CHAPTER TWO

INTRODUCTION TO GROUNDWATER SYSTEMS

Water is one of the most vital of resources and supports all forms of life. Water resources in the U.S. were once plentiful and of pristine quality. Little thought was given to the possible consequences of abusing and exploiting this resource, however, and we have painfully realized these consequences in the present.

Groundwater Storage

Groundwater, the focal point of this manual, can be stored in varying quantities below the surface. The ability of an underlying strata to contain water is a function of its primary and secondary porosity. A rock formation which is capable of storing relatively large quantities of water is referred to as an aquifer.

The volume of openings and voids in a rock or other material indicates its porosity. Porosity is defined as the ratio of the volume of openings or voids to the total volume. Porosity of unconsolidated or loose materials such as sand and gravel is dictated by factors such as packing, sorting and grain shape. A permeable condition exists when voids between individual grains are interconnnected so that water can migrate through rock.

Primary porosity is a function of the composition and structure of the rock as distinct from secondary porosity which occurs due to weathering, faulting and folding, or other phenomenon which creates fractures, fissures, or caverns within the rock formation.

Groundwater Recharge

In temperate climates groundwater is replenished by downward percolation from rain and snow. Normally there is a lower zone in which all pore spaces are filled with water, the zone of saturation. Above this is the zone of aeration where the pores contain some air, through which water filters to reach the zone of saturation. The boundary between the two is the water table which is often uneven and sometimes interrupted.

Various factors affect the rate at which water permeates to the water table. The moisture content of the soil, soil texture, and soil type, as well as the presence of impermeable soil layers called fragipans, all have a bearing on the rate of recharge of groundwater systems. In addition to soil characteristics, the amount and frequency of precipitation is a prime factor in determining the rate of recharge. Another consideration in the determination of rates of recharge is the degree to which the soil has become compacted. The types of soil and the use to which the land is put will determine soil compaction and the subsequent rate of filtration of water through air spaces.

As water penetrates through soil some of it is taken in by plant life and emitted back into the atmosphere as water vapor in a process called transpiration. If precipitation cannot be absorbed fast enough by the soil, it will collect and run-off down the steepest gradient, eventually finding its way to surface water bodies. Water can also return to the atmosphere in the form of vapor through evaporation. The accumulation of water vapor in the air from transpiration and evaporation is called humidity, and under certain meteorological conditions, the air will become saturated causing precipitation, completing the hydrologic cycle. The total amount of water involved in precipitation, evaporation, transpiration, and surface and subsurface storage in a given area is termed the water budget. In order to maintain the water budget, any water extracted from the system must be replaced. This rule applies not only to the system as a whole but to any component of the system. As an example, the amount of water that is being extracted from the system by a well must be compensated by equivalent recharge.

The safe yield of an aquifer refers to the quantity of water which can be pumped out without depleting the water budget. Therefore, the safe yield (output) should be balanced by the recharge (input) in order to maintain the aquifer's base flow. This relationship can be expressed in the following equation:

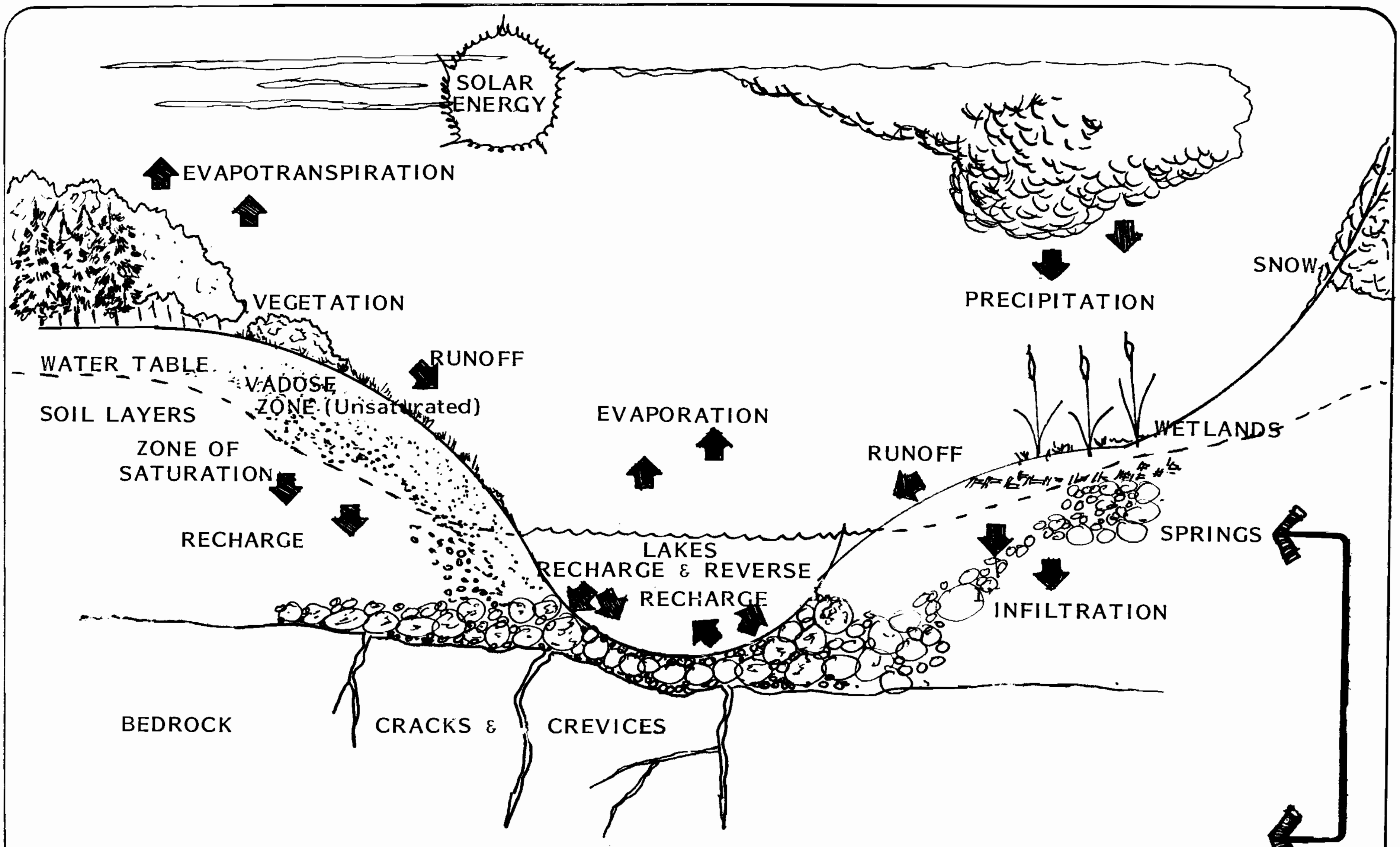
$Y = B + R$
Y = Safe Yield (output)
R = Recharge (input)
B = Base Flow of Aquifer

If a quantity of water greater than the safe yield is withdrawn from the aquifer, overdrafting will occur. An overdrafting situation can only be remedied by additional recharge, whether natural or artificial. An illustration of the entire hydrologic cycle can be found in Figure 2.

Groundwater Movement

The direction of groundwater movement is generally down the slope of the water table, but because it is subject to many fluctuating influences, such as pressure gradients, caused by pumping wells, the actual flow patterns are often quite complex. Groundwater moves in the direction of least resistance, therefore striving for equilibrium. Usually the regional or macro force that propells groundwater movement is gravity. Water particles in a micro environment may move via hydrostatic pressure, in which case movement is from a volume of higher pressure to one of lower pressure.

Suction is created when an aquifer is pumped and water is drawn from other areas. A suction condition can endanger the water quality in an aquifer when neighboring water sources are of lower quality (e.g. saline). Other problems associated with diminishing groundwater will be discussed later in the text.



The Hydrologic Cycle

figure 2

Man's Activities - Their Affect on Groundwater Systems

Man's activities that can have an effect on groundwater systems are many. They include: 1) introducing foreign materials into water systems, directly or indirectly, which eventually may render the water useless as a potable supply or unsuitable to support other life forms; 2) impeding the rate of infiltration of water back into the ground by creating expansive areas of impervious cover (eg. paved parking lots); 3) overtaxing surface and sub-surface water supplies by concentrating human populations beyond what the natural resources can support or by abusing a water source by overdrawing; 4) removing the vegetative cover through construction or agronomic practices that results in accelerated runoff and soil erosion, affecting both water quality and quantity.

