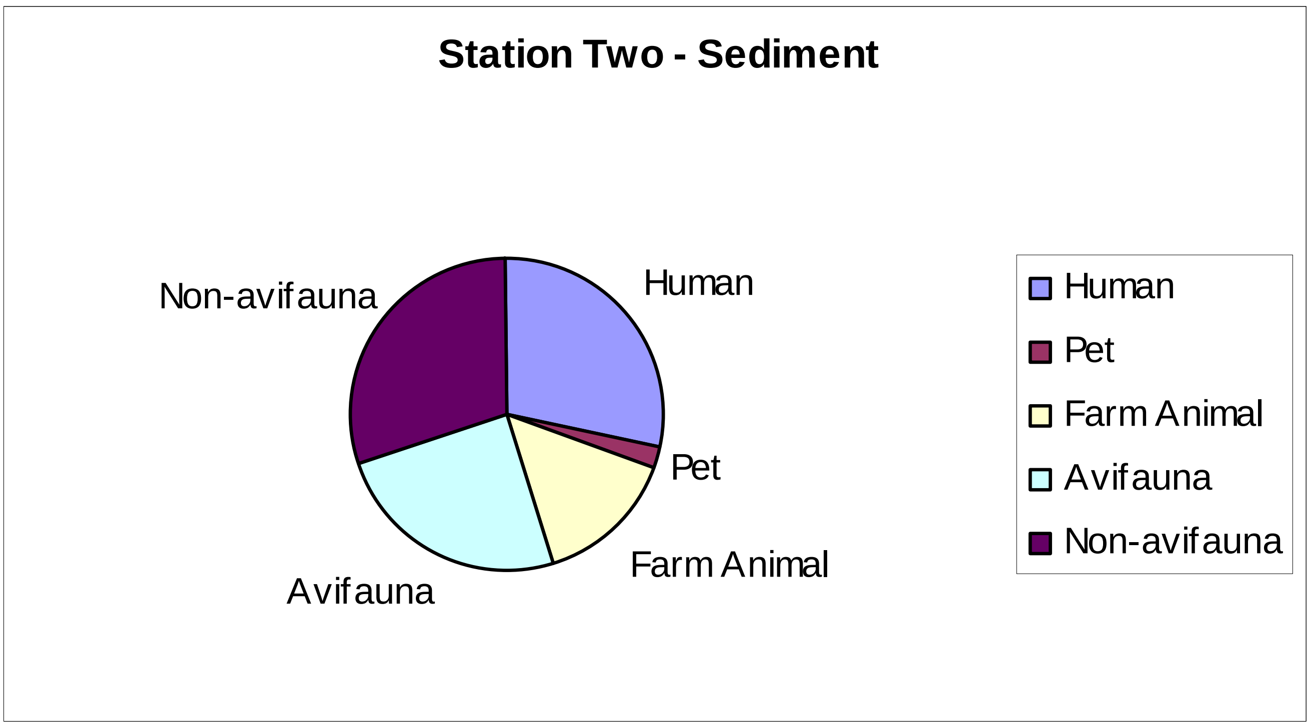
Surface Water Source Summary By Source Category
Based on Mean Relative Abundance – All Sampling Events



Sediment Source Profile:

A very sharp peak of mixed sources in mid June was followed by a slow increase of mixed pollution until early August. This increase was followed by a steep decline. Patterns of pollution were consistent between categories.

Sediment Source Summary by Category
Based on Mean Relative Abundance – All Sampling Events



Station 3: Wreck Pond

Station Location:

Southwestern shore of Wreck Pond south of Ocean Road at the spillway from Black Creek

Site Description:

Station 3 was located in Wreck Pond at the spillway from Black Creek. Ocean Road is crosses between the two ponds directly to the north. The shoreline at the site is stabilized by a bulkhead and a rock/cement wall. A narrow grass buffer surrounds the pond. There is also a sewage lift station on the western shoreline of the pond adjacent to the site. Land use in the vicinity of Station 3 is residential.

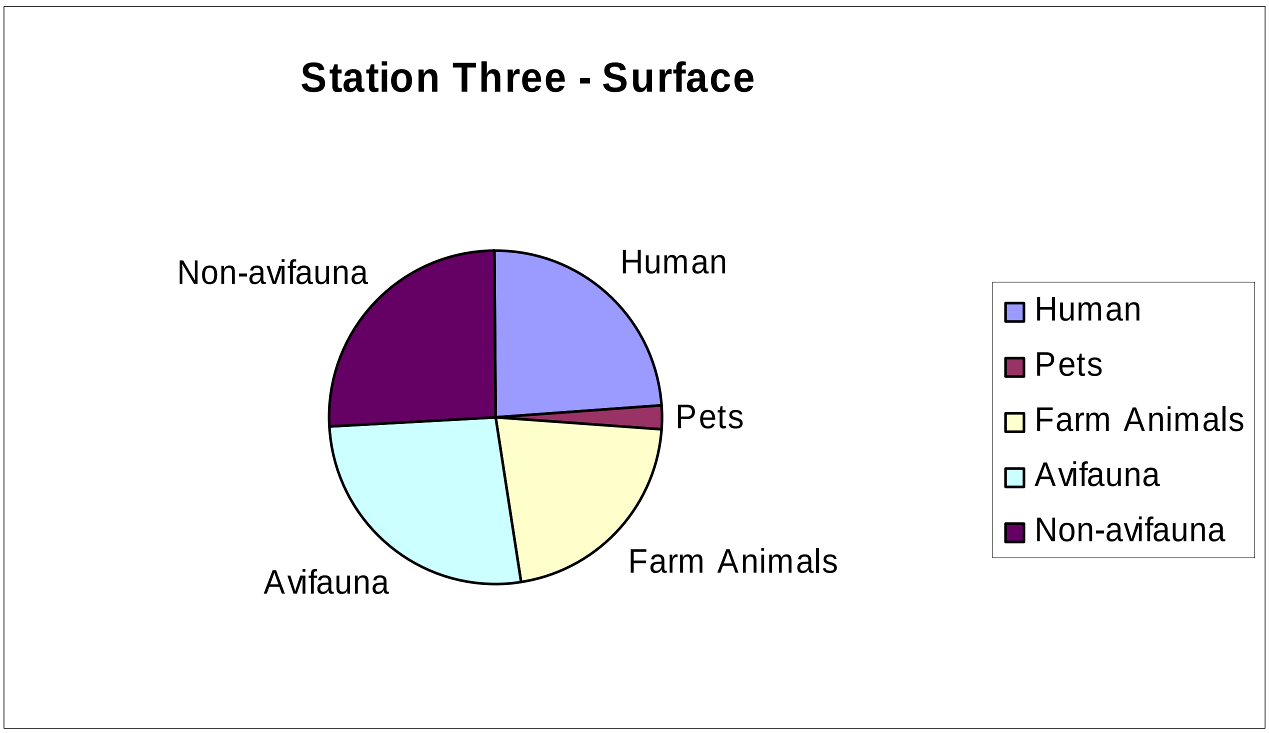
Ambient Water Quality:

Water depth at Station 3 was generally less than half a meter and water transparency was to the bottom. The water temperature at Station 3 ranged from 21.4 to 28.5^{o}C throughout the sampling sessions. Salinity at this station ranged from 0 to 22.3 ppt depending on tidal stage. Dissolved oxygen ranged from 1.7 to 11.2 mg/l with lowest levels recorded in June. The pH at Station 3 ranged from 7.1 to 8.8.

Surface Water Source Profile:

Fecal loadings at Station 3 showed human, farm animal, avifauna, and non-avifauna as major contributors with little contribution from pets. Human and farm animal sources declined from mid June to mid July then peak again at increased levels by early September. Loadings were mixed but generally increased to a peak in August and remained high in September.

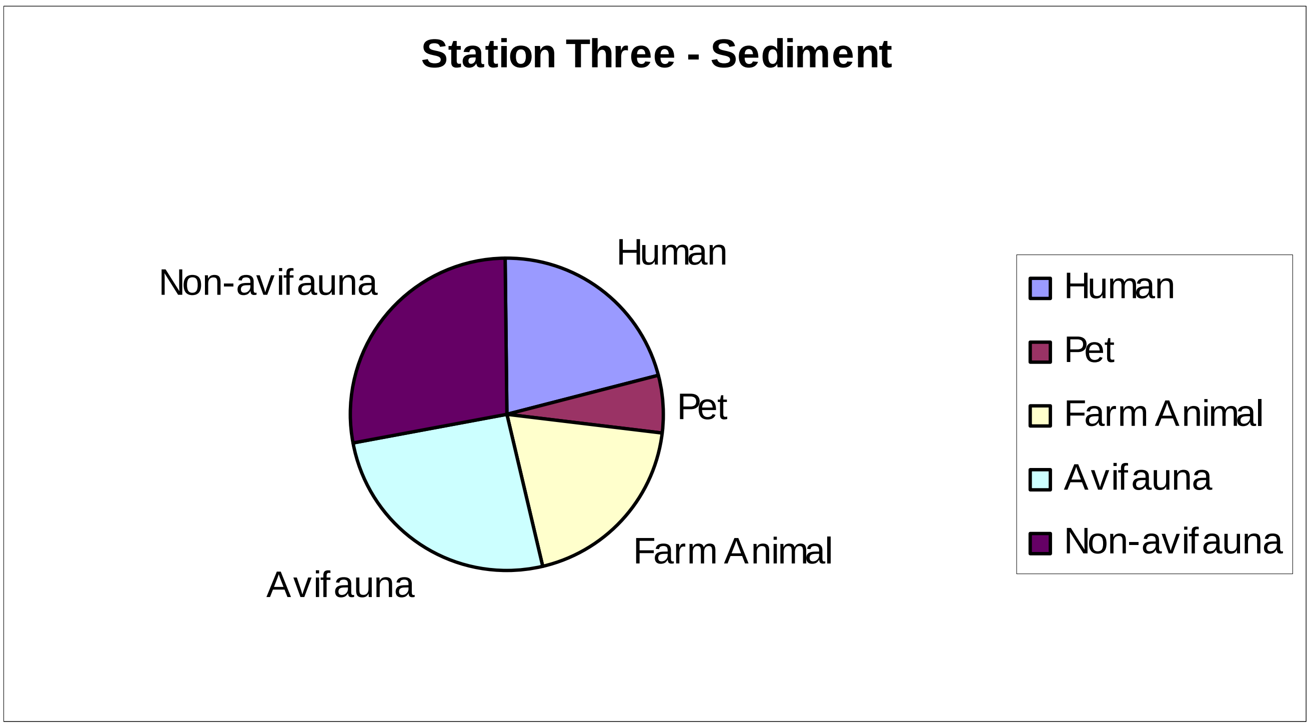
Surface Water Source Summary By Source Category
Based on Mean Relative Abundance – All Sampling Events



Sediment Source Profile

Pollution sources varied sharply between sampling dates. Pollution from mixed sources caused peaks of pollution in mid June, mid July and from early August.

Sediment Source Summary by Category
Based on Mean Relative Abundance – All Sampling Events



Station 4: Black Creek (N. Branch)

Station Location:

Eastern shore of Black Creek at the intersection of Ocean Road and Fourth Avenue

Site Description:

Station 4 was located on the eastern shore of Black Creek which forms a pond adjacent to Wreck Pond. Black Creek is surrounded by grass and shrubs in this area. Ocean Road crosses between the two ponds to the south. Land use surrounding this portion of Black Creek is residential.

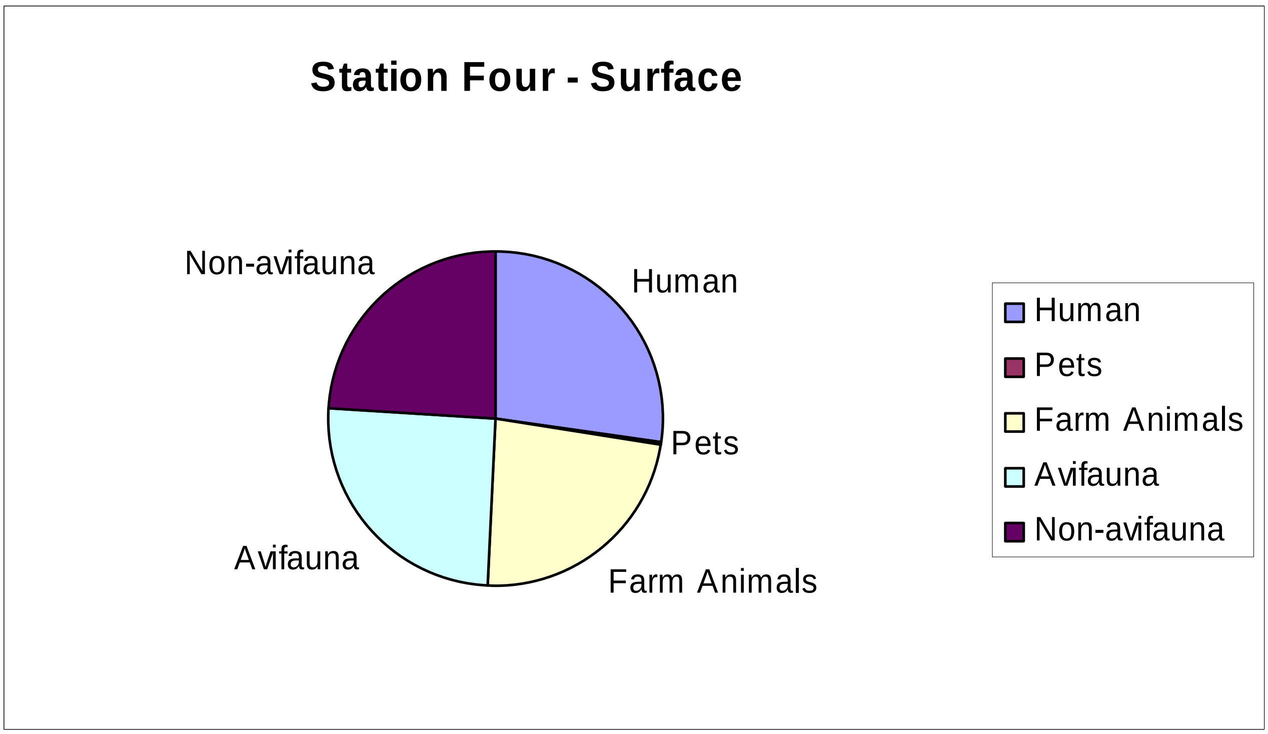
Ambient Water Quality:

Water depth at Station 4 was generally less than half a meter and water transparency was to the bottom. The water temperature at Station 4 ranged from 20.9 to 29.0^{o}C throughout the sampling sessions. Salinity at this station was less than 1.0 ppt. Dissolved oxygen ranged from 1.0 to 9.2 mg/l with lowest levels recorded in June and September. The pH at Station 4 ranged from 6.6 to 7.9.

Surface Water Source Profile:

Fecal loadings at Station 4 showed human, farm animal, avifauna, and non-avifauna as major contributors with little contribution from pets. Loadings rose from mid June to mid July and remained high until mid September. A trough in farm animal contributions was seen at the end of July.

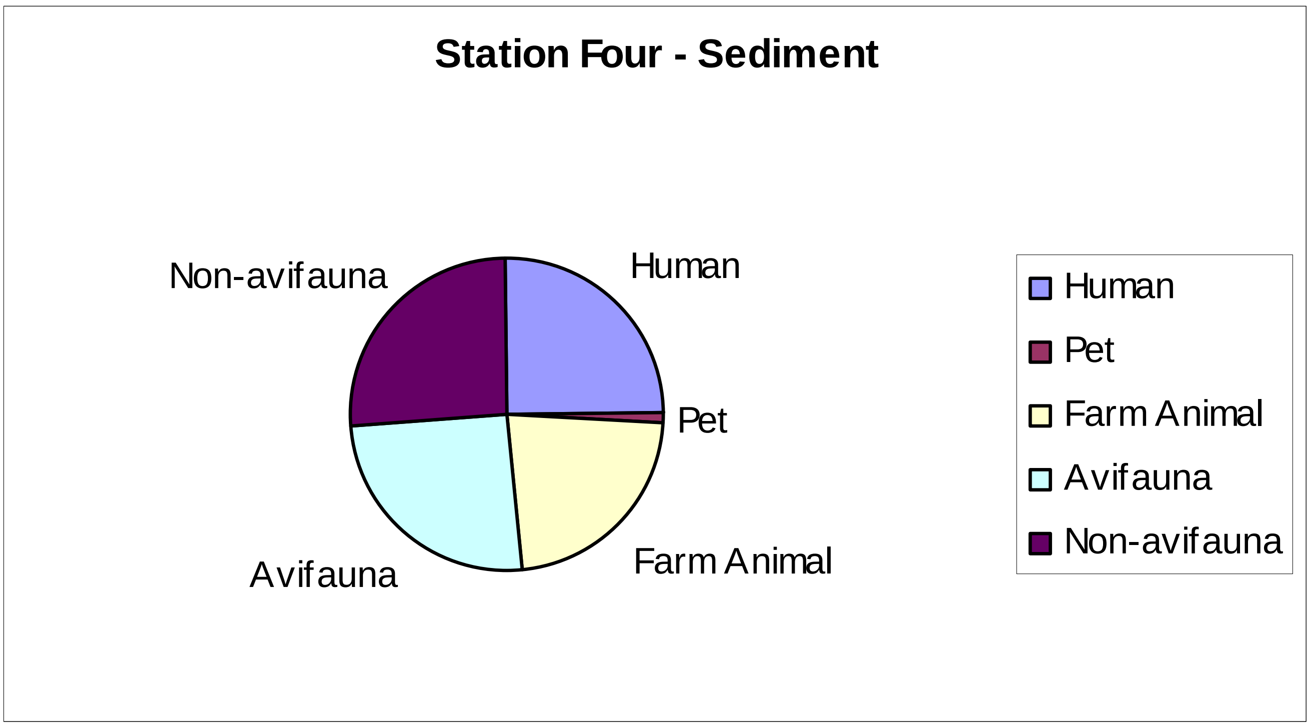
Surface Water Source Summary By Source Category
Based on Mean Relative Abundance – All Sampling Events



Sediment Source Profile:

High loadings from mixed sources increased during the study period, except for a sharp trough in mid July. Pollution patterns were consistent between categories.

Sediment Source Summary by Category
Based on Mean Relative Abundance – All Sampling Events



Station 5: Black Creek (N. Branch)

Station Location:

Stream channel of Black Creek east of Route 71 across from the Spring Lake Golf Club

Site Description:

Station 5 was located on a shallow stream segment of Black Creek downstream from the Spring Lake Golf Club. Steep, stabilized slopes with minimal vegetation border the site on the north and south. The stream continues east with gradually decreasing slopes on the banks into a wetland area. Route 71 crosses the stream west of the sampling site. Runoff from Route 71 flows directly to Black Creek through a number of storm drains located along the shoulder of the road. Land use in proximity of the site is mixed commercial and residential.

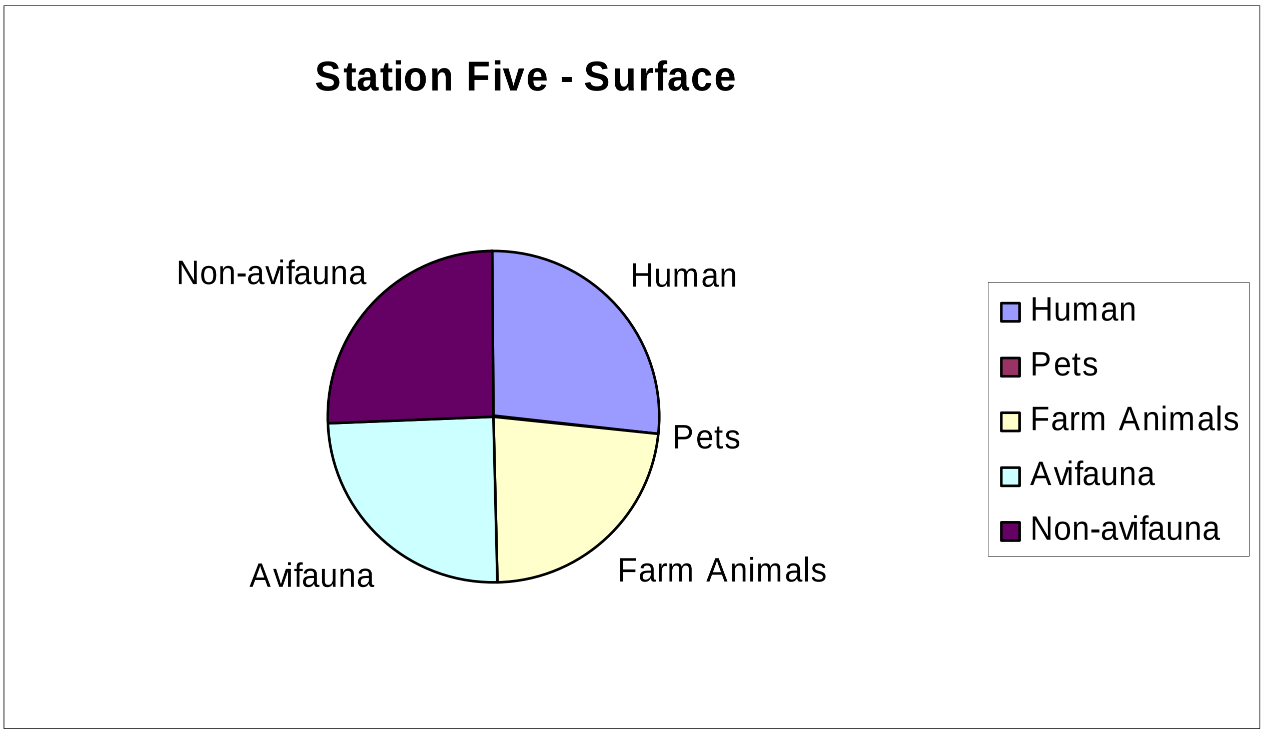
Ambient Water Quality:

Water depth at Station 5 was generally less than a quarter of a meter and water transparency was to the bottom. The water temperature at Station 5 ranged from 20.0 to 29.0^{o}C throughout the sampling sessions. Salinity at this station was less than 1.0 ppt. Dissolved oxygen ranged from 3.6 to 8.8 mg/l with lowest levels recorded in June and July. The pH at Station 5 ranged from 6.5 to 6.9.

Surface Water Source Profile:

Fecal loadings at Station 5 showed human, farm animal, avifauna, and non-avifauna as major contributors with little contribution from pets. High levels were seen throughout the study period with peak levels detected at the end of August.

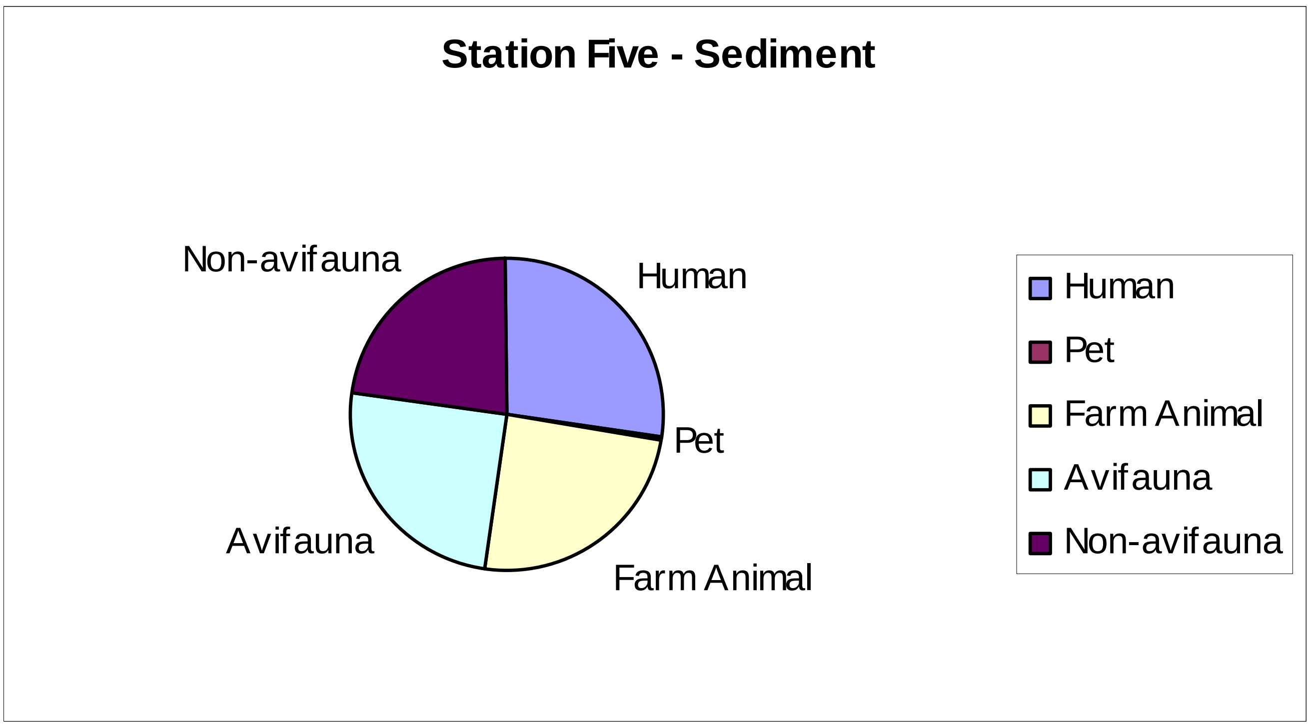
Surface Water Source Summary By Source Category
Based on Mean Relative Abundance – All Sampling Events



Sediment Source Profile

High loadings from mixed sources increased during the study period, except for a sharp trough in late June when unclassified isolates predominated. Patterns were consistent between categories.

Sediment Source Summary by Category
Based on Mean Relative Abundance – All Sampling Events



Station 6: Wreck Pond Brook

Station Location:

Southern shore of Wreck Pond Brook west of Route 71 adjacent to the Jimmy Byrne property

Site Description:

Station 6 was located on the southern shore of Wreck Pond Brook, west of Route 71. The area surrounding the stream at this site is heavily vegetated with shrubs and trees. The Jimmy Byrne property borders the stream to the south. Land use along the northern shoreline is residential, although commercial development exists along the Route 71 corridor.

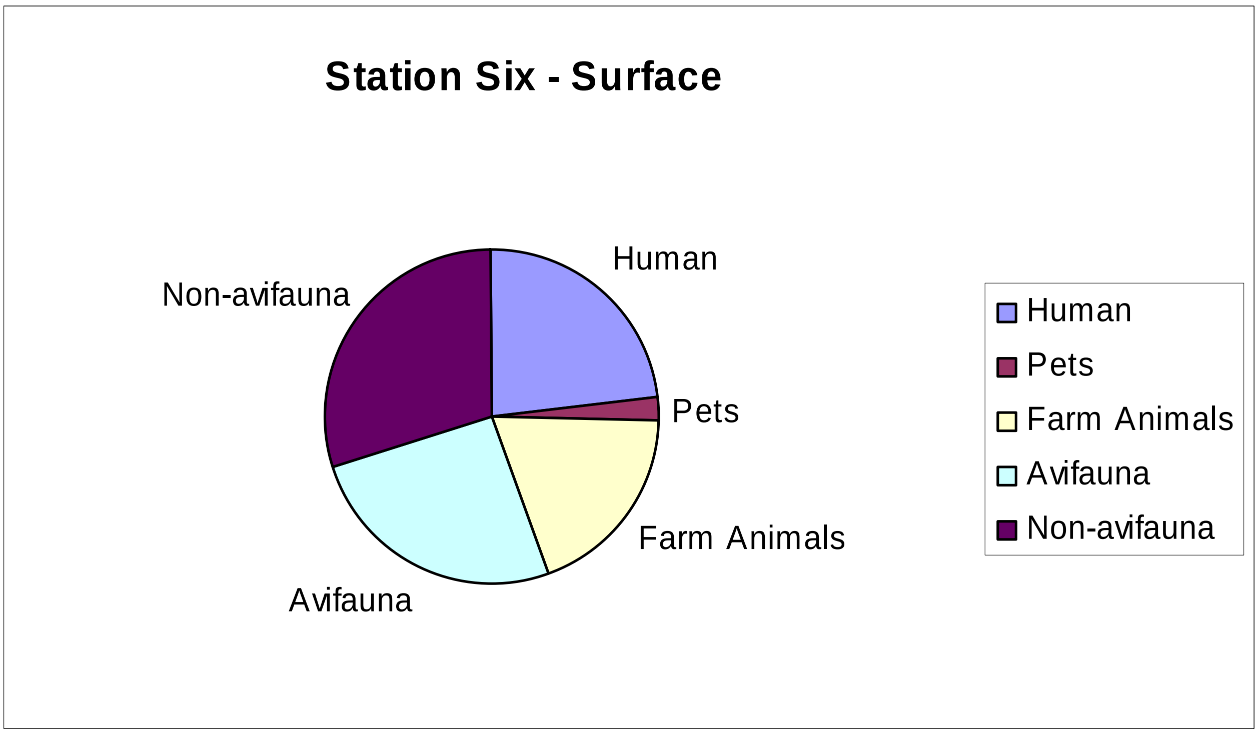
Ambient Water Quality:

Water depth at Station 6 was generally less than a quarter of a meter and water transparency was to the bottom. The water temperature at Station 6 ranged from 20.9 to 27.9^{o}C throughout the sampling sessions. Salinity at this station was less than 1.0 ppt; dissolved oxygen ranged from 5.6 to 13.6 mg/l; and the pH at Station 6 ranged from 6.4 to 6.8.

Surface Water Source Profile:

Contributions from all sources – human, pets, farm animal, avifauna, and non-avifauna – were intermittent at Station 6. A trough of identifiable sources was seen at the end of June and corresponded with a peak of unclassified fecal pollutants. With the exception of pets, all pollution levels followed similar patterns within groups.

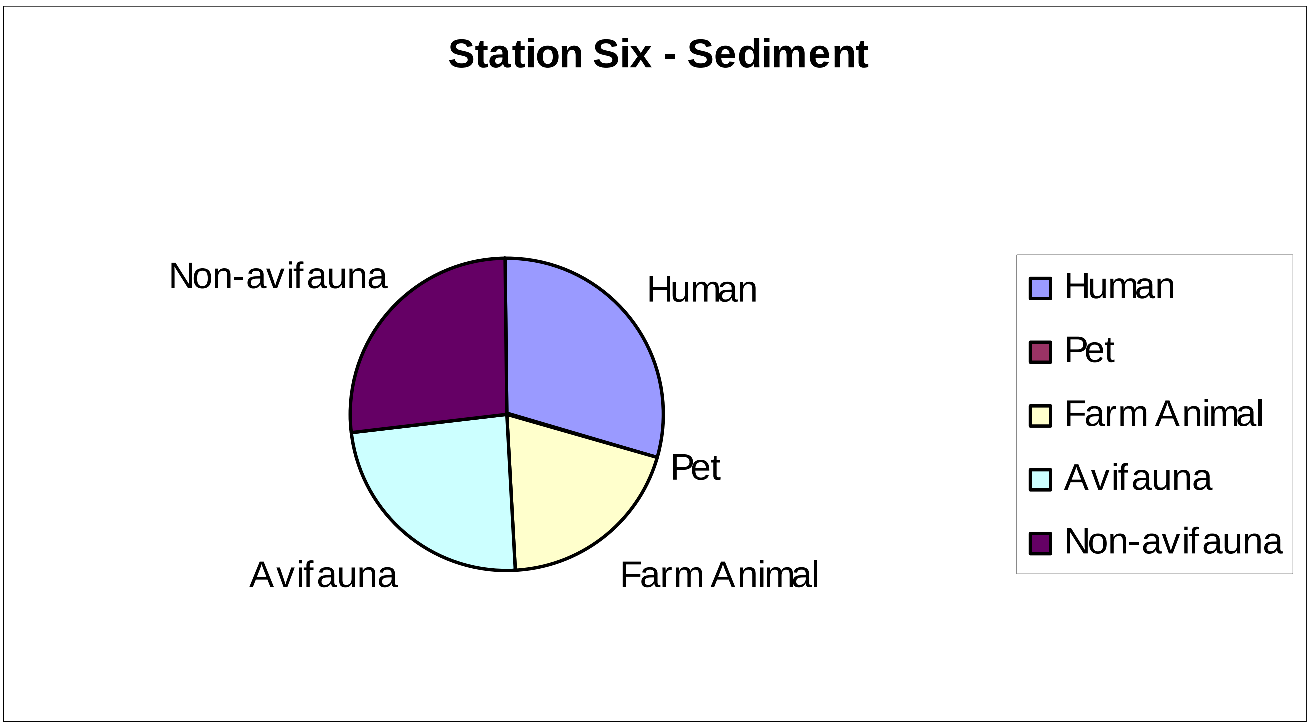
Surface Water Source Summary By Source Category
Based on Mean Relative Abundance – All Sampling Events



Sediment Source Profile

High levels of pollution from mixed sources were seen during the study period, with a sharp trough in late June when unclassified isolates predominated followed by a maximum in mid July. Pollution varied between sampling dates indicating poor mixing.

Sediment Source Summary by Category
Based on Mean Relative Abundance – All Sampling Events



Station 7: Wreck Pond Brook

Station Location:

Wreck Pond Brook downstream from Old Mill Pond east of the Old Mill Road overpass

Site Description:

Station 7 was located on a shallow stream segment of Wreck Pond Brook downstream from Old Mill Pond, east of the Old Mill Road overpass. The stream in this area is surrounded by a grassy slopes and woods. With the exception of The Old Mill Inn restaurant located across Old Mill Road on the banks of Old Mill Pond, residential development is the primary land use in the area surrounding Station 7.

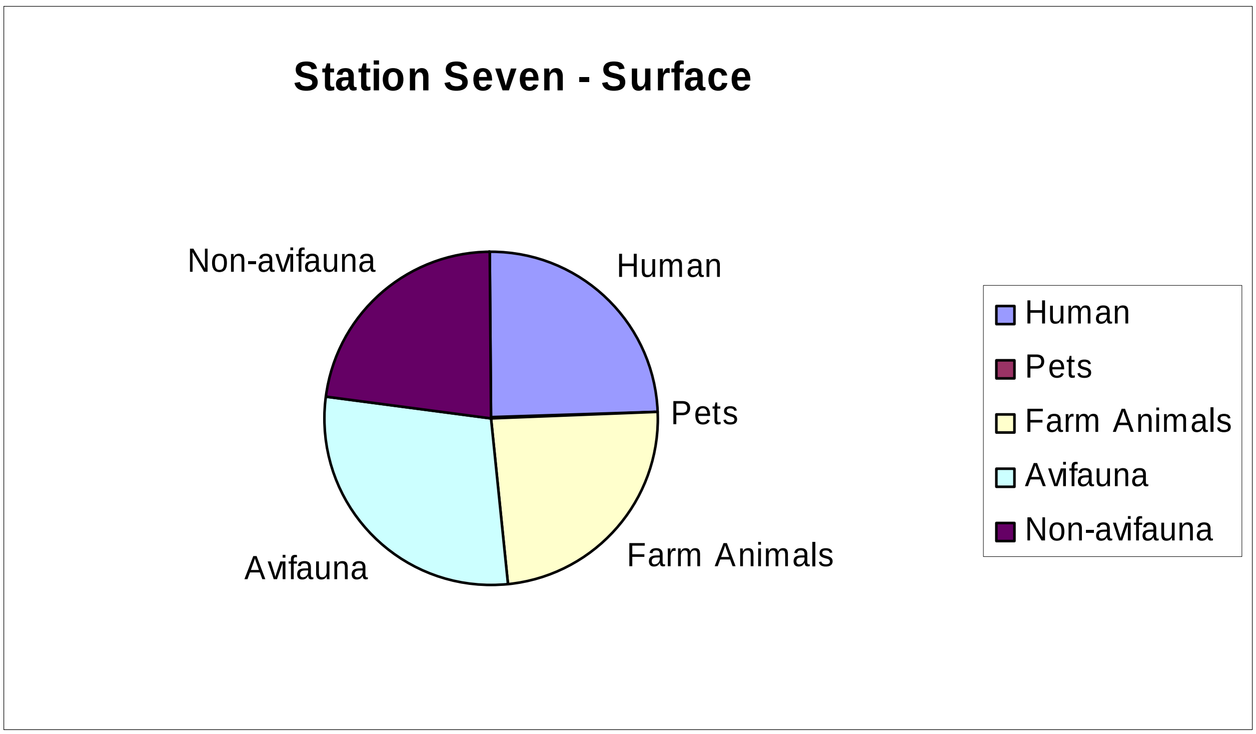
Ambient Water Quality:

Water depth at Station 7 was generally less than a quarter of a meter and water transparency was to the bottom. The water temperature at Station 7 ranged from 17.7 to 20.4^{o}C throughout the sampling sessions. Salinity at this station was less than 1.0 ppt; dissolved oxygen ranged from 7.7 to 10.8 mg/l; and the pH at Station 7 ranged from 6.3 to 6.6.

Surface Water Source Profile:

Fecal loadings at Station 7 showed human, farm animal, avifauna, and non-avifauna as major contributors. There was no detection of pet coliforms. Contributions from the major sources were consistent with the exception of late June, when coliforms were not associated with any group. Additionally, troughs of human and farm animal sources were recorded at the end of July.

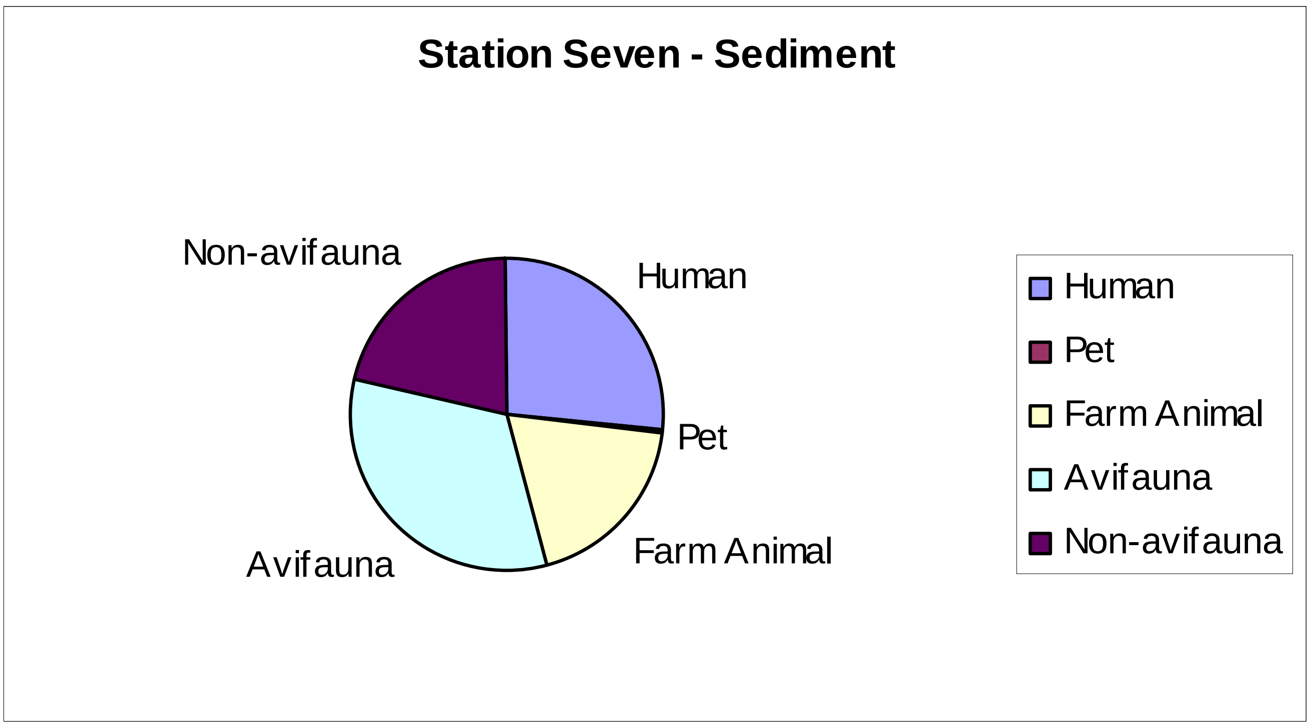
Surface Water Source Summary By Source Category
Based on Mean Relative Abundance – All Sampling Events



Sediment Source Profile

The levels of classified isolates were high in mid June but decreased at the end of the month when the level of unclassified isolates was at its peak. Fecal loadings continued to accumulate from mid July to the end of the study period.

Sediment Source Summary by Category
Based on Mean Relative Abundance – All Sampling Events



Station 8: Old Mill Pond

Station Location:

Northern shore of Old Mill Pond at the Old Mill Inn Restaurant boat ramp

Site Description:

Station 8 was located on the northern shoreline of Old Mill Pond at the foot of a small boat launch ramp. The Old Mill Inn restaurant and restaurant parking lot surround the pond near the site. The remainder of the pond is surrounded by wetlands and woods. Land use in the vicinity of the pond is primarily residential; however, the Route 35 commercial corridor passes the pond to the west.

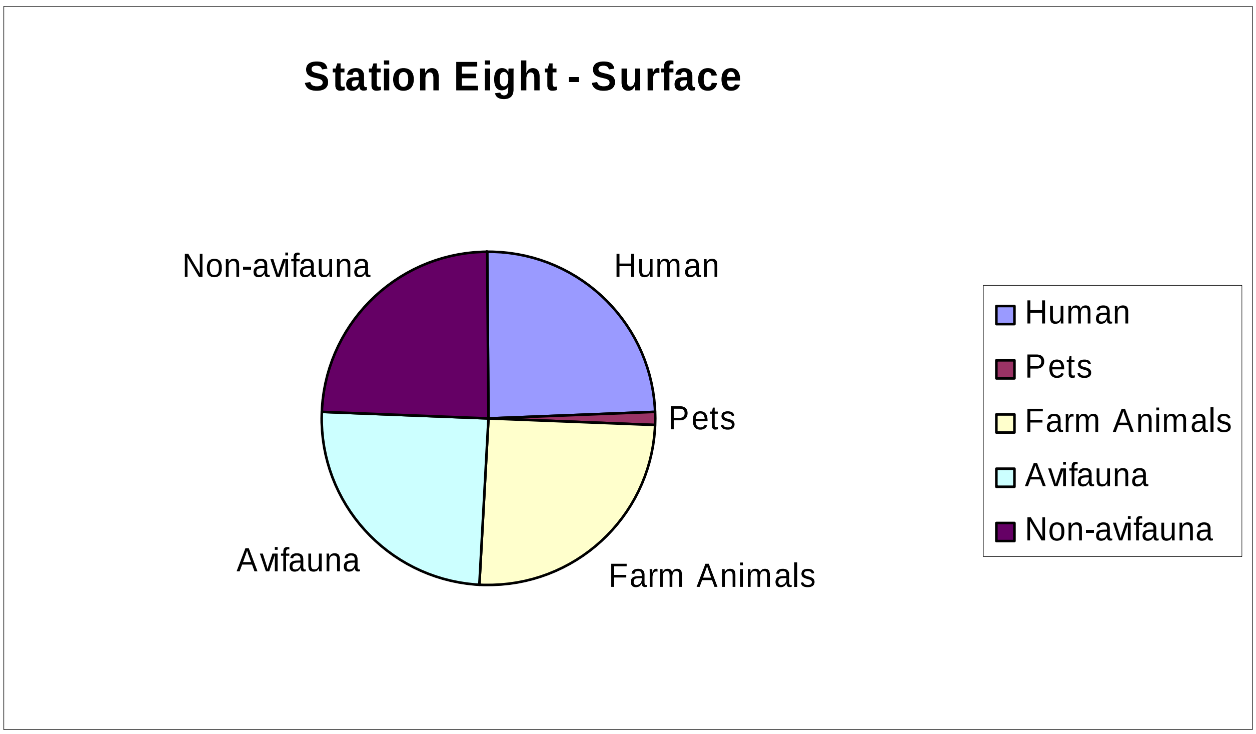
Ambient Water Quality:

Water depth at Station 8 was generally less than a quarter of a meter and water transparency was to the bottom. The water temperature at Station 8 ranged from 20.7 to 26.1^{o}C throughout the sampling sessions. Salinity at this station was less than 1.0 ppt. Dissolved oxygen ranged from 3.5 to 10.3 mg/l with lowest levels recorded in July and August. The pH at Station 8 ranged from 6.2 to 6.8.

Surface Water Source Profile:

Major contributors of fecal loadings at Station 8 were human, farm animal, avifauna, and non-avifauna, with little contribution from pets. In all major contributing groups there was no detection of fecal coliforms in mid July; however, levels peaked later in the month. Loading levels from major contributing groups were consistent and followed similar patterns.

