Monocacy Creek Watershed
Land Use / Water Quality Assessment

LVPC

Prepared by the Lehigh Valley Planning Commission for the Wildlands Conservancy

January 1998
A distinct relationship exists between land use and water quality. Knowledge of this relationship is necessary for both land use planning purposes and protection of water resources. To this end, this report first identifies the basic mechanisms involved in the transport of pollutants to both surface water and groundwater systems. Further, the report identifies potential water pollutants, the land use activities which can generate those pollutants and the water quality and aquatic life impacts of each pollutant. Finally, the report provides an assessment of the correlation between water quality data as collected by the Wildlands Conservancy and existing land use for the Monocacy Creek Watershed. The purpose for the correlation analysis is to identify whether any clear relationship exists between the monitored water quality in the creek and the land use pattern within the watershed. Key findings and recommendations based on the assessment are listed below.

Key Findings

- Significant trends, both increases and decreases, were identified for nine of the 14 water quality parameters analyzed including conductivity, total dissolved solids, phosphate, total hardness, calcium hardness, magnesium hardness, alkalinity, sulfate and chloride.
- Six of the nine land use types within the watershed would appear to have significant water quality trends for certain water quality parameters. The six land use types include institutional, industrial, residential, agricultural, open space and woods.
- Trends identified are only preliminary.
- Insufficient data, both water quality and land use, is available to support any rigorous correlation between water quality and land use.
- Residential land use will increase from about 24% to about 40% of the watershed for a difference of about 16%.
- Industrial land use will increase from about 3% to about 13% of the watershed for a difference of about 10%.

Key Recommendations

- Identified trends should be substantiated through additional water quality sampling over a prolonged period of time and/or alternate analytical means to draw land use correlations.
- Assessment data should be used to focus future efforts for water quality monitoring and land use analysis where preliminary trends are identified.
- Future efforts to correlate land use and water quality should focus on increased residential and industrial development as indicated by zoning.
- Measures to mitigate potential adverse impacts of land use activities on water quality should focus on preliminary trends identified and specific impacts of future residential and industrial development.
I. INTRODUCTION

A distinct relationship exists between land use and water quality. Improperly or inadequately controlled land use activities can greatly impact both surface water and groundwater quality and aquatic life. The severity of the impacts are dependent on the physical and chemical characteristics of the receiving water, the properties of the pollutants involved and both the intensity and nature of the land use activity.

The types of pollutants generated vary with land use activity. Typically, a single pollutant seldom occurs individually. For example, sewage waste is a biodegradable organic substance that contains nutrients and may also contain pathogenic organisms or heavy metals. The combination of pollutants can have serious effects on water quality and aquatic life. However, the full impacts of combined pollutants are often difficult to determine.

Knowledge of the relationship between land use and water quality is necessary for both land use planning purposes and protection of water resources. By knowing the types of water pollution threats and associated land use activities, it may be possible to determine a more preferable location for any given activity. Further, implementation of appropriate management programs for existing activities can prevent additional water quality degradation and improve existing water quality.

This report is organized in three technical components. Section II is a discussion of the transport of pollutants through surface water and groundwater. Section III is a discussion of potential water pollutants, the land use activities which can generate those pollutants and the water quality and aquatic life impacts of each pollutant. Section IV is an assessment of the correlation between water quality data as collected by the Wildlands Conservancy and existing land use for the Monocacy Creek Watershed.
II. TRANSPORT OF POLLUTANTS

Prior to an assessment of the impacts of land use on water quality and aquatic life, it is important to understand the basic mechanisms involved in the transport of pollutants to both surface water and groundwater systems. This section consists of a description of the processes by which a pollutant is transported from its point of origin to the water resource and the conditions that can affect transport.

A. Surface Water

Pollutants are transported to surface water by several methods. Pollutants that are discharged directly to surface water via a confined, single point are point sources of pollution. An example of a point source is a pipe discharging sewage effluent into a stream. Point sources are the simplest method of pollutant transport to control since the point of discharge is readily identifiable.

Non-point sources are much more difficult to control since there is no single visible point of discharge to surface water. Non-point sources can be from a broad area such as farmland or from a small area such as on-site sewage disposal systems. Pollutants from non-point sources are generally carried to surface water along with storm water runoff. Runoff is that part of precipitation that flows over the ground surface. The volume of runoff is not only influenced by the magnitude of the storm event but by the extent the land is altered by human activity. Activities altering the natural features of the landscape such as topography, wetlands and vegetative cover can have a major impact on runoff volume. Pollutants that have accumulated on the land surface due to various human activities can eventually be carried to surface water with the runoff. Pollutants can be carried in runoff in a dissolved state, as a solid particle or attached to a solid particle. As the natural hydrology of the landscape is altered, the pollutant load can increase with an increase in runoff volume if adequate controls are not in place. The types of pollutants found in runoff will vary considerably with the types of land uses within the watershed. Pollutants from land based sources can also be transported to surface water via the wind as solid particles or attached to solid particles. Acid precipitation is also a form of non-point source pollution. Acid precipitation, in the form of rain or snow, can occur as the result of reactions in the atmosphere with compounds emitted by certain industries and during fossil fuel combustion. Acid precipitation can fall directly over a surface water body or be carried as runoff.

An additional method of pollutant transport can occur naturally when surface water is sustained by groundwater which is polluted. Whether surface water is sustained by groundwater is dependent on water table levels and direction of groundwater flow relative to surface water levels. Groundwater flows from areas of high water table elevation to areas of low water table elevation.
B. Groundwater

While groundwater pollution can also occur due to discharges from both direct and indirect sources, the transport of pollutants into groundwater is more complex than that for surface water. The susceptibility of groundwater to pollution is dependent on the degree of the removal of a pollutant that occurs between the pollutant source and the groundwater source. The degree of removal will vary based on site-specific conditions:

I. the distance and time involved for a pollutant to move through unsaturated materials to reach groundwater.
II. the types of geologic materials underlying the ground surface.
III. the environmental conditions.

The longer a pollutant remains in the unsaturated zone, the more likely a greater degree of removal will take place. Therefore, pollutants discharged directly into an aquifer do not have the opportunity for removal within the unsaturated zone. Removal can include physical, chemical and biological processes that can reduce the ultimate impact of the pollutant before it reaches groundwater. The occurrence of these processes depends on both the characteristics of the pollutant and the types of materials encountered by the pollutant.

The types of geologic materials underlying the ground surface are a factor in determining the susceptibility of groundwater to pollution. Fine particle soil materials generally provide a greater degree of removal than coarse particle materials. Fissured rock can act as a direct conduit to an aquifer providing no pollutant removal at all. Carbonate rocks can be highly conducive to the transport of pollutants since carbonate rocks readily dissolve in reaction with carbonic acid found in precipitation. In this way, carbonate rocks can provide a direct solution channel to groundwater. Carbonate rocks have high occurrences of cracks and fractures. As the rock dissolves, these openings are enlarged thereby increasing the ability of pollutants to move into an aquifer. The dissolution of carbonate rocks can also result in the formation of sinkholes. Pollutants introduced at the ground surface can easily enter an aquifer through sinkholes and solution channels.

Environmental conditions that can affect groundwater susceptibility to pollution include precipitation characteristics of a watershed. Precipitation affects groundwater recharge which in turn affects water table elevations. Higher water table elevations will generally result in little pollutant removal.

Polluted surface water can become a source of polluted groundwater when the surface water contributes to groundwater recharge. This situation can occur as a result of human activity or natural hydrogeologic conditions. The pumping of a well adjacent to a surface water body can cause surface water to flow toward the well by lowering the water table. Groundwater can be recharged naturally by surface water, however, this is dependent on water table levels relative to surface water levels.
III. POTENTIAL WATER POLLUTANTS

This section includes a description of various types of substances with the potential for causing a negative impact on both water quality and aquatic life either individually or in combination. A wide variety of these substances, or pollutants, can be generated as a result of human activity. Therefore, for organizational purposes, pollutants are classified and listed according to the type of pollutant. Included with the description of each type of pollutant are those land use activities associated with the generation of the pollutant and the pollutant’s impact on water quality and aquatic life.

A. Sediment

Sediment consists of a mixture of fine, medium and coarse grained minerals such as clay, silt and sand mixed with organic plant and/or animal material. Sediment washed into surface water bodies is considered one of the most significant of the pollutants from non-point sources. In fact, sediment causes the most surface water pollution in Pennsylvania based on volume.\(^1\) Sediment pollution is of great concern because of the impacts on surface water caused both directly by sediment and by other harmful pollutants that have a tendency to adsorb onto sediment. The impacts of the latter are discussed under each relevant pollutant type. Sediment pollution is generally not a significant issue for groundwater resources. Pollutants transported in a dissolved state are the primary concerns for groundwater.\(^3\)

Sediments are transported to a receiving water body as a result of soil erosion. Soil erosion is the movement of soil particles by wind or water from one location to another. Soil erosion occurs both naturally and as a result of human activities which accelerate the rate of natural erosion. There are two basic types of soil erosion caused by water: sheet erosion and stream erosion.

Sheet erosion occurs naturally as rainfall intensity exceeds the infiltration capabilities of the soil. Soil particles are carried along with the resultant stormwater runoff and deposited in a surface water body. The rate of sheet erosion is influenced by rainfall intensity, soil and landscape characteristics and vegetative cover. Vegetative cover provides natural protection against erosion. Human activities that alter the landscape and expose the soil result in serious erosion and sedimentation problems.\(^3\)

Stream erosion occurs naturally as quickly moving water removes stream bed soils and cuts away at the soils of the stream bank. The water velocity of a stream is, therefore, a significant factor in the rate of stream erosion. Human activities that cause an increase in stormwater runoff volume, which directly impacts stream water velocity, serves to accelerate the rate of natural stream erosion.
1. **Land Use Activities**

Any type of land use activity that disturbs vegetative cover, alters natural drainage patterns and increases impervious cover augment the quantity and rate of stormwater runoff, thus increasing the potential for soil erosion. Such activities include urbanization, agriculture, sand, gravel and pit operations, strip mining and logging.

a. **Urbanization**

Urbanization changes the natural hydrology of a watershed. Infiltration characteristics of the soil can be altered by removing or changing the types of natural vegetation and by expanding impervious surface area. Impervious areas include paved streets, sidewalks, driveways, parking areas, rooftops, patios and any other similar surfaces. Even soil that has been compacted can act as an impervious surface since water is prevented from infiltrating the soil. The most important factor in determining the volume of runoff generated by a given storm event is the percentage of impervious cover. Under undeveloped conditions, the volume of runoff is approximately 10% of the precipitation generated during a storm event. As urbanization occurs, the volume of runoff increases with an increase in impervious cover. The runoff volume increases to approximately 55% when 75-100% of the land is covered by impervious surfaces. The extent of impervious cover is dependent on local development policies and zoning requirements.