There exist two basic modes by which contaminants can enter water systems, point source discharges, and non-point discharges. Examples of point discharges are those from wastewater treatment plants, landfill leachate, spills, and industrial waste discharges including the emission of noxious particulates into the air which re-enter the system through precipitation. Non-point contamination stems from stormwater runoff which picks up pollutants in residential, agricultural or industrial areas or from surface mining and silvicultural (forest harvesting) operations. (For the purposes of this manual, on-site septic systems will be considered non-point discharges.) Phenomenon such as overpumping or creating impervious surfaces can result in the concentration of natural salts by reducing the dilution capacity of groundwater, which can have a net result of deterioration in groundwater quality.

This chapter will identify and discuss general groundwater quality and quantity problems and human activities associated with these problems. They are broken down as outlined below

Water Quality

Point Discharges
1. wastewater treatment plants
2. landfill leachate
3. spills
4. improper disposal/storage of hazardous or toxic waste

Non-point Discharges
1. Stormwater runoff from:
    a) residential areas
        1. impervious surfaces
        2. on-site wastewater systems
        3. construction activities
        4. fertilizers/pesticides/herbicides
    b) industrial areas
    c) agricultural areas
    d) surface mining operations
    e) silviculture operations

Water Quantity

Over-Taxation of Groundwater Systems
Reduction of Groundwater Recharge
Concentration of Natural Salts
Out-of-Basin Transfers

Water Quality

Point Discharges

Wastewater Treatment Plants

Regional wastewater treatment systems collect and carry wastewater from its generation point to a treatment facility where it is processed in varying degrees using a variety of methods. A residual sludge material and an effluent are generally the products of the treatment process. Usually the effluent is discharged into a nearby river or stream in accordance with the designated assimilative capacity. The sludge is usually disposed of on land (eg. landfill) or at sea. Ocean disposal of sludge is now regulated by 1981 Federal restrictions with the goal of eventually prohibiting it altogether.

In Sussex County, approximately 85% of area residents (1979 figures) rely on on-site wastewater disposal systems (mostly the standard subsurface septic system). Because of the rural nature of Sussex County and the dispersed development, regional collector sewers have not been feasible in most municipalities. The capital intensiveness of constructing and operating regional sewer systems as well as recent changes in U.S. Environmental Protection Agency funding policies has contributed to the continued reliance on on-site wastewater disposal. Most important, however, is the state-of-the art technology which points to on-site systems as environmentally superior as well as cost-effective when compared to the sewer system approach. Environmental advantages of on-site systems can include; a) allowing the "purified" wastewater effluent to re-enter the groundwater system, therefore replacing the water consumed and not causing a deficit in the water budget (regional collection sewer systems discharge the effluent into rivers and streams and thereby remove the potential source of recharge), b) avoiding a point discharge into a stream or river which, by nature, has a minimal ability to assimilate contaminants as compared to the capability of soils to rehabilitate wastewater.

Landfill Leachate

Although we are currently experiencing a surge in resource recovery technology, landfilling is still the predominent method of solid waste disposal nation-wide. Recent federal legislation (Resource Conservation and Recovery

Act (RCRA) of 1972) has placed stringent requirements on siting, constructing and operating any new sanitary landfills including the use of liners, leachate control systems and monitoring wells. It was the problems which stemmed from "landfills" or dumps in the past, that prompted this legislation. Historically, disposal sites were selected due to characteristics which made them inappropriate or undesirable for any "higher" land use, such as swamps, wetlands, or poor soils. Subsequently, many "dumps" ended up in environmentally sensitive areas and contamination associated with dumps, especially water related, became widespread. In addition to inadequate siting procedures, poor design and operational techniques have compounded the pollution problems. If all the components of solid waste management and landfilling are not properly planned and monitored, the underlying groundwater systems may be jeopodized.

Landfills which existed prior to RCRA in Sussex County and are still operational include Sparta Landfill, Hardyston Landfill, Hopatcong Landfill, Stillwater Landfill, and Hamm's Landfill.

The Sussex County 208 Water Quality Management Plan states that, "Landfills located in the aquifer recharge areas should be closed and sealed to prevent continued percolation of highly polluted water. Monitoring wells should be installed to observe the extent and direction of contaminated groundwater movement." The County plans to be on line with a new county landfill by the end of 1983. The scope of services developed for the consultant firm performing the landfill siting study focuses on finding a site which offers suitable environmental conditions that will attenuate any leachate or other problems if a failure in engineering mechanisms required by RCRA should occur. County landfill siting was intentionally targeted for areas which are not potential groundwater recharge areas for major aquifers.

Technology has been developed to monitor and mitigate groundwater contamination from spills, but this is a costly approach.