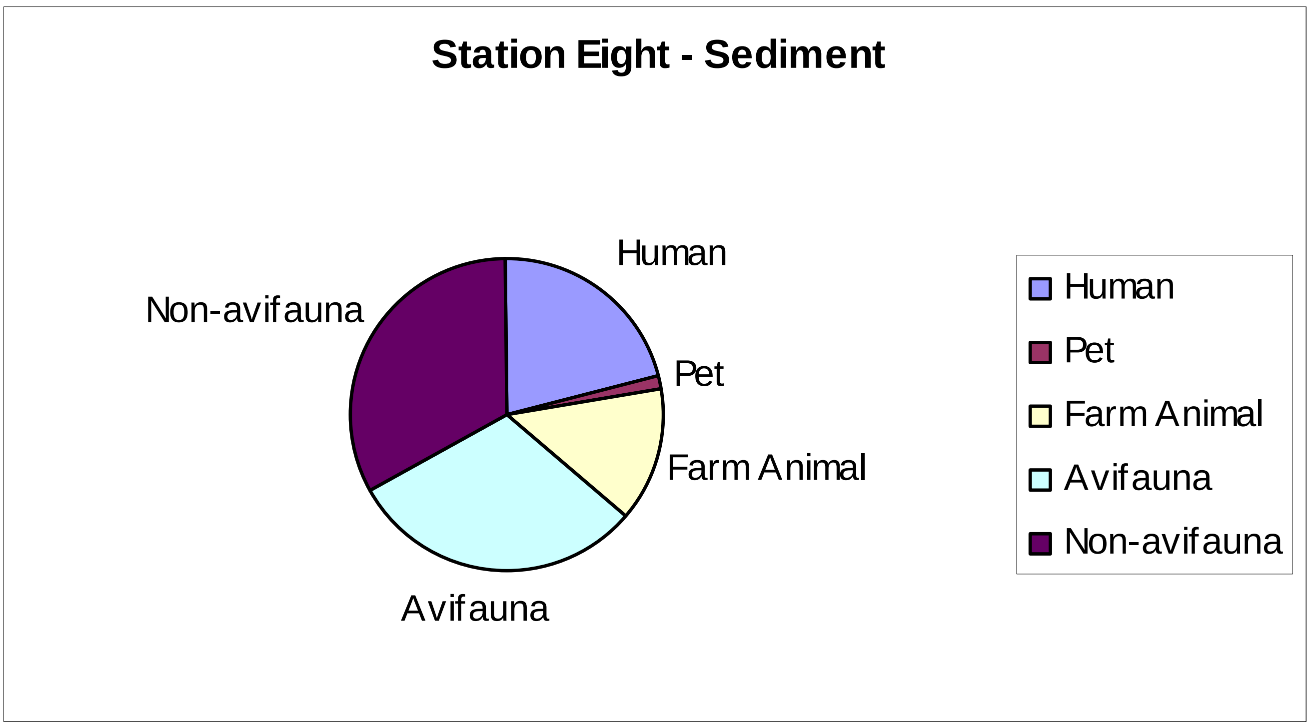
Surface Water Source Summary By Source Category
Based on Mean Relative Abundance – All Sampling Events



Sediment Source Profile

High levels of mixed pollution sources, with the exception of pets, were seen throughout the study period with an slow increase towards September. The pattern changed from roughly equal sources, except pet in mid June to predominantly wild animal in mid September. Human sources also appeared to be important in all cases.

Sediment Source Summary by Category
Based on Mean Relative Abundance – All Sampling Events



Station 9: Osborn Pond

Station Location:

Stream segment of Wreck Pond Brook downstream from Osborn Pond east of Allaire Road

Site Description:

Station 9 was located on a shallow stream segment of Wreck Pond Brook downstream of Osborn Pond. The Allaire Road overpass separates the pond from the brook to the west of the site. The area immediately adjacent to the stream is vegetated, including a wetland fringe. The predominant land use surrounding the site is residential; however, commercial development is located along the Route 35 corridor to the southeast of the site.

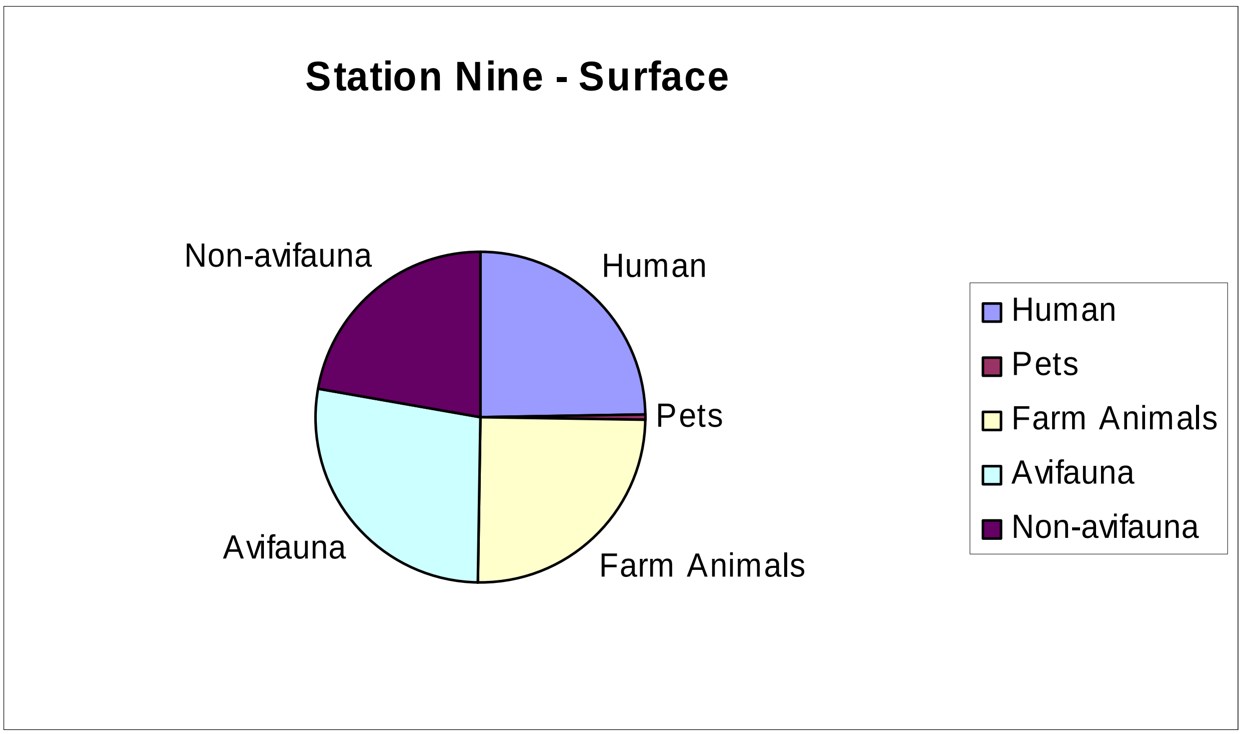
Ambient Water Quality:

Water depth at Station 9 was generally less than a quarter of a meter and water transparency was to the bottom. The water temperature at Station 9 ranged from 18.6 to 23.5^{o}C throughout the sampling sessions. Salinity at this station was less than 1.0 ppt; dissolved oxygen ranged from 5.1 to 9.0 mg/l; and the pH at Station 9 ranged from 6.1 to 6.9.

Surface Water Source Profile:

Major contributors of fecal loadings at Station 9 were human, farm animal, avifauna, and non-avifauna, with little contribution from pets. In the major contributing groups, there was no detection of fecal coliforms in mid June. Results for July and August represent a steady increase in levels, followed by a general peak in mid September. Loading levels from major contributing groups were consistent and followed similar patterns.

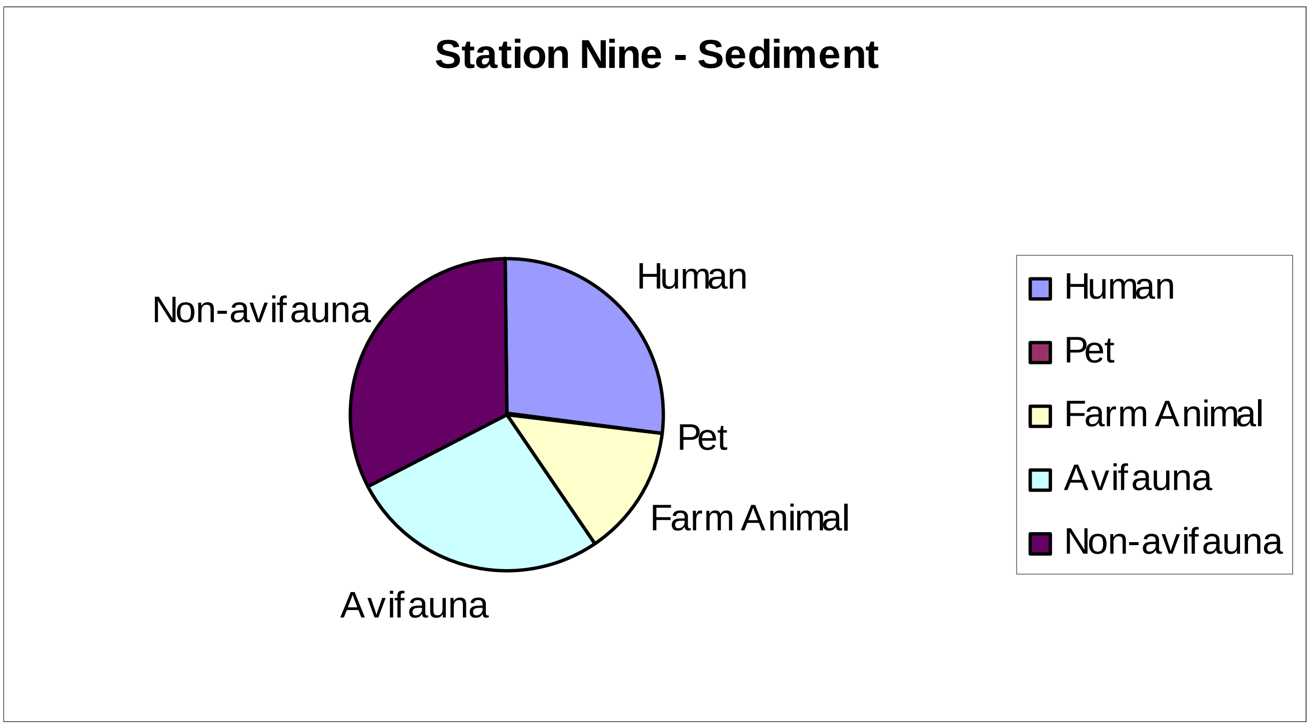
Surface Water Source Summary By Source Category
Based on Mean Relative Abundance – All Sampling Events



Sediment Source Profile

Sediment sampling for mid June and mid July resulted in peaks from mixed pollution sources. Patterns were similar between categories except for a surge in contributions from human and avifauna at the end of August which indicates both biological and physical factors are important at this station.

Sediment Source Summary by Category
Based on Mean Relative Abundance – All Sampling Events



Station 10: Albert Pond

Station Location:

Stream segment of an unnamed tributary downstream from Albert Pond at the intersection of Oxford Lane and a private road

Site Description:

Station 10 was located on a shallow stream segment of an unnamed tributary downstream from Albert Pond. This tributary eventually drains into Osborn Pond. The stream lies in a relatively isolated wooded area. Land use in the surrounding area, including around the pond, is residential.

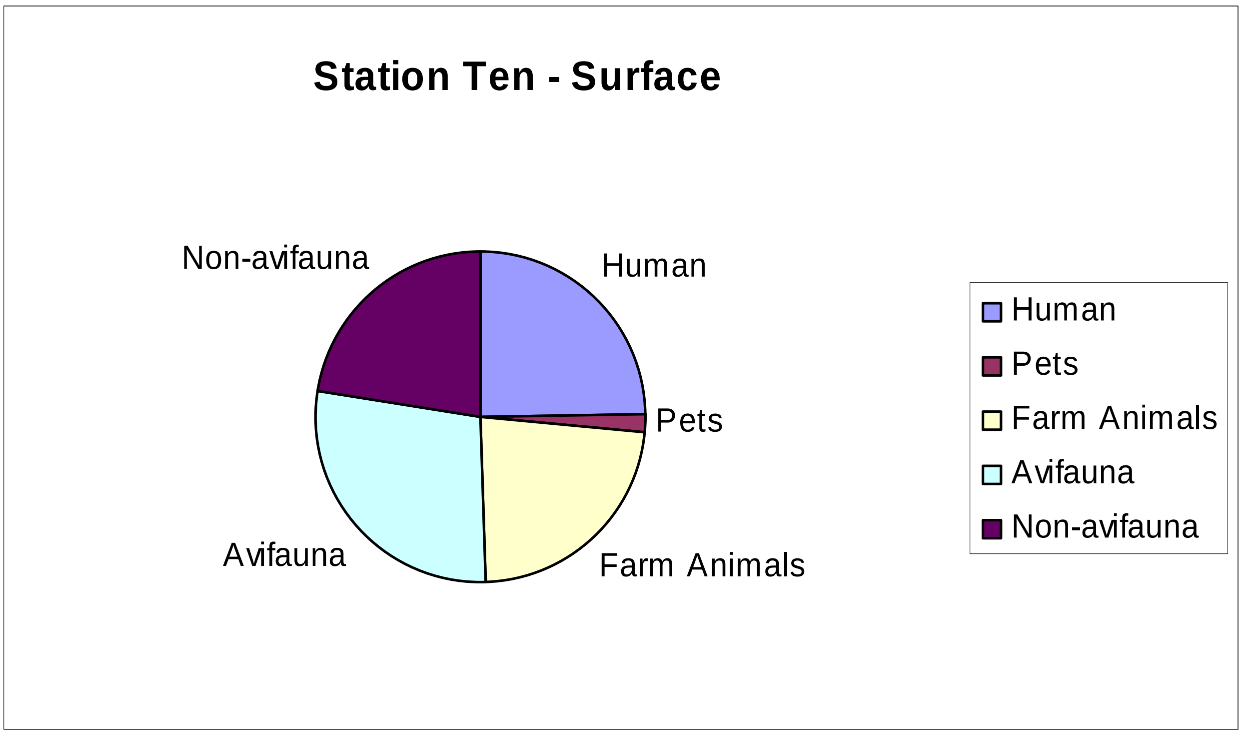
Ambient Water Quality:

Water depth at Station 10 was generally less than a quarter of a meter and water transparency was to the bottom; however, the stream bed was dry during the final two sampling sessions (9/15 and 9/29). The water temperature at Station 10 ranged from 22.5 to 25.5^{o}C throughout the sampling sessions. Salinity at this station was less than 1.0 ppt. Dissolved oxygen ranged from 3.5 to 11.2 mg/l with lowest levels recorded in July and August. The pH at Station 10 ranged from 7.5 to 6.7.

Surface Water Source Profile:

Major contributors of fecal loadings at Station 10 were human, farm animal, avifauna, and non-avifauna, with little contribution from pets. Source levels were intermittent and were not detected for the major contributing groups at the end of June, in late July and mid September. Patterns for the major contributing groups were similar.

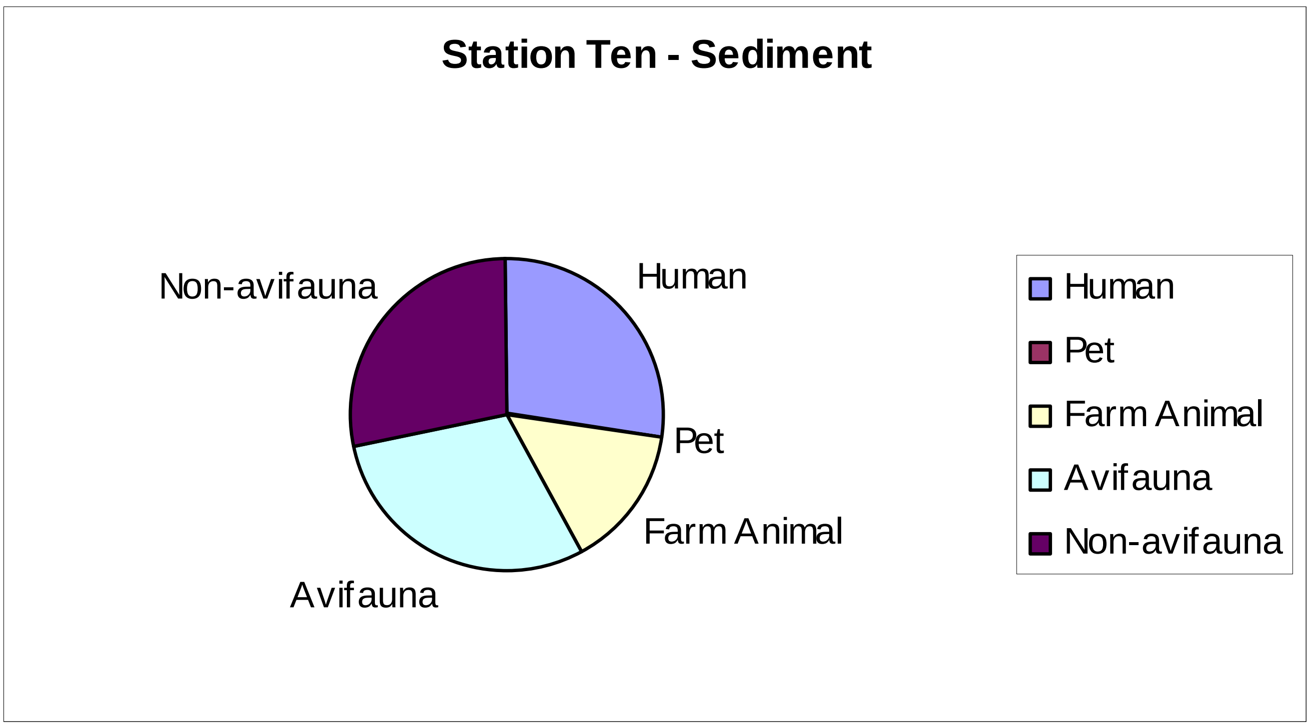
Surface Water Source Summary By Source Category
Based on Mean Relative Abundance – All Sampling Events



Sediment Source Profile

A sharp peak of unclassified sources in mid June was followed by a broad peak of mixed sources from mid July to early August. Human sources peaked at the end of July. Farm animal contributions peaked in early August. Avifauna contributions peaked broadly from late July to early August. Non-avifauna pollution peaked in mid July.

Sediment Source Summary by Category
Based on Mean Relative Abundance – All Sampling Events



Station 11: Hurley Pond

Station Location:

Stream channel of Wreck Pond Brook downstream from Hurley Pond east of the Allenwood Road crossing

Site Description:

Station 11 was located on Wreck Pond Brook downstream from the spillway leading from Hurley Pond. Allenwood Road crosses immediately to the east. The area surrounding the site is heavily vegetated, including some wetlands. No residential structures are immediately adjacent to the sampling site; however, residential development is located to the north and west. Wooded areas are present along the Brook and adjacent pond.

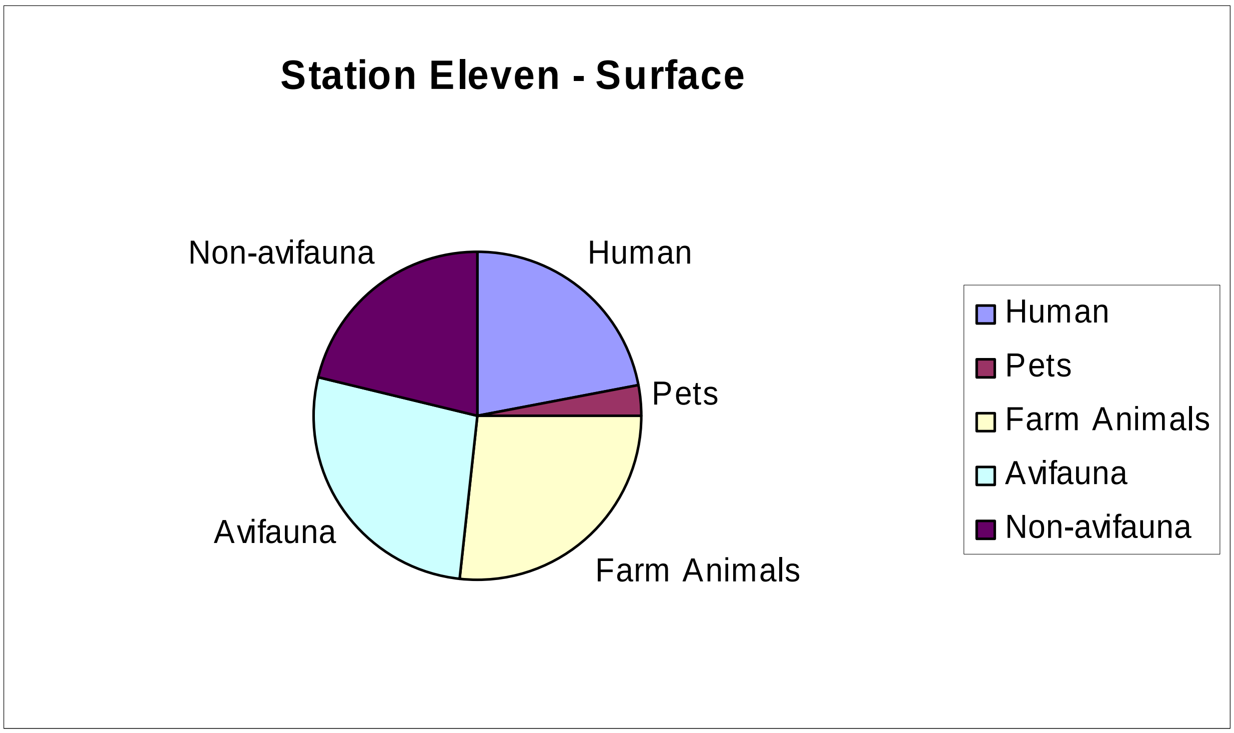
Ambient Water Quality:

Water depth at Station 11 was generally half a meter and water transparency was to the bottom. The water temperature at Station 11 ranged from 19.3 to 25.4^{o}C throughout the sampling sessions. Salinity at this station was less than 1.0 ppt; dissolved oxygen ranged from 5.0 to 7.6 mg/l; and the pH at Station 11 ranged from 6.2 to 9.9.

Surface Water Source Profile:

Major contributors of fecal loadings at Station 11 were human, farm animal, avifauna, and non-avifauna, with little contribution from pets. Sources were at high levels throughout the study period.

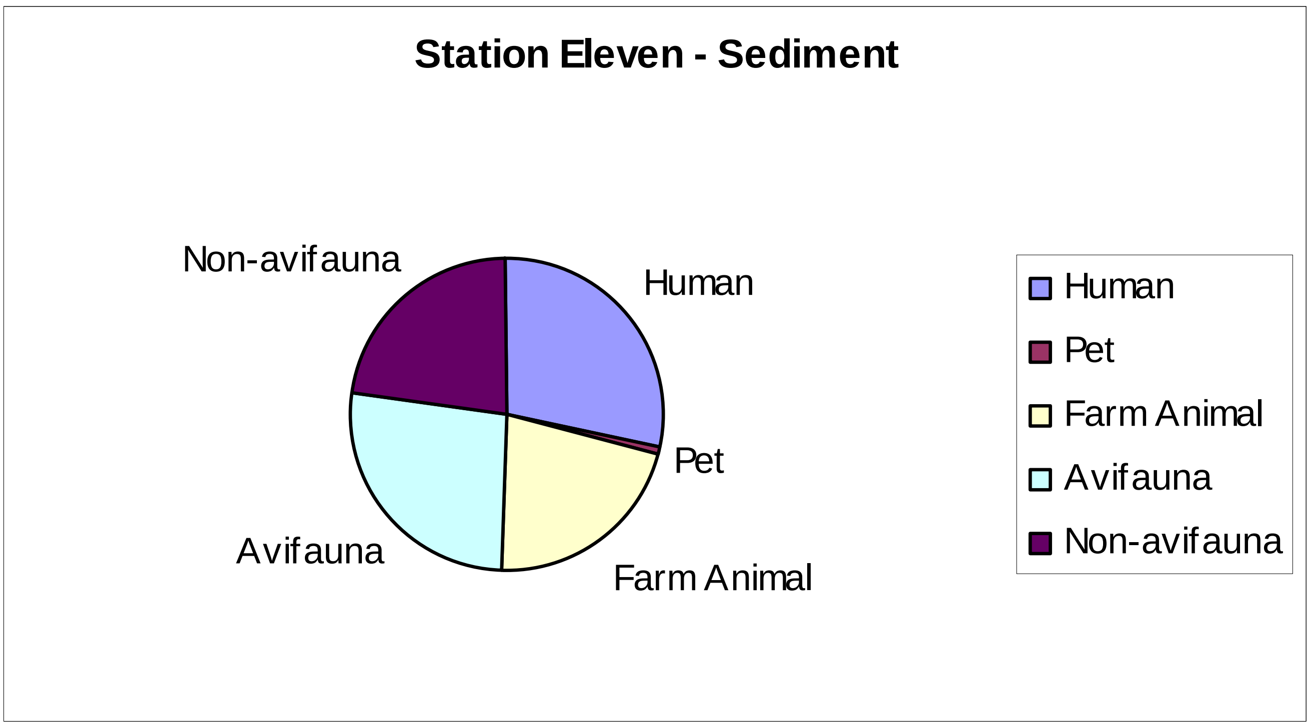
Surface Water Source Summary By Source Category
Based on Mean Relative Abundance – All Sampling Events



Sediment Source Profile

Pollution levels were at their highest in mid July. Levels of mixed sources were high in mid June but decreased in late July and then leveled out in August. In September, levels of mixed sources increased.

Sediment Source Summary by Category
Based on Mean Relative Abundance – All Sampling Events



Station 12: Hannabrand Brook

Station Location:

Stream channel of Hannabrand Brook on south side of Allaire Road across from Bel-Aire County Golf Course

Site Description:

Station 12 was located on Hannabrand Brook downstream from the Bel-Aire County Golf Course. Allaire Road crosses the stream immediately to the north of the sampling site. The area surrounding the stream is characterized by gradually sloping banks which, to the east, are grass covered and maintained by the residence located approximately 25 yards east of the stream. A wooded area is located to the west and downstream of the sampling site.

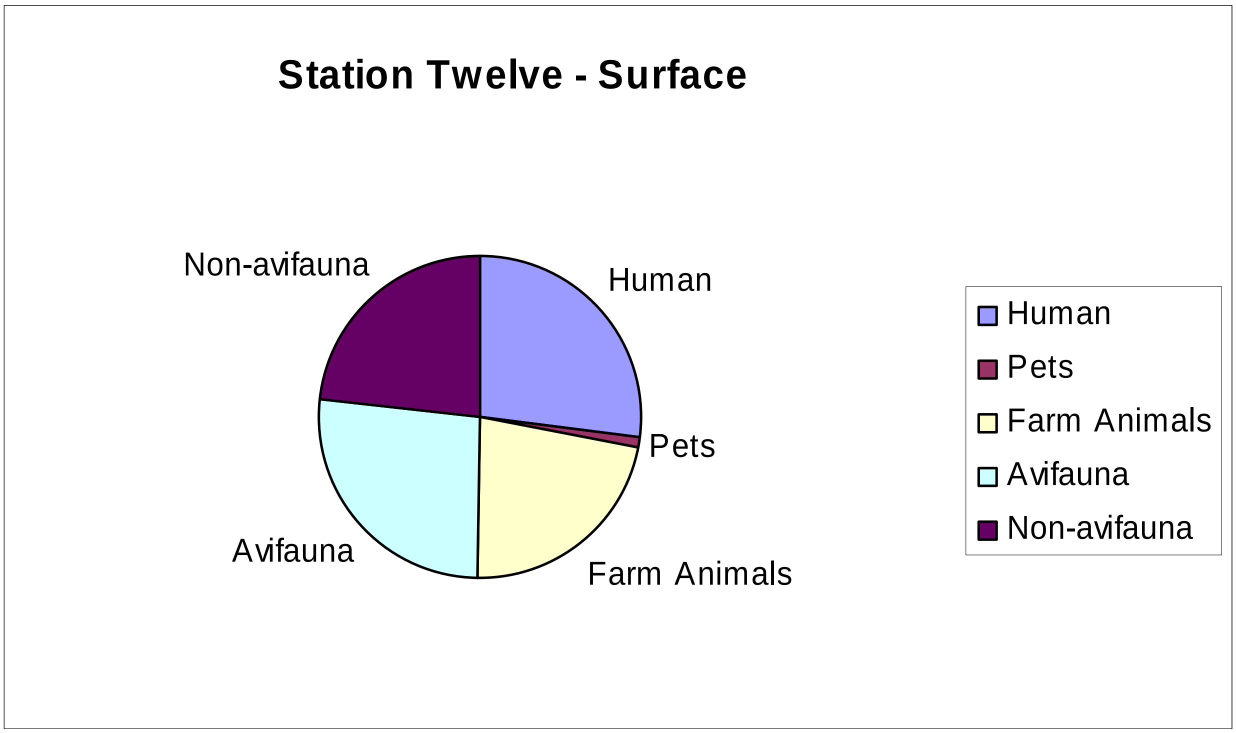
Ambient Water Quality:

Water depth at Station 12 was generally less than a quarter of a meter and water transparency was to the bottom. The water temperature at Station 12 ranged from 19.2 to 23.8^{o}C throughout the sampling sessions. Salinity at this station averaged less than 1.0 ppt. Dissolved oxygen ranged from 4.4 to 9.1 mg/l with lowest levels recorded in June. The pH at Station 12 ranged from 6.1 to 7.3.

Surface Water Source Profile:

Major contributors of fecal loadings at Station 12 were human, farm animal, avifauna, and non-avifauna, with little contribution from pets. Source levels were intermittent and were not detected for the major contributing groups at the end of July.

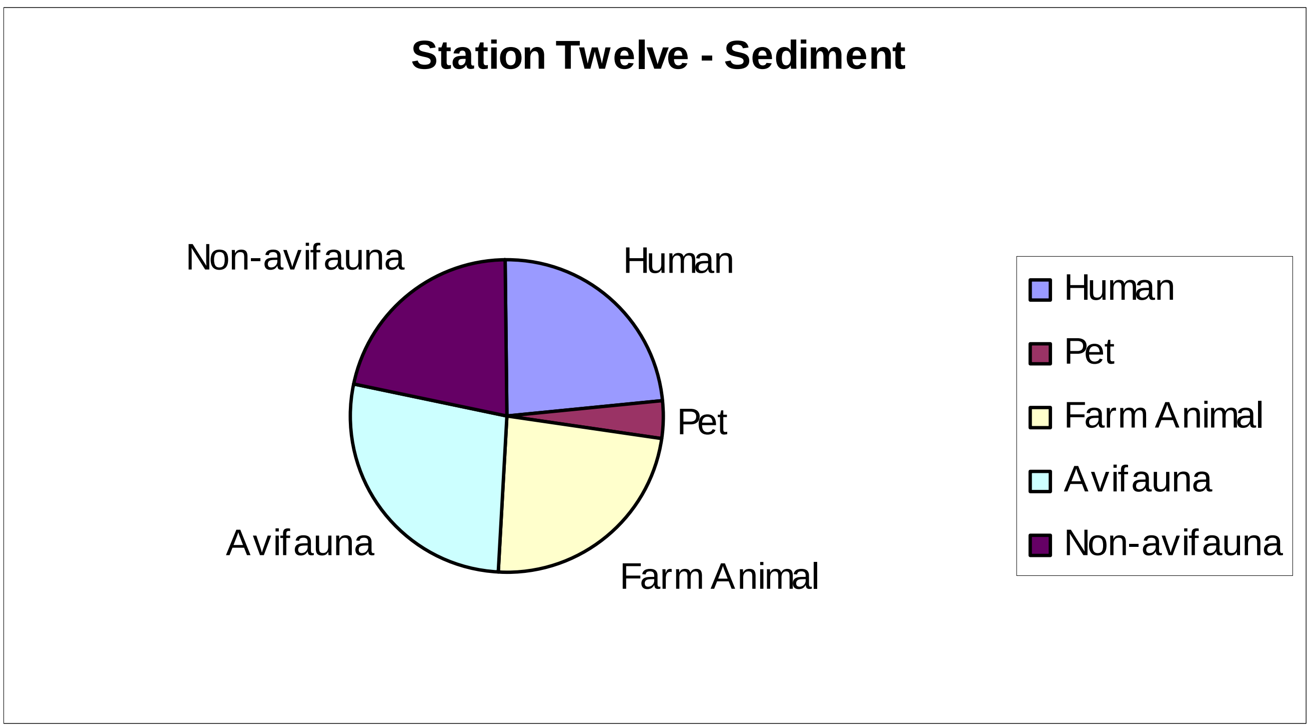
Surface Water Source Summary By Source Category
Based on Mean Relative Abundance – All Sampling Events



Sediment Source Profile:

High levels of mixed contributions were seen for all dates except mid September when a peak of unclassified isolates was seen. Human contributions peaked in mid July and early August. A small sharp peak of pet sources was seen in late August. Farm animal and avifauna contributions peaked in mid July and late August. Non-avifauna pollution peaked in mid June and mid July.

Sediment Source Summary by Category
Based on Mean Relative Abundance – All Sampling Events



5.0 SUMMARY AND RECOMMENDATIONS

Disease-carrying bacteria, viruses, and other pathogens associated with human and animal waste pose threats to humans. When these pathogens are introduced into coastal waters, they frequently persist for a long time and can contaminate seafood, drinking water, and swimming areas. As a result, they can convey diseases directly to humans who come in contact with pathogen impaired waters (see Appendix D for a list of waterborne pathogens of concern and associated illnesses they may cause).

Results of the Wreck Pond Watershed Microbial Source Tracking Study have confirmed that fecal pollution in the watershed does not come from a single source. Mixed sources of fecal pollution including human, avifauna, wildlife, and farm animals are consistently detected in surface waters and sediment in the watershed. General patterns of source inputs suggest that important physical environmental factors such as mixing and seasonal variation in flow through the watershed affects the predominant source detected at any given time.

It has also been well documented that rainfall can have a significant influence on nonpoint source pollutant loadings. A storm event associated with nonpoint source tracking studies is typically defined as an event when the rainfall for the study area is 0.50 inches or greater. Rainfall data corresponding to sampling dates for the Wreck Pond Watershed Microbial Source Tracking Study are listed in Table 7. Typically, during and after a rain event, fluctuations in pollutant sources can be expected. In dryer periods, or during base flow conditions, more predictable patterns of pollution sources may develop. Storm associated peaks indicate mixed pollution sources that result from pollutants being flushed from the adjacent drainage area into, and downstream, in the watershed. Storm events can also resuspend sediment, causing a release of pollutants into the water column.

Table 7. Rainfall Data for the Wreck Pond Watershed

Date Sampled	Rainfall Amount on Sampling Date (inches)	Rainfall Amount on Day Prior to Sampling Date (inches)	Total Amount of Rainfall Seven Days Prior to Sampling Date (inches)
6/16/2005	0.09	0.00	0.07
6/27/2005	1.54	0.00	0.33
7/13/2005	0.58	0.00	1.64
7/25/2005	0.03	0.00	0.14
8/9/2005	0.23	0.16	0.20
8/23/2005	0.00	0.00	0.17
9/15/2005	0.55	0.00	0.00
9/29/2005	0.11	0.00	0.29
Sources: Wall Township Station(Manual): Hospital Road-NJ Water Authority Howell Station(Manual): Manasquan Reservoir- NJ Water Authority Point Pleasant Station(Automated): NJ Weather and Climate Network, http://climate.rutgers.edu/njwxnet/station.jsp?item=foo&station=278			

The presence of *E. coli* from multiple sources in sediments in the watershed has also been confirmed in our study. Since the 1970's, it has been documented that aquatic sediment can serve as a reservoir for pathogens such as *E. coli* (Erkenbrecher, 1981; Goyal *et al*., 1977; Grimes 1975; Grimes 1980; LaLiberte and Grimes, 1982; Matson *et al*., 1978; Sayler et al 1975). Studies concerning survival of *E. coli* in aquatic sediments have demonstrated that *E. coli* can survive extended periods of time in the sediment (Byappanahalli *et al*., 2003; Geldreich and Clarke, 1966; Gerba and Schaiberger, 1973; Grimes, 1975; Grimes, 1980; LaLiberte and Grimes, 1981). For example, Desmarais *et al*. (2002) conducted a study in the North Fork of New River in Fort Lauderdale, Florida which measured high concentrations of *E. coli* in the sediment despite the absence of fecal contamination in the water column. The study found that the indicator bacteria can survive for days in unsterile surficial sediments and provided several reasons for the persistence of *E. coli* in sediments including the ability of *E. coli* to cause inactivation of indigenous microbes in the sediments which reduces competition for nutrients and space as well as eliminates the threat of predation by other microbes. High concentrations and deposition of suspended organic material in the sediment provide ideal conditions for these bacteria to survive in the upper layer of the sediment (Desmarais *et al.*, 2002). Desmarais *et al*. (2002) also found that *E. coli* was able to remain in sediments for long periods of time and was capable of multiplying under stimulated environmental conditions.

This points to the need for a sediment management and reduction strategy coupled with a stormwater management strategy. Sedimentation and particulate matter is increased by erosion and washed into waterbodies either directly or through the stormwater system. Reduction of this process can be achieved by reducing erosion through stream bank stabilization and other restoration methods or by removing sediment after deposition via dredging. However, although dredging is an option, this solution is expensive, will increase turbidity, and may resuspend sequestered pollutants.

The Wreck Pond MST data also suggests the following:

Human Sources –

The consistent detection of human sources of fecal pollution is cause for concern. High levels of enteric pathogens such as *E. coli* are potential public health hazards (Erkenbrecher 1981; LaLiberte and Grimes, 1982). While most isolates of *E. coli* are benign, there is a relationship between *E. coli* levels and other important pathogens that come from the same source. Therefore, even when benign *E. coli* are detected we must suspect the presence of a number of other pathogenic strains. This is a feature of fecal pollution that keeps being confirmed in traditional and advanced studies (Savichtcheva *et al.,* 2007). Harmful microbes often associated with fecal pollution from human sources can include pathogenic strains of *E. coli* and *Salmonella* which may cause gastroenteritis with varying degrees of severity.

It can be assumed that since there are no significant wastewater point source discharges in the watershed, the presence of human related bacteria in the watershed generally indicates sewage system or stormwater system malfunctions or infrastructure problems. Common sources of problems for this type of situation include failing or overloaded sewer systems, illicit connections to the stormwater conveyance system, or lack of regulatory measures to address such problems.

General recommendations for preliminary actions to address human sources of fecal pollution are described in Table 8.

Avifauna and Other Indigenous Wildlife –

Bird and wildlife sources were consistently detected at most sampling sites. A major concern is contributions of pathogens from flocks of waterfowl like Canada geese, Mute swans, and various species of ducks although gulls, pigeons, cormorants, and other species also commonly frequent portions of the watershed. When waterfowl come into contact with waterbodies used for human activities, such as shellfish harvest or contact recreation, a significant human health problem may occur.

For example, a study by Albarnaz *et al.* (2007) linked gulls as the source of pathogenic *Salmonella* contaminating oyster beds. Canada geese can produce pathogenic bacteria in their feces including pathogenic *E. coli* (Hussong *et al.*, 1979) and *Salmonella* (Feare *et al.,* 1999). Geese also carry host adapted *Cryptosporidium* (Zhou *et al.*, 2004). Waterfowl are also an important reservoir for avian influenza virus (Hanson *et al.,* 2005). Pigeons are a reservoir for pathogenic strains of *E. coli* and many other diseases (Haag-Wackernagel and Moch, 2004; Haag-Wackernagel, 2005) and may exchange them with cattle (Pedersen *et al*., 2006). Pigeons and mallard ducks are a reservoir for *Campylobacter* (Kobayashi *et al*., 2002). Double-crested cormorant are also reported to be associated with pathogenic bacteria in their feces (White and Forrester, 1979).

Non-avian wild animal species such as raccoons, opossum, muskrats, and deer are common in some portions of the watershed. While fecal contributions from wild animals are generally considered less of a concern in terms of human health, wildlife feces has been identified as a potential source of *E. coli* (Somarelli *et al.,* 2007), *Campylobacter,* and *Salmonella* pollution (Lillehaug *et al.,* 2005). Many species of wildlife are also carriers of other bacterial and protozoan diseases. However, because humans do not live in close association with wild animals in the watershed and are not responsible for their veterinary care, we are much less aware of their pathologies. Therefore, wildlife must be categorized as a source of unknown or poorly quantified threats; nevertheless, a source that should be dealt with through implementation of appropriate BMPs.

General recommendations for preliminary actions to address waterfowl and wildlife sources of fecal pollution are described in Table 9.

Table 8. Preliminary Actions for Addressing Human Sources of Fecal Pollution

SOURCE CATEGORY	MANAGEMENT STRATEGIES	POTENTIAL RESPONSIBLE ENTITY
Human		
Septic Systems	• Septic system remediation and proper closure	• Individual citizens
	• Conduct sanitary surveys to identify inadequate function, remediation or closure of on-site disposal systems	• Municipalities
	• Strictly enforce septic management ordinances and programs	• Municipalities
Sewage Conveyance Facilities	• Conduct infrastructure surveys and implement corrective actions (maintenance and repair)	• Municipalities • Sewerage Authority
Storm Sewer Systems	• Conduct infrastructure surveys and implement corrective actions (maintenance and repair)	• Municipalities
	• Investigate and repair illicit connections of sanitary sewers to storm sewer systems	• Municipalities • Sewerage Authorities
	• Implement measures required under the municipal stormwater permitting program and any additional measures determined in the future to be needed through the TMDL process	• Municipalities • Regional Planning Group

Table 9. Preliminary Actions for Addressing Waterfowl and Wildlife Sources of Fecal Pollution

SOURCE CATEGORY	MANAGEMENT STRATEGIES	POTENTIAL RESPONSIBLE ENTITY
Wildlife		
Waterfowl	• Educate citizens to avoid feeding waterfowl	• Municipalities • Individual citizens
	• Strictly enforce waterfowl feeding ordinances that prohibit feeding of unconfined waterfowl on public lands	• Municipalities
	• Develop and implement a waterfowl population management plan (habitat modification; reproduction control)	• Municipalities (permits may be needed)
Other Indigenous Wildlife	• Increase animal control efforts (trapping and removal)	• Municipalities
	• Riparian buffer restoration	• Municipalities

Farm Animals –

Approximately 10% of the Wreck Pond watershed is classified as agricultural and the presence of farm animal sources at many sampling sites suggests that inadequate manure management on parcels of land where animals such as steer, donkeys, chickens, pigs, goats, sheep, horses, or exotic pets are housed may be having a negative impact in the watershed.

It has been well established that manure from farm animals can contaminate waterways. In addition to contributing bulk organic matter to watersheds, pathogenic organisms associated with manure can cause disease in humans. Pathogens including bacteria, protozoa, viruses, and parasitic worms can originate in manure pollution (Hoorman, 2007). However, some strains of pathogens are more of a concern in terms of public and environmental health than others. For example, cattle manure can be a source of the very dangerous *E. coli* O157 strain (Stephens *et al.,* 2007) which causes acute bloody diarrhea, abdominal cramps, and sometimes kidney failure. *Campylobacter* are also found in farm manure (Hutchison *et al.,* 2007). Outbreaks of the protozoan *Cryptosporidium* have also been traced to farm pollution (Dorner *et al.,* 2004). This protozoan can cause a diarrheal disease which is particularly serious in children. Giardiasis (also called beaver fever) can be contracted from ruminants such as sheep and cows via pollution of drinking water with manure (Bradford *et al.,* 2006). Symptoms of this disease are severe diarrhea and abdominal cramps.

General recommendations for preliminary actions to address farm animal sources of fecal pollution are described in Table 10.

Pets –

Although pet waste was found to be minimal at most sites sampled in the watershed pet waste can contain dangerous pathogens. For example, intestinal parasites such as the hydatid tape worm (*Echinococcus granulosus*) whose primary host is the dog may also invade humans as a secondary host, causing liver and lung damage (Sanchez *et al*., 2003). *Cryptosporidium* and *Giardia* are also found in dog fecal pollution (Cox *et al.,* 2005) and *Salmonella* may also be found in the feces of some pets especially those with diarrhea (CDC, 2007).

General recommendations for preliminary actions to address pet waste sources of fecal pollution are described in Table 11.

The final objective of this study was to identify and outline potential stormwater runoff Best Management Practice (BMP) strategies that address fecal contamination in the watershed. These strategies are discussed in section 5.1

Table 10. Preliminary Actions for Addressing Farm Animal Sources of Fecal Pollution

SOURCE CATEGORY	MANAGEMENT STRATEGIES	POTENTIAL RESPONSIBLE ENTITY
Farm Animals		
Source Confirmation	• Conduct watershed wide agricultural (livestock) assessment	• Municipalities in collaboration with Rutgers Cooperative Extension
Small Confined Animal Facilities	• Develop and implement on-site conservation plans and manure management plans	• Property/farm owner
	• Allow for as much vegetated area as possible between animals, animal waste and water bodies	• Property/farm owner
	• Select appropriate locations for barns, fields, manure storage containers or compost bins, watering systems, and fencing	• Property/farm owner
	• Store manure in a well-built, covered structure away from adjacent surface waters	• Property/farm owner
	• Transport manure frequently to an appropriate disposal/processing site	• Property/farm owner

Table 11. Preliminary Actions for Addressing Pet Waste Sources of Fecal Pollution

SOURCE CATEGORY	MANAGEMENT STRATEGIES	POTENTIAL RESPONSIBLE ENTITY
Domestic Animals		
Pets	• Educate citizens to clean up pet waste from streets, sidewalks, driveways, and pens • Educate citizens to dispose of pet waste by placing it in the trash or flushing it down the toilet	• Municipalities • Individual citizens
	• Strictly enforce pet waste ordinances	• Municipalities
	• Establish pet waste collection stations throughout the watershed(include educational material, instructions for proper pet waste management, plastic bags for picking up waste, and garbage cans or other receptacles for disposal)	• Municipalities
Feral Cats	• Increase animal control efforts (trapping, removal, neutering)	• Municipalities

5.1 Potential Stormwater Management Strategies to Control Pathogen Contamination in the Wreck Pond Watershed

The federal Clean Water Act requires the U.S. Environmental Protection Agency (US EPA) to regulate stormwater discharges under the National Pollutant Discharge Elimination System (NPDES) program. The NPDES program was established in 1972 and authorizes and distributes permits for discharges to surface waters of the nation. The stormwater program was updated with two phases implemented in response to amendments to the Clean Water Act made in 1987.