Urbanization effectively increases runoff volume and velocity during a storm. This effect gives runoff greater energy to accelerate stream bank erosion and to erode the soils exposed as a result of the disturbance of land surfaces. Sediment volumes are the highest of any pollutant types discharged by urban runoff. Both general construction and road construction disturb natural ground cover, increase erosion and sedimentation and create paved surfaces that alter natural runoff characteristics. Road construction is more susceptible to erosion problems than any other types of construction due to the large land areas that are typically disturbed. Uncontrolled erosion at major construction sites can exceed natural erosion from areas of the same size by a factor of 100 or more.

b. **Agriculture**

A variety of agricultural practices can increase the potential for soil erosion and contribute to the volume of sediment in runoff. Livestock allowed access to stream banks can trample the stream bank causing the soil to collapse into the stream. Livestock allowed to graze along a
stream bank and to over-graze pastureland exposes the soil to erosion. Feed lots or impoundments that contain large concentrations of livestock are typically located near a stream. The livestock eliminate the vegetative cover allowing soils to wash into the stream. Fields allowed to remain bare are also prone to erosion.

c. Sand, Gravel and Pit Operations

Poor management of these types of operations can result in erosion both during operation and after excavation ceases at the site. Slopes can be excavated to the point where large quantities of soil particles are exposed to erosion. After closure of the operation, erosion may continue if the site is not properly protected by methods such as revegetation.

d. Strip Mining and Logging

A strip mine is a type of open mine where the material to be mined runs close to the ground surface. The material is exposed by removing the top soil layers and land cover. Strip mining can cause severe erosion problems if proper control measures are not taken.

Logging removes the natural vegetative cover needed to help keep soils in place. By removing trees, the soil becomes greatly susceptible to erosion.

1. Water Quality Impacts

The majority of sediment is carried in streams in a suspended state. Soil particles suspended in water interfere with light penetration by reducing the depth of penetration. The presence of suspended particles gives water a murky or turbid appearance. This turbid appearance affects the aesthetic and recreational values of the water body. Turbidity is an important parameter of drinking water quality. Suspended particles can provide hiding places for harmful microorganisms and shield them from the disinfection process. Turbidity can also cause an increase in surface water temperature because suspended particles tend to absorb light rays. Increased temperatures will decrease the dissolved oxygen concentration in the water. The solubility of oxygen in water decreases as temperature increases.

As the water velocity in a surface water body decreases after a storm event, suspended particles settle and are deposited as sediment at the bottom of a stream or lake. Sedimentation changes the composition of the bed and causes a decrease in the water carrying and storage capacities of streams and lakes.
Increased sedimentation damages water treatment pumps and related equipment ultimately increasing water treatment costs.

2. **Impacts on Aquatic Life**

Sediment, whether in a suspended state or deposited on the bed of the receiving water body, can have a detrimental effect on aquatic life. A decrease in sunlight penetration caused by suspended particles reduces the photosynthetic activity of aquatic plants. As plant production is reduced, so is the availability of food and cover provided by plants to fish and other organisms. Excess turbidity also interferes with the feeding activities of predators that rely on sight to capture prey. Suspended particles can cause physical abrasion of the body surfaces of fish, especially easily damaged structures such as gills. This type of damage can interfere with respiration and renders fish susceptible to infections. As previously discussed, turbidity can result in decreased dissolved oxygen levels. Certain fish such as trout and salmon are cold water fish and require high levels of dissolved oxygen to survive. Therefore, turbidity can diminish cold water fish populations available for fishing.

As suspended particles begin to settle, spaces between the gravel in the stream bed begin to clog from the finer particles. This situation has a serious effect on the reproduction cycle of salmon and trout. These fish require aerated gravel beds for their nesting sites. By clogging the beds with finer particles, salmon and trout populations can be eliminated with the elimination of suitable nesting sites. In many rivers, the population density of salmon and trout is more dependent on the availability of nesting sites rather than other factors. As the spaces become blocked by fine particles, eggs buried in the gravel beds are smothered since oxygen cannot reach them. Further, these particles affect the development of a juvenile from an egg. A juvenile uses oxygen that enters its gill structures, which are easily clogged by fine particles, affecting both respiration and growth processes.

Particles deposited on the bed smother organisms such as worms and insects that survive on the bottom of the water body. The distribution of invertebrates is influenced by the size of the particles composing the bed. Many invertebrates require a permeable bed such as gravel to live. Deposition of sediment can prevent the organisms from moving and eliminates their habitat and food.

As previously discussed, harmful pollutants such as toxic substances have a tendency to adsorb onto sediment particles. Once the particles are deposited, these pollutants can be mobilized under certain circumstances posing an additional risk to aquatic life. These risks are discussed under each relevant pollutant type.
B. Biodegradable Organic Substances

All living organisms are composed of organic compounds. An organic compound is one that contains the element carbon combined with other elements such as hydrogen, oxygen, nitrogen, phosphorus and sulfur. Biodegradable organic substances can be used as food by microorganisms found in surface water. The microorganisms are in turn used as food by organisms higher in the food chain. Microorganisms break down organic substances into simpler forms and use the energy released for growth and reproduction. Some of the simpler compounds formed become available as nutrients to photosynthetic plants. As these reactions occur, the microorganisms exert a demand on the dissolved oxygen available in the water that is needed to sustain aquatic life. This process occurs naturally as plant and animal material within a surface water body die and are decomposed by microorganisms. Plant and animal material can also be washed into a water body with naturally occurring runoff.

In unpolluted surface water, the amount of organic material available is generally such that the dissolved oxygen used by microorganisms for breakdown can readily be replaced by photosynthesis and reaeration from the atmosphere. However, certain activities can enhance the input of organic material exceeding the ability of the water body to maintain dissolved oxygen levels. This problem occurs as greater amounts of organic material are introduced to a water body due to improperly controlled human activities.

1. Land Use Activities

Land use activities that generate biodegradable organic substances increase the potential for pollution if proper management controls are not in place. Such activities include urbanization, agriculture, individual on-site sewage disposal systems, public sewer systems and land disposal/land application of wastes.

a. Urbanization

As previously discussed, urbanization effectively increases the volume of runoff during a storm event thereby increasing the pollutant load carried by the runoff. Plant debris and animal wastes that would normally decompose on the ground surface and be assimilated by the soil can be washed into a receiving water body with the runoff. Inadequately treated human wastes can also become a component of urban runoff. Large storm events can have a greater impact on dissolved oxygen levels than smaller events due to higher pollutant loads carried in runoff.
b. Agriculture

Poor agricultural practices can result in increased organic load in a water body. Livestock wastes that are inadequately managed can quickly become a component in runoff. Cattle contained in feed lots can generate a half ton of manure per animal during their four to five month impoundment. In large feed lots, the ability of the soil to assimilate the waste can be hindered such that the waste is easily carried with storm runoff. Allowing livestock access to streams also contributes to the organic load.

On-Site Sewage Disposal Systems

A properly working on-site sewage disposal system treats and disposes of household sewage through natural processes. A failing system, however, does not perform these tasks. A system that is improperly located, designed, constructed and/or installed can result in surface discharge of sewage or in untreated or partially treated sewage reaching groundwater. Sewage disposal systems require periodic maintenance. Neglecting proper maintenance procedures can result in the same problems. Wastes discharged to the surface are available to be carried with storm runoff to a surface water body. Groundwater pollution can occur when the soil cannot sufficiently assimilate the wastes. Organic material in sewage is one of the major types of water pollutants.

d. Public Sewer Systems

Prior to discharging sewage into a water body, some degree of sewage treatment is necessary. Under federal law, all sewage treatment plants in the United States must achieve a minimum 85% level of biodegradable organic removal. A higher level of removal may be necessary and is dependent on factors such as the nature of the sewage and the classification of the receiving water body. A permit must be obtained by the treatment plant that will specify the required removal level. Treatment plants having difficulty meeting the permit requirements may release sewage that has not been treated adequately.

Many older sewer systems were designed to collect stormwater runoff along with sewage for delivery to the sewage treatment plant. During a storm event, the treatment plant may not be capable of handling the stormwater and untreated sewage flows. The excess flow is discharged directly into a surface water body. Sewer lines that are old or poorly constructed can result in groundwater pollution where leaking occurs.
e.  Land Disposal/Land Application of Wastes

Landfilled wastes can become a potential source of groundwater pollution if proper controls are not in place. Further, improper land application of human or livestock wastes as a crop fertilizer can pollute both surface water and groundwater through runoff and by the inability of the soil to assimilate the organic substances.

2.  Water Quality Impacts

To some extent, streams and rivers have the ability to assimilate biodegradable organic wastes. This ability depends on the strength and volume of the waste, the physical characteristics of the receiving water and the rate of reaeration. Dissolved oxygen in water is constantly replenished by oxygen from the atmosphere that is dissolved at the surface. Streams that are shallow and fast-moving are reaerated more effectively than streams that are deep and slow-moving. The rate of reaeration in lakes is even less since not much mixing of the water and atmospheric oxygen occurs.

Most biodegradable organic wastes can contain a high level of suspended material. The impacts of this suspended material on a water body are similar in part to those previously discussed in the section on sediment. However, the most significant concern related to organic pollution is the effect on the dissolved oxygen level in the water and bed. Reduced levels of dissolved oxygen in drinking water have no direct effect on public health. Drinking water with little or no oxygen simply tastes flat.

Enhanced levels of biodegradable organics will stimulate increased activity of the decomposer microorganisms. The more organic material that is available, the higher the oxygen demand by the microorganisms will be. When their rate of oxygen consumption exceeds the rate of reaeration of water, then the dissolved oxygen level will fall. The rate of oxygen consumption depends on water temperature, type of organic material and the type of microorganisms exerting the oxygen demand. At higher temperatures, organic material is decomposed at a faster rate by microorganisms than the same quantity of material at lower temperatures. However, the ultimate oxygen demand remains the same.