Spills

A human activity which warrants major concern is the improper disposal or storage of hazardous or toxic materials. Whether accidental or intentional, the introduction of hazardous or toxic waste into the water system, especially groundwater, can cause irreparable damage to all forms of life.

Localized problems have occurred in Sussex County and are discussed later in the text.

Improper Disposal and/or Storage of Hazardous Waste

Hazardous waste, commonly referred to as the "problem of the '80's" has recently received much attention throughout the nation and especially in New Jersey, one of the largest generators of hazardous wastes. A manifest system tracing toxic waste from "cradle to grave" was recently initiated by the State.

All facets of hazardous waste management including technology to transport it, treat it, re-use it, store it, and reduce its generation are in need of improvement. Indiscriminant dumping in rural areas such as Sussex County poses a major problem to groundwater sources and all life forms in general. Such dumping is insidious and may not be discovered for years after which damage may be extensive.

Non-Point Sources

Residential Stormwater Runoff

Residential development can affect the quality of groundwater systems in a variety of ways: from the initial disturbance of the ground during construction to the introduction of foreign materials such as chemical herbicides and fertilizers, or by-products of combusion engines which accumulate in residentially developed areas and are carried by precipitation to water bodies.

Pollution problems from construction can be tied closely to the disturbance of natural features and critical areas. This results in the removal of protective vegetation and the creation of impermeable surfaces. The exposed soil is vulnerable to erosion and contributes to the incorporation of excess sediments into the water system causing increased turbidity. Toxic materials associated with the operation of heavy equipment during construction are also factors which can contribute to the degradation of groundwater by their improper use and disposal. Construction activities warrant special consideration when being undertaken in critical groundwater management areas since susceptibility of groundwater to contamination in these areas is especially high.

Impervious surfaces not only retard groundwater infiltration and recharge, but also serve to increase the quantity and velocity of runoff and therefore increase the ability of stormwater flows to carry contaminants.

The pollution which is picked up and carried by residential stormwater flow comes from a variety of sources including:

- particulates from the air which are dispersed to the earth's surface through precipitation (particulates stemming mainly from industrial emissions e.g. acid rain);
- particles gathered from stormwater running over road and parking lot surfaces which stem from sources such as
  - exhaust emissions from motor vehicles depositing the by-products of fuel combustion,
  - oil, gasoline or other fluid leakage, which contain organic chemicals,
  - de-icing agents such as salt and sand,
  - trash and litter discarded by careless people,
  - organic materials such as dirt and debris (leaf, etc.).
- nutrients or inorganics (such as heavy metals and nitrates) from fertilizers and pesticides which are spread in excessive quantities on lawns and other residential grounds.

All these materials have the potential of invading groundwaters and thereby degrading them especially in areas critical to groundwater management.

On Site Wastewater Disposal Systems

The most common on-site waste water disposal systems are subsurface septic systems. (See figure 3.) A septic system consists of a large settling tank into which waste water is discharged from the home. Solids precipitate in the settling tank, resulting in the formation of sludge on the bottom, and scum floats to the surface forming a layer at the top. Effluent from the tank is discharged into leaching fields, dispersing the effluent into the soil. Adsorption, the capability of the soil to adhere pollutants to soil particles, occurs in the soil medium. In this way, the effluent passing through the soil becomes gradually purified and recharge of the natural water system occurs.

Because of this capability of the soil to "treat" potential contaminants in the effluent, septic systems which are properly located, designed, installed, and maintained do not significantly endanger groundwater quality. However, negligence in any of these areas can result in an improperly functioning system and therefore contamination of groundwater supplies. Proper maintenance is especially key to the effectiveness of the system. It should be standard practice to have the tank inspected regularly and pumped on a periodic basis rather than when failure occurs.

The major threat to groundwater resources that is posed by septic systems is the possibility of nitrate contamination. Nitrate is readily soluble in water and thus easily transportable. Nitrate does not become adsorbed by soil particles, and a relatively small percentage undergoes denitrification. See Figure 2-A for a graphic description of the nitrogen cycle. If the nitrate concentration in groundwater exceeds 10 mg/1, the water is considered unsuitable for potable use by N.J. State standards. As long as there is a sufficient amount of nitrate free water infiltrating into the groundwater system, the nitrate concentration will be diluted. Proper density planning is essential to maintaining necessary levels of nitrate free water. Installing more septic systems than the natural system can dilute would result in a net increase of nitrate above 10 mg/1, rendering the water unsuitable for potable use. This topic is discussed extensively in the manual entitled, "Environmentally Based Growth Management: A Carrying Capacity Approach for Sussex County", also prepared by the S.C. Planning Department and 208 Water Quality Management Program, February 1982.