Phase I of the Stormwater Rules was established in 1990 and addressed stormwater runoff from: (1) medium and large Municipal Separate Storm Sewer Systems (MS4s) generally serving populations of 100,000 or greater; (2) construction activities disturbing 5 acres of land or greater; and (3) ten categories of industrial activity. An MS4 includes any method of conveying surface water, including streets, gutters, ditches, swales, or any other manmade structure that alters and/or directs wet-weather flows.

Phase II of the Stormwater Rules went into effect in 2003 and requires permits for stormwater discharges from: (1) Municipal Separate Storm Sewer Systems (MS4s) located within an urbanized area that has a total population of 50,000 or more and a density of 1,000 persons per square mile; and (2) Construction activities that disturb 1 or more acres of land.

Those MS4 communities permitted under Phase II are required to develop and implement a comprehensive stormwater management program that will reduce pollutants in stormwater to the maximum extent practicable (MEP) to protect water quality. The regulations specify that by January 2008, Municipal Stormwater Management Plans must be developed that address six minimum control measures: (1) public education and outreach; (2) public participation/involvement; (3) illicit discharge detection and elimination; (4) construction site runoff control; (5) post-construction runoff control; and (6) pollution prevention/good housekeeping.

In New Jersey, the New Jersey Department of Environmental Protection (NJDEP) administers the NPDES program, known as the New Jersey Pollutant Discharge Elimination System (NJPDES) program. The NJPDES program for stormwater limits the quality and quantity of discharges under the New Jersey Municipal Stormwater Regulation Program. This program addresses pollutants entering waterways from many MS4s as well as storm drainage systems owned or operated by local, state, interstate, or federal government agencies. The NJDEP's revised NJPDES stormwater rules were signed on January 5, 2004 and appear in the February 2, 2004 edition of the New Jersey Register at 36 N.J.R. 813(a).

The New Jersey Municipal Stormwater Regulation Program regulates, in some form, all 566 municipalities within the state. Municipalities within the state are designated as either Tier A or Tier B. Tier A municipalities are generally located within the more densely populated regions of the state or along or near the coast. Tier B municipalities are generally more rural and in non-coastal regions.

In February 2004, the NJDEP issued four final NJPDES general permits: Tier A Municipal Stormwater General Permit (NJ0141852); Tier B Municipal Stormwater General Permit (NJ0141861); Public Complex Stormwater General Permit (NJ0141879); and Highway Agency Stormwater General Permit (NJ0141887) (NJDEP, 2006). The permits address stormwater quality related issues for new and existing development and redevelopment by requiring the preparation of a comprehensive stormwater management program and implementation of specific permit requirements referred to as Statewide Basic Requirements (SBRs). The Tier B Permit concentrates on new development and redevelopment projects and public education (NJDEP, 2006). The Tier A Permit includes the requirements found in the Tier B permit, plus Best Management Practices (BMPs) aimed at controlling stormwater pollutants from existing development. In addition, NJPDES permits are required for public complexes and highway systems. Public complexes include large, publicly owned or operated military bases, colleges, and hospital complexes. Highway systems include those operated by counties or by transportation agencies such as the New Jersey Department of Transportation, Port Authority of New York and New Jersey, New Jersey Expressway Authority, and the South Jersey Transportation Authority (NJDEP, 2006).

All of the municipalities in the Wreck Pond watershed are Tier A municipalities. The minimum requirements for Tier A municipalities under the NJPDES Municipal Stormwater Regulation Program and NJPDES Municipal Stormwater General Permit NJ0141852 are summarized in Tables 12 and 13.

In response to these regulations, each of the towns within the Wreck Pond watershed have developed draft stormwater management plans which are currently under review by the Monmouth County Planning Board. Unfortunately, most of the draft municipal stormwater management plans do not specifically address many of the concerns that are causing high bacterial loadings in the watershed. While incorporating the requirements of the Phase II regulations in the municipal plans is a good start, the specific issues associated with pathogen contamination need to be openly discussed and linked with ongoing county and municipal stormwater planning and implementation measures.

In particular, as the municipal plans are reviewed at the county and state level, municipalities should be required to amend the plans to address specific measures that will control pathogen loadings at their source. At a minimum, the plans should:

- Discuss bacteria and pathogen problems in the watershed;
- Identify and discuss sanitary sewer and lift station overflows;
- Reference illicit discharge detection and elimination; and
- Identify solutions for these concerns.

In terms of identifying specific pathogen related stormwater BMPs, they can be categorized in several different ways, such as source controls vs. treatment controls, structural controls vs. nonstructural controls, or point source controls vs. nonpoint source controls. Structural controls are defined as built facilities that typically capture runoff, treat it through chemical, physical, or biological means and discharge the treated effluent to receiving waters, ground water, or

Table 12. NJPDES Municipal Stormwater Regulation Program
Summary of Statewide Basic Requirements (SBRs) for Tier A Municipalities

Construction and Post-Construction Stormwater Management in New Development and Redevelopment	
Low Impact Design Ordinance	Requires new development and redevelopment to properly plan to have minimal disturbance to the area during and after development. Considerations for the ordinance include; runoff reduction by using porous building materials, reduction of soil compaction, restrict construction activity near riparian corridors, make use of natural drainageways and preservation of densely vegetated areas.
Post-Construction Ordinances	Ensures compliance with regulations concerning long-term operation and maintenance of storm drains, sewer and septic systems, and other systems that pose potential hazards to waterbodies when not functioning properly.
Maintenance and Yard Operations	
Stormwater Ordinance	Requires proper maintenance of stormwater facilities, regular cleaning of streets, catchbasins and storm drains to prevent bacterial and nutrient pollution and litter from entering the waterbody.
Fertilizer Use Ordinance	Regulates the use of fertilizers by both private and commercial applicators. Phosphorous content of fertilizers is restricted to 0.5% to eliminate events of eutrophication.
Pest Management Ordinance	Restricts the use of pesticides, herbicides, insecticides, fungicides and other plant growth regulators by developing an integrated pest management program that is both effective and environmentally conservative.
Improper Disposal of Waste	
Improper Waste Disposal Ordinance	Prohibits and spilling, dumping and disposing of materials down storm drains and issues fines for noncompliance with ordinance.
Litter Ordinance	Prohibits littering and issues fines for noncompliance with ordinance.
Waterfowl and Wildlife Management Ordinance	Uses a combination of methods such as fencing around shorelines, habitat alteration and boarder collie deployment to control and reduce populations of waterfowl and other wildlife considered a nuisance to the integrity of the waterbody. The ordinance may also introduce a hunting season and "No Feed Ordinances" to reduce populations of waterfowl and wildlife.
Pet Waste Ordinance	Adopting pet waste disposal ordinances, providing signs and strategically placed pet waste bag dispensers in public recreation areas eliminates a potential pollution source. Additionally the ordinance may require municipalities to educate the public of the connection between non-point source pollution and pet waste to encourage clean up in an annual educational pamphlet and issues fines for noncompliance with ordinance.
Septic and Sewer System Ordinance	Requires proper design, installation and maintenance of septic and sewer systems to prevent bacterial and nutrient pollution from entering the waterbody. Identifies and eliminates illegal sewer connections.

Table 13. NJPDES Municipal Stormwater Regulation Program
Summary of Statewide Basic Requirements (SBRs)
Tier A Municipal Stormwater Permit (NJO141852)

Statewide Basic Requirement	Minimum Standard	Implementation Schedule
Stormwater Pollution Prevention Plan (SPPP)	SPPP describes the municipality's stormwater program, which includes details on the implementation of required SBRs.	12 months from effective date of permit authorization (EDPA)
Annual Report and Certification	Summarize the status of compliance with permit.	On or before May 2, 2005 and every 12 months thereafter
Public Notice	Comply with applicable State and local public notice requirements when providing for public participation	Upon EDPA
Post-Construction Stormwater Management in New Development and Redevelopment		
Stormwater Management Plan	Adopt stormwater management (SWM) plan in accordance with N.J.A.C 7:8-4.	Complete 12 mos. from EDPA
Stormwater Management Plan (for Pinelands municipalities)	Adopt stormwater management (SWM) plan in accordance with N.J.A.C 7:8-4.	Complete 3 months from date Department provides draft Pinelands ordinance.
Stormwater Control Ordinance	Adopt stormwater management (SWM) plan in accordance with N.J.A.C 7:8-4. Resubmit "conditionally approved" and "disapproved" municipal stormwater plans and ordinances to the county review agency.	Adopt ordinance 12 months from SEM plan adoption Resubmit 180 days from initial decision
Residential Site Improvement Standards	Ensure compliance with Residential Site Improvement Standards for stormwater management (N.J.A.C 5:21-7), including any exception, waiver, or special area standard approved under N.J.A.C 5:21-3.	Upon EDPA
BMP Operation and Maintenance	Ensure adequate long-term operation and maintenance of BMPs.	EDPA for BMPs on municipal property, 24 months for BMPs elsewhere
Storm Drain Inlets Design Standard for New Construction	New storm drain inlets must meet the design standards specified in Attachment C of the permit.	12 months from EDPA if municipally installed. Otherwise 24 months from EDPA
Local Public Education		
Local Public Education Program	Copy and distribute educational brochure (provide by the Department) annually to residents and businesses, and conduct a yearly educational "event". Have brochure available for this event	Start 12 months from EDPA
Storm Drain Labeling	Label all municipal storm drain inlets that are next to sidewalks, or within plazas, parking areas or maintenance yards.	Within 60 months from EDPA

Improper Disposal of Waste		
Pet Waste Ordinance	Adopt and enforce an ordinance requiring owners and keepers to immediately and properly dispose of their pet's solid waste. Distribute informational brochure with pet licenses.	Complete 18 months and ongoing
Litter Ordinance	Adopt and enforce a litter ordinance, or enforce the existing State litter statute (N.J.S.A 13:1E-99.3)	Complete18 months and ongoing
Improper Waste Disposal Ordinance	Adopt and enforce an ordinance prohibiting spilling, dumping or disposal of any materials other than stormwater into the MS4.	Complete18 months from EDPA and ongoing
Wildlife Feeding Ordinance	Adopt and enforce and ordinance that prohibits feeding of unrefined wildlife in any public park or property owned/operated by the municipality (except environmental education centers and feral cats as part of an approved TNR program).	Complete18 months from EDPA and ongoing
Yard Waste	Adopt and enforce and ordinance that prohibits placing non-containerized yard waste in the street, OR develop a yard waste collection program.	Start 18 months from EDPA and ongoing
Illicit Connection Ordinance	Develop, implement and enforce an ordinance, to the extent allowable under State law, to prohibit illicit connections to the MS4.	Develop and implement 18 months from EDPA
Illicit Connection Elimination Program	Develop, implement and enforce a program to detect and eliminate illicit connections into the municipality's small MS4.	Develop and implement 18 months from EDPA
MS4 Outfall Pipe Mapping	Map all municipal storm sewer outfall pipes which discharge to surface water by dividing the municipality into two sectors for the purposes of outfall mapping	Map 1st sector 36 months from EDPA. Map 2nd sector 60 months from EDPA.
Solids and Floatable Controls		
Monthly Sweeping of Certain Streets in Predominantly Commercial Areas	In predominantly commercial areas, conduct monthly sweeping of curbed streets, roads and highways (with a speed limit $\leq$ 35 mph), weather and street surface conditions permitting.	Start 12 months from EDPA and ongoing
Storm Drain Inlet Retrofitting	Retrofitting of storm drain inlets during road repair, reconstruction, alterations or repaving with inlets that meet the design standards specified in Attachment C of the permit.	Start 12 months from EDPA and ongoing
Stormwater Facility Maintenance	Develop and implement a stormwater facility maintenance program that includes yearly catch basin cleaning and ensures proper function and operation of all municipally operated stormwater facilities	Start 12 months from EDPA and ongoing
Road Erosion Control Maintenance	Develop a roadside erosion control maintenance program to identify and stabilize roadside erosion. Make repair in accordance with the Standards for Soil Erosion and Sediment Control in New Jersey (N.J.A.C. 2:90-1).	Start 18 months from EDPA and ongoing

Outfall Pipe Stream Scouring Remediation	Develop and implement a stormwater outfall pipe scouring detection, remediation and maintenance program to identify and stabilize localized stream and stream bank scouring in the vicinity of outfall pipes operated by the municipality. Repairs shall be in accordance with the Standards for Soil Erosion and Sediment Control in New Jersey (N.J.A.C. 2:90-1).	Start 18 months from EDPA and ongoing
Maintenance Yard Operations		
De-icing Material Storage	Construct permanent indoor storage with an impermeable floor for deicing materials. Seasonal tarping shall be used as an interim BMP until the permanent structure is completed. Uncovered sand may be stored outside if a 50' setback is maintained from any storm sewer inlet.	Comply with tarping and sand storage requirements w/in 12 months, complete perm. Structure w/in 36 months from EDPA.
Fueling Operations	Develop and implement SOPs for vehicle fueling and bulk delivery and implement with the required practices contained in Attachment D of the permit.	Start 12 months from EDPA and ongoing
Vehicle Maintenance	Implement required practices for vehicle maintenance contained in Attachment D of the permit.	Start 12 months from EDPA and ongoing
Equipment and Vehicle Washing	Implement program to eliminate the unpermitted discharge of equipment and vehicle washwater to the waters of the State.	Implement on or before February 28, 2009
Employee Training		
Employee Training	Develop and conduct an employee training program for appropriate employees that covers the required topics contained in the permit	Start 12 months from EDPA and ongoing

stormwater conveyance systems.

Nonstructural practices usually involve changes in activities or behavior and focus on controlling pollutants at their source typically under a regulatory authority or program. Examples of nonstructural practices include developing and implementing regional stormwater management plans, organizing public education campaigns, and practicing good housekeeping at commercial and industrial sites (USEPA, 2006). However, some nonstructural BMPs are actually engineered solutions that, while not as obvious as a stormwater basin, are actually designed to meet specific design and performance standards. These may include vegetated buffers, bioretention swales, and created wetlands.

Another type of non-structural management activity that could be particularly suited for a watershed such as the Wreck Pond system which is subject to redevelopment and infill development types of activities is the disconnection of impervious and pervious cover. Essentially, this amounts to either regrading of a site to separate runoff from pervious and non-pervious areas or making use of pervious areas as filter strips to intercept and partially treat stormwater runoff. In doing so, a decrease in runoff volume and/or pollutant loading could be achieved. The benefit of this approach is that it is particularly well suited for urbanized areas and for the most part does not require an extensive amount of land to implement.

The following sections have been subdivided into general categories of recommendations highlighting potential BMPs that, if implemented, would result in controlling pathogen inputs from stormwater at their source: Regulatory Activities (Section 5.1.1); Stormwater Management and Planning (Section 5.1.2); Infrastructure Management and Improvement (Section 5.1.3); Ordinances for Site Design for Development and Redevelopment (Section 5.1.4); and Education and Outreach (Section 5.1.5). Many of these recommendations overlap and may be cross-referenced in the different sub-sections which follow.

5.1.1 Regulatory Activities

Regulatory approaches are considered nonstructural stormwater control measures and can be subdivided into land use practices and source control practices. Land use practices are aimed at reducing impacts on receiving waters that result from runoff from development by controlling or preventing land use in sensitive areas of the watershed.

Regulatory approaches for source control practices are aimed at preventing or reducing potential pollutants at their source before they come into contact with runoff or ground water by enacting compliance standards. Source controls can also include pollution prevention activities designed to modify behavior through education, such as promoting less application of lawn fertilizers and pesticides and picking up after pets. Regulatory source controls are most successful when adequate oversight and enforcement are provided. The regulation of stormwater discharges and stormwater management are discussed more thoroughly in Section 5.1.2. This section will focus on the regulation of permits and ordinances for land use and development issues.

Local development and subdivision ordinances require development applicants to meet certain land use (e.g., commercial vs. residential), development intensity, and site design requirements (e.g., impervious surface limits or open space, riparian buffer, or setback requirements). Ordinances that apply these requirements to redevelopment projects (not just new development areas) can help mitigate current impacts from existing development. Payment or equivalent off-site mitigation projects could also be considered. Uniform land use criteria applied throughout the watershed would ensure that what happens in one community does not impact others, particularly those downstream.

Municipal officials, land developers, local businesses, and residents in the community may have philosophical differences regarding whether or not land should be preserved, conserved, or developed, and how to go about doing each. These interests typically converge in that all are seeking a healthy, vibrant community. The basic guiding principals for successful environmental and natural resource protection are the preservation and conservation of natural resources and the protection of resources from undue or inadequately mitigated impact. Overall, the objective of resource management is the ability to sustain the resources, aesthetics, and quality of life for the benefit of the local residents and the community at large. Some important goals of natural resource protection include the following:

- Protect, maintain or improve, as needed, the quality and quantity of surface and ground water resources, protect the quality of the air, prevent undue soil erosion, and manage resources in a manner beneficial to the overall quality of life of the local residents.
- Balance the opportunities for economic sustainability, public quality of life needs, and the management of the environment and natural resources.
- Maintain large, intact areas of native vegetation and prevent its fragmentation as a result of development and development related activities, including disturbances associated with new roads and utility corridors.
- Implement BMPs to control, prevent or mitigate the impacts of stormwater runoff, whether these impacts affect the quality or quantity of surface water or ground water, or the ecological functionality and quality of wetland and riparian resources.
- Protect rare and sensitive features from development.
- Maintain connections among habitat types and protect corridors for wildlife movement.
- Maintain significant ecological processes in protected areas. These include processes related to spawning and breeding, foraging and refuge.

To ensure the success of these measures local officials and developers need to better understand the types and sensitivity of the local resources and the resource management goals of the communities in the watershed.

Recommendations for Improving Land Use Regulations –

Source reduction controls, resource conservation, resource preservation, and land use planning are all highly effective methods of minimizing both short and long-term impacts to water quality and sensitive resources from development. These measures can reduce or eliminate environmental impacts before they occur given their inherently preventative nature. Limiting the entry of pollutants into the environment or avoiding the degradation of resources or the disturbance of any remaining sensitive habitats are ultimately preferable to implementing clean-up and mitigation or restoration activities. There are many ways this can be achieved.

In general, municipal land development ordinances should contain provisions governing reviews, requirements and actions related to site development proposals. The following environmental resource protection tools are also recommended:

- Agricultural Easement Provisions
- Aquifer Testing Requirements
- Buffer Size and Landscaping Requirements
- Bulk Storage Restrictions
- Conservation Easement Requirements
- Deed Restriction Requirements (Open Space & Agricultural Preservation)
- Density Standards Development
- Environmental Impact Statement Requirements
- Erosion and Sedimentation Control
- Establishment of Protective Zoning
- Districts (AR, RR, SSR)
- Floodway, Flood Fringe, Floodplain, and Flood Hazard Restrictions
- Height Restrictions
- Maximum Impervious Surface Restrictions
- Minimum Contiguous Land Requirements
- Noise Restrictions
- Odor Restrictions
- Open Space Requirements (Less floodplains, wetlands, and steep slopes) and Listed Conservation
- Percolation Test Requirements
- Proof of Drinking Water and Available Wastewater Treatment
- Residential Cluster and Planned Development Provisions
- Set Back Requirements
- Sign Regulations
- Steep Slope (Critical Area) Regulations
- Stormwater Treatment Requirements
- Stream Corridor Protection Regulations
- Top Soil Removal Restrictions
- Truck Traffic Regulations
- Tree Protection Regulations (SSR Zone)
- Waste Disposal and Storage Restrictions
- Wetland (Critical Area) Regulations
- Woodland Protection

In addition to adoption and enforcement of appropriate ordinances designed to control nonpoint source pollution, the following ordinance recommendations are designed to support and improve existing environmental protection efforts, local zoning, and land development regulations, based upon findings contained in this study.

- **Riparian Protection:**

Preserving, protecting, or expanding a riparian buffer may have a direct effect on reducing fecal pathogens as well as other pollutants from entering waterbodies in the watershed by limiting access and runoff from areas inhabited by geese, gulls, and other waterfowl and limiting runoff from areas used by pedestrians and dog walkers. In addition to serving as a direct barrier between potential sources and a water body, the buffer can also function as a nutrient sink.

Stream corridor degradation can occur as a result of land disturbance activities attributable to agricultural, commercial, and residential development. Even recreational activities (e.g., the construction and maintenance of playing fields and recreational areas) can lead to encroachments into stream corridors. Often overlooked are impacts to stream corridors resulting from homeowner maintenance practices, such as mowing lawns to a stream's edge or the clearing of vegetation adjacent to streams. The vegetative zone along a stream corridor, whether riparian or upland in nature, provides a number of benefits. These benefits include wildlife habitat, protection of the stream bank from scour and erosion, storage of floodwaters, and pollutant removal. These corridors also can function as greenways providing linkages between upland and wetland habitats or contiguous tracts of preserved lands for the movement of wildlife.

The existing stream buffers in the watershed vary. In some areas the system is buffered, but in other areas development encroaches to the banks of the pond and its tributary streams. Due to some of the uncertainties of the status of buffers, it is highly recommended that the first step taken with respect to the management and protection of stream buffers and riparian areas is to formally map the streams and identify the existing State and local buffers. This should include the delineation of the 100 year floodplain.

To ensure adequate riparian corridor protection, at a minimum, the following management strategies should be implemented:

- A stream buffer ordinance establishing an appropriate buffer within which no clearing is permitted is recommended to be adopted by all municipalities in the watershed to protect the stream and limit soil disturbances along its banks. According to the Federal Interagency Working Group (1998) in general, urban stream buffers should have a minimum base width of at least 100 feet to provide adequate stream protection.
- Establishing "No Mow" areas and/or pond and stream bank landscaping/reforestation immediately adjacent to the pond and its tributaries may provide the greatest reduction of pathogens in this BMP category.
- Conservation and drainage easements should continue to be acquired adjacent to streams and other waterways in the watershed. These easements should include the 100-year flood plain, wetland, and wetland transition areas, state open waters, woodlands, and other significant natural and environmental features. Where the 100-year flood plain is not delineated, an easement having a width of 75 feet should be established.
- The county/municipalities should maintain a digital GIS database of riparian and stream buffers, and strengthen local buffer ordinances to add greater protection to stream and riparian resources. This needs to include an inventory of existing easements and inspection of these protected lands from disturbance or encroachment.

- **Open Space Preservation:**

Open space broadly means natural areas that provide important community space, habitat for plants and animals, recreational opportunities, places of natural beauty, and sensitive environmental areas. Open space preservation supports smart growth goals by preserving critical environmental areas, improving a community's quality of life, and guiding new growth into appropriate areas.

In order to foster open space preservation, the following strategies should be considered:

- Identify and prioritize all undeveloped lands for additional open space acquisition to preserve and/or protect wildlife habitats, significant environmental and scenic resources, and water quantity and water quality.
- Prioritize the enlargement of existing parkland with the addition of smaller adjacent lots.
- Establish or enlarge a greenway along the waterfront and any tributary streams to continue preservation and protection of the component waterbodies in the watershed from development encroachment.
- Municipalities should create a digital database of existing conservation easements and develop and implement a comprehensive conservation plan to identify and catalog the location of each conservation easement within each municipality. Efforts should be taken to incorporate an inventory of existing easements into GIS and have the municipalities perform random inspections of conservation easements throughout the year to ensure these areas are not being illegally altered or encroached upon.

- **Parkland Management:**

Parkland management may require more regulatory measures, greater enforcement efforts, and more education and outreach. The following measures would allow municipalities to manage parklands in an environmentally protective manner:

- Consider additional funding for DPW staff to more routinely patrol and cleanup parklands.
- Provide pet waste bags and more trash receptacles in public areas, and increase waste collection.
- Strengthen parkland management ordinances and encourage municipalities throughout the watershed to adopt and enforce these ordinances, especially in waterfront parks in order to address the following issues:
    - No Littering Laws
    - No Pet Waste Laws
    - No Dumping Laws
    - No Feeding Waterfowl
- Implement a waterfowl management plan at parks and golf courses where geese and gulls are a public nuisance and significantly contribute to the bacterial pollutant loading in the watershed. Volunteers can be trained to oil or addle eggs, or deter geese with approved hazing measures. Install flags, balloons, metal images of dogs, or other measures to

discourage gulls and geese from congregating on spillways and other structures, or on lawns near the ponds and stream corridors in the watershed.

- Post signs and educational information that discourages feeding waterfowl. Create no mow areas or enhance landscaping along waterways to reduce access to these areas by waterfowl.
- Implement stream restoration projects by identifying potential areas where the tributaries in the watershed can be enhanced by the following measures:
  - Implement stream bank stabilization
  - Conduct stream clean ups and maintenance
  - Habitat restoration- i.e., creation of pools and riffles
  - Establish stream corridor conservation areas – no mow and reforestation
  - Invasive species management
  - Improve fish passage
  - Wetland creation
  - Upland restoration and reforestation

- **Site Design Improvements and Low Impact Development:**

Although Low Impact Development (LID) is most customarily associated with development activities occurring in raw, virgin landscapes, the concept can be successfully applied to urban development and redevelopment. In essence, the application of LID in these types of circumstances is designed to reduce runoff and may include innovative structures such as green roof buildings and pervious pavement. For example, the City of Chicago has recently adopted an LID strategy designed to reduce the generation of wastewater and stormwater runoff and the conservation of water (see http://www.epa.gov/owow/info/NewsNotes/issue76/76issue.pdf).

As per NJAC 7:8, projects resulting in 1 acre of disturbance and/or an increase of at least ¼ acre of impervious cover must conduct an LID analysis and also submit as part of the development review application a Non-Structural Stormwater Management Strategies Point System (NSPS) analysis spread sheet (www.state.nj.us/dep/stormwater/pdf/nsps_userguide2006013.pdf). The later is particularly useful in identifying if a development is making full use of LID and non-structural stormwater management techniques to minimize, treat, and/or control runoff. Although technically only applicable for new development, these same requirements should be considered for implementation in redevelopment situations, even those that do not exceed the site disturbance/impervious cover thresholds.

Local stormwater ordinances require development applicants to control stormwater peak flows, total runoff volume, or pollutant loading. Stormwater ordinances that extend these requirements to redevelopment projects (not just new development areas) can help mitigate some of the current impacts to water quality that have arisen over time due to existing development. As such, the county should help develop Model Ordinances and encourage local municipal government to adopt and implement new ordinances that modify site plan design standards that promote sustainable development design, limit the amount of impervious cover for residential and commercial development, encourage Low Impact Development, reduce stormwater runoff, and improve stormwater management. Improvements can be achieved by encouraging or mandating that new major developments retrofit these systems before any storm or sanitary sewer connection is allowed, and to meet performance standards set forth in local and regional stormwater ordinances and/or stormwater management plans. When development occurs, Low Impact Development (LID) requirements for both residential and commercial projects that encompass some or all of the following LID practices need to be encouraged and enforced: minimization of disturbance of natural vegetation; minimization of new impervious surfaces; utilization of alternative landscaping; and decreased use of fertilizers and pesticides. Other options include:

- Ordinances that require such LID practices as the use of vegetated best management practices (BMPs) and the use of integrated, small catchment BMPs.
- Ordinances that encourage such LID practices as green roof tops, roof top runoff drywells, pervious/porous pavement, and similar types of stormwater treatment and groundwater recharge techniques.
- Local ordinances should also require new development to address existing failing or stressed stormwater collection systems through projects such as road culvert improvements and maintenance.
- Standards and specifications for such LID BMPs should be integrated into Model Ordinances (see www.lowimpactdevelopment.org).

5.1.2 Stormwater Management and Planning

It is estimated that up to 60% of existing water pollution problems nationwide are attributable to nonpoint source pollution. Stormwater runoff is one of the largest remaining detrimental components of nonpoint source pollution. Since much of the Wreck Pond watershed was developed before stormwater detention was required, most stormwater is directed to street storm drains that carry runoff to waterbodies within the watershed without treatment. Water quality within the watershed has subsequently been impaired by this stormwater runoff. However, these impairments can be addressed through the implementation of stringent municipal and regional stormwater management plans. These tools can serve as a regulatory framework by which stream quality and the biological integrity of aquatic ecosystems, including adjacent riparian areas and forested wetlands, are protected, enhanced, and restored. Water quality can also be enhanced through the education of the public in the control of nonpoint source pollution and through the acquisition and protection of stream corridors in the form of preserved open space.

- **Reducing Fecal Pathogens in Stormwater:**

As previously noted, the draft Municipal Stormwater Management Plans that have been submitted to Monmouth County should be revisited to provide details concerning pollution prevention, the proper management of runoff, and outline potential modifications of existing local land use and land development ordinances that would address bacterial loadings in the watershed. At a minimum, the plans should emphasize the following measures:

- Conduct an inventory to determine the location of outfalls and any existing stormwater management measures.
- Existing stormwater controls should be evaluated to determine whether they are properly sized and being maintained to achieve the most efficient NPS removal rates.

- Identify opportunities where stormwater BMP upgrades, retrofits, and new installations could be implemented to reduce fecal pathogen loadings.
- Identify BMP upgrade/retrofit opportunities associated with redevelopment projects.
- Identify sites or existing BMPs that could be upgraded as mitigation for new or redevelopment projects where full compliance with the NJDEP stormwater regulations cannot be achieved.
- Emphasize the use of nonstructural stormwater management strategies, such as vegetated stormwater BMPs that have high pollutant removal efficiency.
- Emphasize use of innovative structural stormwater management strategies to reduce NPS loadings and sediment loadings.
- Where feasible, implement stormwater BMPs that encourage groundwater recharge and minimize the volume of stormwater runoff, including green roof systems, roof-top runoff drywells and pervious pavement.

A summary of conventional and innovative secondary stormwater treatment practices and potential structural BMPs that can reduce fecal coliforms in stormwater flows are included Appendix E. The tables in Appendix E describe the measures and their advantages.

As can be interpreted from these tables, conventional stormwater management techniques (e.g., water quality swales and vegetated filter strips) may be an appropriate approach in some cases. Within the Wreck Pond watershed the amount of land available for the implementation of many of the more detailed bio-treatment type BMPs is often limited (e.g., created wetlands). This decreases their utility when such systems are designed or intended for use in an "end-of-the pipe" solution intended to contend with large volumes of runoff. Care also has to be taken with wet ponds. While effective in removing nutrients and sediments, these types of BMPs can attract more waterfowl and increase coliform levels. However, with forethought these types of bioretention devises and designs can be used in applications where the catchment area (contributing watershed) is relatively small. Example applications particularly suited for urban and suburban watersheds, encompassing new development and redevelopment, are parking lot median treatment area, sidewalk treatment areas and similar types of structural features that collect water from relatively small catchments (1- 5 acres).

Another group of structural BMPs that have promise, especially in retrofit applications, are the filter cartridge type manufactured treatment devices (MTDs). These systems, though expensive (with units costing at least $75,000) are well suited for application in retrofit situations in urbanized areas and where there is an existing stormwater collection and conveyance system. They are best used in applications where the contributing catchment area is relatively small (< 5 acres). The cartridges have exceptional filtering capacity and can provide a high level of bacteria removal when properly sized and maintained. Besides the high initial cost, the other negative attribute of the filter type MTDs are the specialized maintenance that most require. The filter media needs to be replaced on a regular basis (6 months to 1-year depending on loading rates) and the removal and replacement may require specialized equipment and typically OSHA confined space entry. Even with these short comings, the filter type MTDs do represent a realistic means of dealing with coliform loading.

Each of these BMPs should be evaluated to determine appropriate strategies that can be selected for site specific areas. The U.S. EPA's Handbook for Developing Watershed Plans to Restore and Protect Our Waters (USEPA, 2005) provides a step by step approach to evaluating options and selecting final management strategies that may be helpful in determining appropriate BMPs that can be implemented in specific portions of the watershed.

- **Reducing Nutrients and Other Pollutants in Stormwater:**

While the main focus of this report is the reduction of fecal pathogens in stormwater, many of the same structural and non-structural BMPs used for pathogen control are efficient at controlling nutrients and other pollutants in stormwater. At a minimum, public outreach programs should be implemented at both the county and local level to assist residents and large property owners with implementation of measures that can reduce overall pollutant loadings. These large property owners could include golf courses, townhouse and apartment complexes, office complexes, hospitals, and shopping centers.

- **Reducing Soil Erosion and Sediment in Stormwater:**

Soil erosion can be a major water quality problem contributing to high nutrient levels and low dissolved oxygen. The impacts are typically most dramatic during the construction of a major development project when large quantities of soil may become eroded and transported off-site. Chronic sedimentation problems also quite frequently arise in urbanized watersheds where stormwater discharges create a scour problem which in turn causes stream bank erosion. Reductions in the latter sources of sedimentation are best achieved through the implementation of the stormwater management measures (structural and non-structural) referenced in the preceding sub-sections of this report. Any measure that can reduce the volume, duration and velocity of stormwater runoff has the ability to abate stream bed and bank erosion problems. The former set of problems, which essentially arise due to poor or insufficient soil and sedimentation erosion controls, can be best reduced or avoided through the implementation of technically sound soil erosion control practices.

Municipalities within the watershed are required to adopt up-dated soil erosion control ordinances as part of their MS4, Phase II NPDES stormwater management permit requirements. Compliance with these rules is triggered by any development activity that creates greater than 500 ft^2 of disturbance. In order to properly assess the degree and extent of disturbance and to evaluate if land disturbance is impacting site areas or off-site resources especially sensitive to sedimentation and erosion related impacts, soil erosion control ordinances should require that applicants provide the following information during local level site plan and environmental reviews:

- Areas of excavation, filling, and grading;
- Areas where topsoil is to be stockpiled;
- All temporary and permanent vegetation, drainage, E&S and control features intended to minimize the offsite transport of soil during the construction phase; and
- A schedule showing initiation and completion of major phases and site preparation activities, including the installation of temporary and permanent vegetation and drainage

E&S facilities, anticipated duration of exposure of all major areas of site preparation before installation of E&S measures.

On a regional scale, as previously noted, a sediment reduction and management strategy needs to be developed as part of the regional stormwater management planning process.

- **Maintenance of Stormwater Collection and Treatment Systems:**

Proper training and maintenance will better ensure the effectiveness of any stormwater collection and treatment system. At a minimum, a stormwater maintenance program in each municipality in the watershed should be developed incorporating the following practices:

- **Catch basin and storm inlet maintenance –** Regular cleaning of storm drains and catch basins, and the maintenance of all stormwater conveyance systems are necessary for the long-term performance of these measures. Sediment and debris accumulate in these catchments reducing their efficiency. Municipalities should implement appropriate maintenance measure on all municipally managed structures and should enforce that maintenance measures are implemented at all commercial properties.
- **SORP- Stormwater Overflow Response Plans –** There is a requirement for industry with discharges to MS4s to prepare Sewer Overflow Response Plans. This is a critical first step, but it only addresses industry, and significant discharges from commercial and residential neighborhoods are also likely occurring.
- **Illicit discharge, detection and elimination –** These issues need to be incorporated into all municipal, as well as the regional, stormwater management plans.
- **Retrofitting –** Municipalities in the watershed should identify opportunities for the retrofit and upgrade of "hot spot areas" of existing stormwater collection and treatment systems. Some of these upgrades could be conducted using funding available through State loan and grant programs or through mitigation plans initiated as a result of new development. Focus should also be placed on the implementation of measures that reduce potential bacterial and nutrient loading to the watershed.
- **Street sweeping and responsible bridge and roadway maintenance** – These housekeeping items should be addressed in all municipal, as well as the regional, stormwater management plans and routinely conducted.
- **Monitoring** – Monitoring water quality after stormwater management measures have been installed will help assess improvements to water quality; confirm the need for the measure; support installation at other locations/properties; support potential legal concerns; address state and federal objectives and requirements; and identify if additional measures are needed.

5.1.3 Infrastructure Management and Improvements

The bacterial assessment data compiled in this study clearly shows that human waste is a contributor to pathogen contamination problems in the watershed. Aging and failing infrastructure appear to be the major factor responsible for the problem. Given the age of most of the infrastructure in the watershed, the likelihood of infiltration/inflow (I/I) problems, and the likelihood of illicit and illegal cross-connections of wastewater and stormwater sewer systems, full correction of pathogen impacts in the watershed is a daunting task.

To determine the extent of the necessary improvements to this infrastructure necessitates increased meticulous inspection and monitoring to determine major and minor points of illicit discharges and failing infrastructure. Once identified, engineering designs will be needed for the rehabilitation or replacement of compromised systems and the implementation of better stormwater management control strategies, structures, and techniques. The first step in this process begins at the state and county levels concerning the establishment and enforcement of policies and regulations that prohibit illicit discharges and require the correction of identified connections. Although straightforward in concept, due to the age of the existing infrastructure, establishment of the party responsible for implementing the corrections is often difficult. To facilitate the correction of illicit and illegal connections, a significant funding source that covers the development of these programs and enables long term management, maintenance, and monitoring will be needed.

In addition, it is possible that lift station malfunctions and overflows may be occurring during rain events, where stormwater infiltrates sanitary lines and overflows these facilities, discharging untreated raw sewage. An investigation designed to identify drainage patterns, regional sewer sheds, and particular lift stations and associated outfalls responsible for discharges and overflows may be warranted. Once completed, a priority listing of the necessary improvements and the schedule for their implementation could be developed.

In order to more properly manage all of the stormwater outfalls and discharges in the watershed it may also be necessary to provide some regulatory framework that requires routine monitoring, investigation, and progress reporting on the necessary upgrades to the systems. It is recommended that the communities of the Wreck Pond watershed would be well served if the County or municipalities annually complete and report on the following tasks:

- **Maintenance and Inspection** – Include periodic storm sewer cleaning and sediment removal.
- **Prohibition of Dry Weather Overflows** – Report dry weather overflows; removal of illicit connections; identify an infiltration/inflow (I/I) control program; eliminate small system bottlenecks.
- **Control of Floatables and Settleable Solids** – Identify existing aesthetic problems from floatables and settleable solids in the receiving waters; quantify floatables; identify potential source controls such as booming, skimming, street cleaning, public education, solid waste collection, in line netting, screens, or catch basin hoods; identify where these measures should be implemented.
- **Connection Prohibitions** – Identify any sewer system backups into houses or streets; develop an I/I control program; develop an operation and maintenance plan (OM) and monitoring plan.
- **Control of Runoff** – Create a stormwater ordinance that restricts stormwater runoff from new developments.

Long term planning and infrastructure improvements may be best managed by preparing an annual report that identifies progress on each of the topics outlined above. In addition, the report should also address:

- **Capacity Management**
  - Update maps of all storm and sanitary sewer systems
  - Develop a plan for detecting and eliminating illicit discharges
  - Sewer system rehabilitation
  - Overflow detection
  - Overflow elimination/ structural measures
  - Reduction of stormwater inflow and infiltration to sanitary sewers
  - Monitoring
  - Re-evaluate current enforcement and procedure for illicit discharges

- **Develop an Operation and Maintenance Plan**
  - Inspection program
  - Training employees
  - Sewer cleaning and sediment removal

5.1.4 Ordinances for Site Design for Development and Redevelopment

Local stormwater ordinances require development applicants to control stormwater peak flows, total runoff volume, or pollutant loading. Stormwater ordinances that apply these requirements to redevelopment projects (not just new development areas) can help mitigate current impacts from existing development. Developers could be required to implement stormwater practices such as bioretention cells, stormwater ponds, or constructed wetlands to meet performance standards set forth in the ordinance and stormwater plans.

Included in Appendix E are tables that summarize potential BMPs for green building techniques that can reduce fecal coliforms in stormwater. These BMPs should be evaluated to determine appropriate measures that can be selected for site specific applications when reviewing proposals for new development or redevelopment projects.

5.1.5 Public Education and Outreach

There are several opportunities and measures that require education and coordination from local officials in order for any stormwater management and pathogen reduction strategy to be successful. One important step will be to ensure that consistent model policies, plans, programs, ordinances, work plans, monitoring programs, and educational materials are developed and implemented on both a regional and local level.

Local officials should be well informed about the water quality issues in the watershed; how they impact the quality of life, especially recreational activities; how they impact future redevelopment and growth decisions; how they impact communities, beaches and aquatic life downstream; and how significant state and federal funding may be needed to address these concerns. State and federally elected officials should also be informed to help with funding issues.

There are large property owners in the watershed, including: Monmouth County, municipalities, hospitals, corporate office complexes, major shopping centers, golf courses, and cemeteries. Many of the items identified in this report could be implemented on these properties to improve the stormwater management, improve infrastructure and overall water quality in the watershed. These large property owners also need to be informed about the needs, ongoing efforts and their responsibilities to the community. Pilot programs/retrofits might be best suited for these properties as a demonstration of good faith and commitment for others.

Residents, business operators, facility management companies, and land owners can also help improve the water quality of the watershed by being better informed how their actions and choices can affect water quality, such as walking their pets, discarding their trash, or maintaining their stormwater management systems.

All of these stakeholders can be informed via newsletters, flyers, brochures, utility bill inserts, websites, public service announcements and presentations to local civic groups. This process would also be facilitated by holding regional meetings on a semiannual basis where information can be disseminated to the necessary stakeholders.