3.  Impacts on Aquatic Life

In order for aquatic animals to obtain oxygen from the water, their respiratory surfaces must be moved through the water or water moved over their respiratory surfaces. Moving through water requires a great deal of energy expenditure, and therefore, a high oxygen consumption. The survival of aquatic animals is crucially dependent on how well the oxygen available from
the surrounding environment can provide for the oxygen needs of the animals.\(^6\) As the oxygen level decreases, the oxygen requirements of fish and invertebrates increases. However, some types of aquatic animals are more tolerant than others to oxygen depletion. The distribution of individual invertebrate species in a water body is correlated with dissolved oxygen levels in the water.\(^7\) This means that the distribution patterns of invertebrates can be used as indicators of water quality conditions.

Desirable fish species such as trout and salmon are adapted to high rates of oxygen consumption. Low dissolved oxygen levels can effectively reduce the availability of these species for fishing. Low dissolved oxygen levels can negatively affect the viability of the eggs and the growth processes of juveniles.

A fish at rest in well-oxygenated water ventilates its gills slowly. The resting fish can remove about 80% of the oxygen in the water passing over its gills.\(^8\) If the fish ventilates more quickly, as when the fish’s activity increases, the gills’ efficiency at removing oxygen from water passing over them is decreased. An actively swimming fish can only remove about 30% of the oxygen in the water passing over its gills.\(^9\) A fish must more than double the amount of water pumped over its gills in order to double the rate of oxygen uptake.\(^10\) Muscles used to pump the water over the gills consume a significant proportion of the oxygen obtained from the water. As the fish’s activity increases, this proportion increases dramatically. At the maximum possible rate of oxygen consumption by the fish, the energy cost of working the respiratory muscles is such that there is no oxygen available for the tissues and the fish will die.\(^11\)

C. **Pathogenic Organisms**

Pathogenic organisms are organisms that cause disease and include certain types of bacteria and viruses. Pathogens can be found in the intestinal tract of infected warm-blooded animals and excreted with bodily wastes. Pathogenic pollution can affect both surface water and groundwater. The ability of the soil to remove pathogens prior to entering groundwater is dependent on the thickness of the unsaturated soil layer, moisture content, temperature and pH of the soil.\(^12\) Pathogens are usually destroyed under unsaturated soil conditions within approximately three feet of the source.\(^13\) Recent research has found that pathogens may travel more than four feet through coarse soils after very heavy rains.\(^14\) Pathogens are typically removed by filtration and adsorption by the soil or by death. Once in groundwater or stream flow, however, pathogens can travel hundreds of feet. The travel distance is limited only by survival time. For most bacteria, survival time in saturated conditions can be three to six weeks; viruses may survive longer.\(^15\)
1. **Land Use Activities**

Pathogenic pollution can be caused by any activity that results in the discharge of untreated or inadequately treated bodily wastes into water. Such activities include urbanization, agriculture, on-site sewage disposal systems, public sewer systems and land disposal/land application of wastes.

a. **Urbanization**

As previously discussed, the volume of stormwater runoff is greatly increased with urbanization. This in turn increases the pollutant load carried by runoff. Stormwater runoff can be a significant transport mechanism for pathogens. Pet wastes can quickly become a component of runoff as can human wastes that have not been properly treated. Land uses such as quarries, sand and gravel pits and mines may become direct pathways to groundwater for pathogens from urban runoff. Polluted runoff can enter groundwater through the well hole of improperly constructed or abandoned wells.

b. **Agriculture**

Poor agricultural practices can result in pathogenic pollution of both surface water and groundwater. Improperly managed livestock wastes can increase the potential for pathogens carried in stormwater runoff. Allowing livestock access to a stream can also contribute to pathogenic pollution in surface water. Further, groundwater can be affected by allowing wastes to accumulate in areas where the soils cannot efficiently remove pathogens, such as in areas of shallow water table or highly permeable subsurface material.

c. **On-Site Sewage Disposal Systems**

Sewage systems involving subsurface disposal rely on the renovating capabilities of the underlying soil to remove pathogenic organisms. Improperly designed, constructed, installed or maintained systems can result in surface discharge of sewage or in untreated or partially treated sewage reaching groundwater. Sewage discharged on the ground surface can become a component of runoff. Surface discharge can also result in groundwater pollution in areas defined by sinkholes.

d. **Public Sewer Systems**

Sewer lines that are old or poorly constructed can result in groundwater pollution where leaking occurs. As previously discussed, combined sanitary and stormwater systems may discharge untreated wastes
directly into surface water during periods of rain. Further, treatment plants having difficulty meeting their permit requirements may discharge inadequately treated sewage into surface water.

e. Land Disposal/Land Application of Wastes

Landfilled wastes can become a potential source of groundwater pollution if proper controls are not in place. Further, improper land application of human or livestock wastes as a crop fertilizer can pollute both surface water and groundwater through runoff and by the inability of the soil to remove pathogens.

2. Water Quality Impacts

Pathogenic organisms can cause diseases in humans such as typhoid fever and dysentery. If pathogen-tainted water is consumed by others, the cycle of disease will continue. Inadequately treated wastes discharged into surface water and groundwater not only increase the public health risk but increase the treatment costs for drinking water supplies as well. Swimming areas can be closed if pathogens are detected in the area.

3. Impacts on Aquatic Life

Untreated wastes can introduce disease-causing organisms to aquatic life. Coastal waters polluted with pathogens contribute to shellfish contamination effectively closing shellfishing areas. Many pathogenic bacteria thrive in streams when temperatures are slightly increased, and their abundance can be very harmful to fish. Pathogens can accumulate in the tissues of fish and can cause illness and death.

D. Thermal Pollution

Thermal pollution occurs as the temperature of a surface water body is increased by artificial means. Water temperature can be increased as warm water or effluents are discharged into the receiving water body. Temperature changes in a water body can also occur as the natural landscape of the land is altered by human activity. Water temperature plays a significant role in both the chemical and biological processes that occur in a water body. Therefore, alterations in water temperature can have detrimental effects on water quality and aquatic life.

1. Land Use Activities

Any type of land use activity resulting in the discharge of warm water or effluent into a water body or in the alteration of the natural landscape can
contribute to thermal pollution. Such activities include urbanization, agriculture, power/industrial plants, mining/gravel operations and logging.

a. Urbanization

Urbanization alters the natural landscape of the land. Removing the vegetation along a stream bank alters the input of heat into the stream. The volume of sediment carried in runoff increases with urbanization. Sediments suspended in a water body can absorb light rays resulting in an increase in water temperature. This is discussed in more detail in the Sediment section.

b. Agriculture

Improper agricultural practices can also contribute to the volume of sediment in runoff and therefore in a water body. These practices are discussed in the Sediment section.

c. Power/Industrial Plants

Power plants and industrial plants are often located along rivers. Power plants withdraw water from the river which is used for cooling purposes. Cooling water passes through condensers in the plant where steam is converted back to water. The heated water is then discharged into the river. Industries utilize the river for discharging heated effluents generated during industrial processes. Both types of discharges can result in water temperature increases of 10°C or more below the outfall of the plant. The degree of temperature increase is dependent on the plant size, the method of cooling the water or effluent and the size of the river. The situation can become aggravated when several plants are located along the same river. Some mixing and cooling may occur immediately after discharge. However, since the density of water changes with temperature, the heated water or effluent tends to spread out along the water surface rather than mixing quickly with the receiving water. The rate of cooling is dependent on atmospheric conditions and characteristics of the water body.

d. Mining/Gravel Operations and Logging

Mining and gravel type operations that are improperly managed can also contribute to the suspended sediment load in a water body. As previously discussed, suspended sediment can cause an increase in water temperature.
Removal of trees through logging can contribute to thermal pollution in two ways. First, logging removes the natural vegetative cover needed to help keep soils in place. Soils become available to be carried into a water body with runoff. Second, removing trees from along the banks of streams, especially small streams, can dramatically increase the heat input to the stream. Many streams in forested areas are important spawning grounds for salmon and trout.  

2. Water Quality Impacts

As the water temperature of a water body increases, the solubility of oxygen in the water decreases. Reduced levels of dissolved oxygen in the water have no direct effect on public health. Drinking water with little or no oxygen tastes flat. Many types of pathogens thrive in a warmer environment. Warmer temperatures also stimulate the growth of aquatic plants and algae, some of which can develop into heavy blooms. This reduces both the clarity of the water and aesthetic value of the water body. Excessive plant growth also generates poor tastes and odors. Corrosion of pumps and related equipment are associated with increased water temperatures.

3. Impacts on Aquatic Life

Elevated water temperatures impact the level of dissolved oxygen in a water body. The solubility of oxygen is decreased as the water temperature increases. Dissolved oxygen is necessary to sustain aquatic life. As the dissolved oxygen level decreases, the oxygen requirements of fish and invertebrates increases. The impacts of reduced oxygen on aquatic life are provided in more detail in the section on Biodegradable Organic Substances.

Elevated water temperatures can directly impact aquatic life. An increase of about 5°C can have serious impacts. The maximum temperature in which a fish can survive varies among species. Many species can adapt to slight increases in temperature. However, sharp increases can cause fish to migrate to a new location, or, if that is not possible, death can result. Some species such as carp or pike can thrive in temperatures up to 35°C. In cases of heated discharge, these types of fish tend to gather near the outfall of the plant. If the plant is shut down, the sudden drop in temperature can result in a significant fish kill. Cold water fish such as trout cannot survive in water greater than 25°C. The optimum temperature for trout is 15°C.

Higher temperatures increase the rate at which oxygen is used by fish to burn food for energy and reduces the resistance to disease.
Temperature is an important triggering mechanism for reproduction in fish. Sexual maturity typically occurs when the fish has reached a critical size rather than a critical age. Studies have shown that temperature impacts the growth rate of many fish species by decreasing the efficiency of converting food to body weight. Temperature also impacts the rate of development of fish eggs. For cold water fish such as salmon and trout, successful development of the eggs is greatly decreased at temperatures greater than 15°C. Long-term effects on fish populations may not be serious as long as cooler areas are available to the fish. However, warmer water can diminish the cold water fish population available for fishing.