In addition to nitrate pollution, products used widely in the operation of the household can be introduced into the groundwater system through the septic system and adversely affect the drinking water supply. Some products containing organic compounds are listed below:

1. Shout (R), a stain remover containing tetrachloroethylene
2. Lysol (R), a disinfectant that contains xylenols
3. Drain cleaners which contain 111 trichlorethylene
4. Spot removers and cleaning fluids which contain petroleum hydrocarbons, benzene, trichloroethylene, and 111 trichloroethylene and tetrachloroethylene.

FIGURE 2A

The Nitrogen Cycle

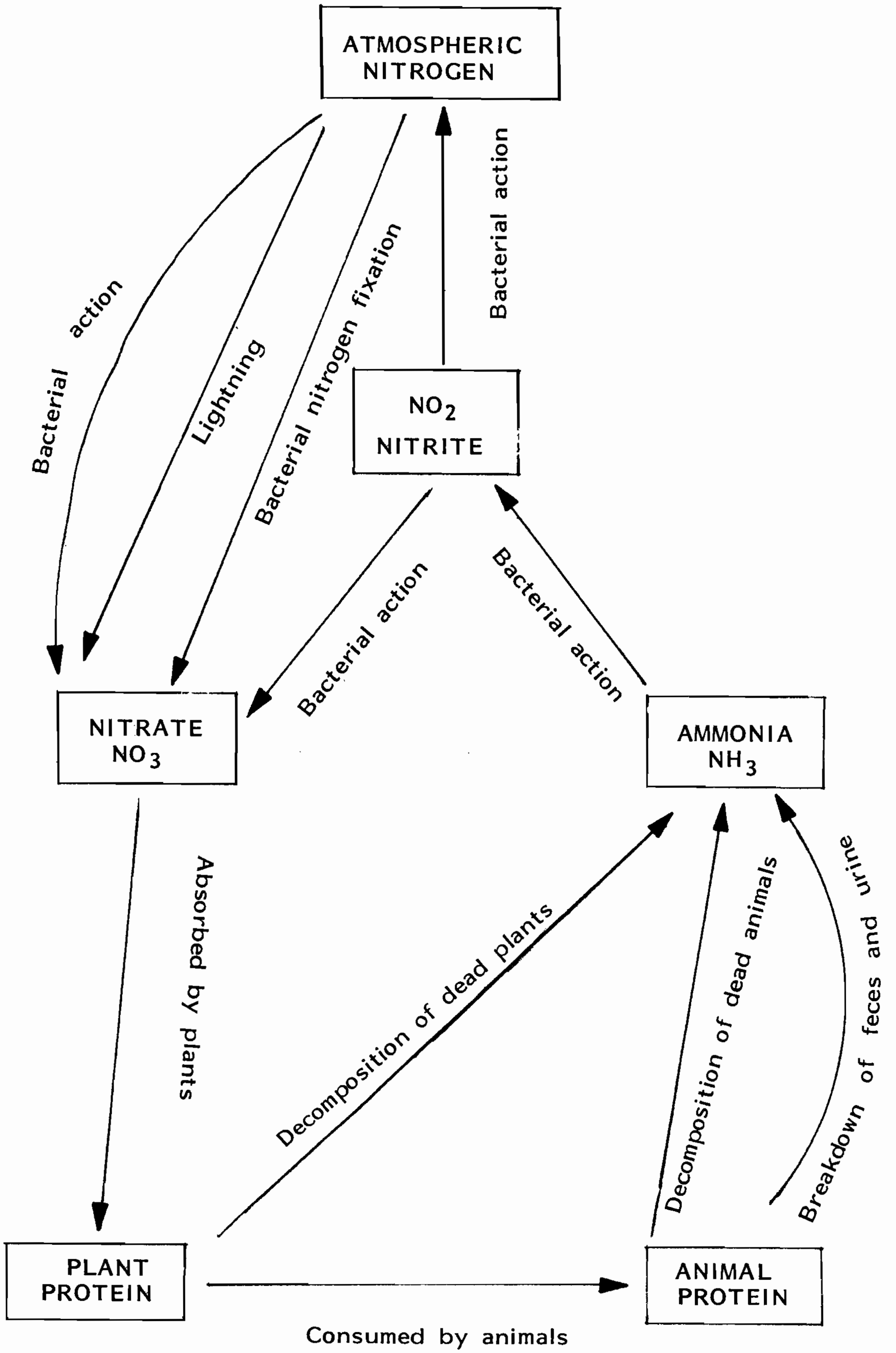