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Appendix A

Wreck Pond Watershed
Ambient Water Quality Data

Wreck Pond Watershed Surface Water Quality Data

June 16, 2005

Station	Time	Temp (^{o}C)	Salinity (ppt)	DO (mg/l)	pH	Depth (m)	Trans (m)
1	9:00:00 AM	20.9	12.3	7.7	8.5	<1.0	bottom
2	9:11:00 AM	21.1	19.2	5.2	7.1	<1.0	bottom
3	9:30:00 AM	24.9	7.9	1.7	7.1	<1.0	bottom
4	9:21:00 AM	23.4	0.0	3.4	7.4	<1.0	bottom
5	9:44:00 AM	23.1	0.0	3.6	6.8	<1.0	bottom
6	9:56:00 AM	21.7	0.0	5.6	6.8	<1.0	bottom
7	10:08:00 AM	17.7	0.0	7.9	6.6	<1.0	bottom
8	10:15:00 AM	22.0	0.0	6.4	6.6	<1.0	bottom
9	10:27:00 AM	20.4	0.0	5.1	6.6	<1.0	bottom
10	10:41:00 AM	25.2	0.0	5.0	7.3	<1.0	bottom
11	11:08:00 AM	23.0	0.0	5.0	6.6	<1.0	bottom
12	10:54:00 AM	21.0	0.0	4.4	6.4	<1.0	bottom

Wreck Pond Watershed Surface Water Quality Data

June 27, 2005

Station	Time	Temp (^oC)	Salinity (ppt)	DO (mg/l)	pH	Depth (m)	Trans (m)
1	11:45:00 AM	17.1	29.6	8.5	7.9	<1.0	bottom
2	11:57:00 AM	23.5	20.4	3.9	8.0	<1.0	bottom
3	12:15:00 PM	25.0	0.0	6.6	7.7	<1.0	bottom
4	12:07:00 PM	24.3	0.0	4.3	7.6	<1.0	bottom
5	12:32:00 PM	23.6	0.0	8.8	6.9	<1.0	bottom
6	12:42:00 PM	22.0	0.0	8.6	6.7	<1.0	bottom
7	12:55:00 PM	19.7	0.0	10.8	6.4	<1.0	bottom
8	1:04:00 PM	23.2	0.0	6.0	6.4	<1.0	bottom
9	1:17:00 PM	20.6	0.0	8.0	6.4	<1.0	bottom
10	1:30:00 PM	25.5	0.0	11.2	7.5	<1.0	bottom
11	1:57:00 PM	24.1	0.0	6.4	9.9	1.0	bottom
12	1:45:00 PM	23.6	0.0	10.3	6.6	<1.0	bottom

Wreck Pond Watershed Surface Water Quality Data

July 13, 2005

Station	Time	Temp (^oC)	Salinity (ppt)	DO (mg/l)	pH	Depth (m)	Trans (m)
1	12:45:00 PM	22.9	28.9	6.4	7.7	0.2	bottom
2	12:35:00 PM	25.0	9.8	7.8	8.1	0.2	bottom
3	12:25:00 PM	26.2	0.0	6.5	8.8	0.2	bottom
4	12:10:00 PM	25.0	0.0	3.4	6.9	0.2	bottom
5	11:55:00 AM	23.3	0.0	3.8	6.5	0.1	bottom
6	11:45:00 AM	23.3	0.0	8.4	6.5	0.2	bottom
7	11:35:00 AM	18.4	0.0	7.7	6.3	0.1	bottom
8	11:30:00 AM	22.7	0.0	3.5	6.3	0.2	bottom
9	11:01:00 AM	21.2	0.0	6.2	6.4	0.2	bottom
10	11:20:00 AM	24.3	0.0	4.7	6.9	0.1	bottom
11	10:34:00 AM	23.3	0.0	6.1	6.2	.05	bottom
12	10:49:00 AM	23.8	0.0	6.5	6.1	0.1	bottom

Wreck Pond Watershed Surface Water Quality Data

July 25, 2005

Station	Time	Temp (^oC)	Salinity (ppt)	DO (mg/l)	pH	Depth (m)	Trans (m)
1	2:41:00 PM	25.5	23.4	7.4	7.6	0.1	bottom
2	2:32:00 PM	26.0	7.4	7.6	7.1	0.1	bottom
3	2:24:00 PM	28.5	16.7	11.2	7.8	0.4	bottom
4	2:20:00 PM	29.0	0.0	7.6	7.1	0.2	bottom
5	2:10:00 PM	25.5	0.0	6.7	6.7	0.1	bottom
6	1:58:00 PM	27.9	0.0	13.6	6.9	0.2	bottom
7	1:02:00 PM	19.9	0.0	8.8	6.4	0.1	bottom
8	12:55:00 PM	26.1	0.0	10.3	6.8	0.1	bottom
9	12:35:00 PM	23.5	0.0	7.2	6.2	0.1	bottom
10	12:44:00 PM	24.5	0.0	3.5	6.7	0.1	bottom
11	12:12:00 PM	25.4	0.0	7.6	6.8	0.2	bottom
12	12:23:00 PM	23.7	0.0	6.7	6.2	0.1	bottom

Wreck Pond Watershed Surface Water Quality Data

August 9, 2005

Station	Time	Temp (^{o}C)	Salinity (ppt)	DO (mg/l)	pH	Depth (m)	Trans (m)
1	12:43:00 PM	25.0	18.6	7.9	7.8	0.2	bottom
2	12:37:00 PM	25.7	17.7	8.6	7.8	0.2	bottom
3	12:29:00 PM	26.4	4.9	7.8	7.5	0.3	bottom
4	12:24:00 PM	25.3	0.0	5.7	7.0	0.3	bottom
5	12:10:00 PM	24.1	0.0	6.4	6.6	0.2	bottom
6	12:02:00 PM	22.9	0.0	7.8	6.5	0.2	bottom
7	11:54:00 AM	20.4	0.0	7.8	6.4	0.3	bottom
8	11:46:00 AM	24.2	0.0	4.8	6.4	0.2	bottom
9	10:56:00 AM	18.6	0.0	6.7	6.9	0.2	bottom
10	11:06:00 AM	22.6	0.0	6.7	6.8	0.1	bottom
11	11:17:00 AM	24.0	0.0	6.5	6.5	0.5	bottom
12	11:35:00 AM	23.4	0.0	7.4	6.4	0.3	bottom

Wreck Pond Watershed Surface Water Quality Data

August 23, 2005

Station	Time	Temp (^oC)	Salinity (ppt)	DO (mg/l)	pH	Depth (m)	Trans (m)
1	12:17:00 PM	24.2	28.4	8.1	7.9	0.3	bottom
2	12:08:00 PM	24.6	24.9	9.7	8.0	0.2	bottom
3	12:00:00 PM	27.2	22.3	9.6	8.1	0.3	bottom
4	11:56:00 AM	25.6	0.0	6.9	7.5	0.2	bottom
5	11:46:00 AM	22.9	0.0	4.2	6.5	0.2	bottom
6	11:37:00 AM	24.5	0.0	7.8	6.4	0.1	bottom
7	11:24:00 AM	18.8	0.0	9.2	6.5	0.1	bottom
8	11:18:00 AM	23.9	0.0	6.7	6.6	0.1	bottom
9	11:09:00 AM	20.6	0.0	8.0	6.3	0.1	bottom
10	10:57:00 AM	22.5	0.0	4.1	6.8	0.1	bottom
11	10:40:00 AM	24.2	0.0	6.7	6.7	0.4	bottom
12	10:27:00 AM	22.8	0.0	8.4	7.3	0.1	bottom

Wreck Pond Watershed Surface Water Quality Data

September 15, 2005

Station	Time	Temp (oC)	Salinity (ppt)	DO (mg/l)	pH	Depth (m)	Trans (m)
1	12:00:00 PM	26.8	23.9	4.8	7.7	0.1	bottom
2	11:45:00 AM	26.1	18.3	5.7	7.6	0.1	bottom
3	11:29:00 AM	26.1	1.9	7.6	8.4	0.2	bottom
4	11:35:00 AM	25.7	0.0	4.8	6.6	0.2	bottom
5	11:18:00 AM	22.9	0.0	7.3	6.7	0.2	bottom
6	11:09:00 AM	23.5	0.0	7.3	6.4	0.3	bottom
7	11:00:00 AM	19.4	0.0	8.1	6.3	0.1	bottom
8	10:50:00 AM	23.7	0.0	6.9	6.2	0.3	bottom
9	10:35:00 AM	20.5	0.0	7.8	6.1	0.2	bottom
10							not sampled
11	10:10:00 AM	23.8	0.0	7.4	6.2	0.5	bottom
12	10:20:00 AM	22.9	0.0	8.7	6.2	0.2	bottom

Wreck Pond Surface Watershed Water Quality Data

September 29, 2005

Station	Time	Temp (^oC)	Salinity (ppt)	DO (mg/l)	pH	Depth (m)	Trans (m)
1	11:41:00 AM	21.7	23.9	8.8	7.9	0.1	bottom
2	11:35:00 AM	21.0	21.2	9.0	7.9	0.1	bottom
3	11:25:00 AM	21.4	1.1	8.9	7.4	0.2	bottom
4	11:21:00 AM	20.9	0.0	9.2	7.9	0.1	bottom
5	11:14:00 AM	20.0	0.0	7.1	6.6	0.1	bottom
6	11:07:00 AM	20.9	0.0	8.9	6.7	0.1	bottom
7	10:59:00 AM	17.9	0.0	9.8	6.5	0.1	bottom
8	10:53:00 AM	20.7	0.0	9.8	6.7	0.1	bottom
9	10:40:00 AM	19.5	0.0	9.0	6.3	0.1	bottom
10							not sampled
11	10:18:00 AM	19.3	0.0	7.0	7.6	0.4	bottom
12	10:31:00 AM	19.2	0.0	9.1	6.7	0.1	bottom

Appendix B

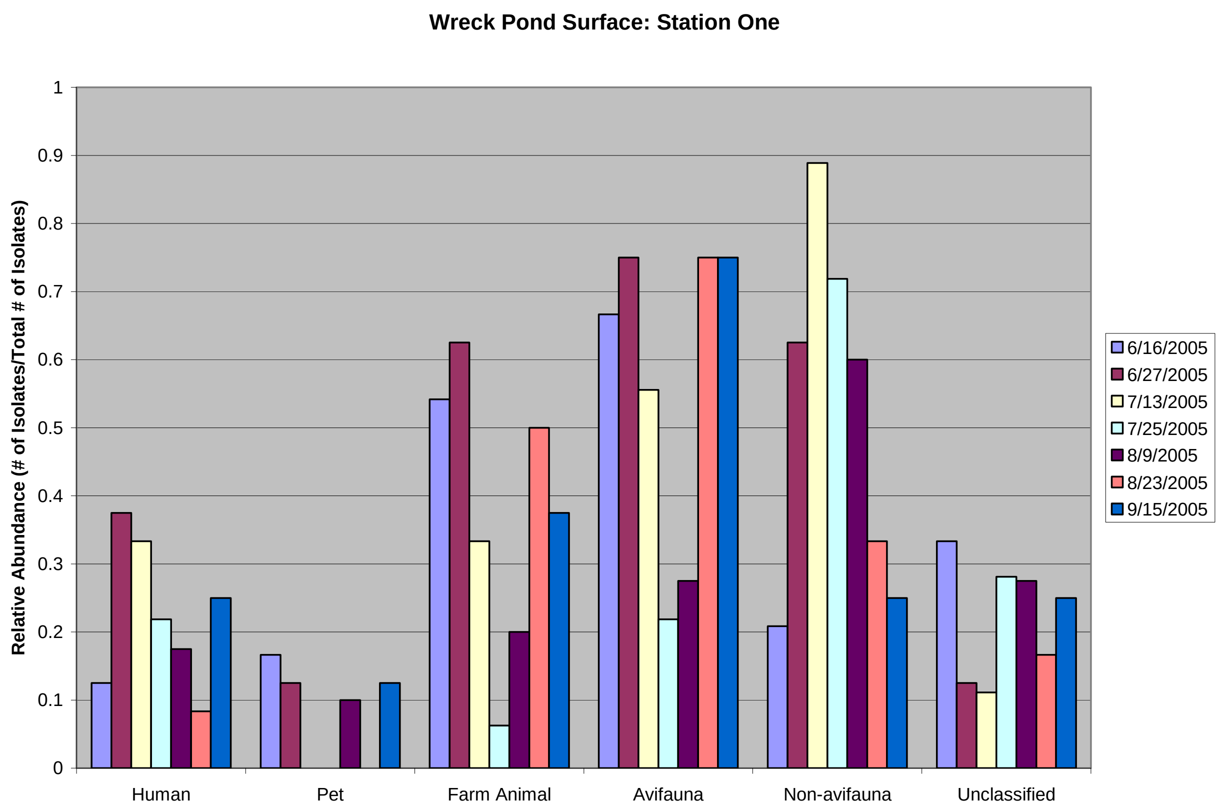
Wreck Pond Watershed
Surface Water Source Profiles

Wreck Pond Microbial Source Tracking Study
Surface Water Source Profile
Station One

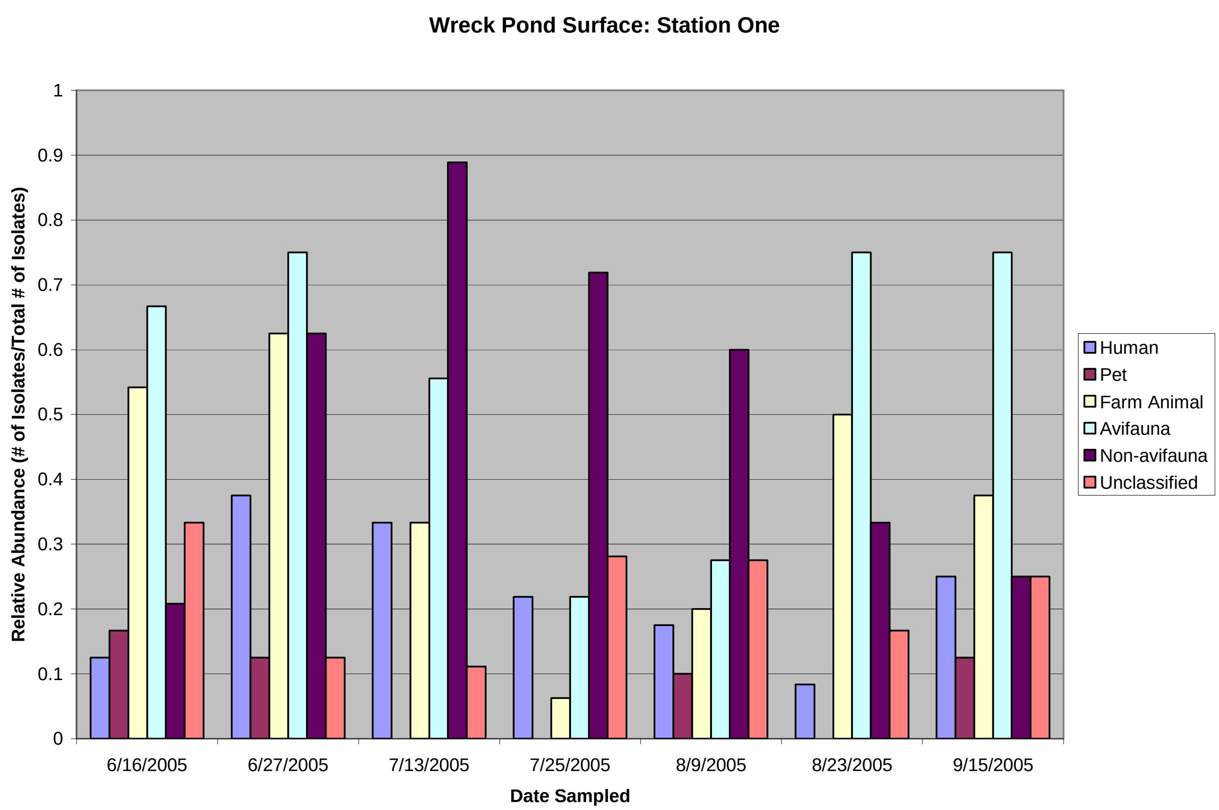
Wreck Pond Surface: Station One							
Relative Abundance by Date Sampled							
Species	6/16/2005	6/27/2005	7/13/2005	7/25/2005	8/9/2005	8/23/2005	9/15/2005
Human	0.125	0.375	0.333333	0.21875	0.175	0.083333	0.25
Pet	0.166667	0.125	0	0	0.1	0	0.125
Farm Animal	0.541667	0.625	0.333333	0.0625	0.2	0.5	0.375
Avifauna	0.666667	0.75	0.555556	0.21875	0.275	0.75	0.75
Non-avifauna	0.208333	0.625	0.888889	0.71875	0.6	0.333333	0.25
Unclassified	0.333333	0.125	0.111111	0.28125	0.275	0.166667	0.25

Surface Water Source Summary
Station One

Source Category	**Percent of Sampling Events Source Detected**	**Mean Relative Abundance**
Human	100%	0.22
Pets	57%	0.07
Farm Animals	100%	0.38
Avifauna	100%	0.57
Non-avifauna	100%	0.52



Wreck Pond Surface: Station One
Relative Abundance (# of Isolates/Total # of Isolates)
1
0.9
0.8
0.7
0.6
0.5
0.4
0.3
0.2
0.1
0
Human
Pet
Farm Animal
Avifauna
Non-avifauna
Unclassified
6/16/2005
6/27/2005
7/13/2005
7/25/2005
8/9/2005
8/23/2005
9/15/2005



Wreck Pond Surface: Station One
Relative Abundance (# of Isolates/Total # of Isolates)
1
0.9
0.8
0.7
0.6
0.5
0.4
0.3
0.2
0.1
0
6/16/2005
6/27/2005
7/13/2005
7/25/2005
8/9/2005
8/23/2005
9/15/2005
Date Sampled
Human
Pet
Farm Animal
Avifauna
Non-avifauna
Unclassified

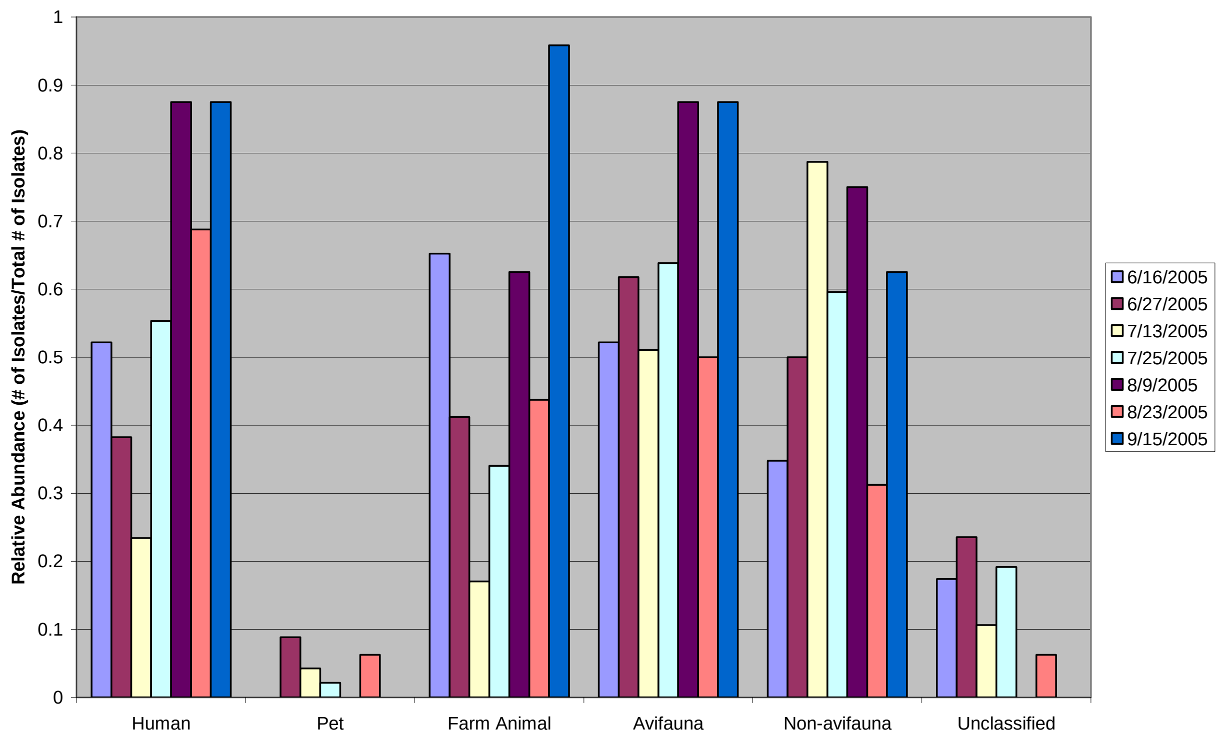
Wreck Pond Microbial Source Tracking Study
Surface Water Source Profile
Station Two

Wreck Pond Surface: Station Two							
Relative Abundance by Date Sampled							
Species	6/16/2005	6/27/2005	7/13/2005	7/25/2005	8/9/2005	8/23/2005	9/15/2005
Human	0.521739	0.382353	0.234043	0.553191	0.875	0.6875	0.875
Pet	0	0.088235	0.042553	0.021277	0	0.0625	0
Farm Animal	0.652174	0.411765	0.170213	0.340426	0.625	0.4375	0.958333
Avifauna	0.521739	0.617647	0.510638	0.638298	0.875	0.5	0.875
Non-avifauna	0.347826	0.5	0.787234	0.595745	0.75	0.3125	0.625
Unclassified	0.173913	0.235294	0.106383	0.191489	0	0.0625	0

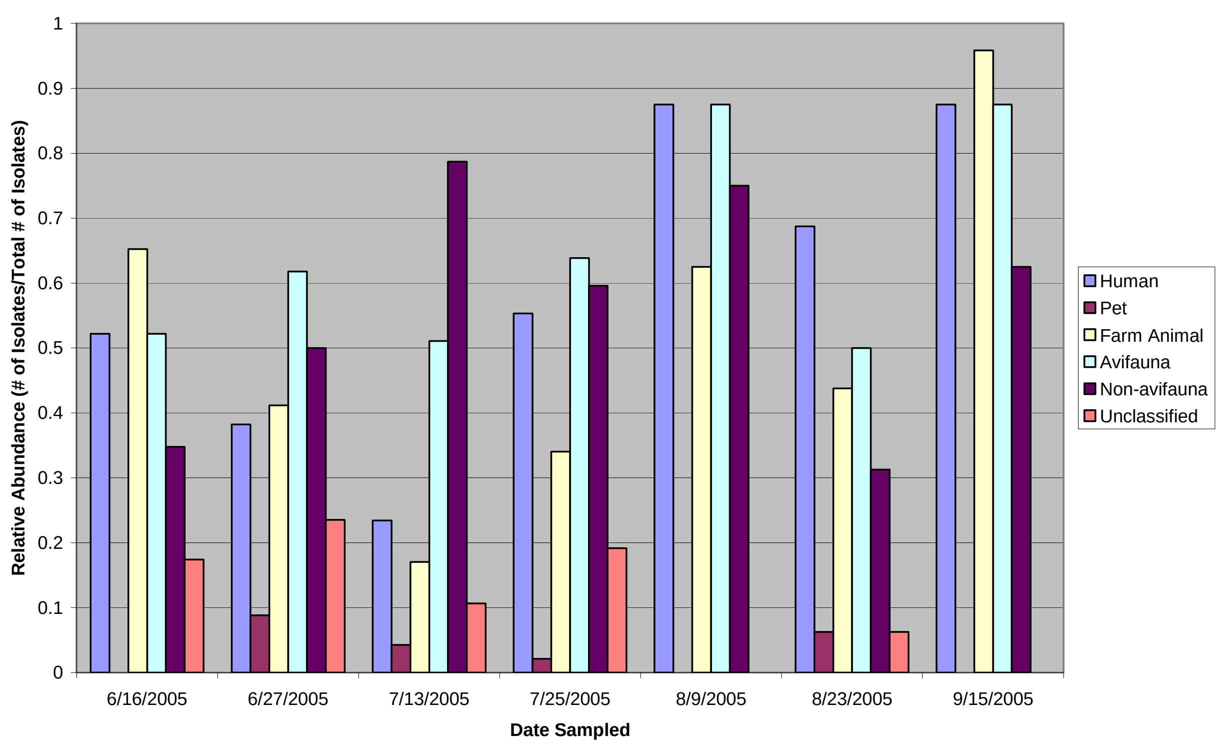
Surface Water Source Summary
Station Two

Source Category	**Percent of Sampling Events Source Detected**	**Mean Relative Abundance**
Human	100%	0.59
Pets	57%	0.03
Farm Animals	100%	0.51
Avifauna	100%	0.65
Non-avifauna	100%	0.56

Wreck Pond Surface: Station Two



Wreck Pond Surface: Station Two

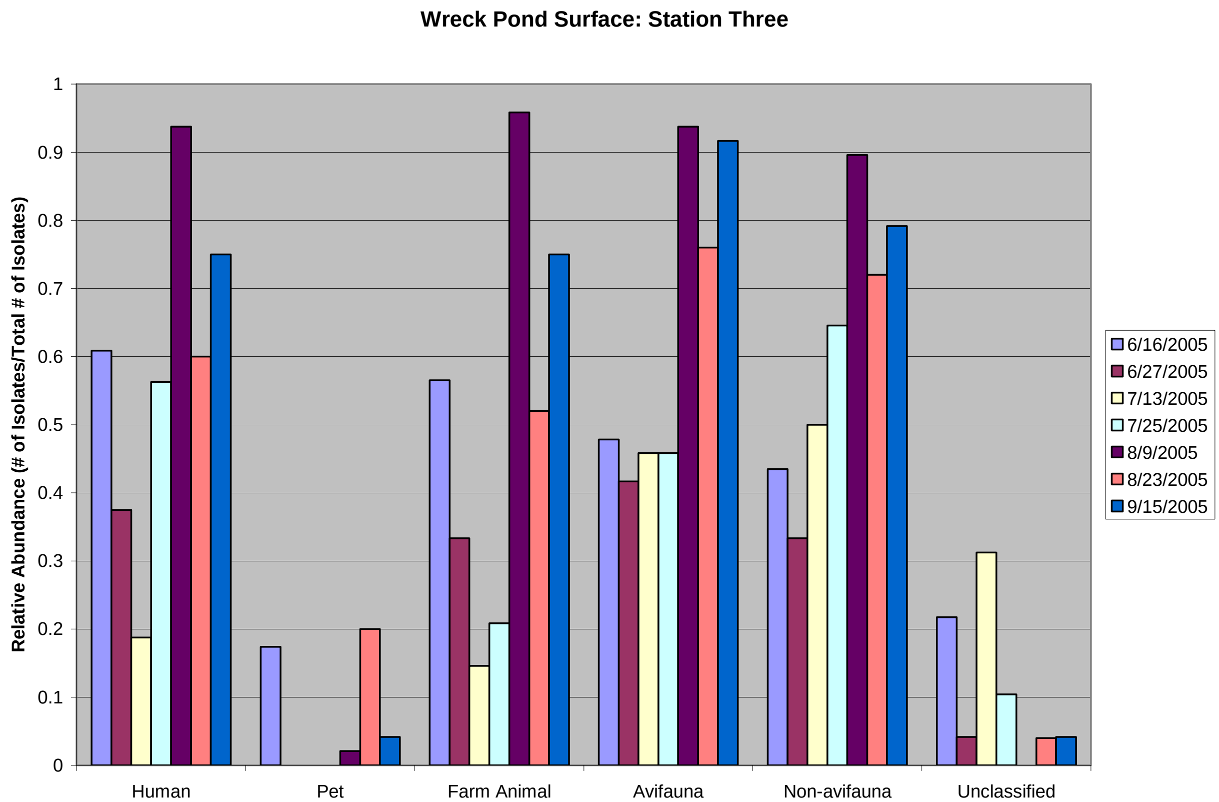


Wreck Pond Microbial Source Tracking Study
Surface Water Source Profile
Station Three

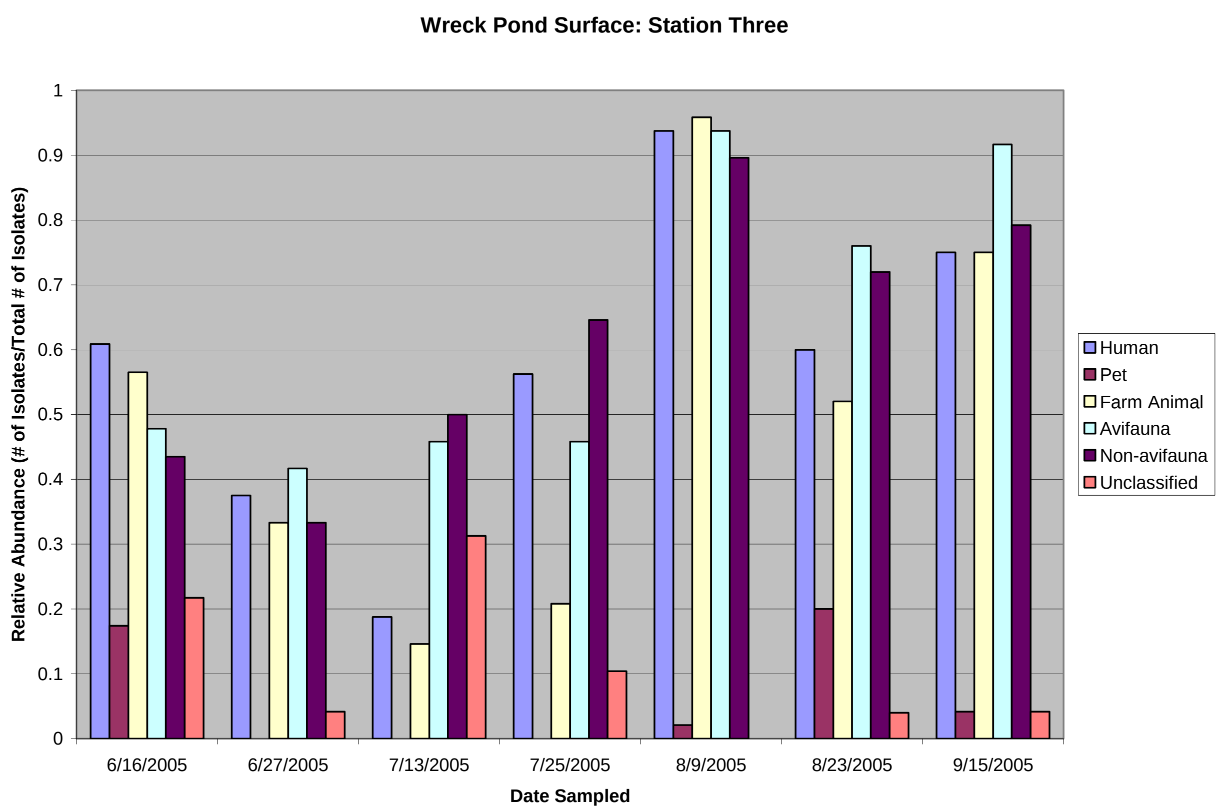
Wreck Pond Surface: Station Three							
Relative Abundance by Date Sampled							
Species	6/16/2005	6/27/2005	7/13/2005	7/25/2005	8/9/2005	8/23/2005	9/15/2005
Human	0.608696	0.375	0.1875	0.5625	0.9375	0.6	0.75
Pet	0.173913	0	0	0	0.020833	0.2	0.041667
Farm Animal	0.565217	0.333333	0.145833	0.208333	0.958333	0.52	0.75
Avifauna	0.478261	0.416667	0.458333	0.458333	0.9375	0.76	0.916667
Non-avifauna	0.434783	0.333333	0.5	0.645833	0.895833	0.72	0.791667
Unclassified	0.217391	0.041667	0.3125	0.104167	0	0.04	0.041667

Surface Water Source Summary
Station Three

Source Category	**Percent of Sampling Events Source Detected**	**Mean Relative Abundance**
Human	100%	0.57
Pets	57%	0.06
Farm Animals	100%	0.50
Avifauna	100%	0.63
Non-avifauna	100%	0.62



Wreck Pond Surface: Station Three
Relative Abundance (# of Isolates/Total # of Isolates)
1
0.9
0.8
0.7
0.6
0.5
0.4
0.3
0.2
0.1
0
Human
Pet
Farm Animal
Avifauna
Non-avifauna
Unclassified
6/16/2005
6/27/2005
7/13/2005
7/25/2005
8/9/2005
8/23/2005
9/15/2005



Wreck Pond Surface: Station Three
Relative Abundance (# of Isolates/Total # of Isolates)
1
0.9
0.8
0.7
0.6
0.5
0.4
0.3
0.2
0.1
0
6/16/2005
6/27/2005
7/13/2005
7/25/2005
8/9/2005
8/23/2005
9/15/2005
Date Sampled
Human
Pet
Farm Animal
Avifauna
Non-avifauna
Unclassified

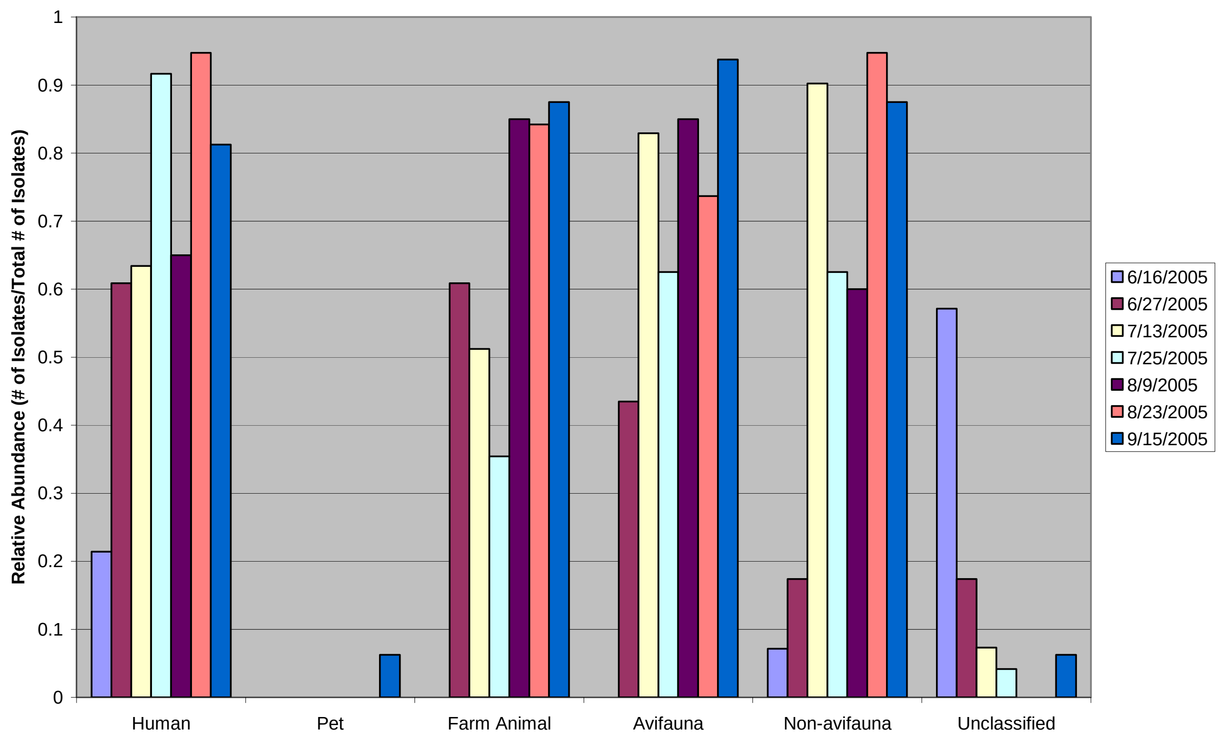
Wreck Pond Microbial Source Tracking Study
Surface Water Source Profile
Station Four

Wreck Pond Surface: Station Four							
Relative Abundance by Date Sampled							
Species	6/16/2005	6/27/2005	7/13/2005	7/25/2005	8/9/2005	8/23/2005	9/15/2005
Human	0.214286	0.608696	0.634146	0.916667	0.65	0.947368	0.8125
Pet	0	0	0	0	0	0	0.0625
Farm Animal	0	0.608696	0.512195	0.354167	0.85	0.842105	0.875
Avifauna	0	0.434783	0.829268	0.625	0.85	0.736842	0.9375
Non-avifauna	0.071429	0.173913	0.902439	0.625	0.6	0.947368	0.875
Unclassified	0.571429	0.173913	0.073171	0.041667	0	0	0.0625

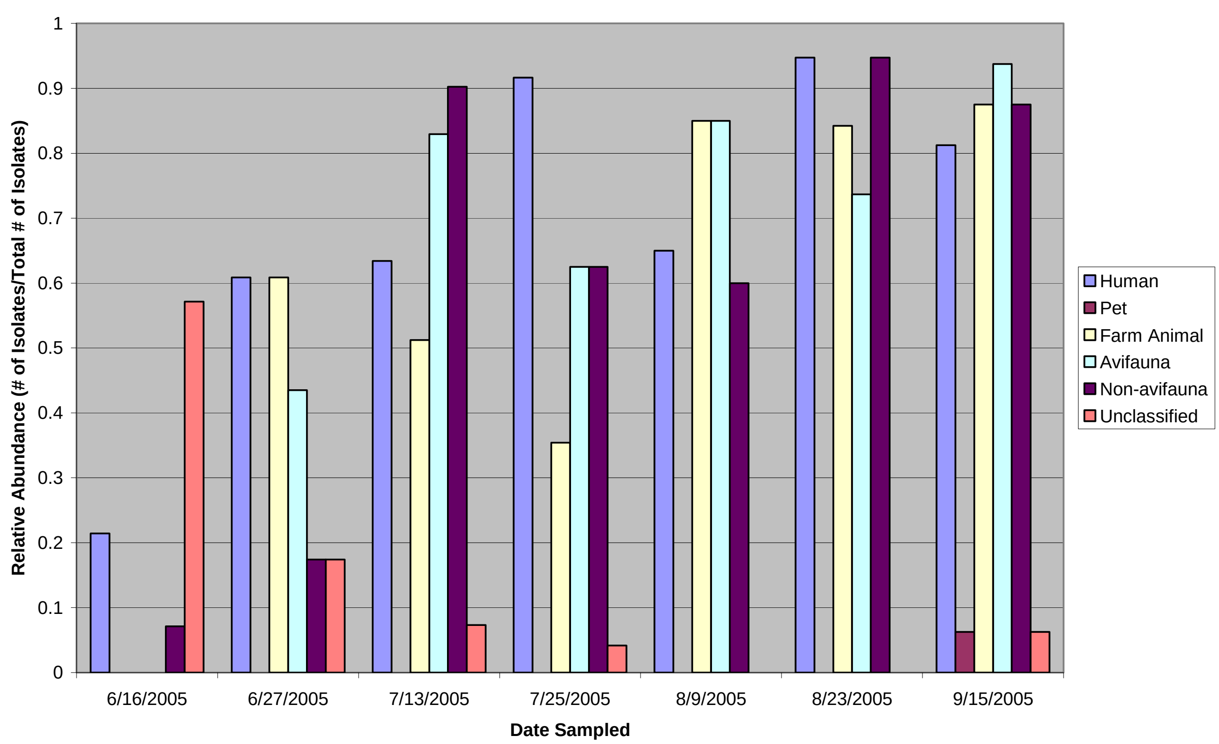
Surface Water Source Summary
Station Four

Source Category	**Percent of Sampling Events Source Detected**	**Mean Relative Abundance**
Human	100%	0.68
Pets	14%	0.01
Farm Animals	86%	0.58
Avifauna	86%	0.63
Non-avifauna	100%	0.60

Wreck Pond Surface: Station Four



Wreck Pond Surface: Station Four

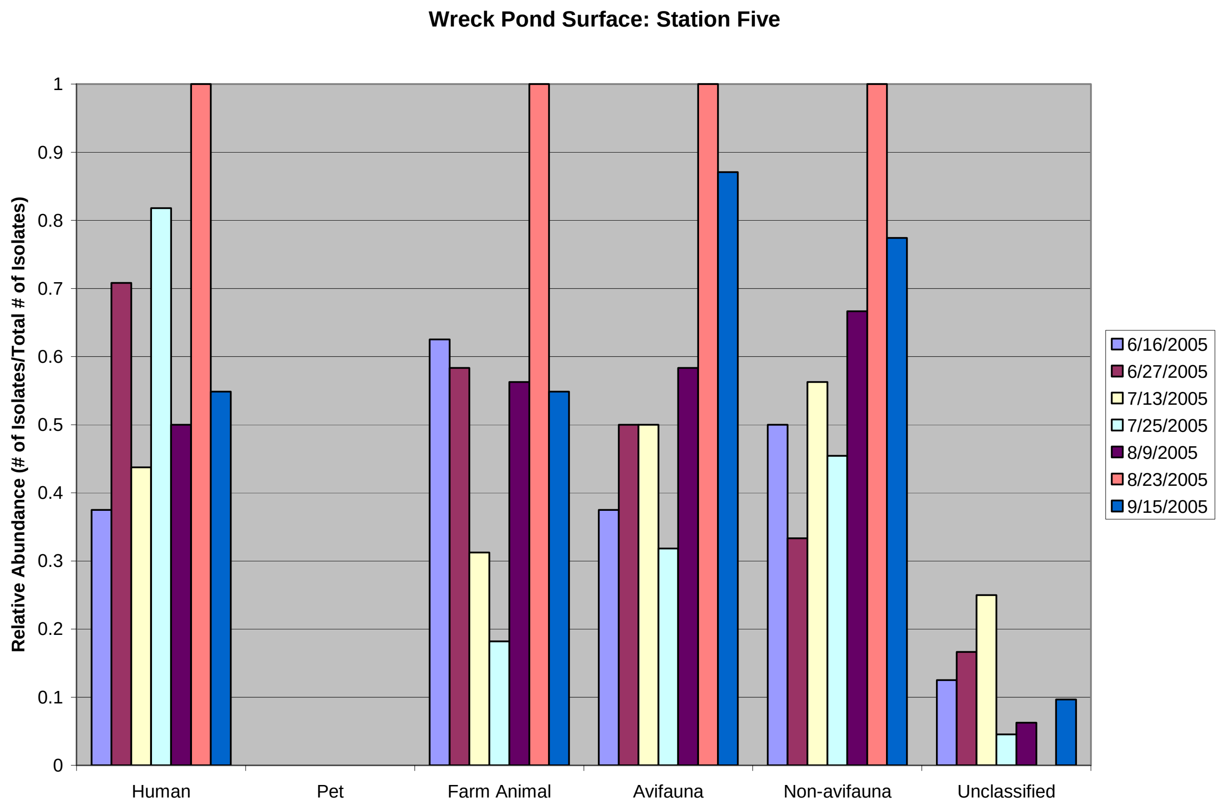


Wreck Pond Microbial Source Tracking Study
Surface Water Source Profile
Station Five

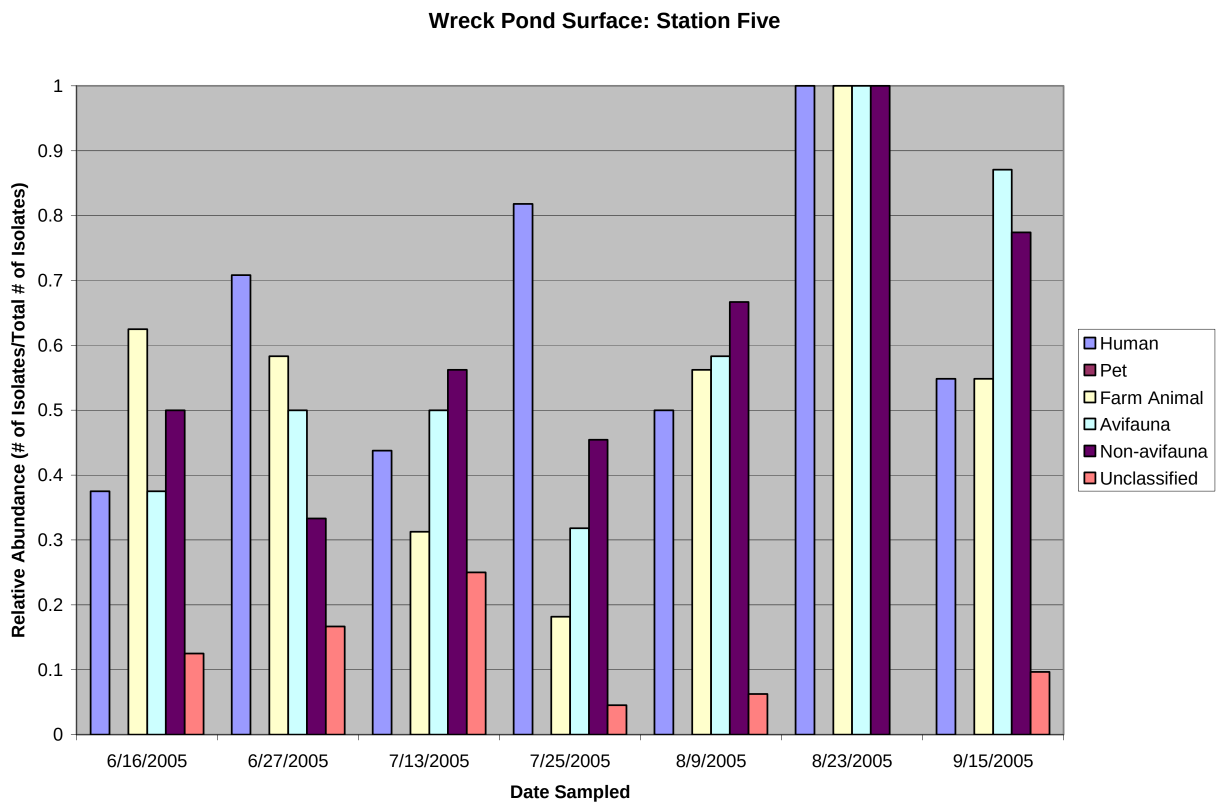
Wreck Pond Surface: Station Five							
Relative Abundance by Date Sampled							
Species	6/16/2005	6/27/2005	7/13/2005	7/25/2005	8/9/2005	8/23/2005	9/15/2005
Human	0.375	0.708333	0.4375	0.818182	0.5	1	0.548387
Pet	0	0	0	0	0	0	0
Farm Animal	0.625	0.583333	0.3125	0.181818	0.5625	1	0.548387
Avifauna	0.375	0.5	0.5	0.318182	0.583333	1	0.870968
Non-avifauna	0.5	0.333333	0.5625	0.454545	0.666667	1	0.774194
Unclassified	0.125	0.166667	0.25	0.045455	0.0625	0	0.096774

Surface Water Source Summary
Station Five

Source Category	**Percent of Sampling Events Source Detected**	**Mean Relative Abundance**
Human	100%	0.63
Pets	0%	0
Farm Animals	100%	0.54
Avifauna	100%	0.59
Non-avifauna	100%	0.61



Wreck Pond Surface: Station Five
Relative Abundance (# of Isolates/Total # of Isolates)
1
0.9
0.8
0.7
0.6
0.5
0.4
0.3
0.2
0.1
0
Human
Pet
Farm Animal
Avifauna
Non-avifauna
Unclassified
6/16/2005
6/27/2005
7/13/2005
7/25/2005
8/9/2005
8/23/2005
9/15/2005



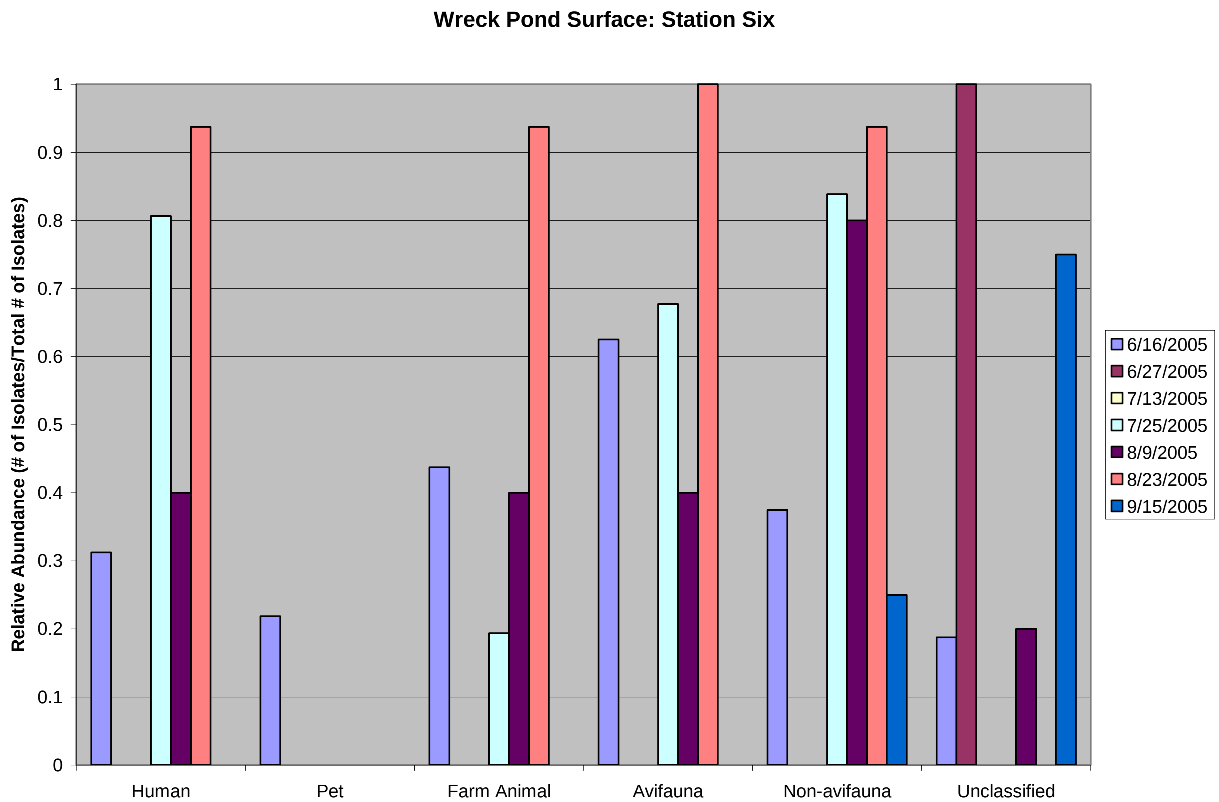
Wreck Pond Surface: Station Five
Relative Abundance (# of Isolates/Total # of Isolates)
1
0.9
0.8
0.7
0.6
0.5
0.4
0.3
0.2
0.1
0
6/16/2005
6/27/2005
7/13/2005
7/25/2005
8/9/2005
8/23/2005
9/15/2005
Date Sampled
Human
Pet
Farm Animal
Avifauna
Non-avifauna
Unclassified