Aquatic plants are also affected by increased temperatures. The death of plants usually occurs only a few degrees above a plant’s maximum growth temperature which varies with species. Higher temperatures generally result in less desirable species which often develop into heavy blooms.

Water temperature also has an affect on the toxicity of other substances. This will be discussed in more detail under the relevant pollutant type.

E. Acidity, Alkalinity and pH

The intensity of acidity and alkalinity is measured by pH. Solutions with pH values less than 7 are acidic while those that are greater than 7 are basic or alkaline. Pure water is neutral with a pH of 7. Each unit of change in pH represents a 10 fold change in the degree of acidity or alkalinity of a solution. For example, a solution with a pH of 4 is 100 times more acidic than one with a pH of 6.

Acidity and alkalinity occur naturally in surface water and act as buffers to resist change in pH. Acidity occurs as carbon dioxide from the atmosphere or from the respiration of aquatic organisms is dissolved in the water. A major source of alkalinity in both surface water and groundwater is carbonate or bicarbonate soils or minerals dissolved in the water. Increased acidic or alkaline inputs due to human activity can exceed the buffering capacity of the water. Acidity is more of a concern in streams and lakes rather than groundwater. Virtually all water has natural alkalinity providing some buffering capability against increased acidic inputs. However, human activity can aggravate the situation in surface water or groundwater that already have natural high alkalinity.

1. Land Use Activities

Land use activities that increase acidic or alkaline inputs to water have the potential to negatively alter the natural pH balance of a water system. Such activities include urbanization and mining.
a. Urbanization

Urbanization through the growth of industry and increase in vehicle usage can result in changes of pH in water. Rain normally has a pH of about 5.5. This lower pH is caused naturally by the reaction of water and carbon dioxide in the atmosphere to form carbonic acid. Acid precipitation is a term used to refer to precipitation with a lower than normal pH caused by human activity. Acid precipitation is a result of the emission of sulfur and nitrogen oxides from vehicles, factories and coal-powered plants. These oxides are converted to sulfuric and nitric acids in the atmosphere and reach the earth in the form of precipitation often many miles away from the source. Acid precipitation can also increase the solubility of contaminants in landfills. Industry can also be a source of alkalinity through the discharge of untreated or inadequately treated wastes from industrial processes.

b. Mining

Mine drainage occurs as water flows through areas disturbed by mining activities. The most common source of acid as a pollutant is acid mine drainage from coal mines. Coal is the source of one third of the total energy used and more than one half of the electricity generated in the United States. Acid mine drainage from abandoned and active coal mines has contaminated thousands of streams and associated groundwater in Pennsylvania and is the most extensive water pollution problem in the state. Western Pennsylvania has one quarter of all the abandoned mines in the United States. It is estimated that abandoned deep and surface mines cause 60% of stream pollution. Acid mine drainage can drain from waste piles and deep or surface mines for decades after mining operations have ceased.

In many mining operations, the ore contains sulfides of metals such as iron, copper, lead and zinc. Sulfides remain stable while buried deep under the ground surface. The most damaging component of acid mine drainage is sulfuric acid. Sulfuric acid is formed when the metal sulfides are exposed to the action of the atmosphere and water. This reaction is greatly accelerated in surface water due to the presence of certain types of bacteria. The reaction occurs much slower in groundwater due to the absence of these bacteria. Only those mines in which metal sulfide ores occur have the potential for acid mine drainage problems.

Alkaline materials that overlie resources such as coal can be exposed to surface or ground waters through strip mining. This activity can further aggravate the pre-existence of high alkalinity in water.
2. Water Quality Impacts

Federal law regulates pH in drinking water as a secondary contaminant. Regulations for secondary contaminants are intended only as suggested guidelines. The suggested level of pH in drinking water is 6.5 to 8.5. As a secondary contaminant, pH is not considered a health concern for humans, but is related to the general acceptability of water. Drinking water with moderate amounts of acidity or alkalinity can be consumed without adverse health effects. However, acidic solutions can taste sour while alkaline solutions can taste bitter. Acidic water can dissolve various heavy metals from soil or rocks and introduce them in toxic levels in water supplies. This will be discussed under the relevant pollutant type.

The measurement of acidity and alkalinity is important in controlling the water treatment process in a water purification facility. Required doses of various chemicals used during treatment depend on the concentrations of acidity or alkalinity or on the pH of the water. Acidic water flowing through a water distribution system and residential/commercial plumbing can dissolve metal piping which can release lead, copper and asbestos fibers into the water. This can be a major water treatment problem.

As acid mine drainage is diluted and the pH rises, a component of the drainage precipitates giving the water body a yellow color. This discoloration produces the effects of suspended particles. A gelatinous layer is formed over the bed as the precipitate settles. The effects of suspended particles are provided under the section on Sediment.

3. Impacts on Aquatic Life

Natural acidity and alkalinity in water provide a buffering action that protects fish and other organisms from changes in pH. However, if the buffering capacity is exceeded, a change in pH will occur. Many species of fish are very sensitive to changes in pH. Each species has its own tolerance level to pH. A pH range of about 5 to 9 is generally harmless to fish. At the lower end of the pH scale, a pH of below 4 is lethal to trout and salmon. Reproduction can be affected at a pH range of 4 to 4.5. On the higher end of the pH scale, a pH over 10.5 is rapidly lethal to trout and salmon. It is unlikely that any fish species can survive in waters with a pH below 3.5 and above 11.

Headwater streams and high altitude lakes are especially susceptible to the effects of acid precipitation and may sustain the loss of fish and other aquatic organisms. Low pH can cause fish kills or cause fish to migrate to a new location, if available.
As pH declines, both plant productivity and diversity decline. Some plant species are tolerant to a pH below 3.5 and can become abundant. The decomposition of plant material in a water body provides the main source of energy for aquatic animals. Low pH affects those organisms responsible for decomposition thereby reducing the rate of decomposition of plant material.  

The toxicity of other compounds such as heavy metals varies with pH. These compounds that can be trapped in the sediments of streams and lakes can be released depending on pH. The toxic effects caused by the release can be lethal to fish even within the 5 to 9 pH range. These effects will be discussed under the relevant pollutant types.

F. Nutrients

Nutrients are essential for both plant and animal growth. The two most important nutrients that can significantly impact water quality and aquatic habitat are nitrogen and phosphorus. Nitrogen and phosphorus can occur naturally in surface water and groundwater, however, human activity can greatly enhance their availability. Nitrogen and phosphorus compounds are the nutrients most commonly associated with water pollution.

Nitrogen occurs naturally in the environment and takes part in many biochemical reactions. About 78% of the atmosphere is nitrogen gas, however, it is not available for use by living organisms in this form. Nitrogen must be converted to a simple, inorganic form that can be used by plants. The form of nitrogen most useable by plants are nitrates. Nitrates are converted to more complex forms in the plant, and upon decay, are converted back to nitrates by bacterial action. Nitrogen is found in animals in complex forms such as proteins. These complex forms are converted to nitrates both during decomposition of bodily wastes and as the animal decays. The nitrates are released into the environment for reuse. Nitrate are persistent in groundwater and can travel unlimited distances. Nitrate do not bind strongly to soil particles and are readily carried by water through soil formations with little removal. Excessive concentrations of nitrates are a problem in both surface and groundwater systems.

Phosphorus occurs in the environment as a natural element of rocks and soils. In this form, phosphorus is not available for use by living organisms. Like nitrogen, phosphorus must be converted to a simple, inorganic form prior to uptake by plants. The form most commonly used by plants is phosphate. Phosphates are released into the environment for reuse upon decay of the plant. Phosphorus compounds are also found in animals and are released into the environment as phosphates upon decomposition of bodily wastes and decay of the animal. Phosphates tend to bind strongly with soil and are not readily transmissible to groundwater. Phosphates are considered a major pollutant of surface water rather than groundwater.
1. Land Use Activities

Land use activities that result in the release of nitrates and phosphates into the environment can increase the potential for nutrient pollution in surface water and groundwater. Such activities include urbanization, agriculture, on-site sewage disposal systems, public sewer systems, land disposal/land application of wastes and mining/gravel operations.

a. Urbanization

Nitrates and phosphates in urban runoff originate from a variety of sources. They include chemical lawn fertilizers, untreated or inadequately treated sewage, pet/wildlife wastes, leaves and grass clippings and atmospheric deposition. Atmospheric deposition of nitrogen compounds is becoming a major source of nitrates in surface water due to emissions of nitrogen oxides from vehicle exhaust and industrial combustion. Urban runoff may enter into groundwater through sinkholes, surface and deep mines or quarries. While these activities may not actually penetrate the water table, the overlying soils may be reduced such that nutrients can easily enter into the groundwater.

b. Agriculture

Nutrients from agricultural sources are cited as the most damaging of non-point source pollutants nationally along with suspended sediment. It is estimated that more than 7 million tons of nitrogen and 0.5 million tons of phosphorus enter surface waters from agricultural areas each year in the United States. A variety of agricultural practices can contribute to nutrient pollution in surface and groundwaters.

Chemical fertilizers containing nitrates and phosphates are applied to agricultural fields to increase the availability of these nutrients to crops. Fertilizers are one of the most significant groundwater contaminants. Contamination can occur when the method, timing or rate of fertilizer application exceed crop needs or when the soils overlying the water table have insufficient removal capacity. Further, overwatering crops during irrigation can provide nitrates with increased mobility through soils. Fertilizers can also be carried by runoff into surface waters making them a significant source of nutrient pollution.

High concentrations of livestock in feedlots are a major source of nutrient pollution. One steer produces approximately 18 times as much waste material as a human. Poor management of these wastes has resulted in high levels of water pollution in rural areas with small
human populations. Surface water in these rural areas can attain the same degree of pollution often found in surface waters in densely populated and highly industrialized areas. Allowing livestock access to surface water further increases nutrient pollution.

c. On-Site Sewage Disposal Systems

Nitrates and phosphates are found in human sewage. On-site sewage disposal systems directly discharge the largest volume of sewage into the subsurface. Each system is estimated to discharge between 49,000 to 75,000 gallons per year per household. Domestic sewage is a major source of groundwater pollution. Improperly located, designed, constructed or maintained systems can result in inadequately treated sewage reaching groundwater. Groundwater supplies in residential areas frequently exceed the federal drinking water standard for nitrates. Sewage disposal systems are a major contributor to this problem. Surface discharges of sewage can also be carried with runoff to surface water.

d. Public Sewer Systems

Sewer lines that are old or poorly constructed can result in groundwater pollution where leaking occurs. Older sewage treatment systems designed to collect both sewage and stormwater may discharge untreated wastes directly into surface water. This situation can occur when the treatment plant is not capable of handling both the storm flow and untreated sewage flow during a storm event.