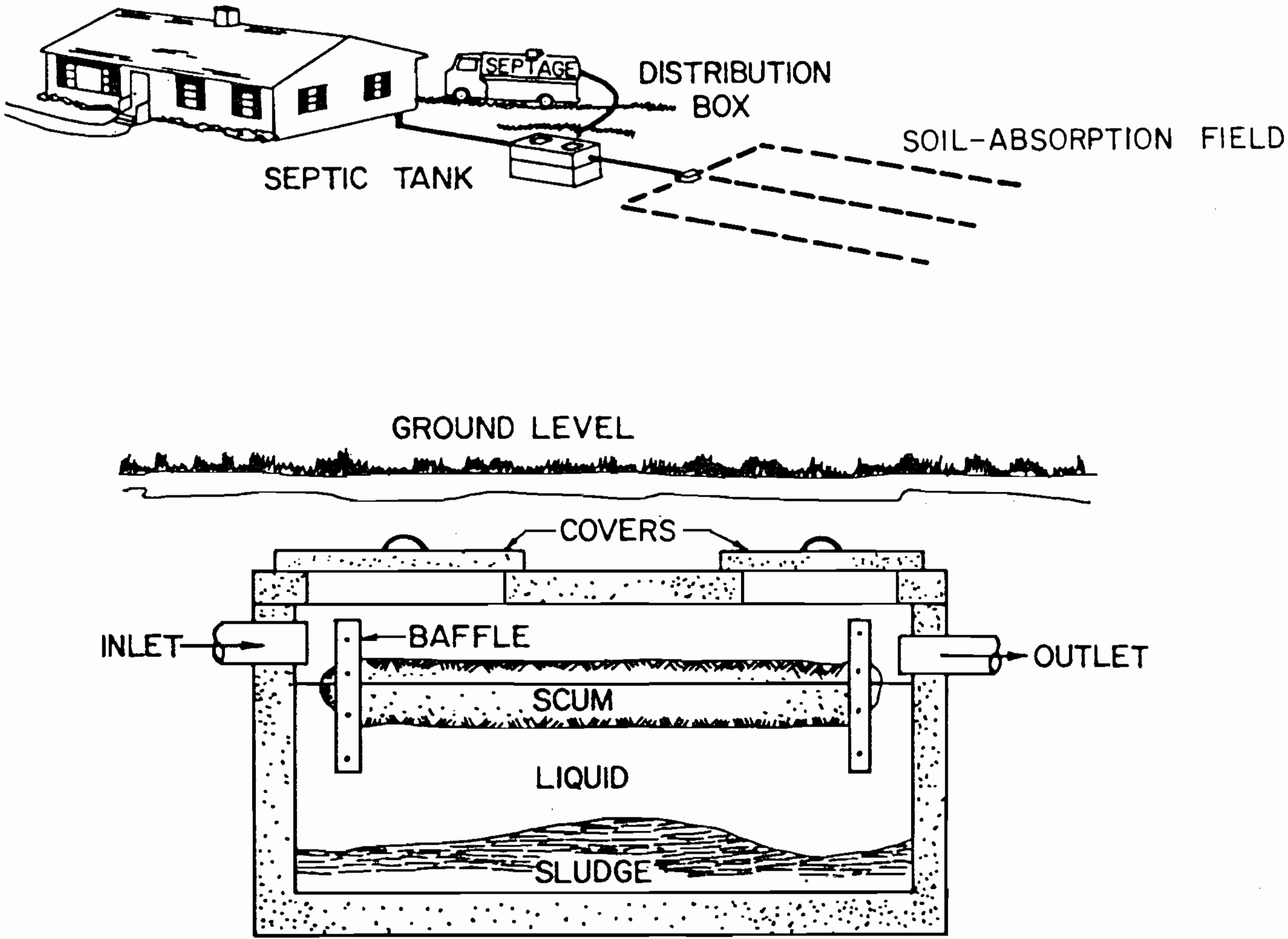


FIGURE 3

TYPICAL SEPTIC-TANK SYSTEM



Source: Pg. 18, Septic Waste Management Plan - Stearns & Wheeler

5. Septic system and cesspool cleaners which contain trichloroethylene and tetrachloroethylene.
6. Paint solvents.

Some of these compounds are found in much greater concentrations in industrial, commercial and agricultural wastes and thus their threat is intensified. The main reason why many organic compounds pose such a potential hazard to groundwater is that they are resistant to biodegradation, adsorption, or chemical bonding in the soil. A general list of common persistant organic compounds follows:

*1. Pesticides
*2. Chlorinated hydrocarbons
*3. Trichloroethylene (TCE)
*4. Perchloroethylene (PCE)
**5. Carbon Tetrachlorides
**6. 1,1 dichloroethylene
**7. 1,2 dichloroethane
**8. Chloroform
*9. Xylenols
*10. Benzenes

In Sussex County, where there is a heavy reliance on septic systems, there is also a serious lack of proper facilities for haulers to dispose of septage (material pumped from tanks). This situation unfortunately encourages some haulers to discharge their cargo illegally on the land in secluded places in the County which may also pose a threat to groundwater quality.

There have been many improvements made in the development of on-site waste water treatment systems that could help alleviate the situation if promoted County-wide. State-of-the-art developments and innovative and alternative technologies (I and A) for on-site waste water treatment have made on-site waste water disposal a more environmentally and economically sound option than regional collector sewers in many areas. These innovations have made on-site systems a permanent wastewater disposal solution rather than a temporary expedient pending the arrival of the "big pipe". A comprehensive approach to assessing I & A technologies for Sussex County is discussed in detail in the manual entitled "Innovative and Alternative Technology Guide for On-site Wastewater Disposal Systems in Sussex County" prepared by the Sussex County 208 Water Quality Management Program under contract, and should be referred to for more information.

Stormwater Runoff From Industrial Areas

The runoff from industrial areas can have varying effects on groundwater systems, depending on the nature of the operation, the kinds of wastes generated, and the manner in which they are handled. Many industrial operations either store or dispose of their wastes on-site. Solid wastes are usually landfilled, if enough space is available, and liquid wastes are often treated in lagoons. Both of these methods lend themselves to the creation of contaminants which may eventually reach groundwater.

---

* *From Lower Raritan/Middlesex County Water Resources Management Program Groundwater Recharge Management Handbook: Draft, FY 1980 Output, page 28.*

** *From Long Island Regional Planning Board, Long Island 208 Study, July 1978, Vol. II, pg. 157.*

Many industrial operations involve the emission of a great deal of waste particulates into the atmosphere, most of which combine with water vapor and fall as precipitation. This contaminated runoff then either soaks into the ground or becomes incorporated into stormwater runoff and eventually surface waters.

Problems with stormwater runoff from lawns and roads occur in industrial areas as they do in residential areas, especially where large expanses of impervious cover characterize the site. Industrial Parks are indicative of this type of development. Management Practices for residential stormwater runoff are often applicable to improving the stormwater situation. These practices can also be utilized along with other appropriate BMP's specific to industrial areas.

Stormwater Runoff From Agricultural Areas

Potential problems of groundwater pollution from agricultural sources are especially pertinent in a county such as Sussex where more land is in farming than any other land use.[1] If not properly managed, some of the following problems may result: The improper tilling of the soil for planting leaves it defenseless to erosion and causes the loss of countless tons of soil. Much of the soil can end up in streams and rivers. Other potential contaminants associated with agricultural by-products can also enter the water supply. Vegetative harvest by-products from cropland, ornamental groves, and orchards are picked up by stormwater or irrigation return flows and soak into the ground. Animal wastes, which include manure, carcasses, and slaughterhouse waste and bedding, as well as seepage from silos present other possible sources of contaminants as does food processing operations and leather manufacturing. Probably the most pervasive,and therefore most serious threat to groundwater from agricultural sources can be traced to herbicides, pesticides, and fertilizers which are applied to the land in massive quantities to maximize crop production. Chemicals involved with the sanitation, washing, and disinfection of milk houses and parlors are also sometimes involved as groundwater contaminants. All of these substances are easily transported by stormwater and can be carried into ground and surface waters.