Wreck Pond Microbial Source Tracking Study
Surface Water Source Profile
Station Six

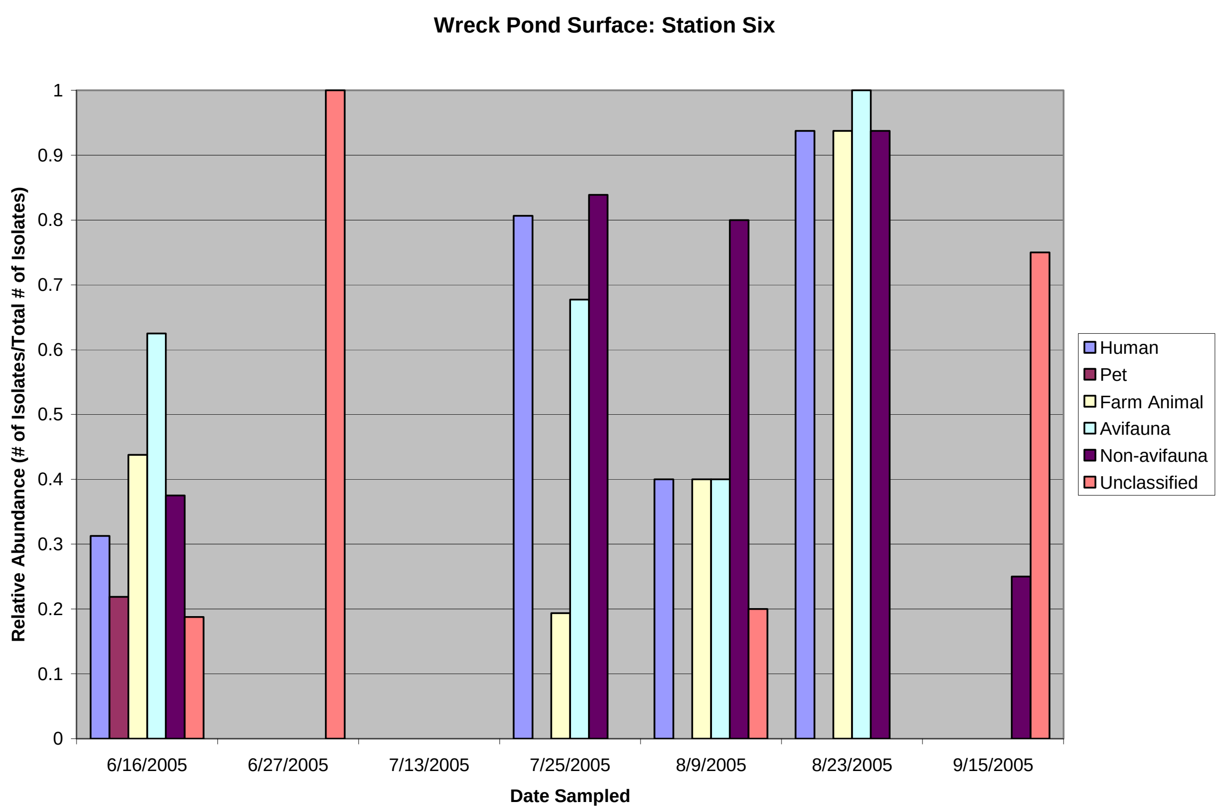
Wreck Pond Surface: Station Six							
Relative Abundance by Date Sampled							
Species	6/16/2005	6/27/2005	7/13/2005	7/25/2005	8/9/2005	8/23/2005	9/15/2005
Human	0.3125	0	0	0.806452	0.4	0.9375	0
Pet	0.21875	0	0	0	0	0	0
Farm Animal	0.4375	0	0	0.193548	0.4	0.9375	0
Avifauna	0.625	0	0	0.677419	0.4	1	0
Non-avifauna	0.375	0	0	0.83871	0.8	0.9375	0.25
Unclassified	0.1875	1	0	0	0.2	0	0.75

Surface Water Source Summary
Station Six

Source Category	Percent of Sampling Events Source Detected	Mean Relative Abundance
Human	67%	0.41
Pets	17%	0.04
Farm Animals	67%	0.33
Avifauna	67%	0.45
Non-avifauna	83%	0.53



Wreck Pond Surface: Station Six
Relative Abundance (# of Isolates/Total # of Isolates)
1
0.9
0.8
0.7
0.6
0.5
0.4
0.3
0.2
0.1
0
Human
Pet
Farm Animal
Avifauna
Non-avifauna
Unclassified
6/16/2005
6/27/2005
7/13/2005
7/25/2005
8/9/2005
8/23/2005
9/15/2005



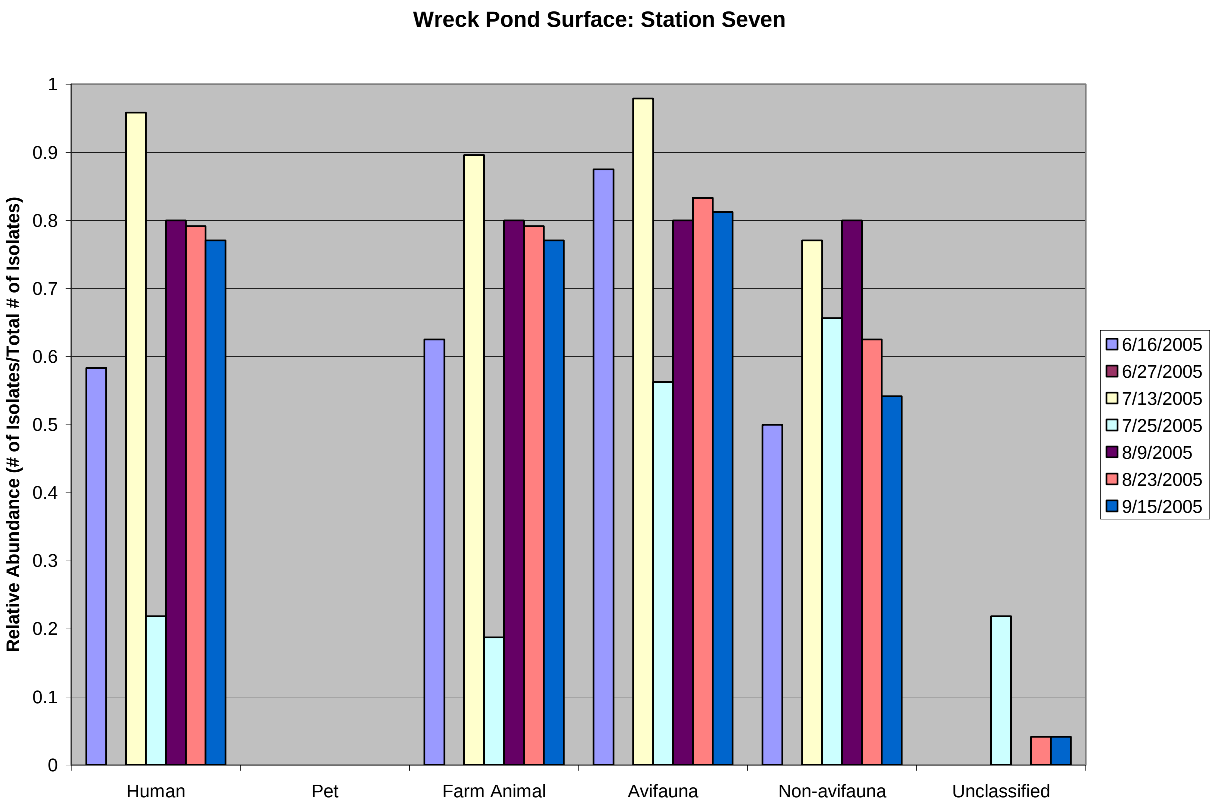
Wreck Pond Surface: Station Six
Relative Abundance (# of Isolates/Total # of Isolates)
1
0.9
0.8
0.7
0.6
0.5
0.4
0.3
0.2
0.1
0
6/16/2005
6/27/2005
7/13/2005
7/25/2005
8/9/2005
8/23/2005
9/15/2005
Date Sampled
Human
Pet
Farm Animal
Avifauna
Non-avifauna
Unclassified

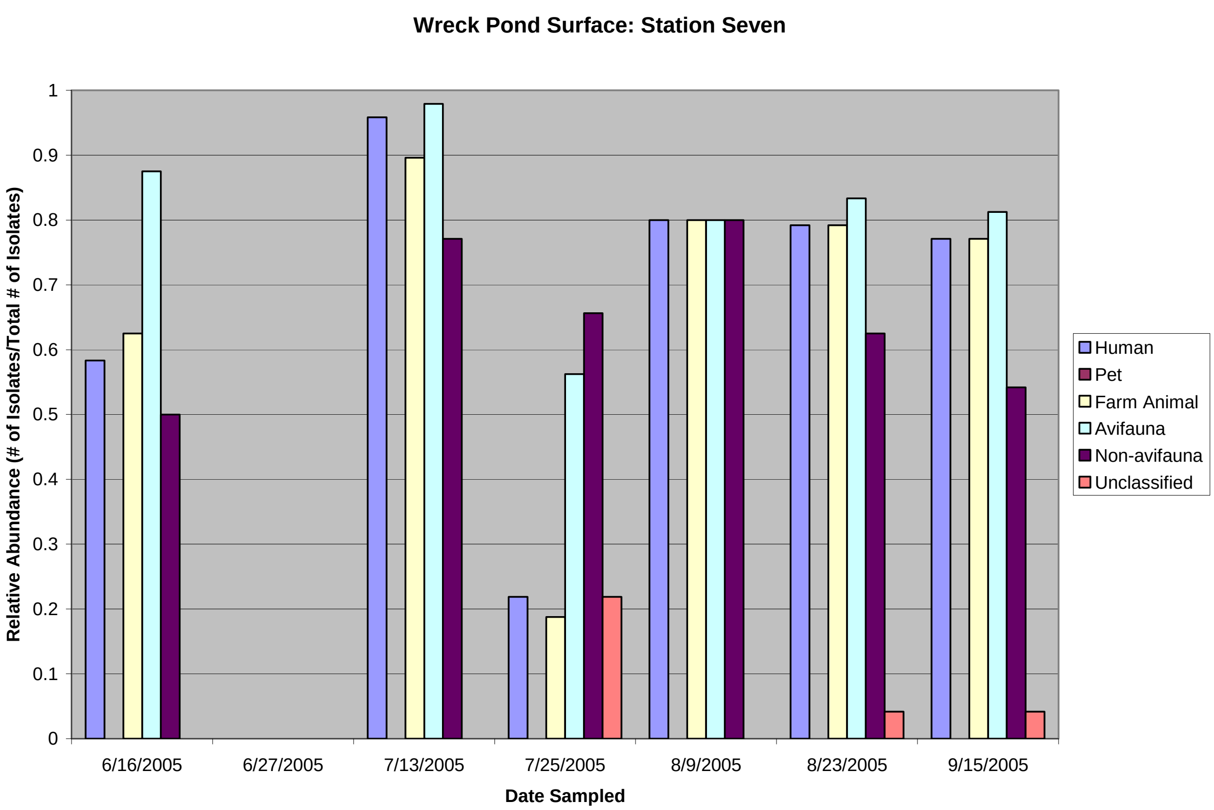
Wreck Pond Microbial Source Tracking Study
Surface Water Source Profile
Station Seven

Wreck Pond Surface: Station Seven							
Relative Abundance by Date Sampled							
Species	6/16/2005	6/27/2005	7/13/2005	7/25/2005	8/9/2005	8/23/2005	9/15/2005
Human	0.583333	0	0.958333	0.21875	0.8	0.791667	0.770833
Pet	0	0	0	0	0	0	0
Farm Animal	0.625	0	0.895833	0.1875	0.8	0.791667	0.770833
Avifauna	0.875	0	0.979167	0.5625	0.8	0.833333	0.8125
Non-avifauna	0.5	0	0.770833	0.65625	0.8	0.625	0.541667
Unclassified	0	0	0	0.21875	0	0.041667	0.041667

Surface Water Source Summary
Station Seven

Source Category	**Percent of Sampling Events Source Detected**	**Mean Relative Abundance**
Human	100%	0.69
Pets	0%	0
Farm Animals	100%	0.68
Avifauna	100%	0.81
Non-avifauna	100%	0.65


Wreck Pond Surface: Station Seven
Relative Abundance (# of Isolates/Total # of Isolates)
1
0.9
0.8
0.7
0.6
0.5
0.4
0.3
0.2
0.1
0
Human
Pet
Farm Animal
Avifauna
Non-avifauna
Unclassified
6/16/2005
6/27/2005
7/13/2005
7/25/2005
8/9/2005
8/23/2005
9/15/2005


Wreck Pond Surface: Station Seven
Relative Abundance (# of Isolates/Total # of Isolates)
1
0.9
0.8
0.7
0.6
0.5
0.4
0.3
0.2
0.1
0
6/16/2005
6/27/2005
7/13/2005
7/25/2005
8/9/2005
8/23/2005
9/15/2005
Date Sampled
Human
Pet
Farm Animal
Avifauna
Non-avifauna
Unclassified

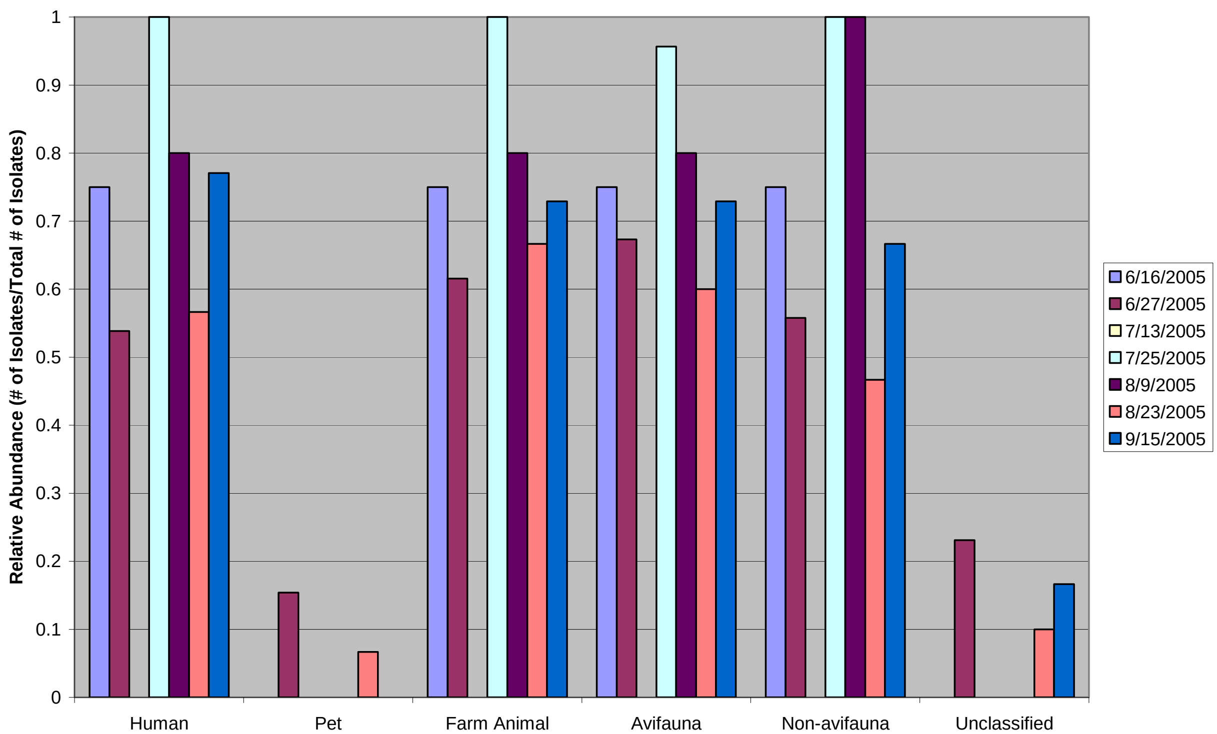
Wreck Pond Microbial Source Tracking Study
Surface Water Source Profile
Station Eight

Wreck Pond Surface: Station Eight							
Relative Abundance by Date Sampled							
Species	6/16/2005	6/27/2005	7/13/2005	7/25/2006	8/9/2005	8/23/2005	9/15/2005
Human	0.75	0.538462	0	1	0.8	0.566667	0.770833
Pet	0	0.153846	0	0	0	0.066667	0
Farm Animal	0.75	0.615385	0	1	0.8	0.666667	0.729167
Avifauna	0.75	0.673077	0	0.956522	0.8	0.6	0.729167
Non-avifauna	0.75	0.557692	0	1	1	0.466667	0.666667
Unclassified	0	0.230769	0	0	0	0.1	0.166667

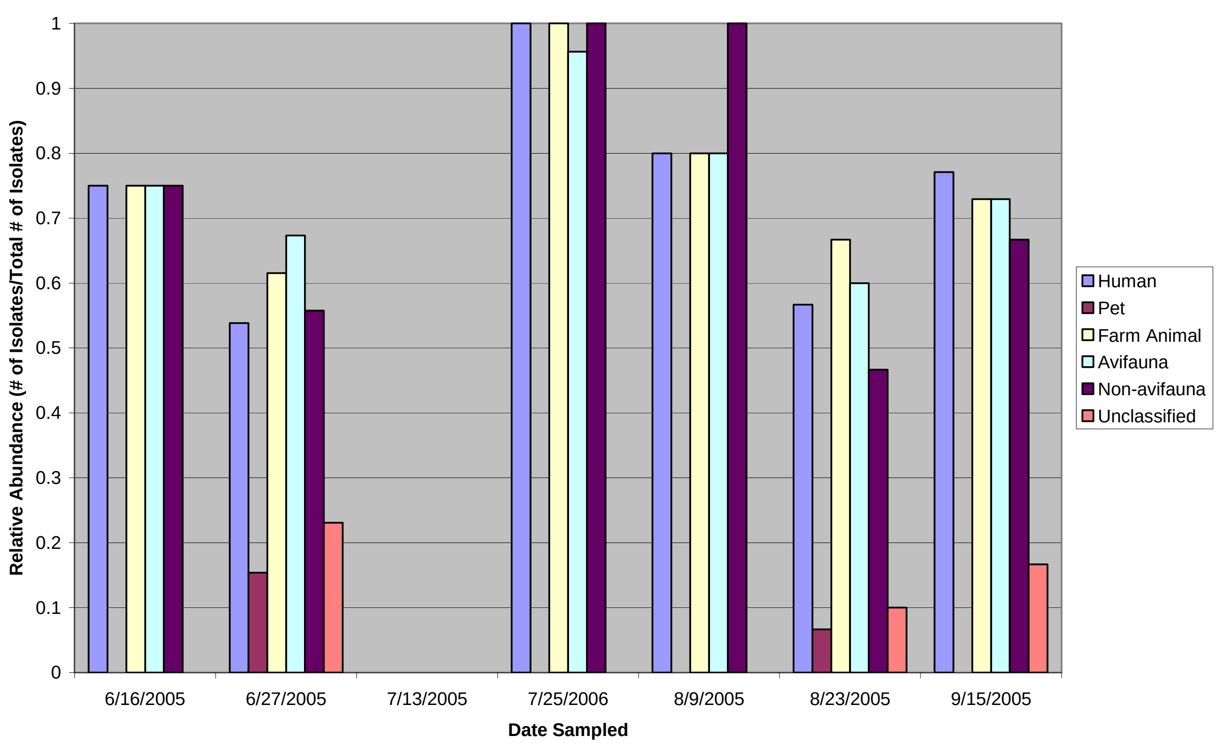
Surface Water Source Summary
Station Eight

Source Category	**Percent of Sampling Events Source Detected**	**Mean Relative Abundance**
Human	100%	0.74
Pets	33%	0.04
Farm Animals	100%	0.76
Avifauna	100%	0.75
Non-avifauna	100%	0.74

Wreck Pond Surface: Station Eight



Wreck Pond Surface: Station Eight



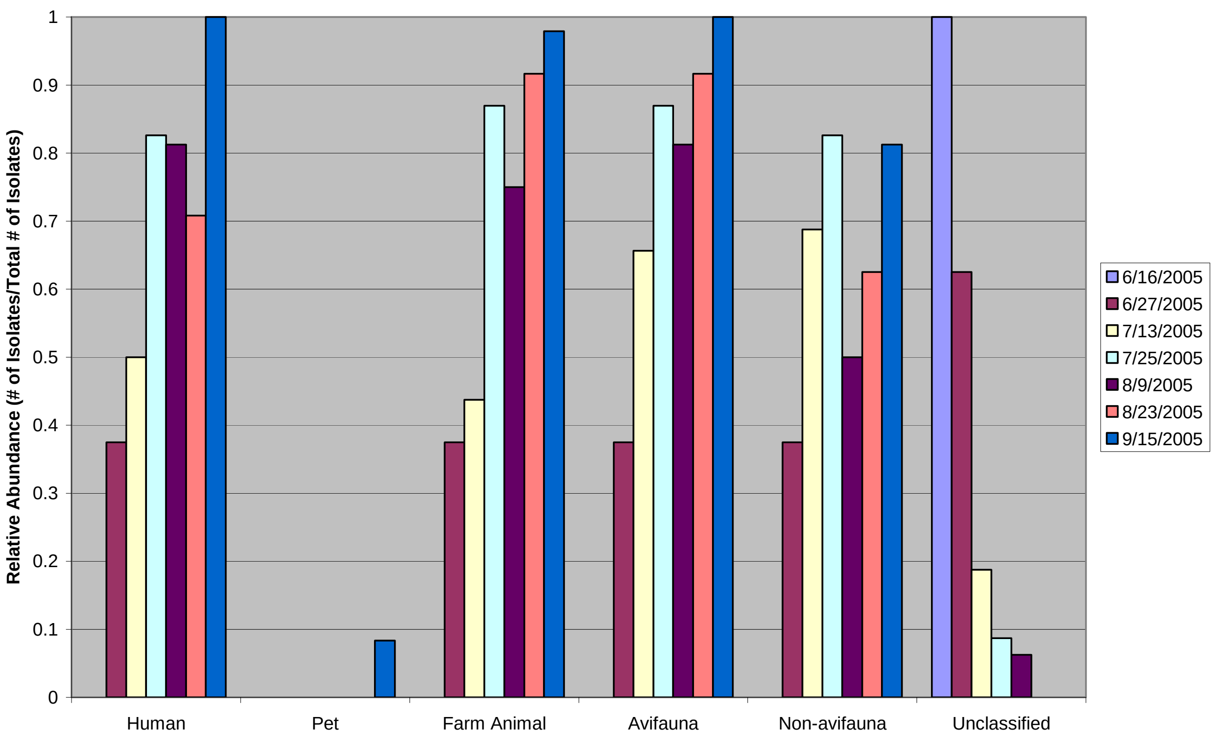
Wreck Pond Microbial Source Tracking Study
Surface Water Source Profile
Station Nine

Wreck Pond Surface: Station Nine							
Relative Abundance by Date Sampled							
Species	6/16/2005	6/27/2005	7/13/2005	7/25/2005	8/9/2005	8/23/2005	9/15/2005
Human	0	0.375	0.5	0.826087	0.8125	0.708333	1
Pet	0	0	0	0	0	0	0.083333
Farm Animal	0	0.375	0.4375	0.869565	0.75	0.916667	0.979167
Avifauna	0	0.375	0.65625	0.869565	0.8125	0.916667	1
Non-avifauna	0	0.375	0.6875	0.826087	0.5	0.625	0.8125
Unclassified	1	0.625	0.1875	0.086957	0.0625	0	0

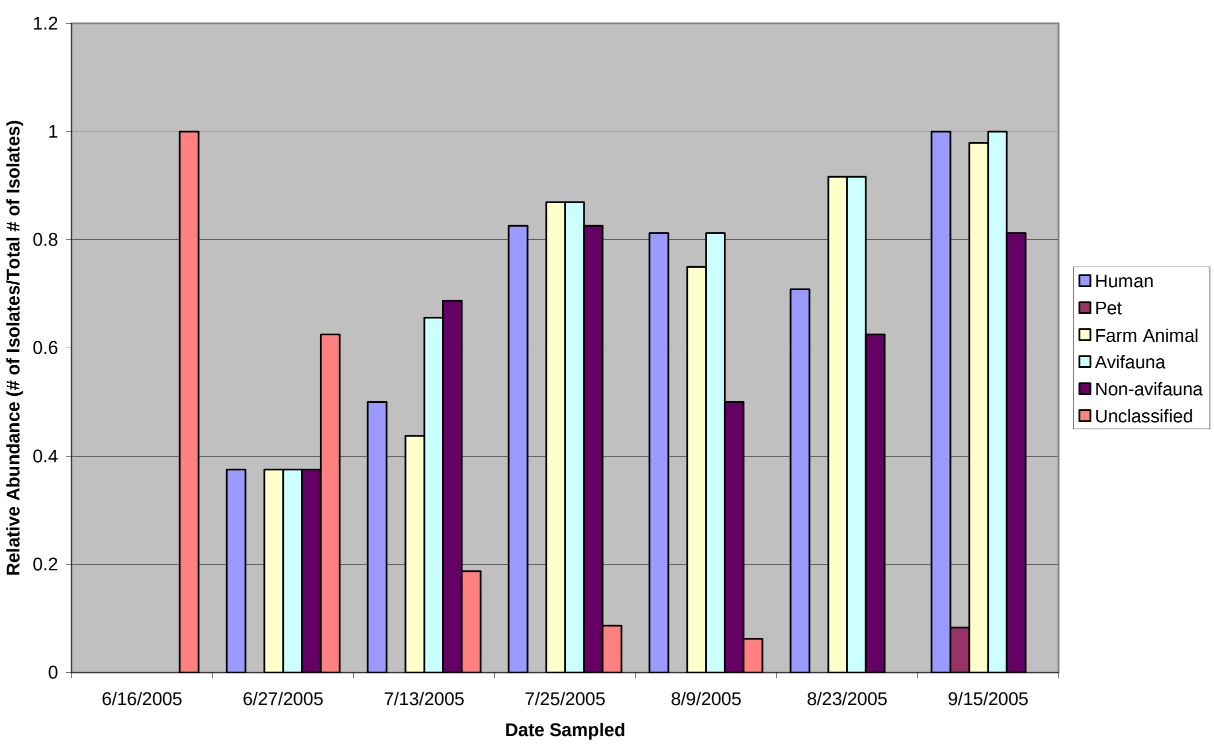
Surface Water Source Summary
Station Nine

Source Category	**Percent of Sampling Events Source Detected**	**Mean Relative Abundance**
Human	86%	0.61
Pets	14%	0.01
Farm Animals	86%	0.62
Avifauna	86%	0.67
Non-avifauna	86%	0.55

Wreck Pond Surface: Station Nine



Wreck Pond Surface: Station Nine

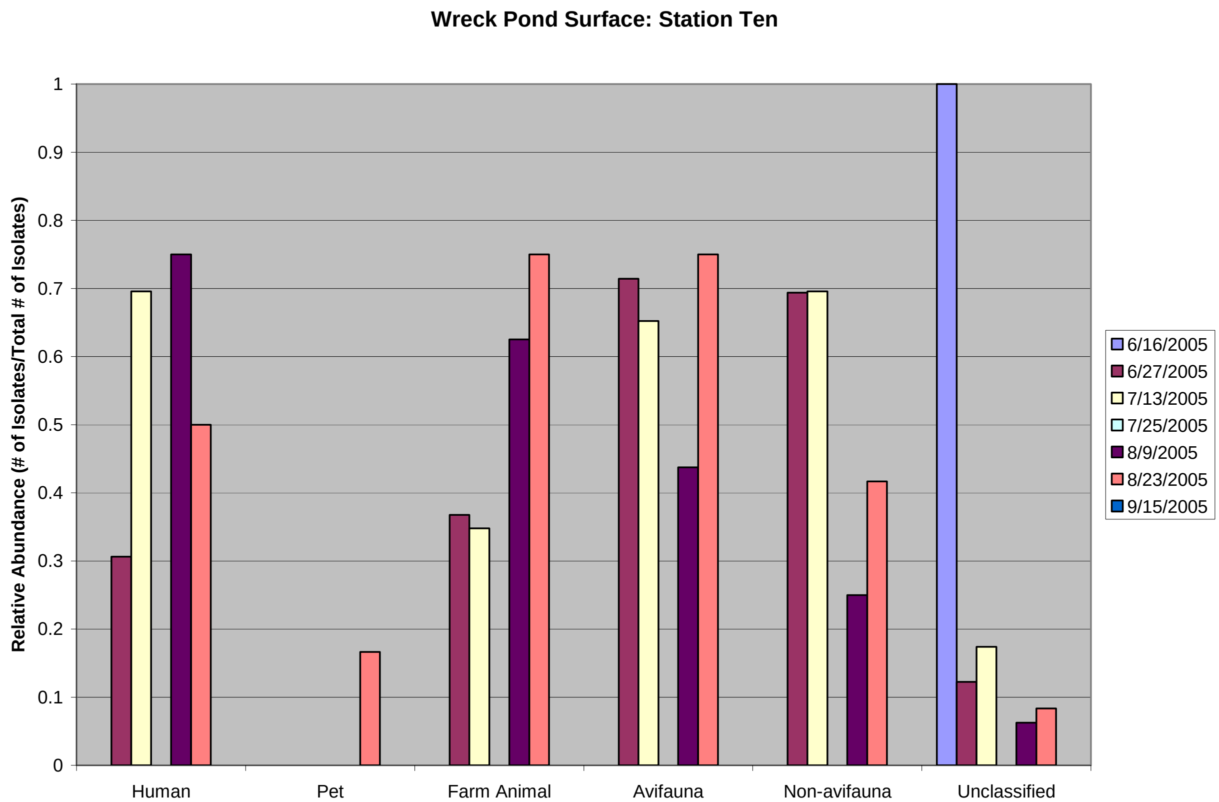


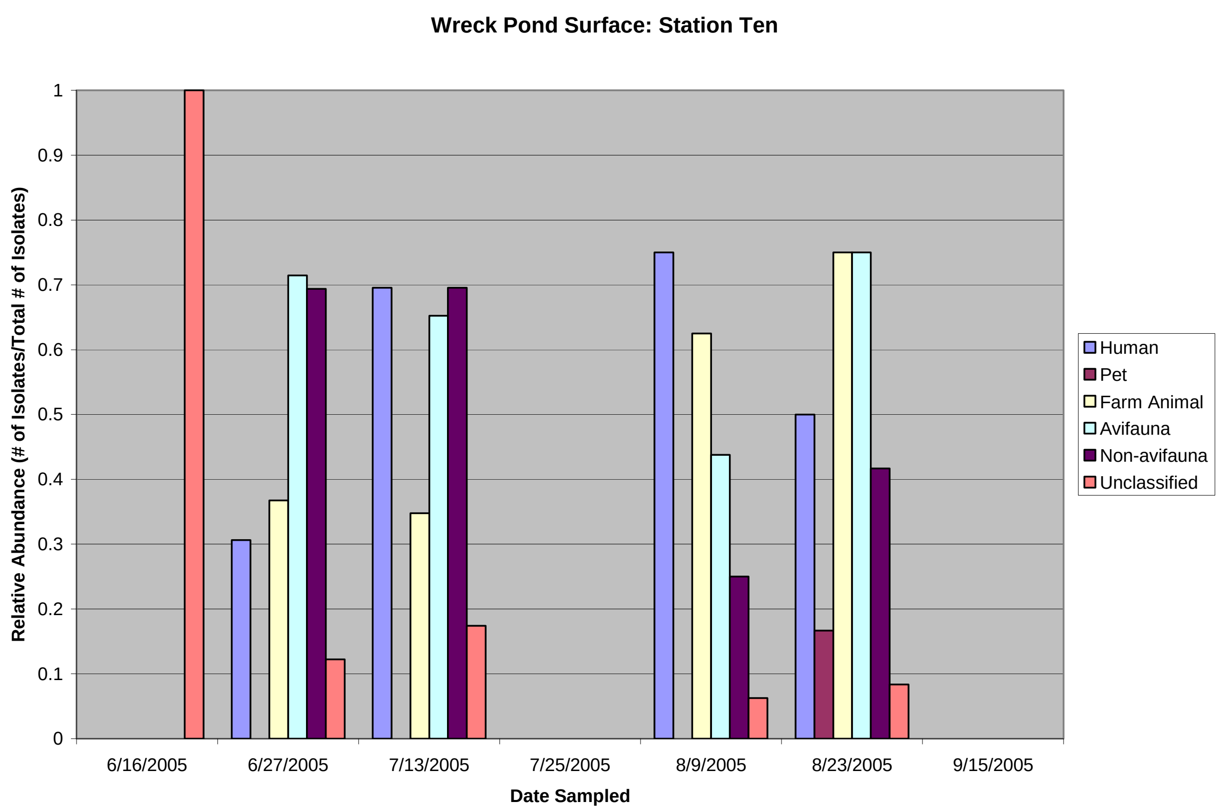
Wreck Pond Microbial Source Tracking Study
Surface Water Source Profile
Station Ten

Wreck Pond Surface: Station Ten							
Relative Abundance by Date Sampled							
Species	6/16/2005	6/27/2005	7/13/2005	7/25/2005	8/9/2005	8/23/2005	9/15/2005
Human	0	0.306122	0.695652	0	0.75	0.5	0
Pet	0	0	0	0	0	0.166667	0
Farm Animal	0	0.367347	0.347826	0	0.625	0.75	0
Avifauna	0	0.714286	0.652174	0	0.4375	0.75	0
Non-avifauna	0	0.693878	0.695652	0	0.25	0.416667	0
Unclassified	1	0.122449	0.173913	0	0.0625	0.083333	0

Surface Water Source Summary
Station Ten

Source Category	**Percent of Sampling Events Source Detected**	**Mean Relative Abundance**
Human	80%	0.45
Pets	20%	0.03
Farm Animals	80%	0.42
Avifauna	80%	0.51
Non-avifauna	80%	0.41


Wreck Pond Surface: Station Ten
Relative Abundance (# of Isolates/Total # of Isolates)
1
0.9
0.8
0.7
0.6
0.5
0.4
0.3
0.2
0.1
0
Human
Pet
Farm Animal
Avifauna
Non-avifauna
Unclassified
6/16/2005
6/27/2005
7/13/2005
7/25/2005
8/9/2005
8/23/2005
9/15/2005

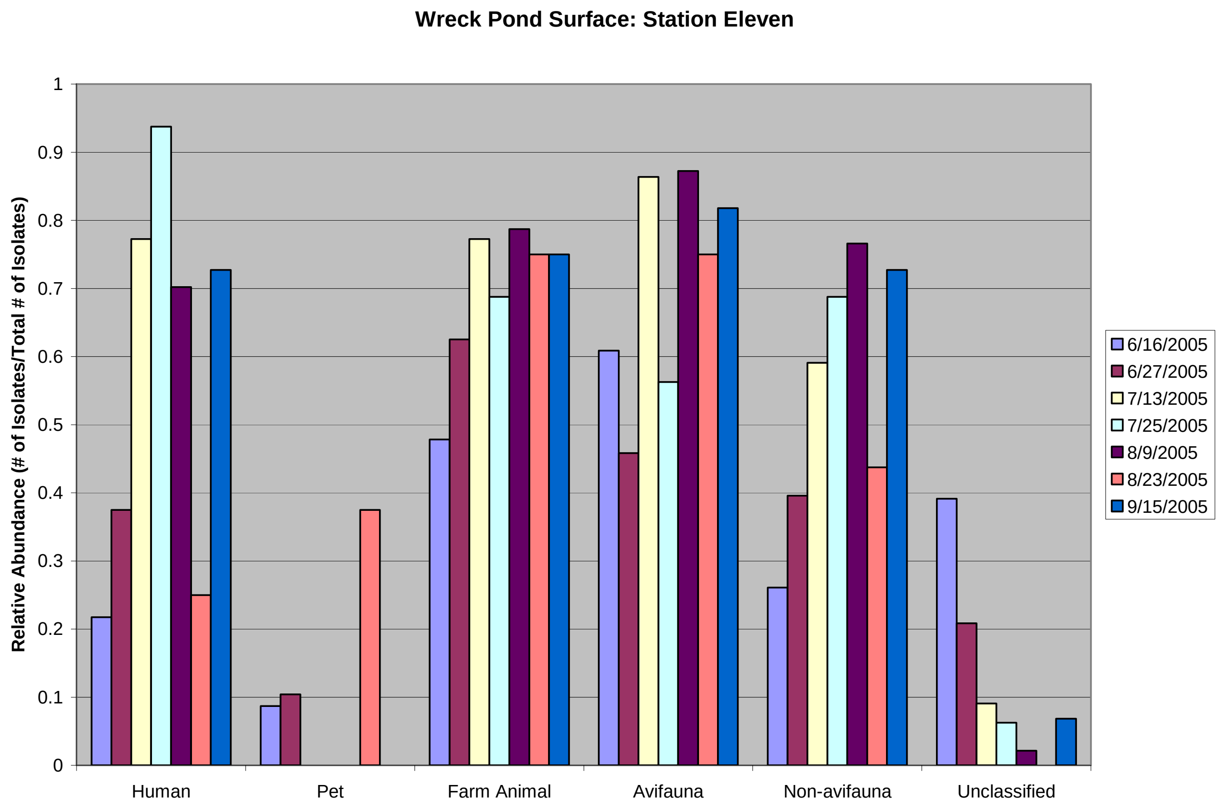

Wreck Pond Surface: Station Ten
Relative Abundance (# of Isolates/Total # of Isolates)
1
0.9
0.8
0.7
0.6
0.5
0.4
0.3
0.2
0.1
0
6/16/2005
6/27/2005
7/13/2005
7/25/2005
8/9/2005
8/23/2005
9/15/2005
Date Sampled
Human
Pet
Farm Animal
Avifauna
Non-avifauna
Unclassified

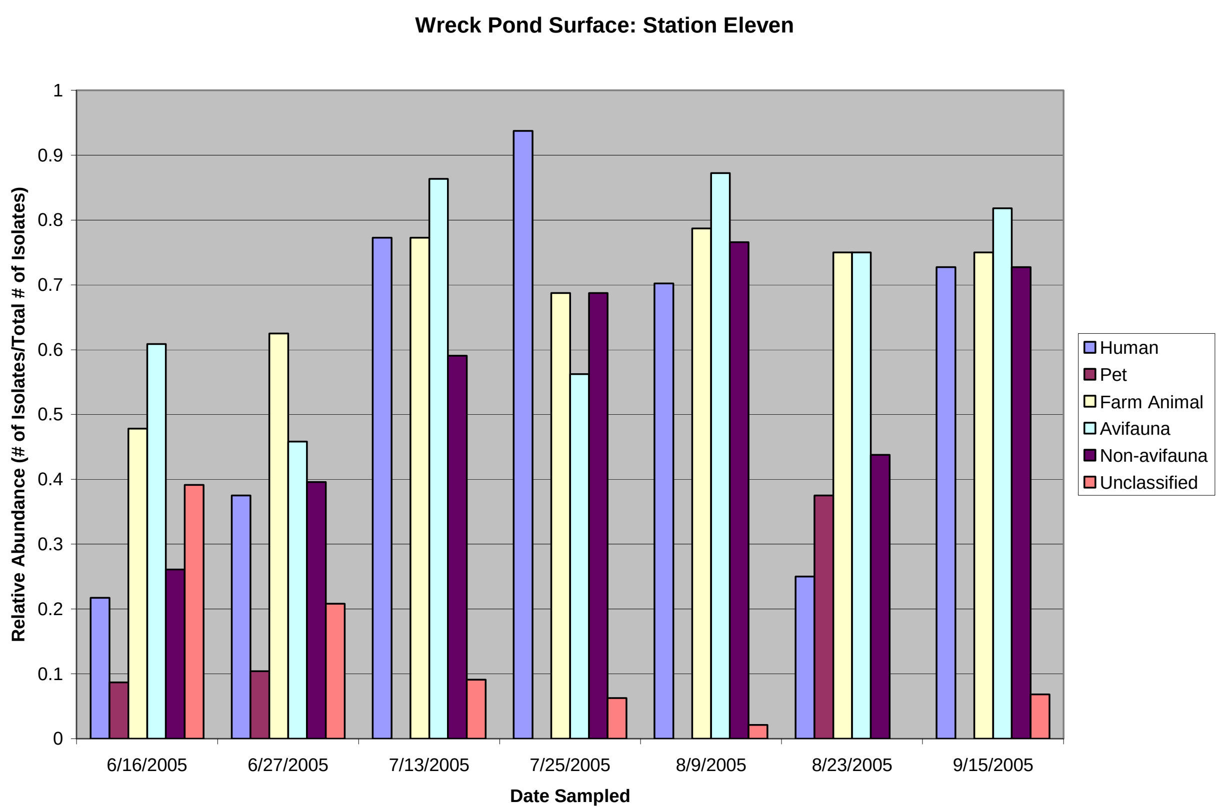
Wreck Pond Microbial Source Tracking Study
Surface Water Source Profile
Station Eleven

Wreck Pond Surface: Station Eleven							
Abundance by Date Sampled							
Species	6/16/2005	6/27/2005	7/13/2005	7/25/2005	8/9/2005	8/23/2005	9/15/2005
Human	0.217391	0.375	0.772727	0.9375	0.702128	0.25	0.727273
Pet	0.086957	0.104167	0	0	0	0.375	0
Farm Animal	0.478261	0.625	0.772727	0.6875	0.787234	0.75	0.75
Avifauna	0.608696	0.458333	0.863636	0.5625	0.87234	0.75	0.818182
Non-avifauna	0.26087	0.395833	0.590909	0.6875	0.765957	0.4375	0.727273
Unclassified	0.391304	0.208333	0.090909	0.0625	0.021277	0	0.068182

Surface Water Source Summary
Station Eleven

Source Category	**Percent of Sampling Events Source Detected**	**Mean Relative Abundance**
Human	100%	0.57
Pets	43%	0.08
Farm Animals	100%	0.69
Avifauna	100%	0.70
Non-avifauna	100%	0.55


Wreck Pond Surface: Station Eleven
Relative Abundance (# of Isolates/Total # of Isolates)
1
0.9
0.8
0.7
0.6
0.5
0.4
0.3
0.2
0.1
0
Human
Pet
Farm Animal
Avifauna
Non-avifauna
Unclassified
6/16/2005
6/27/2005
7/13/2005
7/25/2005
8/9/2005
8/23/2005
9/15/2005

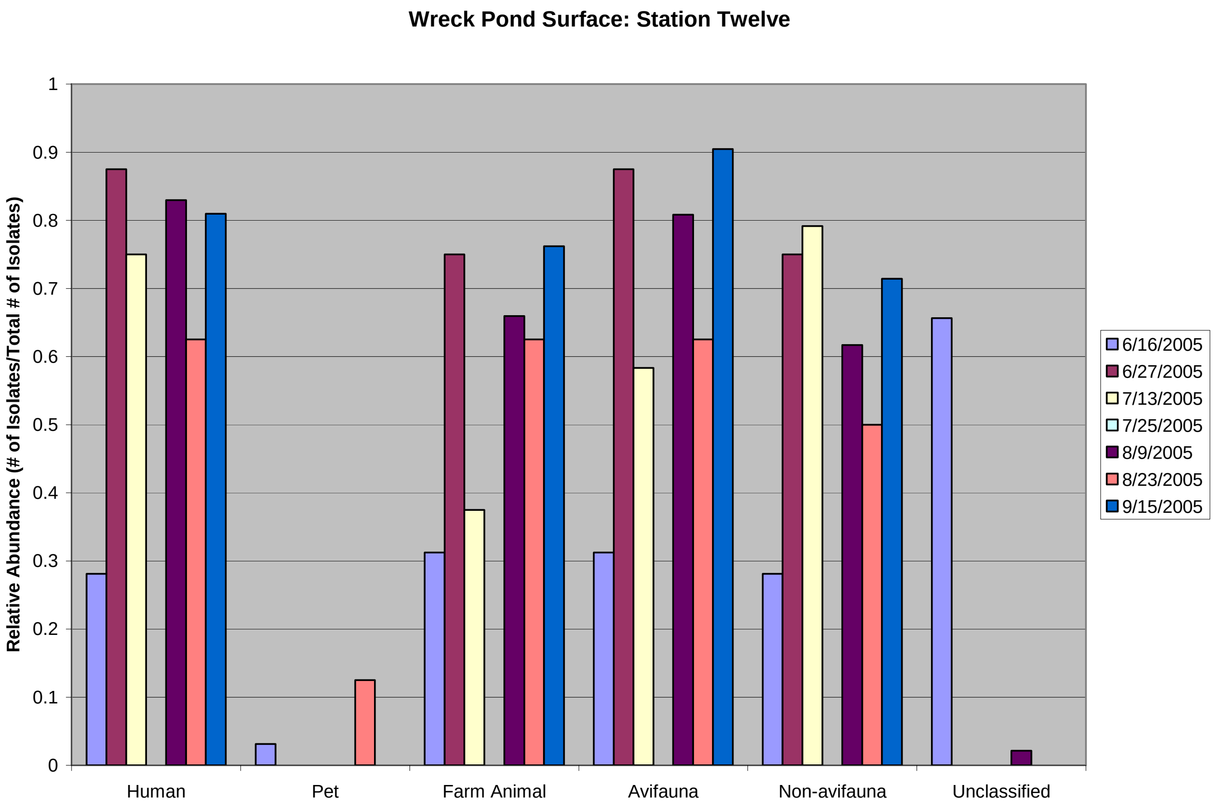

Wreck Pond Surface: Station Eleven
Relative Abundance (# of Isolates/Total # of Isolates)
1
0.9
0.8
0.7
0.6
0.5
0.4
0.3
0.2
0.1
0
6/16/2005
6/27/2005
7/13/2005
7/25/2005
8/9/2005
8/23/2005
9/15/2005
Date Sampled
Human
Pet
Farm Animal
Avifauna
Non-avifauna
Unclassified