Advanced sewage treatment may be required prior to discharge to decrease or remove nitrates and phosphates in the effluent. The level of removal is dependent on the classification of the receiving water body. Treatment plants having difficulty meeting the requirements could release sewage that has not been treated adequately.

e. Land Disposal/Land Application of Wastes

Landfilled human wastes can become a potential source of nutrient pollution in groundwater if proper controls are not in place. Further, improper land application of human or livestock wastes as a crop fertilizer can pollute both surface water and groundwater through runoff and by the inability of the soil to remove the nutrients.
f. **Mining/Gravel Operations**

Mining and gravel operations that are improperly managed can also contribute to phosphate loading in surface water. Phosphorus occurs as a natural element in soils and rock and may be carried with runoff if proper erosion control measures are not taken.

2. **Water Quality Impacts**

Nitrates in drinking water can result in serious public health effects. For this reason, nitrates are regulated as a primary contaminant under federal law. The maximum allowable concentration of nitrates in drinking water is 10 milligrams per liter (mg/l). Excessive nitrate concentrations are a health threat to both infants and fetuses. Nitrates react in the body effectively reducing the blood's ability to carry oxygen. This results in a disease called methemoglobinemia or blue baby syndrome. High nitrate levels may also harm livestock by causing bovine infertility and low milk yields. The presence of phosphorus in drinking water, however, has little effect on public health.

Enhanced levels of nitrates and phosphates encourage the rapid growth of algae in surface water. However, phosphates in water require greater control since only a small concentration of 0.02 mg/l can result in algal blooms or excessive algal growth. The occurrence of algal blooms is unlikely in the presence of high nitrate levels if the phosphate level is under 0.02 mg/l.

Algal blooms form a slimy mat on a lake surface interfering with recreational activities and decreasing the aesthetic value of the water body. Algal blooms give the water a murky or turbid appearance. The impacts of turbidity on water quality is provided under the section on Sediment.

The impacts of nutrient pollution on lakes are generally more serious than those on streams and rivers. This is due to the physical characteristics of a lake such as depth, volume and flushing rate. Water in a stream or river is constantly in motion providing a flushing action for pollutants. Since there is little movement of water in a lake, some pollutants including nutrients can remain in the lake for years to become available at a later time. Phosphates, which bind to soil particles, can be trapped in lake sediments. The depletion of oxygen along the lake bottom can cause the release of phosphates from sediment. This in turn increases the availability of phosphates for plant uptake. Enhanced nutrient levels can cause rapid algal growth. These plants eventually die and settle at the bottom of the lake. Microorganisms decompose the plants exerting an oxygen demand in the process. This may result in depletion of dissolved oxygen in some parts of the lake. Decaying plants, along with sediment from runoff, accumulate at the bottom of the lake.
accelerating the natural aging process of a lake. This natural process is termed eutrophication and results in the gradual filling in of a lake from both decaying plants and sediment. Excessive algal growth caused by human activity accelerates the filling in process and is termed cultural eutrophication.

The effects of increased algal growth raises the costs involved with water treatment. Algae tends to clog filters in a treatment facility necessitating more frequent cleaning. Further, additional chemicals may be required to control taste and odor problems associated with algae. For drinking water, nitrates must be removed such that the federal maximum allowable level of 10 mg/l is not exceeded.

3. Impacts on Aquatic Life

Nutrient pollution promotes excessive algal growth. Algal blooms give the water a turbid appearance which inhibits the photosynthetic activity of aquatic plants. This reduces the availability of food and cover provided by plants to fish and other organisms. Turbidity interferes with the feeding activities of predators that rely on sight to capture prey. Turbid conditions tend to increase water temperatures while lowering dissolved oxygen levels. As these plants decompose, the available dissolved oxygen can be reduced or depleted. The impacts of reduced or depleted dissolved oxygen on aquatic life are provided under the section on Biodegradable Organic Substances. As the water body becomes shallower and warmer, less desirable fish species are favored over more desirable species such as trout and salmon.

G. Toxic Substances

Toxic substances are poisons that can be harmful to living organisms by negatively affecting tissues, organs or the life processes of the exposed organism such as growth, reproduction and lifespan. These substances include heavy metals and organic compounds. Heavy metals include cadmium, zinc, mercury, lead and copper. Organic compounds include pesticides, petroleum products and many industrial chemicals.

Exposure to toxic substances may result in immediate death or irreparable harm to an organism that may not be noticeable until many years after exposure. Possible long-term effects are cancer or birth defects in the offspring of an exposed organism. Whether a substance is toxic to a particular organism depends on a number of factors:

- the type of organism exposed
- the amount and form of the substance
- the physical/chemical characteristics of the water body
• the duration and frequency of exposure
• the combination with or presence of other potentially toxic substances

It is difficult to determine the specific effects of a toxic substance since often times other substances are present that may impact toxicity. Most studies involve a single pollutant, while an aquatic organism is usually exposed to several pollutants simultaneously. Further, there is a wide range of environmental conditions that exist in different water bodies that can impact toxicity. Finally, the physiology of the organisms exposed are widely different.

Most available research on toxic substances centers on the concentration of a substance that would result in the death of an organism. For many toxic substances, little research has been completed on the long-term effects of low level exposure to animals. It is more likely that an aquatic system would be subjected to low levels of a toxic substance over long periods rather than exposure resulting in rapid death.61

1. Land Use Activities

Any land use activity that generates, stores, utilizes or disposes of heavy metal materials and organic compounds increases the potential for toxic pollution. Such activities include urbanization, agriculture, land disposal/application of wastes and mining.

a. Urbanization

Urban runoff can be a significant source of toxic substances in surface water. Toxic runoff may also be a problem for groundwater quality in sinkhole prone areas. Certain areas of the urban landscape produce significantly greater loadings of heavy metals and organic compounds.62 These areas tend to be those where vehicles are fueled and serviced or where many vehicles are parked. They include gas stations, vehicle maintenance areas, convenience stores and commuter parking lots. Streets are also a significant contributor to toxic pollution in runoff due to leaks from vehicles. Some of the substances associated with these areas are gasoline, motor oil, antifreeze, solvents and metals associated with batteries. Heavy metals typically having the highest concentrations in urban runoff are copper, lead, zinc and cadmium.63

Industry can be a significant source of heavy metals and organic chemicals through the infiltration of material spills, waste discharges into water or runoff from storage or production areas. Industry sources include metal plating shops, dry cleaners, machine shops and chemical manufacturers. The metals cadmium and zinc are common water and sediment pollutants in harbors surrounded with industrial facilities.64
Petroleum products stored in underground storage tank systems are one of the greatest threats to groundwater quality. The United States Environmental Protection Agency estimates that approximately one-third of all underground storage tanks in the United States are leaking.\textsuperscript{65} Hundreds of gallons of fuel may be discharged into the subsurface, and subsequently into groundwater, over a period of several months. Leakage is generally small enough to go unnoticed for a short time period.

The use of pesticides on the urban landscape can contribute to toxic pollution of receiving waters. Pesticides can enter surface water or groundwater through runoff or infiltration at any point in their manufacture, transport, use, storage and disposal. Pesticides are commonly applied to athletic fields, parks, golf courses, lawns and gardens. It is estimated that over 90\% of the homes in the United States use pesticides for lawn and garden care and account for about 5\% to 10\% of all pesticides used in the nation.\textsuperscript{66} Residential applications of pesticides are generally in the range of 5.3 to 10.6 pounds per acre.\textsuperscript{67}

Homeowners may also impact surface water and groundwater through improper disposal of such pollutants as used oil, solvents and paint thinners by dumping them on the ground or into an on-site sewage disposal system.

Immediate toxicological impacts on aquatic organisms exposed to urban runoff does not typically occur. This is due to brief exposures during storm events, dilution in urban creeks and the fact that many toxic pollutants are strongly bound to sediments and are not readily available for uptake by aquatic life.\textsuperscript{68} However, aquatic life exposed to urban runoff is subjected to longer term toxicity than to other types of runoff. The effects are variable due to the diversity of species and toxicity of both metals and organic compounds. According to some studies, movement of toxic substances through the food chain is especially pronounced in urban receiving waters.\textsuperscript{69}

development

b. Agriculture

Farmers apply pesticides to agricultural lands to control pests that threaten their crops. The use of pesticides in the United States has increased from about 540 million pounds of active ingredient in 1964 to about 1.1 billion pounds in 1993. Of this total, the agricultural use of pesticides accounts for about 75\%.\textsuperscript{70} Agricultural applications may average about 2.6 pounds per acre.\textsuperscript{71} The application rate on crop lands is much less than that for residential areas.
The application of pesticides by aircraft may result in direct pollution of surface water as pesticides may be carried to surface water by wind. Agricultural runoff and erosion due to precipitation or irrigation can carry pesticides to surface water. Groundwater may also become polluted as pesticides percolate through the soil. Whether this occurs is dependent on the water table elevation, type of soil and topography of the area and the characteristics of the pesticides.

c. Land Disposal/Application of Wastes

Landfilled wastes can become a potential source of groundwater pollution if proper controls are not in place. Pollution can occur if precipitation infiltrates through waste containing materials such as batteries, used oil or organic chemicals. Whether this highly toxic water reaches groundwater depends on the type of soil, amount of moisture in contact with the waste and the volume and nature of the pollutants.

Auto junkyards can be a source of toxic pollution to groundwater since auto materials such as grease, used oil and batteries are present on the site.

The land application of municipal sewage sludge can be a source of heavy metals in surface water and groundwater if industries generating or using these materials discharge into the sewage treatment system.

2. Water Quality Impacts

Currently, waterborne toxic substances pose the greatest threat to the safety of the water supplies in industrialized nations. This is due to the large number of industrial sources having the potential to release toxic pollutants into the water supplies.

a. Heavy Metals

Some heavy metals occur naturally in surface water in very small amounts. However, even in small amounts, there may be a danger to public health. Heavy metals are not typically found naturally in groundwater. Heavy metals in water can occur in a dissolved or particulate form and may be combined with other toxic substances. In fact, heavy metals rarely occur as the sole pollutant in water. They may also be adsorbed to soil particles. In surface waters, about 95% of heavy metals tend to settle out in bottom sediments. However, some metals such as copper and zinc tend to be soluble in water. In groundwater, heavy metals generally sink to the bottom of the aquifer and flow along the bottom.
A number of heavy metals are regulated under federal law as primary contaminants for drinking water. Due to the potential for serious health threats, these metals have a maximum allowable concentration in drinking water. Heavy metals such as cadmium, mercury, lead and copper bind to cell membranes in animals hindering transport processes through the cell wall. Metal poisoning in humans can result in a number of serious health problems such as neurological damage, birth defects, kidney and liver damage, high blood pressure and blindness. Death may also occur in more severe cases.

The occurrence of heavy metals in raw drinking water sources increases treatment costs. Heavy metals can also form deposits in water pipes reducing carrying capacity.

Over time, heavy metals can accumulate in fish tissues. This can result in the restriction of sport fishing in an area.

b. Organic Substances

There are thousands of organic substances in commercial production with varying degrees of toxicity, decomposition and persistence properties. Little is actually known about the public health effects related to organically polluted drinking water. Only a small number of substances have been examined for their short-term and long-term effects. Maximum allowable concentrations in drinking water have not been established for many organics or the products formed as a result of their decomposition. Further, established maximum concentrations are based on individual substances only, not the possible cumulative effects that may occur if other organics are present.

Most organic substances are relatively insoluble in water and may persist for many years usually in the bottom sediments. However, these substances can be soluble to the point that, even if present in very small dissolved concentrations, they can pose health threats. Non-biodegradable or poorly biodegradable organic substances are of most concern in drinking water. They include benzene and toluene which are components of gasoline. Benzene is a known human carcinogen. These types of substances must be treated by physical and chemical means for complete removal thereby increasing treatment costs. Substances that do undergo decomposition are not necessarily rendered harmless. Substances formed from decomposition of some organics are more toxic than the original substance.

A variety of health disorders have been associated with the long-term use of organically polluted drinking water. They include higher than
normal incidences of childhood leukemia, birth defects and elevated risks of childhood diseases affecting the lungs and respiratory system, kidneys and urinary tract and neurological and sensory functions.

Petroleum products may initially float on the water surface as a noticeable sheen or film. However, they have a strong tendency to bind with soil particles which eventually settle out in the bottom sediments. They can accumulate rapidly in the sediments of lakes and estuaries causing dissolved oxygen depletion. They may persist in these water bodies for long periods. In groundwater, they may float at the top of the water table or sink to the bottom of the aquifer and flow along the bottom. Gasoline and light oils tend to float on the top of the water table, have low solubility and are persistent in groundwater. Heavier oils have low solubility and are less mobile than gasoline. They tend to sink to the aquifer bottom.

Pesticides are more likely to enter surface water through sediment transport than to enter groundwater. Many pesticides are readily adsorbed to soil particles or broken down in the soil. However, even extremely small concentrations of pesticides in water can be significant to public health. Many pesticides degrade more readily in the presence of oxygenated sediments. Further, their persistence in water can be dependent on pH. Pesticides may cause noticeable odors in water. Sport fishing may be restricted if pesticides are found in fish tissue.

3. Impacts on Aquatic Life

a. Heavy Metals

Aquatic life is more likely to be negatively impacted by heavy metals than humans. In freshwater, the long-term impacts on aquatic life are more common than lethal toxicity. Plant and animal species have different tolerance levels to metals, however, many heavy metals at low concentrations may cause harm to most species. In general, trout and salmon tend to be more susceptible to heavy metals and react more quickly than most fish to toxic conditions.

The toxicity of metals is affected by characteristics of a water body such as pH, temperature, dissolved oxygen concentration and hardness. In acidic surface and groundwaters, heavy metals are more soluble, and therefore, more toxic to aquatic life. For example, aluminum is highly toxic to fish at a pH of 5.26 In alkaline waters, metals generally become insoluble and will precipitate out of solution. In general, higher water temperatures may reduce the survival time of an exposed organism. Reduced dissolved oxygen concentrations may also increase heavy
metal toxicity. Some metals such as zinc may be less toxic to aquatic life, such as trout in hard water rather than soft water. Many fish are less susceptible to the ill-effect of toxic metals in hard water.

The form in which a metal is present can have an influence on its toxicity. For example, most inorganic forms of mercury are relatively insoluble and less toxic to aquatic life. However, when mercury is present in a soluble, organic form, it is highly toxic. This form of mercury is formed by bacteria in sediments where decay is occurring in the absence of oxygen.

As previously discussed, most heavy metals will settle out and accumulate in the bottom sediments. This poses a risk to the bottom feeding organisms which may develop high concentrations of metals. These bottom dwelling invertebrates are generally less tolerant than fish to heavy metals. Some metals such as zinc may interfere with the process of biodegradable organic decay by decomposer organisms thus eliminating a major food source of the invertebrates.

Heavy metals may be taken up by organisms thereby entering the food chain. Heavy metals are stored in fish tissue. Heavy metals may continue to accumulate in fish tissue by way of ingestion or contact with metals in the water, from their food or from solution. This may continue until harmful levels of metals in the tissues are reached. As these animals are eaten, the accumulation of metals is passed through the food chain.

Heavy metals may affect the reproductive rates and life spans of aquatic organisms. Low concentrations of zinc have resulted in a low hatching rate and high mortality rate for juvenile trout. Low concentrations of zinc, copper and cadmium inhibit algal growth. Photosynthesis of aquatic plants may be hindered as well.

Species not directly affected by heavy metals may be impacted by the removal of a more sensitive species. If a predator is deprived of its prey due to lethal toxicity, its population may also be reduced or eliminated.

b. Organic Substances

The most common effect on aquatic plants is the direct impairment of photosynthesis. Further, some types of pesticides such as insecticides allow algal blooms to develop. The effects of organic pollution on aquatic animals are frequently unknown, especially long term exposure at low pollutant levels. Many organic substances accumulate in bottom sediments where they may cause adverse impacts on bottom-dwelling
organisms. Insecticides appear to be more toxic to these invertebrates than to fish. Pesticides may accumulate in the fatty tissues of organisms. As exposed organisms are eaten by larger organisms, the concentration of pesticides in the tissues of the predator may increase. This may result in the death of some fish or other aquatic organisms. Reproduction rates in some fish may be lowered. The embryos may be poisoned due to significant pesticide concentrations in the egg yolk.
IV. **ANALYSIS OF MONOCACY CREEK LAND USE / WATER QUALITY CORRELATION**

The Wildlands Conservancy obtained water samples from a total of 18 sites within the Monocacy Creek and tributaries. Figure 1 is a location map of the sampling sites (as provided by Wildlands Conservancy). Sampling occurred from July 1997 to October 1997. Laboratory analyses were completed for 14 water quality parameters. The Wildlands Conservancy is preparing an assessment of the water sampling data to document the general water quality of the creek compared to established standards, to identify any significant differences in the water quality by location and to identify possible explanations for monitored water quality based on geology, land use, locations of springs and other factors. Regarding land use, the Wildlands Conservancy analyses would attempt to identify a specific land use (i.e. specific industry) which might explain the finding of any unusually high pollutant level by location. The purpose for the analysis contained herein is to identify whether any clear correlation exists between the monitored water quality in the creek and the generalized land use pattern within the watershed. The method used to prepare this assessment will be to determine the percent of a given land use upstream of a given monitoring point, the associated water quality data by parameter at that monitoring point and compare that relationship to the other monitoring points throughout the watershed. The final product will be an assessment of percent land use versus water quality to identify any stray linkages and to help determine any land use measures needed to protect water quality.

Prior to correlating land use and water quality, it was necessary to delineate the land areas draining to each of the 18 sampling sites. Based on existing land use, the percentage of each of nine land use types within the delineated areas was determined. Table 1 is a listing of the water quality sampling sites and their associated existing land use percentages. With this information, it was possible to graph average values of each parameter versus the percentage of each existing land use type across all sampling locations. An example of the land use/water quality graphs is included as Figure 2. The graph shows the percent of existing industrial land use at the sampling locations versus the alkalinity measured at that location. The water quality data at each station is shown with a diamond at the average value of all samples and with a bracket showing the range of sampling results. Graphing of the data has also included creation of a “best fit” straight line through the data representing a trend line. The best fit lines are based on mathematical equations which consider the data variations such that a best fit line is possible even if the data by eye doesn’t correspond to a straight line very well. The graphs and trend lines must be used cautiously to avoid misinterpretation. Only strong trends in the data which can be conceptually explained will be considered valid. The average water quality values (diamonds) are used to develop the trend lines. The graphs for all combinations of land use/water quality types are included in Appendix A. The best fit lines can be used to indicate water quality trends as the percentage of a land use increases. In this way, water quality can be correlated with future zoning. It should be noted that the usefulness of the best fit line is dependent on the reliability of the data used in its calculation.
FIGURE 1
Monocacy Creek Watershed
Sampling Sites

Key
- Monocacy Creek and Tributaries
- Water Bodies
- County Boundaries
- Townships, Boroughs, and Municipalities
- Sample Sites

Data Sources
Northampton County Tax Assessment Office - Political Boundaries Data
PA Department of Environmental Protection - Streams
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<td>0.37%</td>
<td>1.80%</td>
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</tr>
</tbody>
</table>
FIGURE 2

% EXISTING INDUSTRIAL VS ALKALINITY

Y = 40.50X + 72.736

-34-
Note from Appendix A that there was not sufficient variation in the percent land use for either transportation or big impervious areas within the watershed (values ranged from 0 to less than 1 percent by sampling location) such that no valid trends could be determined from the data. Also note that the range of data for institutional, commercial and industrial land uses was between 0 and 9 percent and any identified trends should not be extrapolated to significantly higher land use percentages. The data for residential, agricultural, open space and woods land uses represent a larger range of percentages and any identified trends may be used with more confidence than for other land use types. Significant trends are identified below based on strong upward or downward trends by land use where the data appears to support the trend line. The results are shown in Table 2.