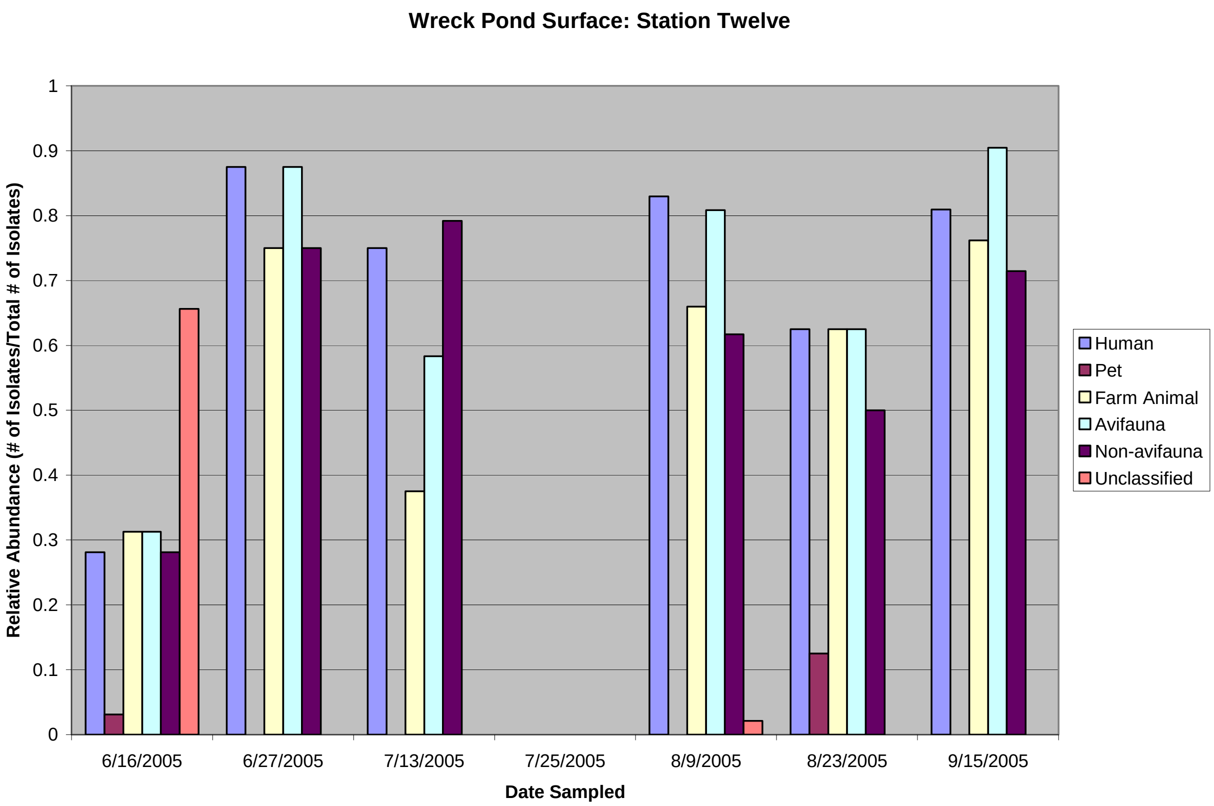
Wreck Pond Microbial Source Tracking Study
Surface Water Source Profile
Station Twelve

Wreck Pond Surface: Station Twelve							
Relative Abundance by Date Sampled							
Species	6/16/2005	6/27/2005	7/13/2005	7/25/2005	8/9/2005	8/23/2005	9/15/2005
Human	0.28125	0.875	0.75	0	0.829787	0.625	0.809524
Pet	0.03125	0	0	0	0	0.125	0
Farm Animal	0.3125	0.75	0.375	0	0.659574	0.625	0.761905
Avifauna	0.3125	0.875	0.583333	0	0.808511	0.625	0.904762
Non-avifauna	0.28125	0.75	0.791667	0	0.617021	0.5	0.714286
Unclassified	0.65625	0	0	0	0.021277	0	0

Surface Water Source Summary
Station Twelve

Source Category	**Percent of Sampling Events Source Detected**	**Mean Relative Abundance**
Human	100%	0.70
Pets	33%	0.03
Farm Animals	100%	0.58
Avifauna	100%	0.68
Non-avifauna	100%	0.61


Wreck Pond Surface: Station Twelve
Relative Abundance (# of Isolates/Total # of Isolates)
1
0.9
0.8
0.7
0.6
0.5
0.4
0.3
0.2
0.1
0
Human
Pet
Farm Animal
Avifauna
Non-avifauna
Unclassified
6/16/2005
6/27/2005
7/13/2005
7/25/2005
8/9/2005
8/23/2005
9/15/2005


Wreck Pond Surface: Station Twelve
Relative Abundance (# of Isolates/Total # of Isolates)
1
0.9
0.8
0.7
0.6
0.5
0.4
0.3
0.2
0.1
0
6/16/2005
6/27/2005
7/13/2005
7/25/2005
8/9/2005
8/23/2005
9/15/2005
Date Sampled
Human
Pet
Farm Animal
Avifauna
Non-avifauna
Unclassified

Appendix C

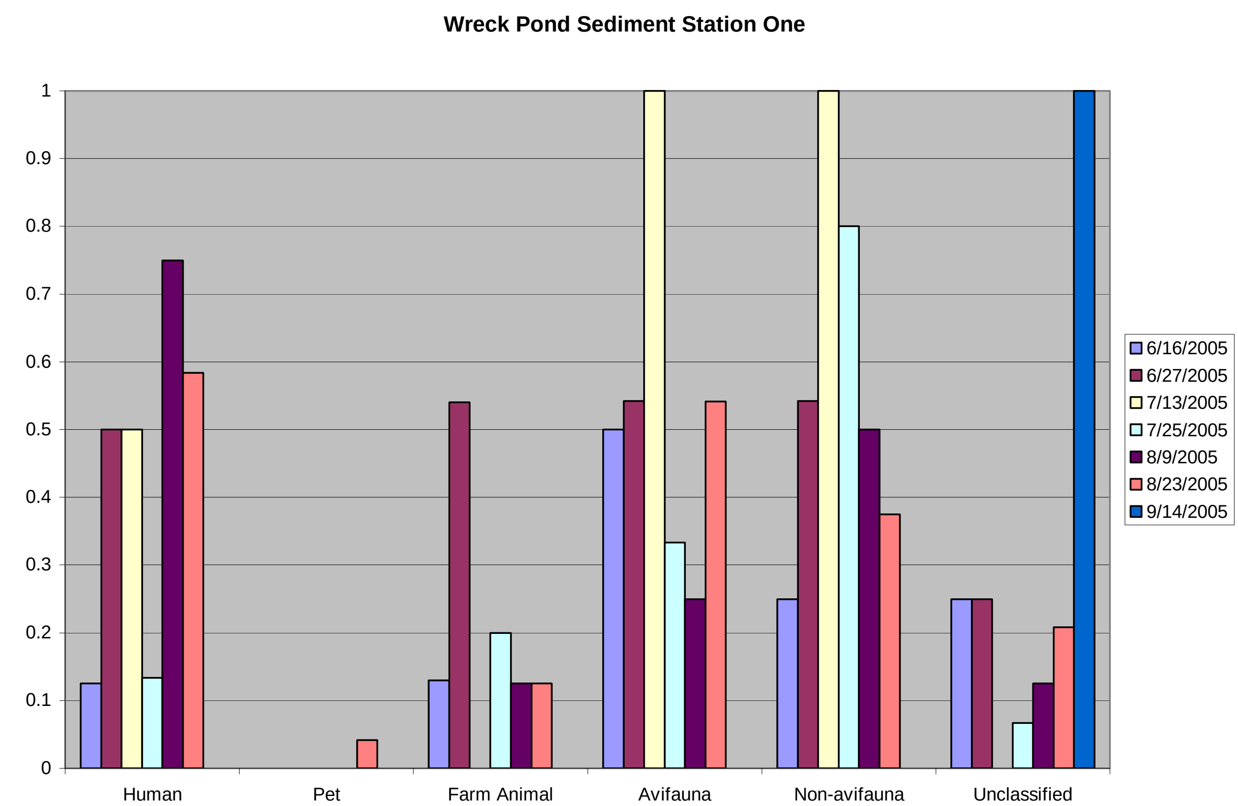
Wreck Pond Watershed
Sediment Source Profile

Wreck Pond Microbial Source Tracking Study
Sediment Source Profile
Station One

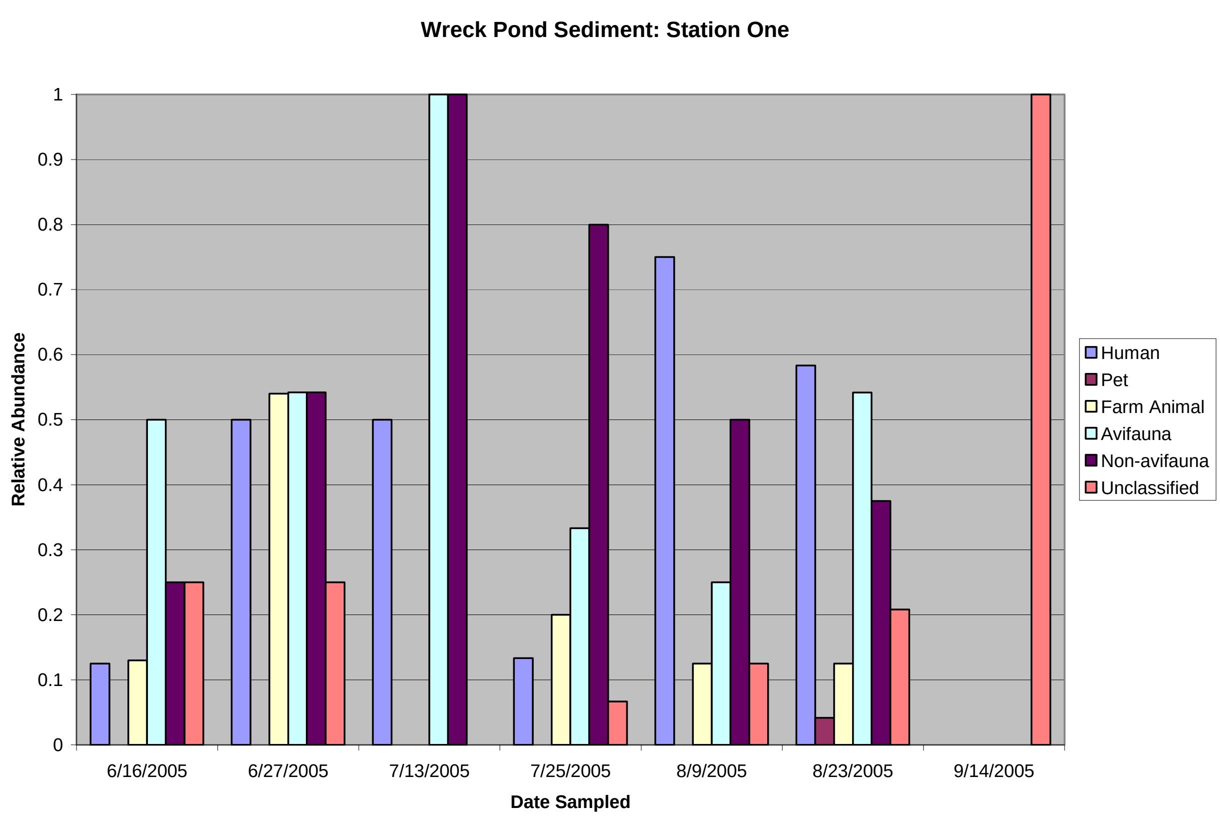
Wreck Pond Sediment: Station One							
Percent Relative Abundance by Date Sampled							
Species	6/16/2005	6/27/2005	7/13/2005	7/25/2005	8/9/2005	8/23/2005	9/14/2005
Human	0.125	0.5	0.5	0.133333	0.75	0.583333	0
Pet	0	0	0	0	0	0.041667	0
Farm Animal	0.13	0.54	0	0.2	0.125	0.125	0
Avifauna	0.5	0.542	1	0.333333	0.25	0.541667	0
Non-avifauna	0.25	0.542	1	0.8	0.5	0.375	0
Unclassified	0.25	0.25	0	0.066667	0.125	0.208333	1

Sediment Source Summary
Station One

Source Category	Percent of Sampling Events Source Detected	Mean Relative Abundance
Human	86%	0.37
Pets	14%	0.01
Farm Animals	71%	0.16
Avifauna	86%	0.45
Non-avifauna	86%	0.50



Wreck Pond Sediment Station One
1
0.9
0.8
0.7
0.6
0.5
0.4
0.3
0.2
0.1
0
Human
Pet
Farm Animal
Avifauna
Non-avifauna
Unclassified
6/16/2005
6/27/2005
7/13/2005
7/25/2005
8/9/2005
8/23/2005
9/14/2005



Wreck Pond Sediment: Station One
Relative Abundance
1
0.9
0.8
0.7
0.6
0.5
0.4
0.3
0.2
0.1
0
6/16/2005
6/27/2005
7/13/2005
7/25/2005
8/9/2005
8/23/2005
9/14/2005
Date Sampled
Human
Pet
Farm Animal
Avifauna
Non-avifauna
Unclassified

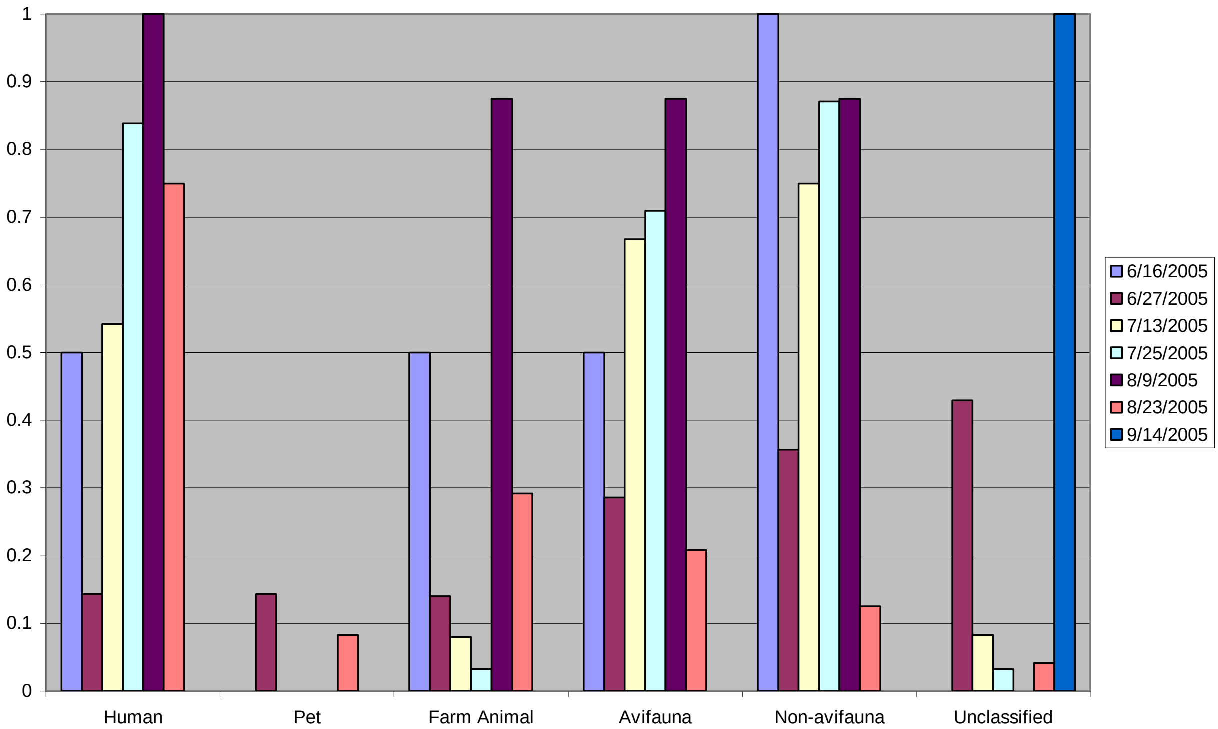
Wreck Pond Microbial Source Tracking Study
Sediment Source Profile
Station Two

Wreck Pond Sediment: Station Two							
Percent Relative Abundance by Date Sampled							
Species	6/16/2005	6/27/2005	7/13/2005	7/25/2005	8/9/2005	8/23/2005	9/14/2005
Human	0.5	0.143	0.542	0.83871	1	0.75	0
Pet	0	0.143	0	0	0	0.083333	0
Farm Animal	0.5	0.14	0.08	0.032258	0.875	0.291667	0
Avifauna	0.5	0.286	0.667	0.709677	0.875	0.208333	0
Non-avifauna	1	0.357	0.75	0.870968	0.875	0.125	0
Unclassified	0	0.429	0.083	0.032258	0	0.041667	1

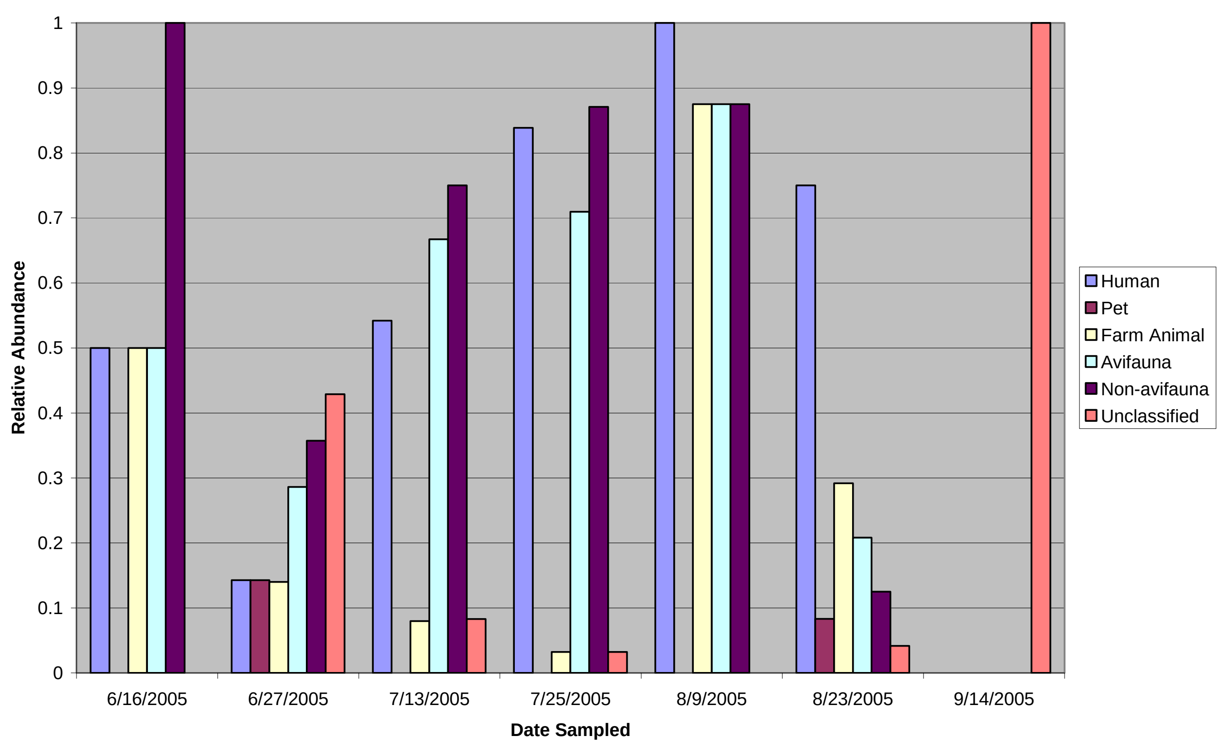
Sediment Source Summary
Station Two

Source Category	**Percent of Sampling Events Source Detected**	**Mean Relative Abundance**
Human	86%	0.54
Pets	28%	0.03
Farm Animals	86%	0.27
Avifauna	86%	0.46
Non-avifauna	86%	0.57

Wreck Pond Sediment Station Two



Wreck Pond Sediment: Station 2

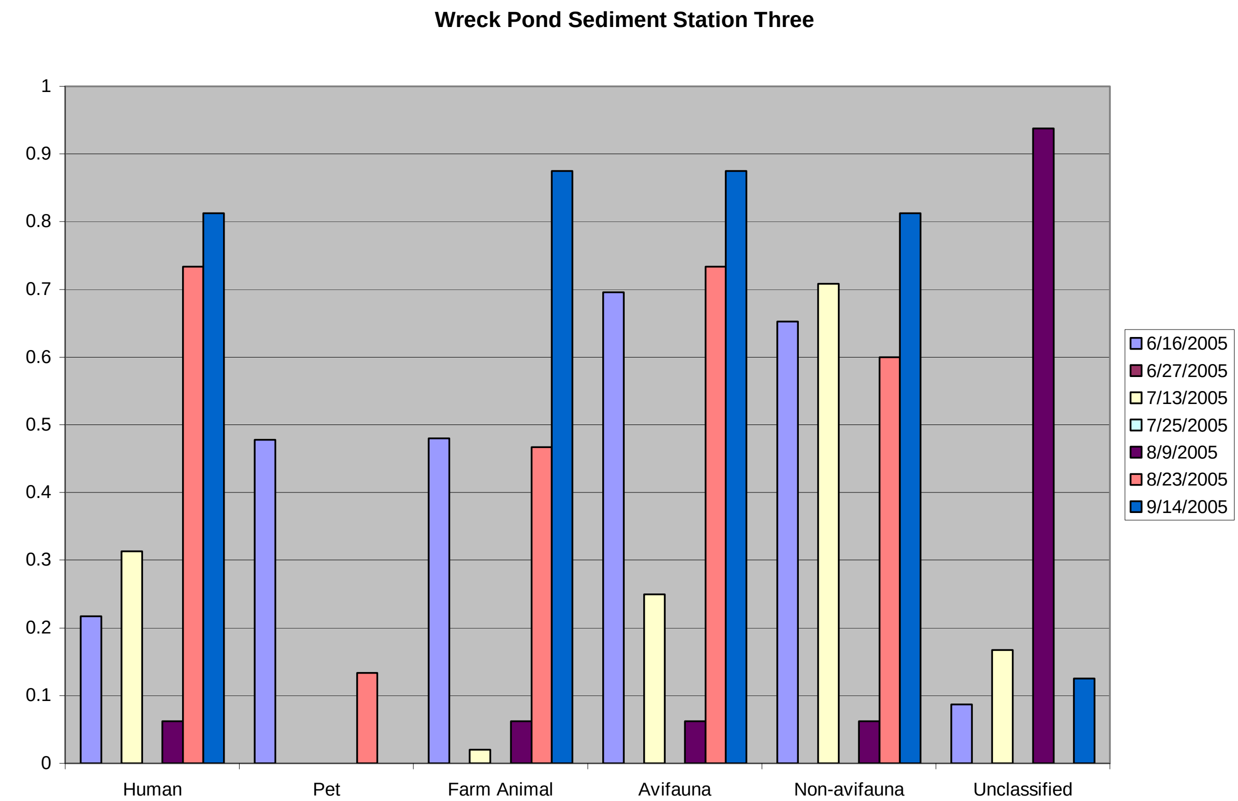


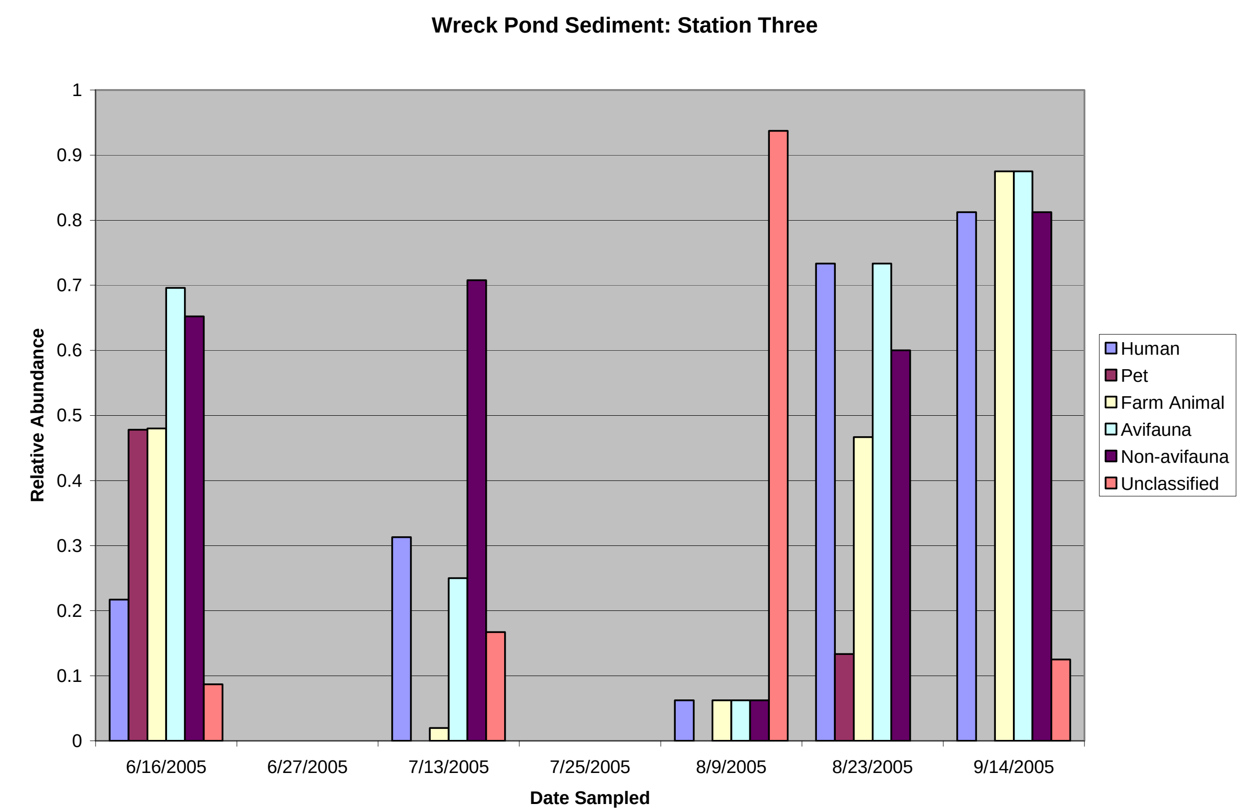
Wreck Pond Microbial Source Tracking Study
Sediment Source Profile
Station Three

Wreck Pond Sediment: Station Three							
Percent Relative Abundance by Date Sampled							
Species	6/16/2005	6/27/2005	7/13/2005	7/25/2005	8/9/2005	8/23/2005	9/14/2005
Human	0.217		0.313		0.0625	0.733333	0.8125
Pet	0.478		0		0	0.133333	0
Farm Animal	0.48		0.02		0.0625	0.466667	0.875
Avifauna	0.696		0.25		0.0625	0.733333	0.875
Non-avifauna	0.6522		0.708		0.0625	0.6	0.8125
Unclassified	0.087		0.167		0.9375	0	0.125

Sediment Source Summary
Station Three

Source Category	**Percent of Sampling Events Source Detected**	**Mean Relative Abundance**
Human	71%	0.31
Pets	28%	0.09
Farm Animals	71%	0.27
Avifauna	71%	0.37
Non-avifauna	71%	0.41


Wreck Pond Sediment Station Three
0
0.1
0.2
0.3
0.4
0.5
0.6
0.7
0.8
0.9
1
Human
Pet
Farm Animal
Avifauna
Non-avifauna
Unclassified
6/16/2005
6/27/2005
7/13/2005
7/25/2005
8/9/2005
8/23/2005
9/14/2005


Wreck Pond Sediment: Station Three
Relative Abundance
0
0.1
0.2
0.3
0.4
0.5
0.6
0.7
0.8
0.9
1
6/16/2005
6/27/2005
7/13/2005
7/25/2005
8/9/2005
8/23/2005
9/14/2005
Date Sampled
Human
Pet
Farm Animal
Avifauna
Non-avifauna
Unclassified

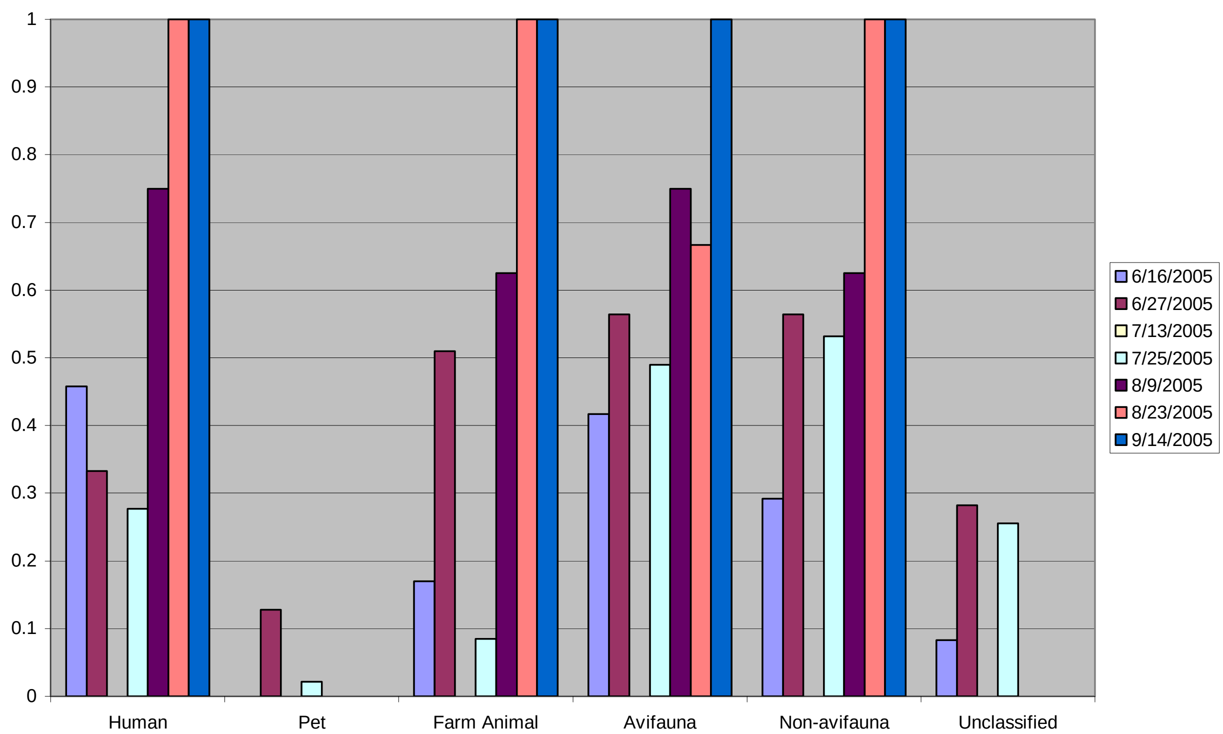
Wreck Pond Microbial Source Tracking Study
Sediment Source Profile
Station Four

Wreck Pond Sediment: Station Four							
Percent Relative Abundance by Date Sampled							
Species	6/16/2005	6/27/2005	7/13/2005	7/25/2005	8/9/2005	8/23/2005	9/14/2005
Human	0.458	0.333		0.276596	0.75	1	1
Pet	0	0.128		0.021277	0	0	0
Farm Animal	0.17	0.51		0.085106	0.625	1	1
Avifauna	0.417	0.564		0.489362	0.75	0.666667	1
Non-avifauna	0.2917	0.564		0.531915	0.625	1	1
Unclassified	0.083	0.282		0.255319	0	0	0

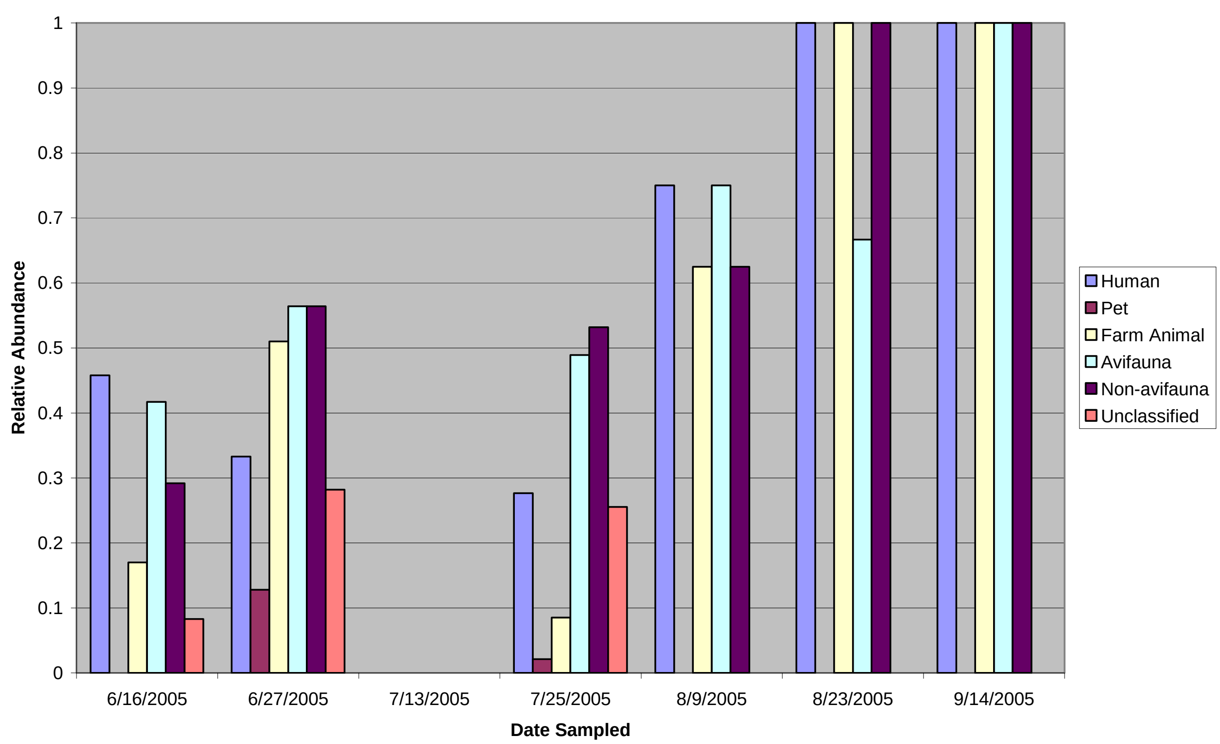
Sediment Source Summary
Station Four

Source Category	**Percent of Sampling Events Source Detected**	**Mean Relative Abundance**
Human	86%	0.55
Pets	28%	0.02
Farm Animals	86%	0.48
Avifauna	86%	0.56
Non-avifauna	86%	0.57

Wreck Pond Sediment Station Four



Wreck Pond Sediment: Station Four



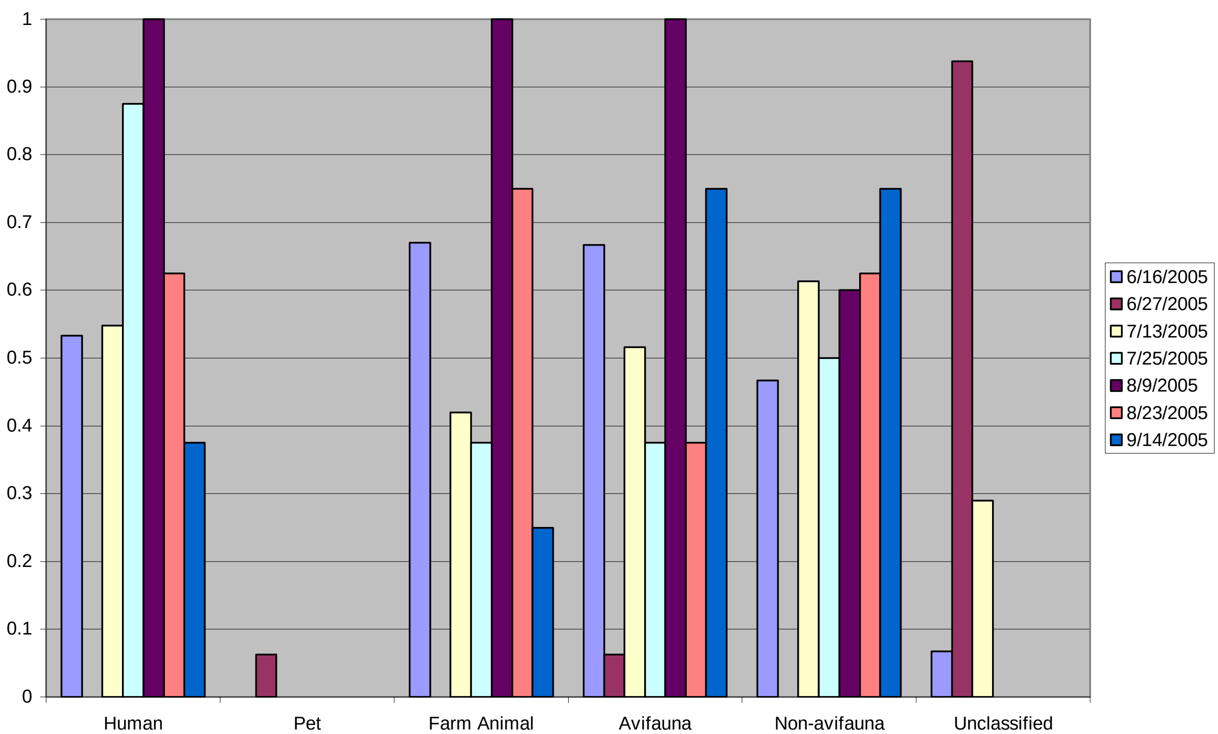
Wreck Pond Microbial Source Tracking Study
Sediment Source Profile
Station Five

Wreck Pond Sediment: Station Five							
Percent Relative Abundance by Date Sampled							
Species	6/16/2005	6/27/2005	7/13/2005	7/25/2005	8/9/2005	8/23/2005	9/14/2005
Human	0.533	0	0.548	0.875	1	0.625	0.375
Pet	0	0.063	0	0	0	0	0
Farm Animal	0.67	0	0.42	0.375	1	0.75	0.25
Avifauna	0.667	0.063	0.516	0.375	1	0.375	0.75
Non-avifauna	0.4667	0	0.613	0.5	0.6	0.625	0.75
Unclassified	0.067	0.938	0.29	0	0	0	0

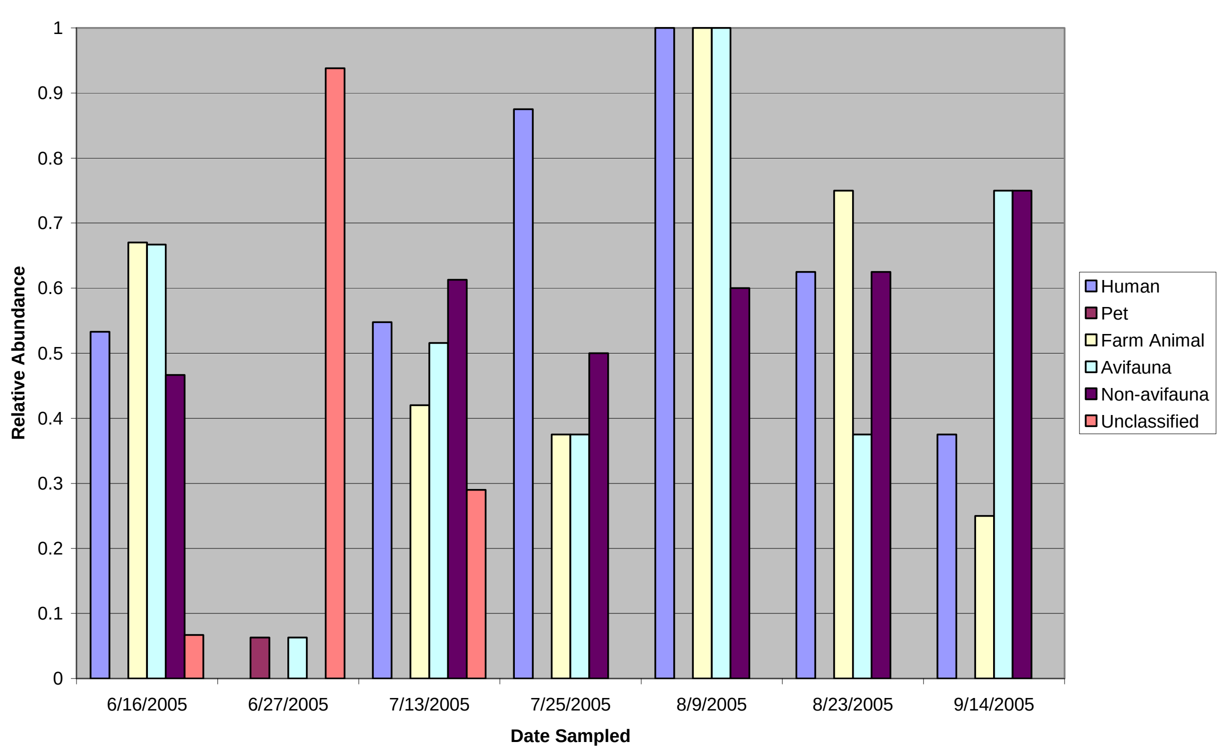
Sediment Source Summary
Station Five

Source Category	**Percent of Sampling Events Source Detected**	**Mean Relative Abundance**
Human	86%	0.57
Pets	14%	0.01
Farm Animals	86%	0.50
Avifauna	100%	0.51
Non-avifauna	86%	0.48

Wreck Pond Sediment Station Five



Wreck Pond Sediment: Station Five



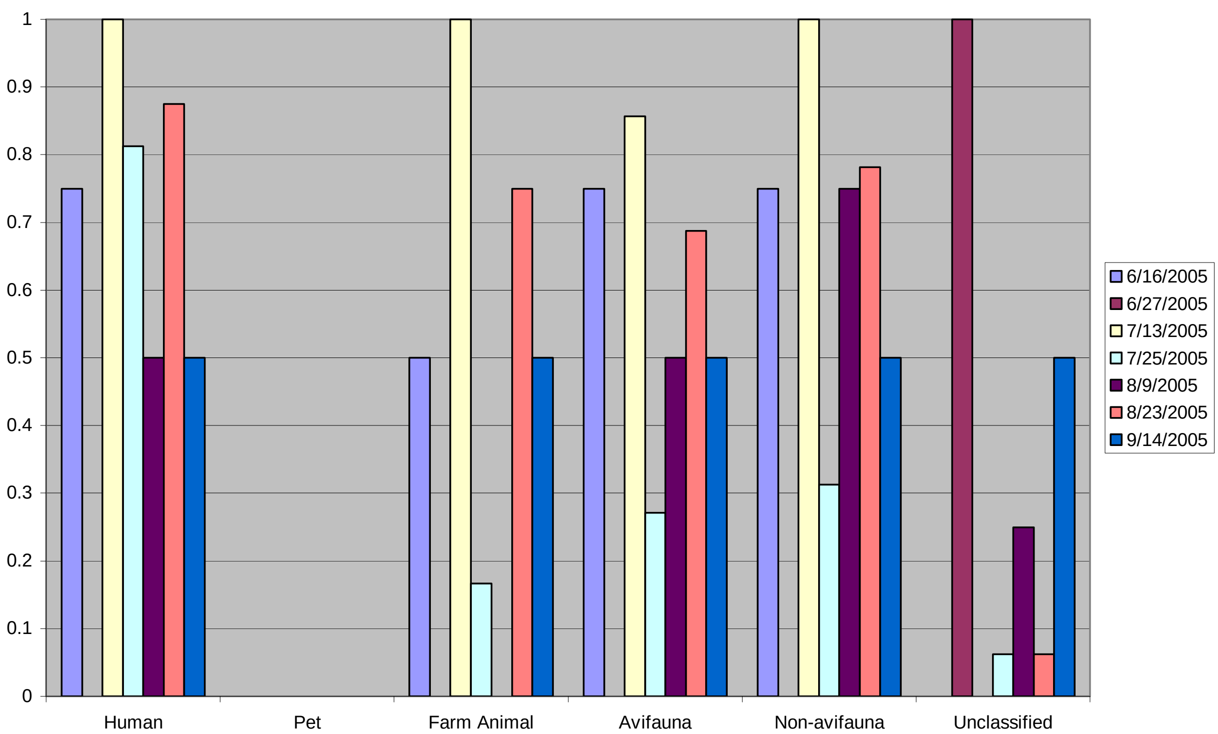
Wreck Pond Microbial Source Tracking Study
Sediment Source Profile
Station Six

Wreck Pond Sediment: Station Six							
Percent Relative Abundance by Date Sampled							
Species	6/16/2005	6/27/2005	7/13/2005	7/25/2005	8/9/2005	8/23/2005	9/14/2005
Human	0.75	0	1	0.8125	0.5	0.875	0.5
Pet	0	0	0	0	0	0	0
Farm Animal	0.5	0	1	0.166667	0	0.75	0.5
Avifauna	0.75	0	0.857	0.270833	0.5	0.6875	0.5
Non-avifauna	0.75	0	1	0.3125	0.75	0.78125	0.5
Unclassified	0	1	0	0.0625	0.25	0.0625	0.5

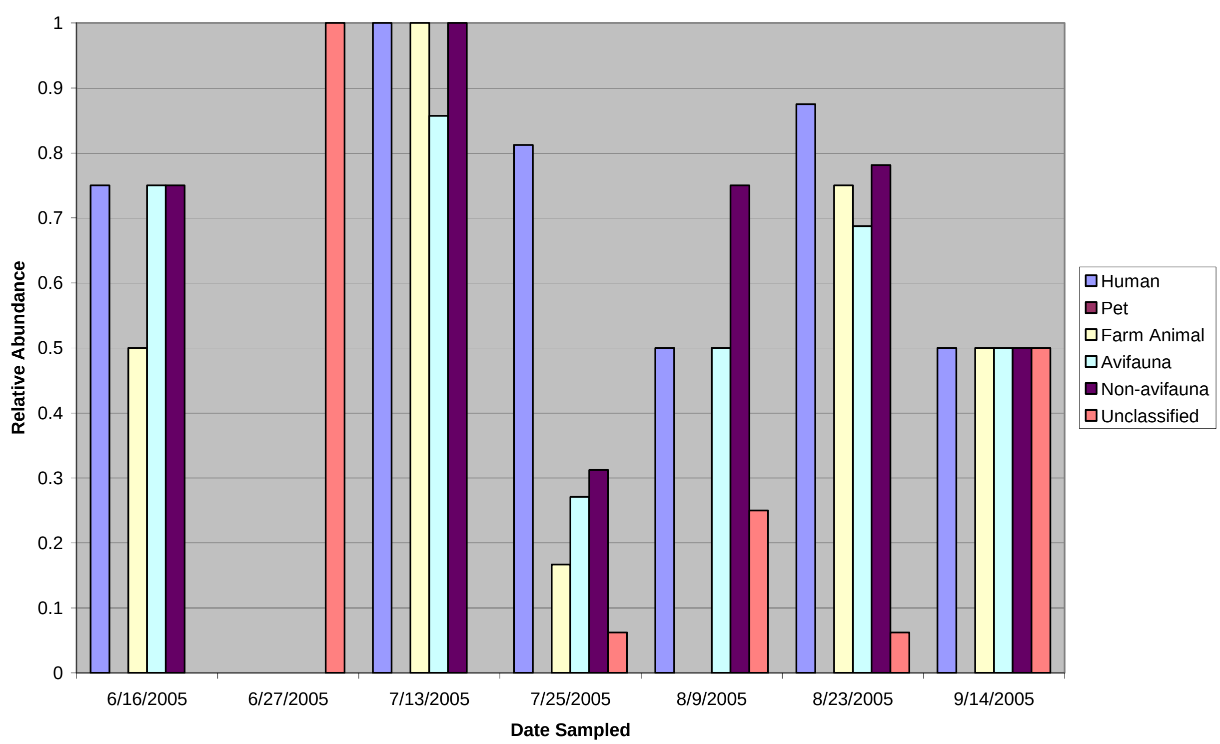
Sediment Source Summary
Station Six

Source Category	**Percent of Sampling Events Source Detected**	**Mean Relative Abundance**
Human	86%	0.63
Pets	0%	0.00
Farm Animals	71%	0.42
Avifauna	86%	0.51
Non-avifauna	86%	0.58

Wreck Pond Sediment Station Six



Wreck Pond Sediment: Station Six

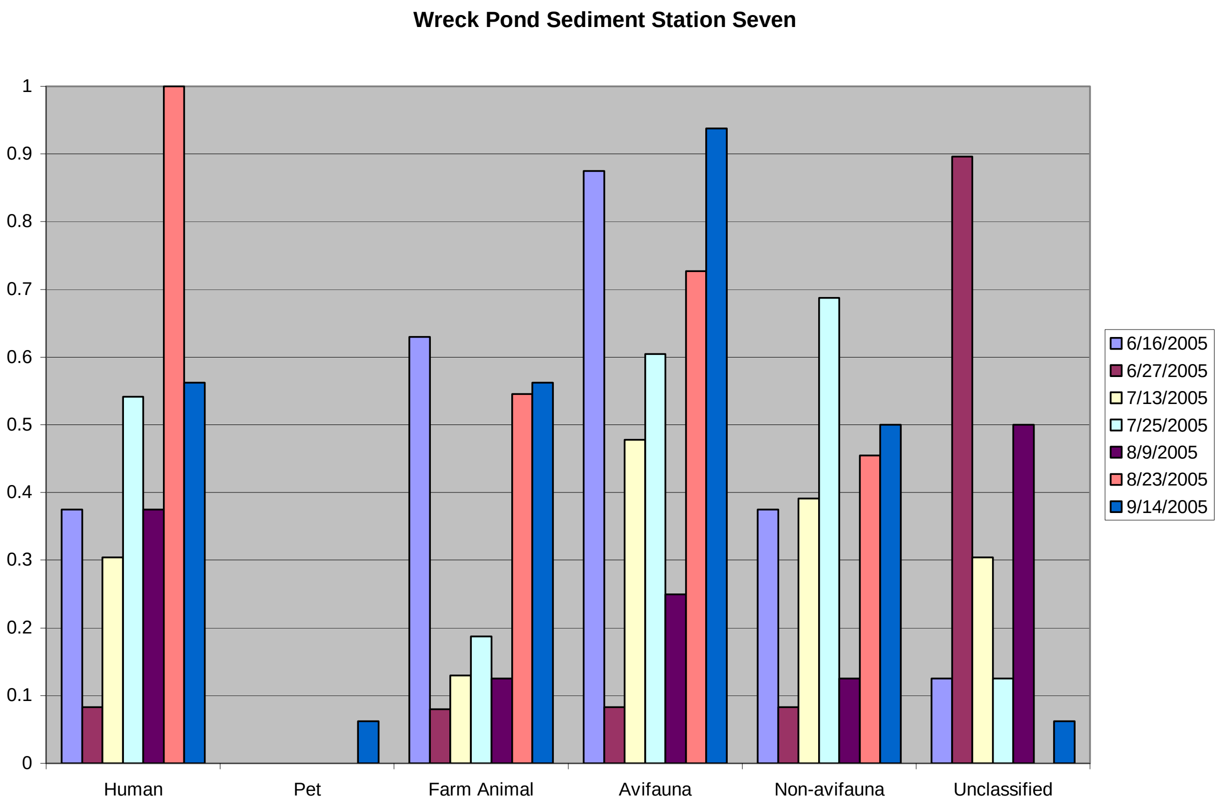


Wreck Pond Microbial Source Tracking Study
Sediment Source Profile
Station Seven

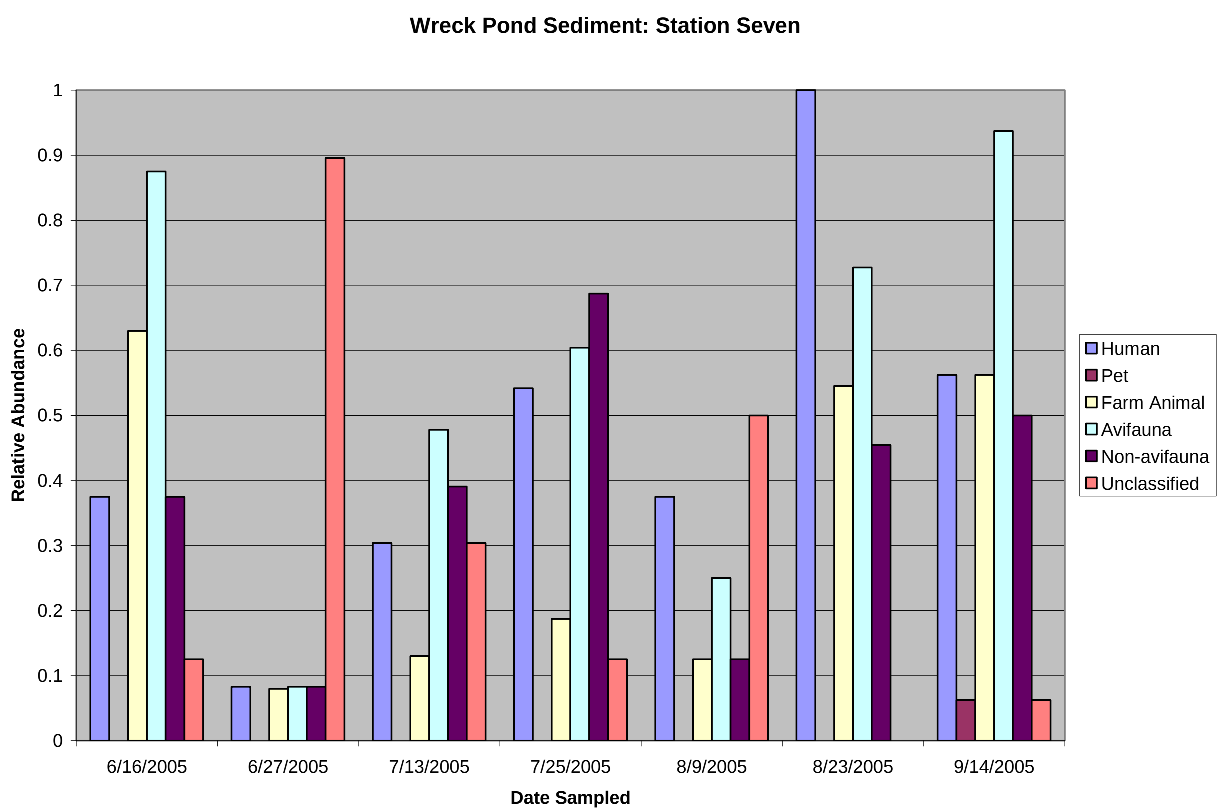
Wreck Pond Sediment: Station Seven							
Percent Relative Abundance by Date Sampled							
Species	6/16/2005	6/27/2005	7/13/2005	7/25/2005	8/9/2005	8/23/2005	9/14/2005
Human	0.375	0.083	0.304	0.541667	0.375	1	0.5625
Pet	0	0	0	0	0	0	0.0625
Farm Animal	0.63	0.08	0.13	0.1875	0.125	0.545455	0.5625
Avifauna	0.875	0.083	0.478	0.604167	0.25	0.727273	0.9375
Non-avifauna	0.375	0.083	0.391	0.6875	0.125	0.454545	0.5
Unclassified	0.125	0.896	0.304	0.125	0.5	0	0.0625

Sediment Source Summary
Station Seven

Source Category	Percent of Sampling Events Source Detected	Mean Relative Abundance
Human	100%	0.46
Pets	14%	0.01
Farm Animals	100%	0.32
Avifauna	100%	0.56
Non-avifauna	100%	0.37



Wreck Pond Sediment Station Seven
1
0.9
0.8
0.7
0.6
0.5
0.4
0.3
0.2
0.1
0
Human
Pet
Farm Animal
Avifauna
Non-avifauna
Unclassified
6/16/2005
6/27/2005
7/13/2005
7/25/2005
8/9/2005
8/23/2005
9/14/2005



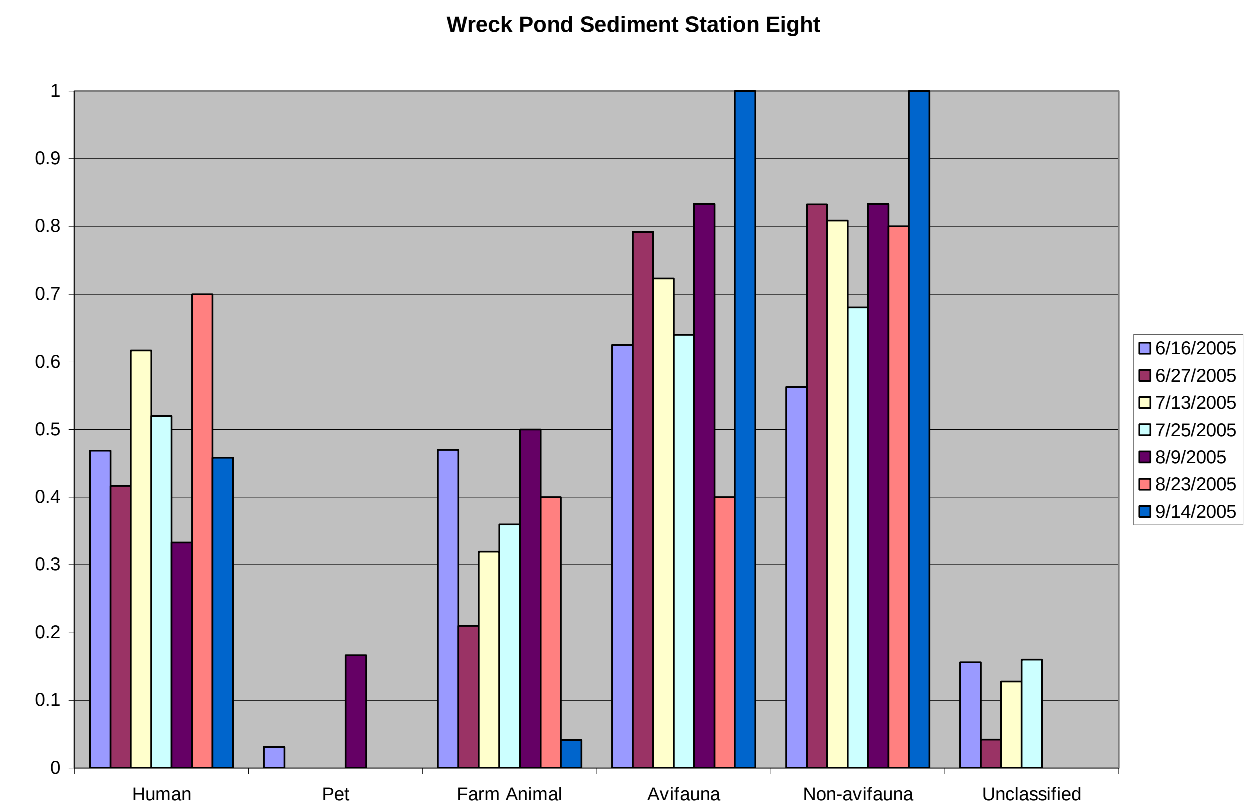
Wreck Pond Sediment: Station Seven
Relative Abundance
1
0.9
0.8
0.7
0.6
0.5
0.4
0.3
0.2
0.1
0
6/16/2005
6/27/2005
7/13/2005
7/25/2005
8/9/2005
8/23/2005
9/14/2005
Date Sampled
Human
Pet
Farm Animal
Avifauna
Non-avifauna
Unclassified

Wreck Pond Microbial Source Tracking Study
Sediment Source Profile
Station Eight

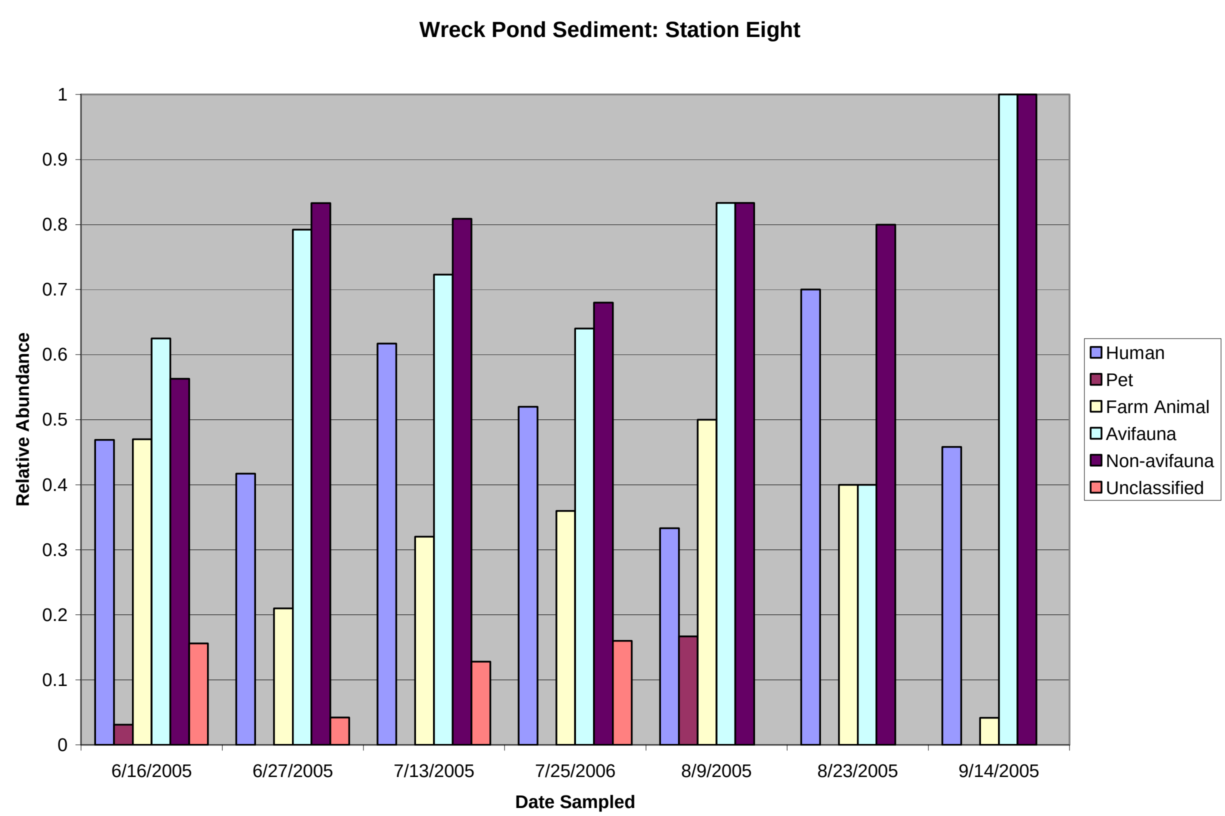
Wreck Pond Sediment: Station Eight							
Percent Relative Abundance by Date Sampled							
Species	6/16/2005	6/27/2005	7/13/2005	7/25/2006	8/9/2005	8/23/2005	9/14/2005
Human	0.469	0.417	0.617	0.52	0.333333	0.7	0.458333
Pet	0.031	0	0	0	0.166667	0	0
Farm Animal	0.47	0.21	0.32	0.36	0.5	0.4	0.041667
Avifauna	0.625	0.792	0.723	0.64	0.833333	0.4	1
Non-avifauna	0.563	0.833	0.809	0.68	0.833333	0.8	1
Unclassified	0.156	0.042	0.128	0.16	0	0	0

Sediment Source Summary
Station Eight

Source Category	**Percent of Sampling Events Source Detected**	**Mean Relative Abundance**
Human	100%	0.50
Pets	28%	0.03
Farm Animals	100%	0.33
Avifauna	100%	0.72
Non-avifauna	100%	0.79



Wreck Pond Sediment Station Eight
1
0.9
0.8
0.7
0.6
0.5
0.4
0.3
0.2
0.1
0
Human
Pet
Farm Animal
Avifauna
Non-avifauna
Unclassified
6/16/2005
6/27/2005
7/13/2005
7/25/2005
8/9/2005
8/23/2005
9/14/2005



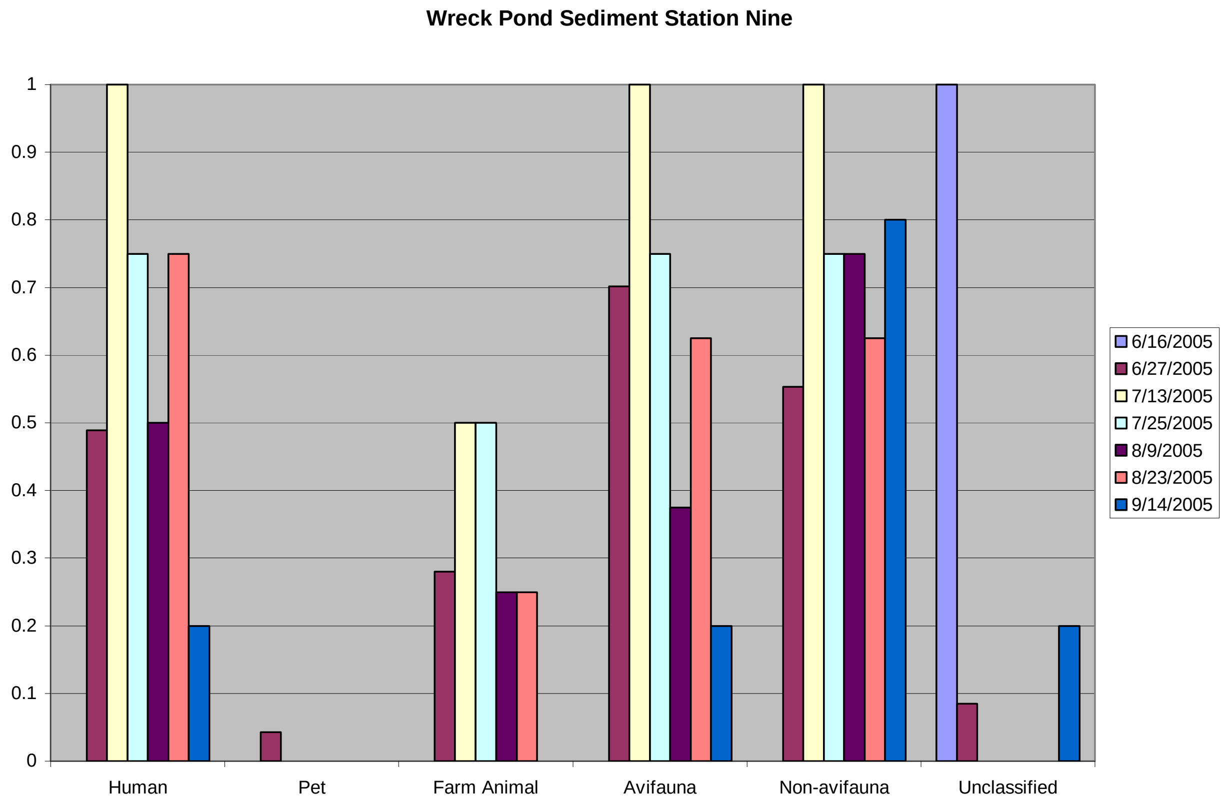
Wreck Pond Sediment: Station Eight
Relative Abundance
1
0.9
0.8
0.7
0.6
0.5
0.4
0.3
0.2
0.1
0
6/16/2005
6/27/2005
7/13/2005
7/25/2006
8/9/2005
8/23/2005
9/14/2005
Date Sampled
Human
Pet
Farm Animal
Avifauna
Non-avifauna
Unclassified

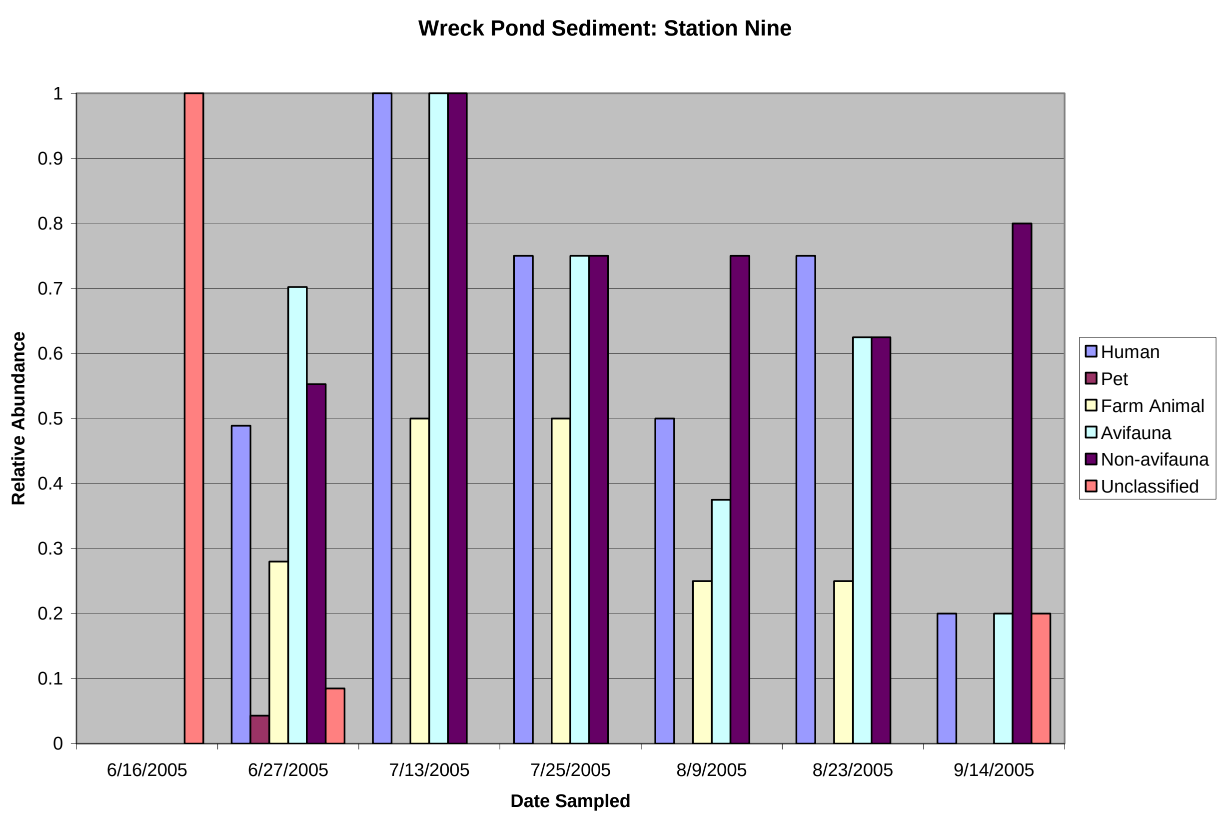
Wreck Pond Microbial Source Tracking Study
Sediment Source Profile
Station Nine

Wreck Pond Sediment: Station Nine							
Percent Relative Abundance by Date Sampled							
Species	6/16/2005	6/27/2005	7/13/2005	7/25/2005	8/9/2005	8/23/2005	9/14/2005
Human	0	0.489	1	0.75	0.5	0.75	0.2
Pet	0	0.043	0	0	0	0	0
Farm Animal	0	0.28	0.5	0.5	0.25	0.25	0
Avifauna	0	0.702	1	0.75	0.375	0.625	0.2
Non-avifauna	0	0.553	1	0.75	0.75	0.625	0.8
Unclassified	1	0.085	0	0	0	0	0.2

Sediment Source Summary
Station Nine

Source Category	**Percent of Sampling Events Source Detected**	**Mean Relative Abundance**
Human	86%	0.53
Pets	14%	0.01
Farm Animals	71%	0.25
Avifauna	86%	0.52
Non-avifauna	86%	0.64





Wreck Pond Sediment

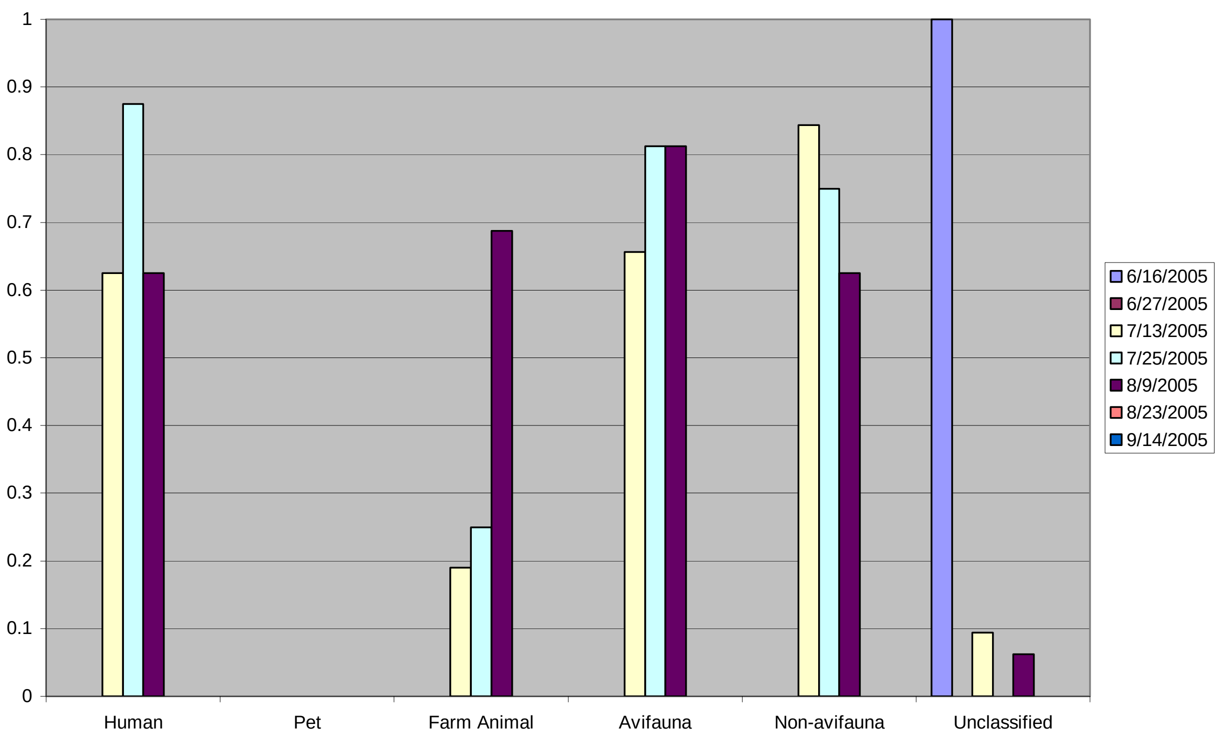
Wreck Pond Microbial Source Tracking Study
Sediment Source Profile
Station Ten

Wreck Pond Sediment: Station Ten							
Percent Relative Abundance by Date Sampled							
Species	6/16/2005	6/27/2005	7/13/2005	7/25/2005	8/9/2005	8/23/2005	9/14/2005
Human	0		0.625	0.875	0.625		
Pet	0		0	0	0		
Farm Animal	0		0.19	0.25	0.6875		
Avifauna	0		0.656	0.8125	0.8125		
Non-avifauna	0		0.844	0.75	0.625		
Unclassified	1		0.094	0	0.0625		

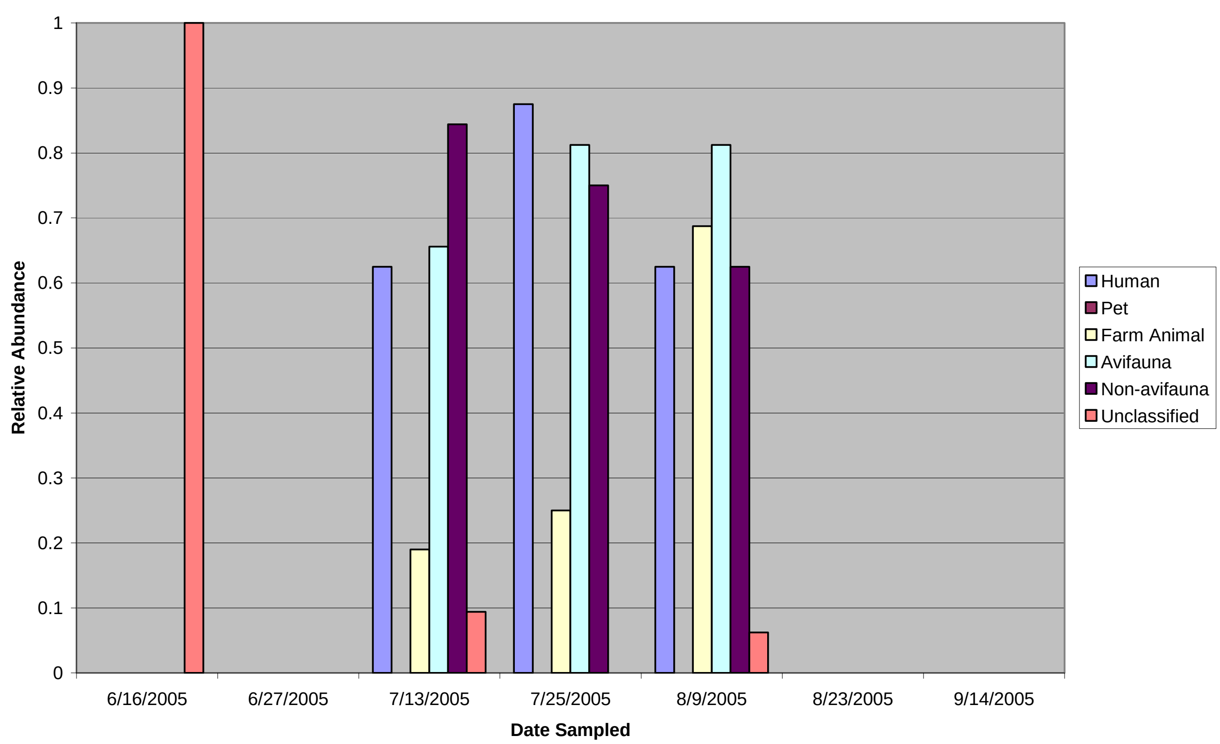
Sediment Source Summary
Station Ten

Source Category	Percent of Sampling Events Source Detected	Mean Relative Abundance
Human	43%	0.30
Pets	0%	0.00
Farm Animals	43%	0.16
Avifauna	43%	0.33
Non-avifauna	43%	0.32

Wreck Pond Sediment Station Ten



Wreck Pond Sediment: Station Ten



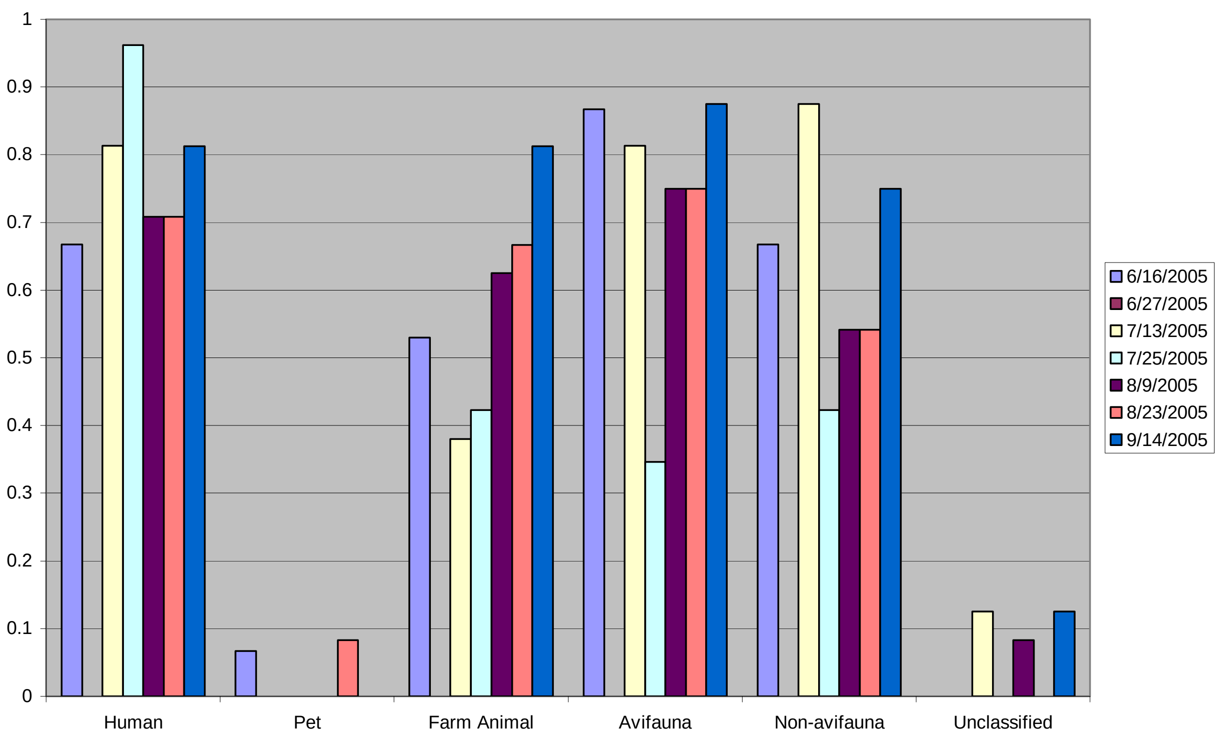
Wreck Pond Microbial Source Tracking Study
Sediment Source Profile
Station Eleven

Wreck Pond Sediment: Station Eleven							
Percent Relative Abundance by Date Sampled							
Species	6/16/2005	6/27/2005	7/13/2005	7/25/2005	8/9/2005	8/23/2005	9/14/2005
Human	0.667		0.813	0.961538	0.708333	0.708333	0.8125
Pet	0.067		0	0	0	0.083333	0
Farm Animal	0.53		0.38	0.423077	0.625	0.666667	0.8125
Avifauna	0.867		0.813	0.346154	0.75	0.75	0.875
Non-avifauna	0.667		0.875	0.423077	0.541667	0.541667	0.75
Unclassified	0		0.125	0	0.083333	0	0.125

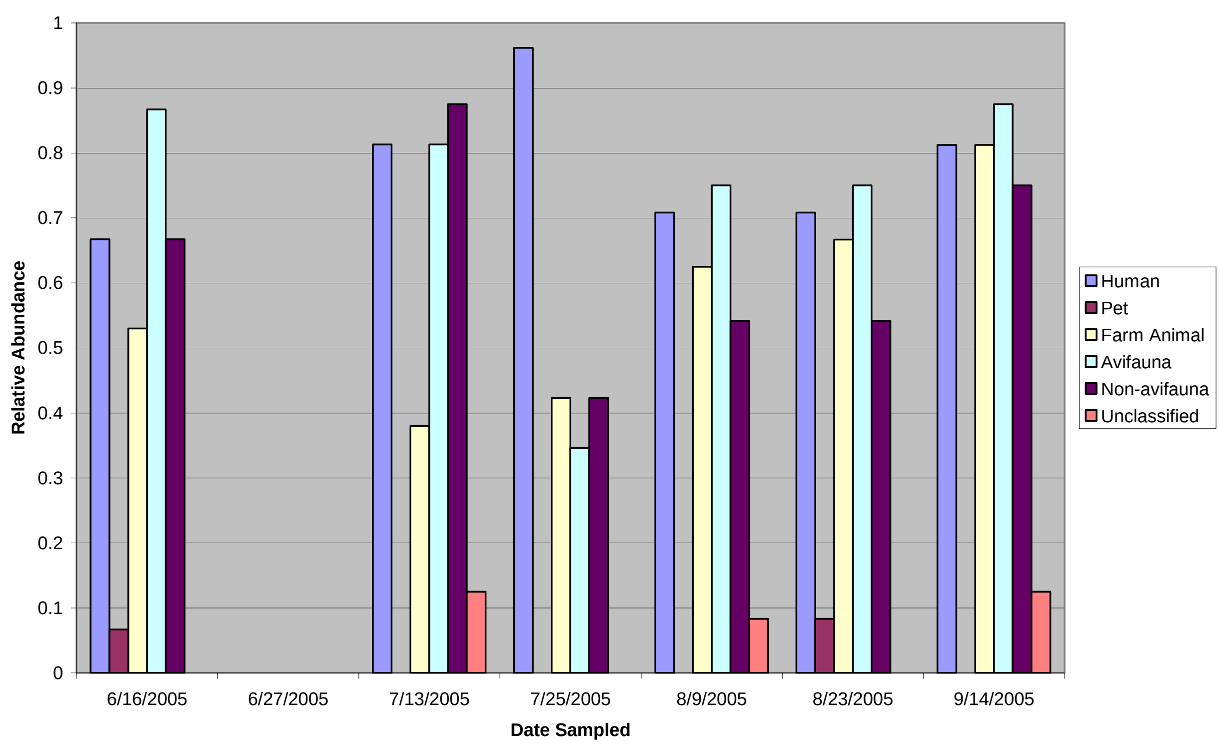
Sediment Source Summary
Station Eleven

Source Category	Percent of Sampling Events Source Detected	Mean Relative Abundance
Human	86%	0.67
Pets	28%	0.02
Farm Animals	86%	0.49
Avifauna	86%	0.63
Non-avifauna	86%	0.54

Wreck Pond Sedimnet Station Eleven



Wreck Pond Sediment: Station Eleven



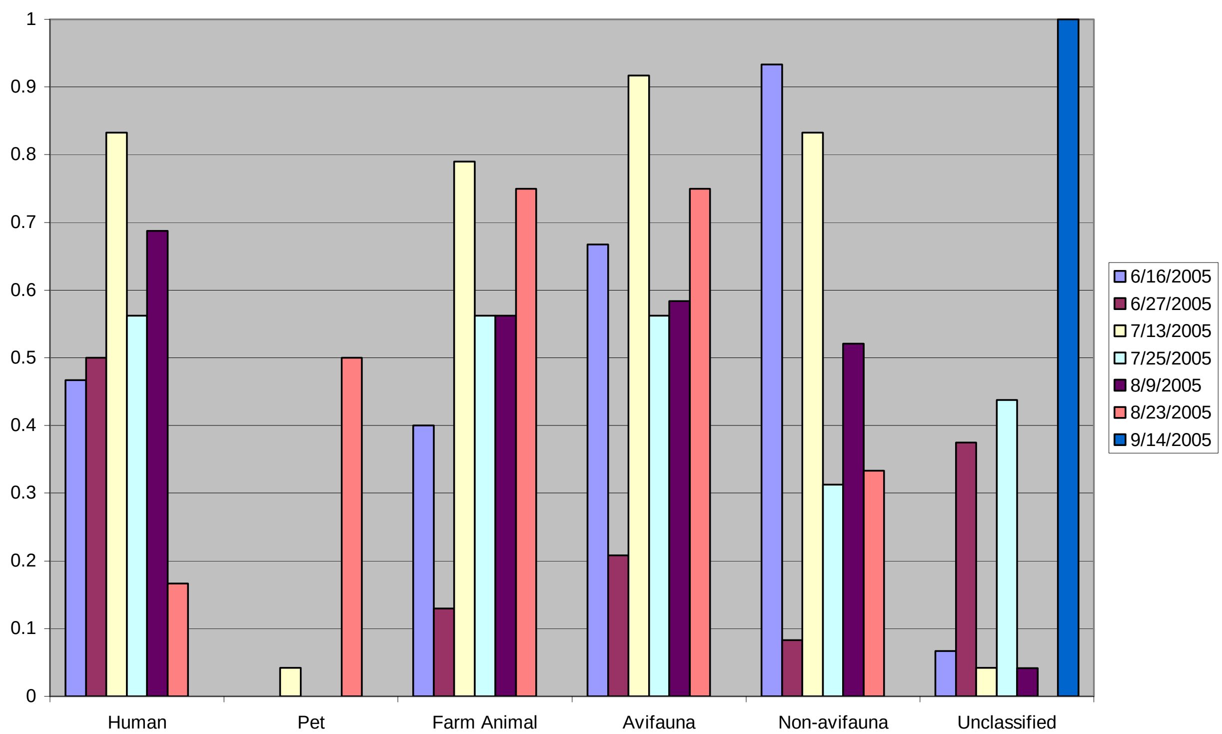
Wreck Pond Microbial Source Tracking Study
Sediment Source Profile
Station Twelve

Wreck Pond Sediment: Station Twelve							
Percent Relative Abundance by Date Sampled							
Species	6/16/2005	6/27/2005	7/13/2005	7/25/2005	8/9/2005	8/23/2005	9/14/2005
Human	0.467	0.5	0.833	0.5625	0.6875	0.166667	0
Pet	0	0	0.042	0	0	0.5	0
Farm Animal	0.4	0.13	0.79	0.5625	0.5625	0.75	0
Avifauna	0.667	0.208	0.917	0.5625	0.583333	0.75	0
Non-avifauna	0.933	0.083	0.833	0.3125	0.520833	0.333333	0
Unclassified	0.067	0.375	0.042	0.4375	0.041667	0	1

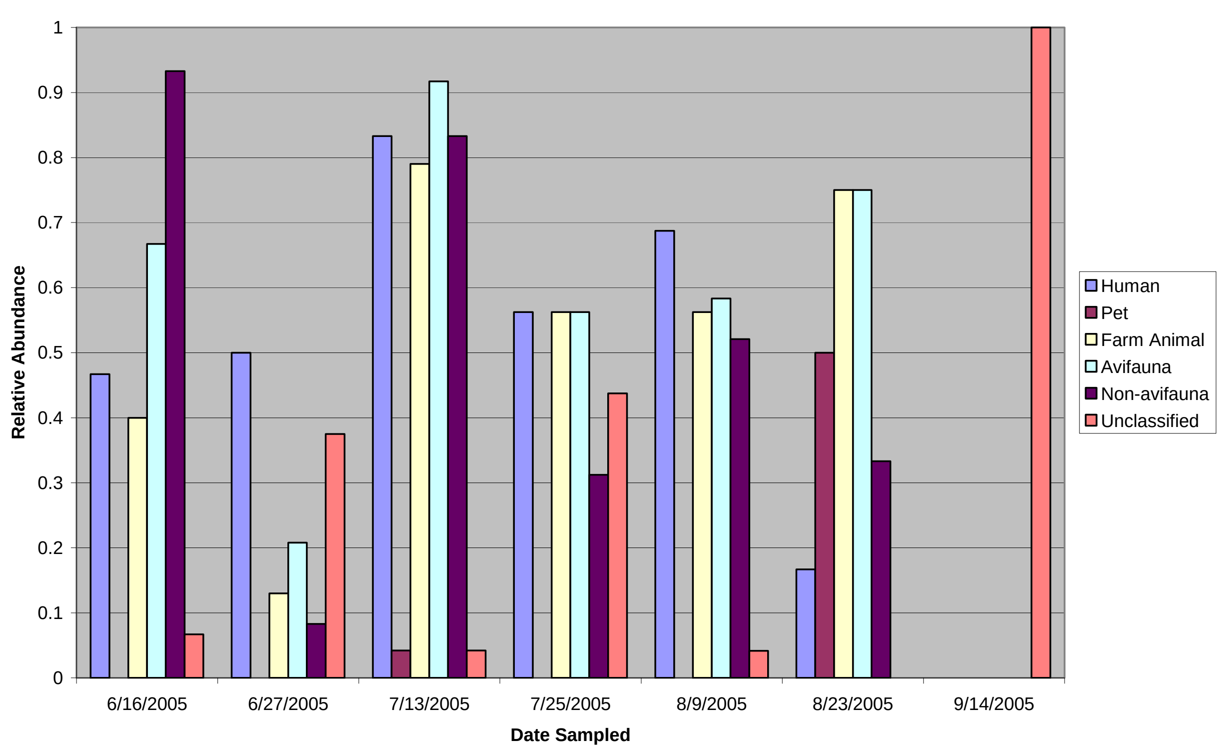
Sediment Source Summary
Station Twelve

Source Category	**Percent of Sampling Events Source Detected**	**Mean Relative Abundance**
Human	86%	0.46
Pets	28%	0.08
Farm Animals	86%	0.46
Avifauna	86%	0.53
Non-avifauna	86%	0.43

Wreck Pond Sediment Station Twelve



Wreck Pond Sediment: Station Twelve



Appendix D

Waterborne Pathogens of Concern

Note: This is a pooled list of waterborne pathogens that have been associated with improperly managed fecal wastes. While contact with these pathogens may not always cause illness in humans, this illustrates the need to remediate bacterial loadings in pathogen impaired waters.