**pH**
No significant trends were identified based on land use percentage.

**Water Temperature**
No significant trends were identified based on land use percentage.

**Dissolved Oxygen**
No significant trends were identified based on land use percentage.

**Conductivity**
A significant increase in the trend line for conductivity was identified with an increase in percentage of open space land use. Significant decreases were identified for both residential and agricultural land uses.

**Total Dissolved Solids (TDS)**
A significant increase in the trend line for TDS was identified with an increase in percentage of industrial and open space land uses. Significant decreases were identified for residential, agricultural and wooded land uses.

**Nitrate**
No significant trends were identified based on land use percentage.

**Phosphate**
A significant increase in the trend line for phosphate was identified with an increase in the percentage of the residential land use. According to the background documentation provided in this report in Section III, residential development is a likely source of phosphate. Phosphate is found in chemical lawn fertilizers, untreated or inadequately treated sewage and pet wastes.

**Total Hardness**
Significant increases in the trend line for total hardness were identified with increases in percentage of institutional, industrial and open space land uses. Conversely, the total hardness trend line decreased significantly with an increase in percentage of agricultural and wooded land use.
### Table 2
**Monocacy Creek Watershed Land Use/Water Quality Trends**

<table>
<thead>
<tr>
<th>Land Use Type</th>
<th>pH</th>
<th>Water Temp.</th>
<th>Dissolved Oxygen</th>
<th>Conductivity</th>
<th>Total Dissolved Solids</th>
<th>Nitrate</th>
<th>Phosphate</th>
<th>Total Hardness</th>
<th>Calcium Hardness</th>
<th>Magnesium Hardness</th>
<th>Alkalinity</th>
<th>Sulfate</th>
<th>Manganese</th>
<th>Chloride</th>
</tr>
</thead>
<tbody>
<tr>
<td>Transportation*</td>
<td></td>
<td></td>
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<tr>
<td>Big Impervious*</td>
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<td></td>
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<td></td>
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</tr>
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<td>I</td>
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<td>D</td>
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<td>I</td>
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<td>I</td>
<td>I</td>
<td>I</td>
<td>I</td>
<td>D</td>
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<td>I</td>
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</tr>
</tbody>
</table>

* = Insufficient quantities of this land use to establish valid trends.
I = Significant increase in water quality values with an increase in land use percentage.
D = Significant decrease in water quality values with an increase in land use percentage.
Calcium Hardness
A significant increase in the trend line for calcium hardness was identified with an increase in percentage of open space land use. Significant decreases were identified for residential and agricultural land uses.

Magnesium Hardness
A significant increase in the trend line for magnesium hardness was identified with an increase in percentage of institutional, industrial and open space land uses. Conversely, magnesium hardness trend lines decreased significantly with increases in percentage of residential and agricultural land uses.

Alkalinity
Significant increases in the trend line for alkalinity were identified with increases in percentage of industrial and open space land uses. Industrial land uses can be a source of alkalinity and could be attributed to the discharge of untreated or inadequately treated wastes from industrial processes. Increased alkalinity from open space can possibly be attributed to characteristics of the natural landscape. A significant decrease in the trend line was identified for wooded land uses.

Sulfate
A significant increase in the trend line for sulfate was identified with an increase in percentage of open space land use. Conversely, the sulfate trend line decreased significantly with an increase in percentage of residential land use.

Manganese
No significant trends were identified based on land use percentage.

Chloride
A significant increase in the trend line for chloride was identified with an increase in percentage of open space land use. A significant decrease was identified for agricultural land use.

From Table 2, significant trends, both increases and decreases, were identified for nine of the 14 water quality parameters. They include conductivity, TDS, phosphate, total hardness, calcium hardness, magnesium hardness, alkalinity, sulfate and chloride. Six of the nine land use types would appear to have significant water quality trends for certain water quality parameters. These land uses include institutional, industrial, residential, agricultural, open space and woods.

Significant trend line decreases were identified for conductivity, TDS, total hardness, calcium hardness, magnesium hardness, alkalinity, sulfate and chloride. These decreases took place with residential, agricultural and wooded land uses. The trend line decreases...
for these parameters would not likely pose a water quality concern. However, the reason for the decrease is not clear.

Significant trend line increases for certain land uses were identified for all nine of the water quality parameters which displayed strong trends. These increases took place with institutional, industrial, residential and open space land uses. Trend line increases for these parameters would indicate a water quality concern should the percentage increase in the future for the involved land uses. It is interesting to note that open space increases resulted in a significant trend line increase for eight of the nine parameters. The reason for this trend is not clear. Based on documentation provided in Section III, a trend line increase for phosphate due to residential development is very reasonable. This is also true for alkalinity and industrial development.

The above analysis for significant land use/water quality trends is a very subjective assessment of the graphical data in Appendix A. The basic deficiency of this analysis is the lack of sufficient data to support any rigorous correlation with land use. Water quality monitoring data over a prolonged period of time would be required to firmly establish trends. Insufficient occurrences of certain existing land use types (e.g. transportation) make any correlations impractical. Trends identified are only preliminary and would need to be substantiated through additional water quality sampling and/or alternate analytical means to draw land use correlations. The data included herein might be most beneficially used to focus future efforts for water quality monitoring and land use analysis where preliminary trends are identified.

As part of this effort, future land use percentages for each sampling site were developed based on zoning. The future land use percentages by sampling site are included in Table 3. It was intended that any strong trends in water quality by land use could be extrapolated to future zoned land use to identify potential problems. In general, the correlation analysis did not provide sufficiently clear, defensible trends to support this type of extrapolation. However, a comparison between the existing land use percentages in Table 1 and future land use percentages in Table 3 at the mouth of the watershed (site 20) identify two land use types that may be a cause for concern. The comparison indicates that residential land use will increase from about 24% to about 40% of the watershed for a difference of about 16%. Further, industrial land use will increase from about 3% to about 13% of the watershed for a difference of about 10%. Future efforts to correlate land use and water quality should focus on increased residential and industrial development as indicated by zoning. Measures to mitigate the potential adverse impacts of land use activities on water quality should focus on the preliminary trends identified herein and the specific impacts of future residential and industrial development.
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<th>Residential</th>
<th>Industrial</th>
<th>Commercial</th>
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</tbody>
</table>

*Percentages are based on zoning only and do not include existing land use percentages
NOTES

1. Stream Bank Fencing, Penn State College of Agricultural Sciences, p. 3.


15. Ibid., p. 105.


17. Ibid., p. 38.

18. Ibid., p. 37.

19. Ibid., p. 37.

20. Ibid., p. 37.

21. Ibid., p. 51.


24. Ibid.

25. Ibid.


30. Ibid., p. 719.

31. Ibid., p. 719.

33. Ibid., p. 134.

34. Ibid., p. 134.

35. Ibid., p. 104.


37. Ibid., p. 53.


42. Ibid.


47. Ibid., p. 89.


54. Ibid., p. 469.


56. Ibid., p. 112.


60. Ibid., p. 143.


67. Ibid., p. 138.


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*Groundwater: A Primer for Pennsylvanians*, Pennsylvania Groundwater Policy Education Project.


*Safeguarding Wells and Springs From Bacterial Contamination*, Penn State College of Agriculture Cooperative Extension, Extension Circular 345.


*Stream Bank Fencing*, Penn State College of Agricultural Sciences, Extension Circular 397.


APPENDIX A

Land Use/Water Quality Graphs
% EXISTING TRANSPORTATION VS. pH

\[ y = 2.1547x + 7.3813 \]
% EXISTING BIG IMPERVIOUS VS. pH

\[ y = 14.714x + 7.5956 \]
% EXISTING INSTITUTIONAL VS. pH

% INSTITUTIONAL

pH

y = 0.1836x + 7.3486
% EXISTING COMMERCIAL VS. pH

\[ y = 0.087x + 7.6302 \]
% EXISTING RESIDENTIAL VS. pH

\[ y = -0.042x + 8.579 \]
% EXISTING AGRICULTURE VS. pH

\[ y = -0.0155x + 8.5602 \]
% EXISTING TRANSPORTATION VS. WATER TEMPERATURE

\[ y = -1.7031x + 18.458 \]
% EXISTING BIG IMPERVIOUS VS. WATER TEMPERATURE

\[ y = -20.652x + 18.382 \]

- TEMP AVG
- Linear (TEMP AVG)
% EXISTING COMMERCIAL VS. WATER TEMPERATURE

\[ y = 0.0393x + 18.076 \]
% EXISTING RESIDENTIAL VS. WATER TEMPERATURE

$y = -0.0792x + 19.745$

- TEMP AVG
- Linear (TEMP AVG)
% EXISTING AGRICULTURE VS. WATER TEMPERATURE

\[ y = 0.0468x + 15.646 \]

- TEMP AVG
- Linear (TEMP AVG)
% EXISTING OPEN SPACE VS. WATER TEMPERATURE

\[ y = -0.0427x + 18.629 \]

- TEMP AVG
- Linear (TEMP AVG)
% EXISTING TRANSPORTATION VS. DISSOLVED OXYGEN

\[ y = 0.8001x + 9.1547 \]
EXISTING BIG IMPERVIOUS VS. DISSOLVED OXYGEN

% BIG IMPERVIOUS

Dissolved Oxygen

y = 2.8301 x + 0.003

DO AVG

Linear (DO-AVG)
% EXISTING INSTITUTIONAL VS. DISSOLVED OXYGEN

\[ y = 0.0899x + 0.0982 \]
% EXISTING INDUSTRIAL VS. DISSOLVED OXYGEN

y = 0.1401x + 9.6503
% EXISTING RESIDENTIAL VS. DISSOLVED OXYGEN

\[
y = -0.0004x + 9.2965
\]
% EXISTING INSTITUTIONAL VS. CONDUCTIVITY

\[ y = 59.634x + 351.57 \]
% EXISTING COMMERCIAL VS. CONDUCTIVITY

\[ y = 5.505x + 470.32 \]
% EXISTING RESIDENTIAL VS. CONDUCTIVITY

\[ y = -11.606x + 709.79 \]
% EXISTING OPEN SPACE VS. CONDUCTIVITY

$y = 23.4x + 228.88$
% EXISTING WOODS VS. CONDUCTIVITY

\[ y = 7.48x + 57.24 \]
% EXISTING TRANSPORTATION VS. TDS

y = 255.26x + 191.11
% EXISTING BIG IMPERVIOUS VS. TDS

\[ y = 1081x + 223.13 \]
% EXISTING INSTITUTIONAL VS. TDS

% INSTITUTIONAL

TDS

y = 27.273x + 175.48
% EXISTING COMMERCIAL VS. TDS

Linear (TDS AVG)