Pathogen	**Clinical Syndrome**	**Potential Contributing Source**
Bacteria		
Actinobacter sp.	Pneumonia, infections of organ systems with high fluid content –urinary tract infections, upper respiratory tract infections, blood and wound infections.	Human
Actinomyces sp.	Chronic bacterial disease localized in the jaw, thorax or abdomen associated with swelling and induces abscess formation. Infection may spread to other organs	Human
Aeromonas sp.	Enterotoxin causes acute diarrhea, cellulitis, open wound and ear infections, septicemia, meningitis, endocarditis, corneal ulcers	Human, Animals, Environment
Bacteroides sp.	Intra-abdominal abscess in individuals with intestinal wounds, induces abscess formation, chronic otitis media, chronic sinusitis	Human
Campylobacter sp.	Bloody diarrhea, vomiting; bacteria may enter blood stream and cause serious life-threatening infection	Human, Farm Animal, Avifauna, Wild Animal
Clostridium sp.	Members of Clostridium genus produce some of the most potent toxins; form dormant cells that are resistant to heat, desiccation, chemicals and detergents. Enterotoxin causes diarrhea, open wound infection, gas-gangrene, Botulism, tetanus, acute clostridial infections, gas gangrene.	Human, Pets, Farm Animal, Avifauna, Wild Animal
Corynebacterium sp.	Toxin causes diphtheria, meningitis, septicarthritis, urinary tract infections	Human
Enterobacter sp.	Bacteremia, lower respitatory tract infections, skin infections, soft tissue infections, urinary tract infections, endocarditis, intra-abdominal, septicarthritis, osteomyelitis	Human
Enterococcus sp.	Bacteremia, endocarditis, urinary tract infections, wound infection, intra-abdominal infections, pelvic infection	Human
Escherichia coli	Pathogenic strains with potent enterotoxins such as E.coli O157:H7, Diarrheagenic E. coli, Enterohemorrhagic E. coli and Enterotoxigenic E. coli may cause bacterial meningitis in infants, severe cases of bloody diarrhea, fever, abdominal cramps, bacteremia and urinary tract infections.	Human, Pet, Farm Animal, Avifauna, Wild Animal
Fusobacterium sp.	Adhere to and invade host tissue cells and modulate the host immune response. Infections of head, neck, chest, lung, liver and abdomen	Human

Helicobacter sp.	Active gastritis, duodenal ulcers, gastric ulcers, dyspepsia	Human, Pets
Klebsiella sp.	Enteritis (occasionally) Pneumonia, Necrosis, inflammation, and hemorrhage within lung tissue, septicemia, urinary tract infections, wound infection, autoimmune disease	Human
Morganella sp.	Septicemia, respiratory tract, urinary tract and wounds	Human, Pet, Farm Animal, Avifauna, Wild Animal
Mycobacterium sp.	Skin infections such as “swimming pool granuloma” and progressive subcutaneous ulceration	Human
Peptostreptococcus sp.	Infections of the central nervous system, head, neck, chest, abdomen, pevis. Some members of genus induce abscess formation and enhance the growth of anaerobic microbes in the intestines	Human
Plesiomonas shigelloides	Gastroenteritis associated with greenish/yellowish, foamy and blood tinged diarrhea, septicemia, meningitis	Human, Pets, Farm Animal, Avifauna, Wild Animal, Environment
Proteus sp.	Bacteremia, sepsis, struvite stones, interstitial cystitis, prostatitis, deep infections in the urinary tract and abdominal cavity	Human
Providencia sp.	Gastroenteritis, urinary tract and blood and infections	Human, Farm Animal
Pseudomonas sp.	gastrointestinal infections, urinary tract infections, otitis externa and otitis media; follicular dermatitis, respiratory system infections, dermatitis, soft tissue infections, bone and joint infections, bacteremia and systemic infections	Human, Environment
Salmonella sp.	Gastroenteritis, Typhoid fever	Humans, Pet, Avifauna, Wild Animal
Shigella sp.	Shigellosis	Human
Staphylococcus sp.	Wound and skin infections	Human
Streptococcus	Skin infection, throat infection, toxic shock syndrome, necrotizing fasciitis, acute pharyngitis, impetigo, pyoderma, scarlet fever and pneumonia	Human
Vibrio sp.	Gastroenteritis, pneumonia, septicemia, cholera dysentery, wound and ear infections, conjunctivitis, salpingitis	Human
Yersinia sp.	Enteritis, ileitis, cellulitis, conjunctivitis, meningitis, osteomyelitis, pharyngitis, pneumonia, urinary tract infection, bacteremia.	Pets, Farm Animals, Wild Animal

Viruses		
Adenovirus	Gastroenteritis, pharyngitis, rhinitis, cough, swollen lymphnodes, respiratory infection, conjunctivitis, otitis media	Human
Coxsackie viruses	Herpangina, paralysis, mycocarditis, pericarditis, encephalitis, epidemic pleurodynia, transient paralysis	Human
Echovirus	Meningitis, enteritis	Human
Hepatitis A	Hepatitis A Infection	Human
Norovirus sp.	Gastroenteritis	Human
Rotavirus	Gastroenteritis with severe diarrhea	Human
Protozoa		
Balantidium sp.	Parasites invades the submucosa of the large intestine causing severe colitis, ulcerations and Balantidial dysentery	Human, ,Farm Animal
Cryptosporidum sp.	Common waterborne parasites cause cryptosporidiosis. *Cryptospordium* species are protected by an outer shell that allows it to survive outside the body in the environment for extended periods of time	Human, Pets, Farm Animal, Avifauna,
Cercarea of parasitic schistosomes	Parasites cause cercarial dermatitis when larvae of flatworms burrow into skin of infected individual	Avifauna, Wild Animal (Aquatic)
Echinococcus sp.	Ingestion of *Echinococcus* eggs shed in feces causes infection of cysts in liver, lungs, brain, bones, kidney, spleen and other tissue. Infection can spread as it passes through the blood stream.	Pet
Entamoeba sp.	Trophozoites of the parasites invade intestinal wall and cause amoebic dysentery. From intestinal wall trophozoites may travel elsewhere in the body via the blood stream.	Human, Pet, Farm Animal, Avifauna, Wild Animal
Giardia sp.	Common waterborne parasites cause giardiasis. *Giardia* species are protected by an outer shell that allows it to survive outside the body in the environment for extended periods of time	Human, Pets, Farm Animals
Isospora sp.	Parasites invades the epithelial cells of small intestine and cause coccidiosis	Pets
Toxoplasma sp.	Parasites cause cooccidiosis, toxoplasmosis	Pets, Farm Animal, Wild Animal

Helminths		
Ascaris sp.	Ascariasis	Human, Farm Animal
Ancylostoma sp.	Hookworm disease	Human, Pets
Paragonimus sp.	Paragonimus	Human, Pets, Farm Animal, Wild Animal
Spirometra mansoni	Sparganosis	Human, Pets, Farm Animal, Avifauna, Herbivorous Wild Animal
Taenia sp.	Taeniasis	Human, Farm Animal, Herbivorous Wild Animals
Trichostrongylus sp.	Trichostrongyliasis	Human, Farm Animal, Herbivorous Wild Animals

Definitions (Taken from WebMD and Medline Plus)

Amoebic dysentery: an inflammation of intestines caused by infection with amoeba; severe slimy diarrhea with foul odor, ulceration in intestines; amoeba may burrow through intestinal wall and spread through the blood stream to other organs (NetDoctor 2007).

Ascariasis: roundworm infection of small intestine; infection occurs with ingestion of *Ascaris* eggs shed in feces of infected individuals (CDC 2007).

Bacteremia (Septicemia): the presence of bacteria in the blood, blood infection associated with severe disease (eMedicine 2007).

Balantidial dysentery: intestinal infection with *Balantidium sp.* causing intestinal inflammation and symptoms associated with colitis (Wrong Diagnosis? 2007).

Botulism: a serous illness caused by the bacterium *Clostridium botulinum* associated with difficulty swallowing and speaking, progressive weakness and paralysis, nausea and vomiting, abdominal cramps, double vision, and difficulty breathing (CDC 2007).

Cellulitis: an infection of the lower layers of skin and subcutaneous tissues or areas around the skin. Area of infection shows symptoms of inflammation (eMedicine 2007).

Cercarial dermatitis (Swimmers Itch): infection of the skin by the cercariae of certain species of schistosomes (CDC 2007).

Cholera dysentery: a dysentery infection associated with watery diarrhea, vomiting and leg cramps, dehydration, shock. Cholera dysentery may lead to death if left untreated (CDC 2007).

Coccidiosis: a severe gastrointestinal infection produced by sporozan parasite causing diarrhea, fever, abdominal pain and nausea (Britannica Online 2007).

Colitis: inflammation of the colon; symptoms include diarrhea, ulcers, abdominal pain, bloating, bloody stools and fever (eMedicine 2007).

Conjunctivitis (Pink eye): infection and inflammation in the conjunctiva (eMedicine 2007).

Corneal ulcers: erosion or an open sore in the outer layer of the cornea (eMedicine 2007).

Cryptosporidiosis: an infection of the small intestine associated with watery diarrhea; infection may move to digestive or respiratory tract (CDC 2007).

Dermatitis: infection and inflammation of the skin associated with symptoms of redness, itching and blistering (Medline plus 2007).

Dysentery: an infection of the gut caused by a bacterium. Dysentery is highly contagious and associated with symptoms such as watery diarrhea - sometimes with blood and mucus, nausea and vomiting, abdominal pain, fever and general malaise (BBC 2007).

Encephalitis: inflammation of the brain causing severe headaches, sudden fever, drowsiness, vomiting, confusion and seizures (Medline plus 2007).

Endocarditis: an inflammation of the inside the lining of the heart chambers and heart valves (Medline plus 2007).

Enteritis: an inflammation of the small intestine that may lead to abdominal pain, diarrhea, fever and dehydration (Medline plus 2007).

Enterotoxin: a toxic substance produced by bacteria that causes stomach problems like cramps and diarrhea when released into the intestines (Medline plus 2007).

Epidemic pleurodynia: complications of infection with serious chest pain attacks, fever, malaise, head aches (eMedicine 2007).

Gas gangrene: a severe form of gangrene, tissue death usually cause by *Clostridium perfringes, Group A Streptococcus*, *Staphlyococcus aureus* and *Vibrio vulnificus* (Medline plus 2007).

Gastroenteritis: inflammation of the lining of the intestines caused by virus, bacteria or parasite. Symptoms include diarrhea, abdominal pain, vomiting, headache, fever and chills (Medline plus 2007).

Giardiasis: a diarrheal illness caused when *Giardia* infects intestines of host (CDC 2007).

Herpangina: a viral illness characterized by painful, white-grey ulcers and lesions with a reddish border in the mouth and on the hands and feet, sore throat and fever (Medline plus 2007).

Hepatitis A Infection: infection of the liver caused by Hepatitis A virus that causes jaundice, fatigue, abdominal pain, nausea and diarrhea (CDC 2007).

Hookworm disease: a gastrointestinal infection leading to loss of blood and iron depletion. Infection occurs with ingestion of *Ancylostoma* eggs shed in feces of infected individuals (eMedicine 2007).

Ileitis: infection and inflammation of the ileum, the farthest segment of the small intestine (Britannica Online 2007).

Impetigo: a bacterial skin infection characterized by crusting skin lesions (Medline plus 2007).

Interstitial cystitis: discomfort or pain in the bladder and abdomen associated with the frequent need to urinate. Interstitial cystitis is more common in women than in men (Medline plus 2007).

Intra-abdominal infection: an infected pocket of fluid and pus present in the abdominal cavity. Intra-abdominal infections may lead to peritonitis (eMedicine 2007).

Infection: the presence of various agents in the body that triggers a host response, such as inflammation, to the microbe or toxin produced by the microbe (Britannica Online 2007).

Meningitis: an infection of the fluid of the spinal cord and the fluid that surrounds the brain that causes inflammation. Viral or non-bacterial meningitis is generally less severe and does not need treatment. Bacterial meningitis is more severs and may cause brain damage, hearing loss, learning disability or death (CDC 2007).

Mycocarditis: inflammation of the heart muscle that casues fever, chest pain, joint pain and swelling, abnormal breathing, swelling in the legs, fatigue (eMedicine 2007).

Necrotizing fasciitis: a progressive, rapidly spreading, inflammatory infection of the soft tissue covering the muscles, known as the fascia. Infection is usually caused by the toxin of gas producing microorganisms where it destroys skin and soft tissue and may spread through the blood to the lungs and other organs (eMedicine 2007).

Osteomyelitis: an acute or chronic bone infection caused by bacteria. Symptoms of osteomyelitis include pain in the bone, localized swelling, fever, nausea and general malaise (Medline plus 2007).

Otitis media: middle ear infection (eMedicine 2007).

Otiitis externa: an infection of the external ear canal (eMedicine 2007).

Paragonimus (Human fluke infection): fluke infection mainly in the lungs that occurs with ingestion of *Paragonimus* eggs shed in feces of infected individual (CDC 2007).

Pericarditis: inflammation of the pericardium, the lining sac surrounding the heart causing chest pain, difficulty breathing when lying down, dry cough, swelling in feet and ankles, fatigue and fever (Medline plus 2007).

Peritonitis: an inflammation of the peritoneum, the tissue that lines the wall of the abdomen and covers the abdominal organs. Symptoms associated peritonitis include abdominal pain and distention, fever, low urine output, nausea and vomiting, tenderness and thirst (Medline plus 2007).

Pharyngitis: infection of the pharynx or tonsils that results in inflammation and a sore throat (Medline plus 2007).

Pneumonia: an infection of the lungs; symptoms range from mild to severe and include cough with yellowish green mucus bloody sputum, fever, sharp chest pain and shortness of breath (Medline plus 2007).

Prostatitis: infection and inflammation of the prostate gland. Symptoms associated with prostatitis include localized swelling of the infected area, painful urination and ejaculation (eMedicine 2007).

Pyoderma: a skin condition that causes large painful ulcers on the skin (eMedicine 2007).

Rhinitis: inflammation and irritation of nasal passages associated with funny nose, sneezing, itching, stuffy nose and congestion (MedicineNet 2007).

Salpingitis: infection and inflammation of the oviducts in female upper genital tract (eMedicine 2007).

Scarlet fever: a rash caused by Group A Streptococci usually associated with strep throat. Scarlet fever spreads easily from person to person contact (CDC 2007).

Sepsis: a systemic response to a severe bacterial infection of the bloodstream caused by bacterial toxins usually originating from infection of the kidneys or upper urinary tract infection, liver or gallbladder, bowel, skin or lungs (Medline plus 2007).

Shigellosis (Shigella enteritis): an acute infection of the lining of the intestines associated with symptoms such as bloody diarrhea, fever, stomach cramps (CDC 2007).

Sinusitis: an inflammation of the sinuses. Chronic sinusitis is when sinuses are inflamed for over three weeks (eMedicine 2007).

Sparganosis: plerocercoid tapeworm larvae infection from *Spirometra mansoni*; infection occurs with ingestion of eggs shed in feces of infected individual; surgical removal of parasite is the only cure for infection (The Merck Manuals Online Medical Library 2007).

Struvite stones: a complex of magnesium and phosphate formed by bacterial infection of kidney with bacteria that are able to split urea and urine into ammonium. Stones form and bacteria get trapped within them, growing in the kidney. Struvite stones cause kidney damage and may even induce cancer (eMedicine 2007).

Systemic infection: an infection in the blood stream that affects the entire body (Medline plus 2007).

Taeniasis: tapeworm infection in organs; infection occurs with ingestion of *Taenia* eggs shed in feces of infected individual (Medline plus 2007).

Tetanus: a potentally deadly nervous system disease due to infection with Clostridium tetani. Symptoms associated with tetanus include fever, spasms and tightening of the jaw muscle, stiffness and spasms in various muscle groups (neck, chest, abdominal, back) and titanic seizures or painful muscle contractions (Medline plus 2007).

Toxic shock syndrome: a severe disease that involves fever, shock and problems with the function of organs. Symptoms associated with toxic shock syndrome include high fever, malaise, nausea, vomiting, diarrhea, widespread rash, seizures, hypotension and organ failure (Medline plus 2007).

Toxoplasmosis: infection with parasite may have no symptoms or infected individual may have flu-like symptoms such as swollen glands, fever, jaundice, blurry vision and sensitivity to light. Sever cases may cause damage to the brain, eyes and other organs; parasite may infect infants in womb of infected mother or during birth, causing serious eye and brain damage, seizures, hearing loss and mental retardation (CDC 2007).

Transient paralysis: paralysis following seizure; rare disease (Wrong Diagnosis? 2007).

Trichostrongyliasis: gastrointestinal infection caused by infection with *Trichostrongylus sp* (Disease Database 2007).

Typhoid fever: a bacterial infection characterized by diarrhea, systemic disease and a rash usually caused by *Salmonella typhi* (Medline plus 2007).

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Appendix E

Best Management Practice Recommendations

Summary of Conventional Secondary Stormwater Treatment Practices		
Practice	**Reasons for Limited Use**	**Suitable Applications**
Dry Detention Ponds	• Not intended for water quality treatment. Designed to empty out between storms; lack permanent pool or extended detention required for adequate stormwater treatment • Settled particulates can be resuspended between storms	• Flood control and channel protection
Catch Basins	• Limited pollutant removal • No volume control • Resuspension of settled particulates	• Pretreatment or in combination with other stormwater treatment practices • Stormwater retrofits
Conventional Oil/Particle Separators	• Limited pollutant removal • No volume control • Resuspension of settled particulates	• Pretreatment or in combination with other stormwater treatment practices • Highly impervious areas with substantial vehicle traffic
Underground Detention Facilities	• Not intended for water quality treatment • Particulates can be resuspended between storms	• Flood control and channel protection • Space-limited or ultra-urban sites
Permeable Pavement	• Reduced performance in cold climates due to clogging by road sand and salt • Porous asphalt or concrete recommended for limited use	• Modular concrete paving blocks, modular concrete or plastic lattice, or cast-in-place concrete grids are suitable for use in spillover parking, parking aisles, residential driveways and roadside rights of way
Dry Wells	• Not intended as stand-alone stormwater runoff quality or quantity control. • Potential for clogging/failure • Applicable to small drainage areas • Potential groundwater quality impacts	• Infiltration of clean rooftop runoff • Stormwater retrofits • Space-limited ultra-urban • Pretreatment or in combination with other stormwater treatment practices
Vegetated Filter Strips	• Typically cannot alone achieve the 80% TSS removal goal	• Pretreatment or in combination with other treatment practices • Limited groundwater recharge • Outer zone of a stream buffer • Residential applications and parking lots
Grass Drainage Channels	• Typically cannot alone achieve the 80% TSS removal goal	• Part of runoff conveyance system to provide pretreatment • Replace curb and gutter drainage • Limited groundwater recharge
Level Spreaders	• Typically cannot alone achieve the 80% TSS removal goal	• Pretreatment or in combination with other treatment practices • Use with filter strips and at outlets of other treatment practices to distribute flow • Groundwater recharge

Summary of Innovative Secondary Stormwater Treatment Technologies		
Practice	**Reasons for Limited Use**	**Suitable Applications**
Catch Basin Inserts	• Limited performance data available • High maintenance and susceptible to clogging	• Stormwater retrofits, ultra-urban sites • Small drainage areas without excessive solids, loadings • Pretreatment or in combination with other treatment practices
Hydrodynamic Separators	• Limited performance data available • Performance varies with flow rate	• Stormwater retrofits, ultra-urban sites • Pretreatment or in combination with other treatment practices
Media Filters	• Limited performance data available	• Stormwater retrofits, ultra-urban sites • Pretreatment or in combination with other treatment practices
Underground Infiltration Systems	• Limited performance data available	• Groundwater recharge • Stormwater retrofits
Alum Injection	• Requires ongoing operation and monitoring • Limited performance data available • Potential for negative impacts to downstream receiving waters	• Stormwater retrofits, ultra-urban sites • Pretreatment or in combination with other treatment practices
Advanced Treatment	• Requires ongoing operation and monitoring • High cost and level of complexity • Limited performance data available	• Only required where other primary or secondary practices are insufficient

Potential Best Management Strategies That Target Stormwater		
Product Name	**Advantages**	**Brief Description**
CDS Technologies		
Offline Unit http://www.cdstech.com/stormwater/offlineunit.htm	■ Self-operating, gravity driven system has no moving parts ■ Low maintenance ■ Large sump storage capacity ■ Stainless steel screens and hardware resist corrosion ■ 80% TSS removal ■ Removes 100% of floatables and neutrally buoyant material, plus oil and grease ■ Effectively controls oil and grease. When sorbents are added, the permanent capture efficiency increases to 80-90% ■ The diversion weir is designed to bypass excessive flows without affecting the operation of the unit or storm drain system. Bypass flows do not wash out any of the captured pollutants ■ The self cleaning screen has a removal rate of 100%fpr particles the size of the aperture or larger	With patented continuous deflective separation (CDS) technology, the Offline Unit uses the hydraulic energy of water to concentrate, screen and trap storm water pollutants. Offline Units from CDS Technologies are designed to treat storm water flow ranges from 1 to 300 cubic feet per second (cfs) and higher. Treatment flow is diverted from a storm channel or pipeline into the Offline Unit. This type of storm water treatment can be placed offline anywhere on the network with minimum retrofitting costs. Since the units are compact and easy to place in confined areas, space requirements are minimal.
Inline Unit http://www.cdstech.com/stormwater/inlineunit.htm	■ One structure meets multiple engineering objectives ■ Patented non-blocking screening ■ No moving parts ■ Low maintenance ■ Removes 80% of TSS ■ Removes 100% of floatables and neutrally buoyant material, plus oil and grease ■ The sump prevents scour because deposited material is not stored within the treatment flow path ■ The self cleaning screen has a removal rate of 100%fpr particles the size of the aperture or larger	Placed on the main storm drain within one manhole, this system's unique configuration meets multiple engineering objectives by combining both treatment and bypass capabilities in one structure. By utilizing CDS' patented non-blocking screening technology, the Inline Unit ensures removal of both fine and suspended solids along with oil, grease, trash and debris. Offering a small footprint, this system can be incorporated into new development projects or retrofitted into existing storm water collection systems.

Potential Best Management Strategies That Target Stormwater		
Product Name	**Advantages**	**Brief Description**
CDS Technologies		
Drop Inlet Unit http://www.cdstech.com/stormwater/dropinletunit.htm	■ Lowest cost per cfs treated ■ Installed underground to save valuable land ■ Gravity driven system has no moving parts or power requirements ■ Patented non-blocking screen will not clog ■ 80% suspended solids removal ■ Traps virtually 100% of gross particulate material ■ Low maintenance ■ Unit's internal oil baffle controls oil and grease. With the addition of sorbents, the permanent capture efficiency is increased to 80-90% ■ The self cleaning screen has a removal rate of 100%fpr particles the size of the aperture or larger	Using patented (CDS) technology, this system effectively and efficiently removes suspended solids, sediments, trash, debris, oil and grease along with floatable materials from storm water flows. The Drop Inlet Unit provides the lowest cost per cfs processed when compared to other structural Best Management Practices. Its patented non-blocking screen and non-mechanical function make it a low maintenance storm water treatment solution for very small developments.
Media Filtration System http://www.cdstech.com/stormwater/mediafiltrationsystem.htm	■ 82% TSS removal Single float control assembly is the system's only moving part ■ Single float valve ensures that treatment flow matches inflow, which provides the lowest possible hydraulic loading rate on each cartridge and translates to higher removal efficiencies than siphon-activated systems Cartridges designed to accept various types of media to target and remove site-specific pollutants ■ Sediment bay stores pollutants up to 16 inches thick ■ Cartridges designed to variably handle 7.5 – 18 gallons per minute	When regulations call for higher removal of a finer gradation of fine and suspended particles, the CDS Media Filtration System can be relied on to meet the challenge. The basics of water treatment using media filtration require that pollutants or solids precipitate, adsorb or absorb themselves to the media, and CDS has designed its system to do just that. Composed of rechargeable media-filled cartridges, the CDS Media Filtration System provides more fine media filtration per plan view square foot area than any storm water filter product available today.

Potential Best Management Strategies That Target CSOs		
Product Name	**Brief Description**	**Advantages**
CDS Technologies		
Raked Bar Screen http://www.cdstech.com/csosso/rakedbarscreen.htm	■ Cost-effective screening system for large combined sewer overflows (CSOs). ■ Incorporates a horizontal fixed stainless steel bar-rack and a TIVAR™ screen comb. ■ The bars are continually raked by the hydraulically driven comb assembly. ■ Requires minimal maintenance; performed from the top/clean water side of the screen.	■ Screen modules are installed horizontally onto the storm discharge weir. This configuration as opposed to vertical screens) ensures that all flows, high or low, are screened with minimum velocities through the screen. ■ The entire flow is in contact with the screen, so that the perpendicular flow path screens more efficiently. ■ Horizontal orientation assures equal loading across the surface. ■ Symmetrical distribution of forces on the cleaning rakes minimize jamming and breaking of comb tines.
Cyclone http://www.cdstech.com/csosso/cyclone.htm	■ Patented self-powered drum screen is ideal for storm water tank discharges, pumping station overflows, sewage treatment plant by-passes, and small CSOs ■ Achieves 100% removal of 6mm particles for two dimensions.	■ Virtually maintenance free ■ Requires no external power source ■ The 6 mm aperture screen is self-cleansing ■ Ideal for treating small CSOs ■ Simple, rapid installation; projected 20-year life span
Tipping Bucket http://www.cdstech.com/csosso/tippingbucket.htm	■ Provides a simple solution for flushing retention tanks. ■ Can be used to clean rectangular storm tanks and humus tanks, as well as Crosswave Screens (see below)	■ Stainless steel construction ■ Cleans a retention tank up to 185 ft in length and 54 ft in width with a single flush ■ Multiple Tipping Buckets can be used for tank widths in excess of 54 ft ■ Can be installed for use with new underground tanks or retrofitted with existing concrete tanks ■ Cleans both above and below ground retention tank
Crosswave Screen http://www.cdstech.com/csosso/crosswavescreen.htm	■ Patented design features, such as the waved shape and smooth electro-polished screening surface, increases performance and enhances the 'drop-off' of screenings as the water level within the chamber falls. ■ Curved, wave-shaped screen lends itself to below ground onto an existing CSO chamber, a storm storage tank overflow, or pumping station wet well.	■ Ideal for mid-range flows ■ Can be sized to fit virtually any CSO application ■ Quick and easy maintenance ■ Versatile device

Potential Best Management Strategies That Target CSOs		
Product Name	**Brief Description**	**Advantages**
SANSEP http://www.cdstech.com/csosso/sansep.htm	■ Provides efficient level of solids removal in excess sanitary flow treatment. ■ Utilizes patented technology that screens solids without blocking. ■ Reduces impact of excess wet weather sanitary flows by removing all visible solids and associated pollutants and returning them directly to the sewer.	■ Patented non-blocking screen ■ No moving parts ■ Unobtrusive components ■ High-separation efficiency ■ Low maintenance ■ Effluent can be UV disinfected
FLOCCSEP **FC removal rate of 99.5% http://www.cdstech.com/csosso/floccsep.htm	■ Represents new way of managing sewage, resulting in cost savings, and minimized contamination. ■ Process can be applied to CSO/SSO abatement, advanced primary treatment, peak load lopping, construction site runoff and compact treatment plants. ■ After raw sewage is screened to remove all solids, the resulting flocs are captured and screened out. The result is clear fluid, representing approximately 99% of the inflow. Fluid can then be disinfected and readied for reuse.	■ Low capital cost ■ Compact process (separator loading rates >45gpm/ ft^2) ■ High levels of solids removed ■ High-rate liquid/solid separation ■ Instant start-up (<2 minutes-within the residence time of the treatment train) ■ Performance independent of flow ■ Real-time treatment ■ Cost effective sewage treatment for small communities
HydroInternational		
Hydro-Static® Screen http://www.hydrointernational.biz/us/cso_us/hydrostaticscreen.php	■ Provides screening down to 4mm in two directions. ■ Intercepts and retains floatables and solids at all states of flow up to the peak design flow. ■ Collected material is returned to the CSO after the storm event. ■ An emergency overflow weir is incorporated into the screen should the peak design flow be exceeded.	■ No moving parts. ■ No power requirement. ■ Small footprint. ■ Inexpensive screening solution. ■ Patented flow-modifying components provide partial cleansing and reduce maintenance costs. ■ Ideal for smaller CSO sites
Hydro-Jet® Screen http://www.hydrointernational.biz/us/cso_us/hydrojetscreen.php	■ Self-cleansing, non-powered screening system for the control of floatables in CSOs. ■ Can be installed and used for various applications including the retrofit of existing CSO structures. ■ Easy placement in a purpose built chamber or as a standalone unit.	■ No power requirement. ■ No moving parts. ■ High hydraulic throughput. ■ Low headloss. ■ Small footprint ■ Low capital cost and low life cycle cost ■ Minimal maintenance. ■ Upgradeable to tighter screen specifications. ■ Ideal for small to medium size CSO sites.

Potential Best Management Strategies That Target CSOs		
Product Name	**Brief Description**	**Advantages**
Heliscreen®	■ Compact, powered screening system with ability to operate under surcharged conditions. ■ A powered screening system for the removal of floatables, solids and other sewer debris greater than 6mm in two directions. ■ Has the ability to operate under submerged conditions. ■ It is ideal for installation at new or existing CSO facilities where a low maintenance system is required but site constraints, hydraulic levels and/or chamber dimensions preclude the use of a self-cleansing screen.	■ All screenings are retained on the foul side of the overflow weir. ■ Operates under surcharged conditions. ■ Low headloss. ■ Compact design. ■ Ability to handle high concentrations of screenings. ■ Minimal maintenance due to efficient and robust design ■ Easily retrofitted into existing CSO chambers. ■ Screen surface cleaned by rotating helical brushes.
Storm King® with Swirl Cleanse™ http://www.hydrointernational.biz/us/cso_us/stormking.php	■ Hydrodynamic vortex separator with self-cleansing, non-powered screen designed to effectively capture a wide range of sewer solids. ■ Screens and removes all solids and floatables greater than 4mm in two directions ■ Ideal for satellite treatment within the collection system. ■ Cost effective when installed at the source (reduces the need for increasing conveyance capacity)	■ No moving parts. ■ No power requirement. ■ Up to a 50% reduction in overall project costs when compared to conventional solutions. ■ 100% removal of 4 mm solids including floatables, gross solids and neutrally buoyant material. ■ Removes up to 95% of grit and sediment. ■ Minimal maintenance. ■ Low system headloss
Storm King® http://www.hydrointernational.biz/us/cso_us/stormkingR.php	■ Ideal as a satellite treatment system at facilities with new or existing CSOs, ■ Hydrodynamic vortex separator is used for the effective removal of floatables, settleable solids and associated pollutants. ■ Can also be used as a contact chamber for chemical disinfection and chemically assisted sedimentation or floatation (coagulation / flocculation). ■ Offers a smaller footprint than most conventional devices. ■ Cost effective when installed at the source (reduces the need for increasing conveyance capacity)	■ No moving parts. ■ No power requirements. ■ Resilient to shock loads. ■ Capable of meeting primary treatment standards. ■ Minimal maintenance. ■ Lower whole-life costs ■ Low system headloss. ■ Ideal for chemical disinfection, coagulation and flocculation

Potential Best Management Strategies That Target CSOs		
Product Name	**Brief Description**	**Advantages**
Reg-U-Flo ® Vortex Valve http://www.hydrointernational.biz/us/cso_us/reguflovortex.php	■ Self-activating device uses vortex technology to control and attenuate flow in collection systems with patented features that reduce maintenance requirements. ■ With clear openings up to 600% larger than conventional flow control devices, the risk of clogging is reduced. ■ The unique head discharge characteristics reduces storage volume requirements, lowers project costs on applications ranging from CSO diversion structures and flood control to storage facilities, treatment plants and stormwater management schemes for new developments.	■ No moving parts. ■ No power requirements. ■ Self-activating and self-cleansing. ■ Reduces storage requirements. ■ Improves capture of the “first foul flush.”

Best Management Strategies: Green and Bioengineering Alternatives for Stormwater Management				
Type	**Brief Description**	**Advantages**	**Pollutant Removal Efficiencies (if known)**	**Costs (if known)**
Bioretention Systems	These systems mimic the functions of a natural forest ecosystem, treating stormwater runoff by filtering it through vegetation, soil, and sand and then infiltrating it through the soil and into the groundwater. A portion may also be conveyed through pipes to a storm sewer system or waterbody. The systems have three main components: 1) a soil bed planted with native vegetation 2) a sand layer 3) an underground gravel layer (w/ or w/o perforated drainage pipes)	■ Flexibility: can be designed in a variety of sizes and installed in lawns, median strips, parking lot islands, unused lot areas and certain easements. ■ Can provide groundwater recharge and reduce volume of water discharging into receiving streams. ■ Can remove a variety of pollutants including solids, nutrients, metals, hydrocarbons and bacteria. ■ Can reduce peak runoff rates and increase stormwater infiltration. ■ Native vegetation can remove some nutrients and other stormwater pollutants, improve aesthetics of the site, and provide wildlife habitat and shade. Environment around root systems can also break down some pollutants.	TSS: 90% TP: 60% TN: 30% (NJDEP 2004)	Costs include excavating and grading the site, adding soil and planting wetland vegetation.
Rain Gardens	Rain gardens are built in low-lying areas using layers of soil, sand, and organic mulch that filter the rain. This soil absorbs and stores the rainwater and nourishes the trees, grasses, and other native plants. Thus, the rain garden filters and reuses the water reducing storm water pollution and providing attractive landscaping	■ Increase infiltration of water into soil ■ Remove pollutants from storm water ■ Aesthetically pleasing ■ Substantial labor and material cost saving can be gained in areas where gardens are used instead of traditional structural systems.	N/A	Costs depend on size but are generally less than traditional structural systems
Constructed Wetlands	Constructed stormwater wetlands are designed to temporarily store stormwater runoff in shallow, vegetated pools. Similar to bioretention systems, they mimic natural systems by using wetland plants to filter runoff, remove pollutants and provide erosion and flood control.	■ Can remove sediment and pollutants adhering to sediment particles (e.g., phosphorus, metals and hydrocarbons) ■ Wetland plants and ponds can improve the aesthetic value of a site and provide wildlife habitat. ■ Water is generally flushed through the	TSS: 90% TP: 50% TN: 30% (NJDEP 2004)	EPA estimates costs as $57,100 for a 1 acre-foot facility, $289,000 for a 10 acre-foot facility and $1.47 million for a 100 acre-foot

	They usually have three zones: 1) Pool: 2 to 6 ft deep, supports submerged and floating vegetation, provides most particulate settling 2) Marsh (high or low, depending on standing water depth): 6 to 18 in. deep, mainly emergent wetland vegetation 3) Semi-wet: located above pool and marsh zones, inundated only during storm events, supports both wetland and upland plants	wetlands within a week, reducing opportunities for mosquito breeding.		facility. (CWP 1998 and Schueler 1987 in EPA 2002)
Extended Detention Basins	These basins provide temporary storage of stormwater runoff, detaining it for a prescribed period of time (typically 24 hrs) and then releasing it slowly through an appropriately-sized outlet to a downstream system. They address stormwater quantity by slowing runoff and infiltrating some of it, and improve stormwater quality by allowing sediment particles and associated pollutants to settle out into the basin. (The longer the detention time, the greater the pollutant removal efficiency.) Extended detention basins are effective on sites of 10 acres or more.	■ Flexibility: can be used at residential, commercial, and industrial development sites; can be used with almost all soils and geology; can be used on sites with slopes up to about 15%. ■ Considered by EPA to be one of the least expensive stormwater BMPs (cost per unit area treated). ■ Can accept runoff from "hot spots" provided there is adequate separation from seasonal high water table (min. 1 ft) ■ Useful retrofit: existing basins can be modified to function as extended detention; new extended detention basins can be constructed to capture runoff from existing development.	TSS: 40% TP: 20% TN: 20% (NJDEP 2004)	EPA estimates costs are $41,600 for a 1 acre-ft basin, $239,000 for a 10 acre-ft basin and $1.38 million for a 100 acre-ft basin. (CWP 1998 and Schueler 1987 in EPA 2002)
Wet Ponds	Wet ponds can provide flood control, channel protection and pollutant removal, but do not provide groundwater recharge. They can also provide aquatic habitat if the permanent pool is maintained at a depth of 3 to 6 ft. A wet pond must be able to maintain a permanent pool level and is especially suitable for areas where groundwater is close to the surface. If the soil is not sufficiently impermeable, an impermeable liner must be used or other soil modifications must be completed	■ Relatively long lifespan (up to 20 yrs). ■ If properly landscaped, can provide habitat and aesthetic values. ■ Cost-effective water supply for fire protection and/or irrigation (e.g., golf courses). ■ Useful on sites with upstream slopes up to 15%. ■ Can accept runoff from "hot spots" (areas that generate highly contaminated runoff) provided there is adequate separation from seasonal high water table (min. 1 foot). ■ Wide applicability; few limits on soils or	TSS: 50% TP: 50% TN: 30% (NJDEP 2004)	EPA estimates costs are $45,700 for a 1 acre-foot pond, $232,000 for a 10 acre-foot pond and $1.17 million for a 100 acre-foot pond. Annual maintenance is about 3 to 5% of construction costs; sediment removal (every 5 to 10 years) may be 20 to 40% of initial costs. (CWP 1998 and Schueler 1987 in EPA

		geology. ■ Useful retrofit: existing flood control detention ponds can be modified to include a permanent wet pool for water quality control and a smaller outlet structure for channel protection.		2002)
Vegetated Filters	Vegetative filters are designed to remove suspended solids and other pollutants from stormwater runoff flowing through them. They may be composed of planted and/ or naturally occurring grasses and herbaceous and woody vegetation.	■ Effective in reducing sediment and other solids and particulates, as well as associated pollutants such as hydrocarbons, heavy metals, and nutrients. ■ Very useful for parking and driveway areas on residential and commercial sites. ■ Can provide wildlife habitat. ■ Can create shade along waterbodies, lowering aquatic temperatures.	TSS: - turf grass – 60% - native grasses, meadow, planted woods - indigenous woods – 80% TP: 30% TN: 30% (NJDEP 2004)	EPA uses the cost of seed ($0.30/ft2) and sod ($0.70/ft2) to calculate a range of $13,000 to $30,000/acre of vegetative filter area or impervious area treated (EPA 2002). Typical maintenance costs are about $350/acre/year (EPA 2002) and may overlap with regular landscape maintenance costs.
Infiltration Structures	These basins must be constructed within highly permeable soils (min. rate of 0.5 in/hour) that provide temporary storage of stormwater runoff. Normally, outflow from these structures infiltrates through the surrounding soil into the groundwater, rather than being conveyed through a structural outlet downstream. When designed and maintained properly, infiltration basins can recharge the groundwater and remove pollutants as runoff is filtered through the soil.	■ Cost-effective; typically consumes only about 2 to 3% of the drainage area. ■ Relatively high pollutant removal rate as compared to other BMPs. ■ Provides infiltration into soil	TSS: 80% TP: 60% TN: 50% (NJDEP 2004)	EPA estimates the total cost for a ¼-acre basin at $2/ft^3$ of SW treated, and the cost for trenches at $5/ft^3$ of SW treated. Long term maintenance costs (estimated at 5 to 10% of construction costs, or $0.10 to $0.20/ft^3$) must be considered.
Permeable Pavement	Pervious paving systems are paved areas that infiltrate rain or runoff either through a permeable layer of pavement or through the spaces between	■ Flexibility: can be used in intensely developed residential and commercial areas and on small urban sites. ■ Useful for driveways, streets and	TSS: – Porous paving - 80%	EPA estimates the cost of a pervious paving system at $2.00 to $3.00 per ft2

	individual pavers, reducing runoff from a site and filtering pollutants. There are three types: 1) Porous paving: porous asphalt or concrete 2) Permeable pavers with storage bed 3) Permeable pavers without storage bed	commercial parking areas. ■ Can reduce stormwater volume and allow for infiltration	− Permeable pavers with storage bed - 80% TP: 60% TN: 50% (NJDEP 2004)	(CWP 1998 and Schueler 1987 in EPA 2002), which is equivalent to \$87,120 to \$130,680 per impervious acre treated. Associated vacuum sweeping costs may also be substantial.
Downspout Disconnect	Disconnecting residential downspouts may be an important way to reduce the amount of runoff to streams. By allowing the relatively clean rain water to flow from the roof to the ground, the total amount of water flowing into the sewer system will be reduced. This has the added benefit of reducing flooding potential since the flow of water will be stretched over a longer period of time.	■ Flexibility: can be used in intensely developed residential and commercial areas and on small urban sites. ■ A relatively easy project for homeowners, good outlet for public participation ■ Can reduce stormwater volume and allow for infiltration	N/A	Costs should be minimal
Rainwater Collection	The added bonus of harvesting rainwater is that it conserves water: instead of turning on the hose to water lawns and gardens or wash the car, rainwater can be re-used for these tasks. This is a simple project for homeowners and a good outlet for public participation. By using rainwater in the garden or lawn, water has the chance to infiltrate back into the ground	■ Reduces amount of stormwater volume ■ A relatively easy project for homeowners, good outlet for public participation and education.	N/A	Costs should be minimal but depend on size and material of rainwater collection basin
Green Roofs	A green roof consists of: an insulation layer, a waterproof membrane to protect the building from leaks, a root barrier to prevent roots from penetrating the waterproof membrane; a drainage layer, usually made of lightweight gravel, clay, or plastic; a geotextile or filter mat that allows water to soak through but prevents erosion of fine soil particles; a growing medium;	■ Decreases energy expenses ■ Aesthetically pleasing ■ Decreases amount of stormwater that flows to rivers ■ Estimated to last up to twice as long as conventional roofs, resulting in decreased maintenance and savings in replacement costs	Research and modeling is still being developed.	Costs vary from type of roof, design and site dimensions.

	plants; and, sometimes, a wind blanket. Green roofs improve air quality, conserve energy, reduce stormwater runoff and help reduce the urban heat island effect. The plants reflect heat, provide shade and help cool the surrounding air through evapo-transpiration. Plants also filter the air, which improves air quality by using excess carbon dioxide to produce oxygen. There are two basic types of green roofs: intensive and extensive.			

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