$y = 5.2668x + 221.00$

TDS AVG
% EXISTING INDUSTRIAL VS. TDS

TDS AVG

$y = 30.14x + 1.6722$

% INDUSTRIAL
% EXISTING RESIDENTIAL VS. TDS

$y = -5.2753x + 338.67$

- TDS AVG
- Linear (TDS AVG)
% EXISTING OPEN SPACE VS. TDS

$y = 10.892x + 117.23$
% EXISTING TRANSPORTATION VS. NITRATE

\[ y = 6.4035x + 12.017 \]
% EXISTING BIG IMPERVIOUS VS. NITRATE

\[ y = 81.2x + 1.225 \]

Nitrate (%) vs. % Big Impervious
% EXISTING INSTITUTIONAL VS. NITRATE

\[ y = 0.4039x + 12.241 \]
% EXISTING COMMERCIAL VS NITRATE

\[ y = 0.5506x + 11.732 \]
% EXISTING INDUSTRIAL VS. NITRATE

\[ y = 0.8779x + 11.612 \]
% EXISTING RESIDENTIAL VS. NITRATE

\[ y = 0.1322x + 10.483 \]
% EXISTING OPEN SPACE VS. NITRATE

\[ y = 0.109x + 14.278 \]
% EXISTING WOODS VS. NITRATE

y = -0.2409x + 18.036

NIT AVG
Linear (NIT AVG)
% EXISTING TRANSPORTATION VS. PHOSPHATE

\[ y = -0.2494x + 0.3124 \]

- PHOS AVG
- Linear (PHOS AVG)
% EXISTING INSTITUTIONAL VS. PHOSPHATE

\[ y = -0.0766x + 0.4347 \]
% EXISTING COMMERCIAL VS. PHOSPHATE

% COMMERCIAL

PHOSAVG (PHOS AVG)
% EXISTING INDUSTRIAL VS. PHOSPHATE

\[ y = 0.060x + 0.3564 \]

- PHOS AVG
- Linear (PHOS AVG)
% EXISTING RESIDENTIAL VS. PHOSPHATE

\[ y = 0.0217x - 0.1594 \]
% EXISTING AGRICULTURE VS. PHOSPHATE

$y = -0.0041x + 0.4778$

- PHOS AVG
- Linear (PHOS AVG)
% EXISTING OPEN SPACE VS. PHOSPHATE

\[ y = 0.0091x + 0.3654 \]
% EXISTING WOODS VS. PHOSPHATE

- PHOS AVG
- Linear (PHOS AVG)

Y = 0.0 + 0.18X

Phosphate

% Woods
% EXISTING TRANSPORTATION VS. TOTAL HARDNESS

\[ y = 271.56x + 135.19 \]

<table>
<thead>
<tr>
<th>% TRANSPORTATION</th>
<th>TOTAL HARDNESS</th>
</tr>
</thead>
<tbody>
<tr>
<td>0.00</td>
<td>450.00</td>
</tr>
<tr>
<td>0.10</td>
<td>400.00</td>
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<tr>
<td>0.20</td>
<td>350.00</td>
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<tr>
<td>0.30</td>
<td>300.00</td>
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<tr>
<td>0.40</td>
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<tr>
<td>0.50</td>
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</tr>
<tr>
<td>0.60</td>
<td>150.00</td>
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<tr>
<td>0.70</td>
<td>100.00</td>
</tr>
<tr>
<td>0.80</td>
<td>50.00</td>
</tr>
</tbody>
</table>

Graph showing the relationship between % existing transportation and total hardness.
% EXISTING INSTITUTIONAL VS. TOTAL HARDNESS

\[ y = 37.56x + 148.21 \]
% EXISTING INDUSTRIAL VS. TOTAL HARDNESS

\[ y = -0.026x + 190.57 \]

THIRD AVG
Linear (THIRD AVG)
% EXISTING AGRICULTURE VS. TOTAL HARDNESS

\[ y = -4.5489x + 459.21 \]

Linear (THIRD AVG)

THIRD AVG
$y = -0.6866x + 326.84$

% EXISTING WOODS VS. TOTAL HARDNESS

TOTAL HARDNESS

% WOODS
EXISTING INSTITUTIONAL VS. CALCIUM HARDNESS

% INSTITUTIONAL

CALCIUM HARDNESS

y = 4.000x + 54.353
EXISTING COMMERCIAL VS. CALCIUM HARDNESS

% COMMERCIAL VS. CALCIUM HARDNESS

y = 1.2673x + 59.904
EXISTING INDUSTRIAL VS. CALCIUM HARDNESS

\[
y = 4.7367x + 10.00
\]

LINEAR (CHRD AVG)

% EXISTING INDUSTRIAL VS. CALCIUM HARDNESS

CALCIUM HARDNESS

% INDUSTRIAL
EXISTING RESIDENTIAL VS. CALCIUM HARDNESS

\[ y = -0.8458x + 79.792 \]

CHRD AVG

Linear (CHRD AVG)

\% EXISTING RESIDENTIAL vs. Calcium Hardness

Calcium Hardness

\% RESIDENTIAL

0.00 10.00 20.00 30.00 40.00 50.00 60.00 70.00 80.00 90.00 100.00
% EXISTING AGRICULTURE VS. CALCIUM HARDNESS

CHRD AVG
Linear (CHRD AVG)

$y = 0.6465x + 33.627$
EXISTING OPEN SPACE VS. CALCIUM HARDNESS

\[ y = 1.375x + 48.267 \]
EXISTING WOODS VS. CALCIUM HARDNESS

% WOODS VS. CALCIUM HARDNESS

\[ y = 0.3226x + 60.63 \]
% EXISTING INSTITUTIONAL VS. MAGNESIUM HARDNESS

MHRD AVG
Linear (MHRD AVG)

\[ y = 33.662x + 93.684 \]

MAGNESIUM HARDNESS

% INSTITUTIONAL
EXISTING AGRICULTURE VS. MAGNESIUM HARDNESS

\[ y = 3.97x + 367.04 \]
EXISTING OPEN SPACE VS. MAGNESIUM HARDNESS

% OPEN SPACE

MAGNESIUM HARDNESS

y = 11.985x + 37.729
$y = 1497.5x + 126.74$
% EXISTING INSTITUTIONAL VS. ALKALINITY

\[ y = 22.597x + 93.284 \]

ALKAVG - Linear (ALKAVG)
% EXISTING INDUSTRIAL VS. ALKALINITY

\[ y = 40.5888 + 72.738 \]

ALK AVG

Linear (ALK AVG)
% EXISTING RESIDENTIAL VS. ALKALINITY

$y = -1.1353x + 164.65$
EXISTING AGRICULTURE VS. ALKALINITY

\[ y = -2.4201x + 273.15 \]
$y = -9.0049x + 26.19$

% WOODED VS. ALKALINITY

$\text{ALK AVG}$

Linear (ALK AVG)

ALK AVG

% WOODED AREA

% WOODED AREA
% EXISTING BIG IMPERVIOUS VS. SULFATE

\[ y = -518.65x + 57.9 \]

SUL AVG vs. % BIG IMPERVIOUS

Linear relationship

SUL AVG
% EXISTING INDUSTRIAL VS. SULFATE

\[ y = -1.769x + 55.513 \]

- SUL AVG
- Linear (SUL AVG)
% EXISTING RESIDENTIAL VS. SULFATE

\[ y = -3.3827x + 119.86 \]
% EXISTING AGRICULTURE VS. SULFATE

\[ y = -0.9539x + 100.83 \]
% EXISTING OPEN SPACE VS. SULFATE

SULAVG

Linear (SUL AVG)

\[ y = 4.188x - 7.6174 \]
% EXISTING WOODS VS. SULFATE

SULAVG

Linear (SUL AVG)

\[ y = 1.711x + 31.887 \]
% EXISTING TRANSPORTATION VS. MANGANESE

\[ y = 8.7327x + 4.3126 \]
% EXISTING BIG IMPERVIOUS VS. MANGANESE

\[ y = 59.048x + 5.1873 \]

- MANG AVG
- Linear (MANG AVG)
% EXISTING INSTITUTIONAL VS. MANGANESE

$y = 0.564x + 4.5570$

- Linear (MANG AVG)

- MANG AVG
% EXISTING COMMERCIAL VS. MANGANESE

\[ y = 0.3442x + 4.9367 \]
% EXISTING INDUSTRIAL VS. MANGANESE

y = 1.299x + 3.5652
% EXISTING RESIDENTIAL VS. MANGANESE

\[ y = 0.1156x + 3.4831 \]
EXISTING AGRICULTURE VS. MANGANESE

\[ y = -0.365x + 12.935 \]
% EXISTING OPEN SPACE VS. MANGANESE

\[ y = 0.0928x + 4.7838 \]

Graph showing the relationship between % existing open space and manganese, with a linear trend line.

Linear (MANG AVG)
% EXISTING WOODS VS. MANGANESE

\[ y = 0.257x + 8.92 \]

MANGAVG

Linear (MANGAVG)
% EXISTING TRANSPORTATION VS. CHLORIDE

\[ y = 17.494x + 17.326 \]

- CHL AVG
  - Linear (CHL AVG)
% EXISTING INSTITUTIONAL VS. CHLORIDE

\[ y = 0.8137x + 18.517 \]
EXISTING COMMERCIAL VS. CHLORIDE

% EXISTING COMMERCIAL VS. CHLORIDE

\[ y = 0.1084x + 20.626 \]

CHL AVG (CHL AVG)
% EXISTING RESIDENTIAL VS. CHLORIDE

y = -1.063x + 22.46

Linear (CHL AVG)
% EXISTING AGRICULTURE VS. CHLORIDE

\[ y = -0.22x + 3.68 \]

CHL. AVG
Linear (CHL AVG)
% EXISTING OPEN SPACE VS. CHLORIDE

Y = 0.5468X + 14.38
% EXISTING WOODS VS. CHLORIDE

CHL AVG
Linear (CHL AVG)

\[ y = -0.2383x + 22.977 \]