The substances which are contained in agricultural by-products that can become harmful to groundwater include nutrients, heavy metals, bacteria, soluble organics, and suspended solids. Many farmers are trying to recycle some of these substances back to the soil to maintain its productivity. The storage and land application of manure is common practice, but the capability of soil to handle it is limited by plant nutrient requirements and soil characteristics. Approximately 300,000 tons of manure and bedding are produced annually in Sussex County.[2] If this amount of manure were spread on all available crop-

---

1. *Warren J. Welsh, "A Cow's Eye View of Sussex County", A Pamphlet produced by the Sussex County Extension Service.*
2. *The County of Sussex, <u>'208' Water Quality Management Plan,</u> April, 1979, Page VIII 29.*

land pasture in the County, the average application rate would range between 1.4 and 9.1 tons per acre per year.[3a] For the purpose of comparison, the recommended maximum base application rate on crop requirements for nitrogen, as proposed in the Sussex-Warren Resource Conservation and Development Program, is 20 tons per acre per year.[3b]

Surface Mining[4]

Surface mining, or the above-ground extraction of earth materials such as sand and gravel is also a common activity in Sussex County, where the remains of previous glaciation can be found in numerous sand and gravel deposits. Limestone is also mined in Sussex County, as well as other stone used in the construction industry. The mining is usually performed by large machinery which cuts away portions of a slope, exposing the parent material.

Surface mining operations have the potential to generate large volumes of sediment. As long as the sediment generated is contained on the mining site, it usually does not present a problem. However, if it washes into neighboring water courses, it becomes a resource-out-of-place and a pollutant by definition. The following is a list of some detrimental effects associated with surface mining:

- Occupies water storage in reservoirs
- Fills lakes and ponds
- Clogs stream channels
- Settles on productive land
- Destroys aquatic habitat
- Creates turbidity that detracts from recreational use of water and reduces photosynthetic activity
- Degrades water for consumptive uses
- Increases water treatment costs
- Damages water distribution systems
- Acts as a carrier of other pollutants (plant nutrients, insecticides, herbicides, heavy metals)
- Acts as a carrier of bacteria and viruses

Many of the above are also pertinent with respect to agricultural runoff.

Sediment can be transported long distances by high flows. But, being heavier than water, it is deposited ultimately in stream channels, ponds, reservoirs, and on floodplain lands. These deposits are an obstruction to navigation, water supply storage, flood control, and power generation in downstream areas. Sediment deposition also destroys the habitat of many forms of aquatic life and decreases the value of floodplain areas for recreational and agricultural uses.

The suspension of particles picked up by stormwater runoff causes turbidity that degrades the usefulness of water for many purposes and increases the costs of water treatment. Turbidity also has substantial

---

3a & b. The County of Sussex, '208' Water Quality Management Plan, April, 1979, Page VIII 29.

4. portions extracted verbatim from Erosion and Sediment Control, Surface Mining in the Eastern U.S., U.S.E.P.A. Technology Transfer, October, 1976.

biological effects in decreasing the amount of sunlight that reaches aquatic plants and in decreasing the oxygen that is available to fish.

That small particles of suspended sediment muddy the water is only the tip of the iceberg. These small particles are also capable of carrying some of the microscopic elements in soils along with them. Suspended sediment particles transport nutrients, fertilizers, pesticides, heavy metals, and disease organisms.

The major sources of sediment in surface mining operations are areas being cleared, grubbed, and scalped; roadways; spoil piles and areas of active mining; and areas being reclaimed. Common causes of sediment yield from these sources are discussed in the B.M.P. section of the manual.

Silviculture

Silviculture, which is conducted on a large scale in Sussex County, is the practice of systematically raising and harvesting timber. As with agriculture there can be detrimental effects of silviculture on water quality. Once again, the land is being deprived of vegetative cover which lessens erosion with leaves and roots as well as reducing soil moisture evaporation. Also, as in agriculture, cultivating large stands of trees involves residues from harvesting, pesticides, and other chemicals, which are leached into water supplies. These practices may also cause thermal pollution. Herbicides are often used to discourage regrowth of certain species. (Also, herbicides are used on some cleared utility rights-of-way).

Groundwater Quantity

Over-taxation of Groundwater Systems

A potential effect of over-pumping, or overdrafting, is that the resulting cone of depression or influence interferes with that of another well or well field and alters the production of surrounding wells. (See figure 4). Depending on the extent of the overdrafting, the cone of influence can be severe enough to cause wells to become dry. Another possible effect of overtaxation is the reduced flow or even drying up of adjacent stream beds. As mentioned earlier, this condition may result in the intrusion of water of less desirable quality which can permanently degrade the aquifer to the point where it is useless for consumption.

The Environmental Resources Division of the Metro-Dade County Planning Department in Florida has used the "cone of influence" determinations of its public wells on which to base a "well field" ordinance.[5] Most of Dade County is underlain by a large porous limestone formation which is saturated with water. This aquifer is the drinking water source for the entire county, as millions of gallons per day of high

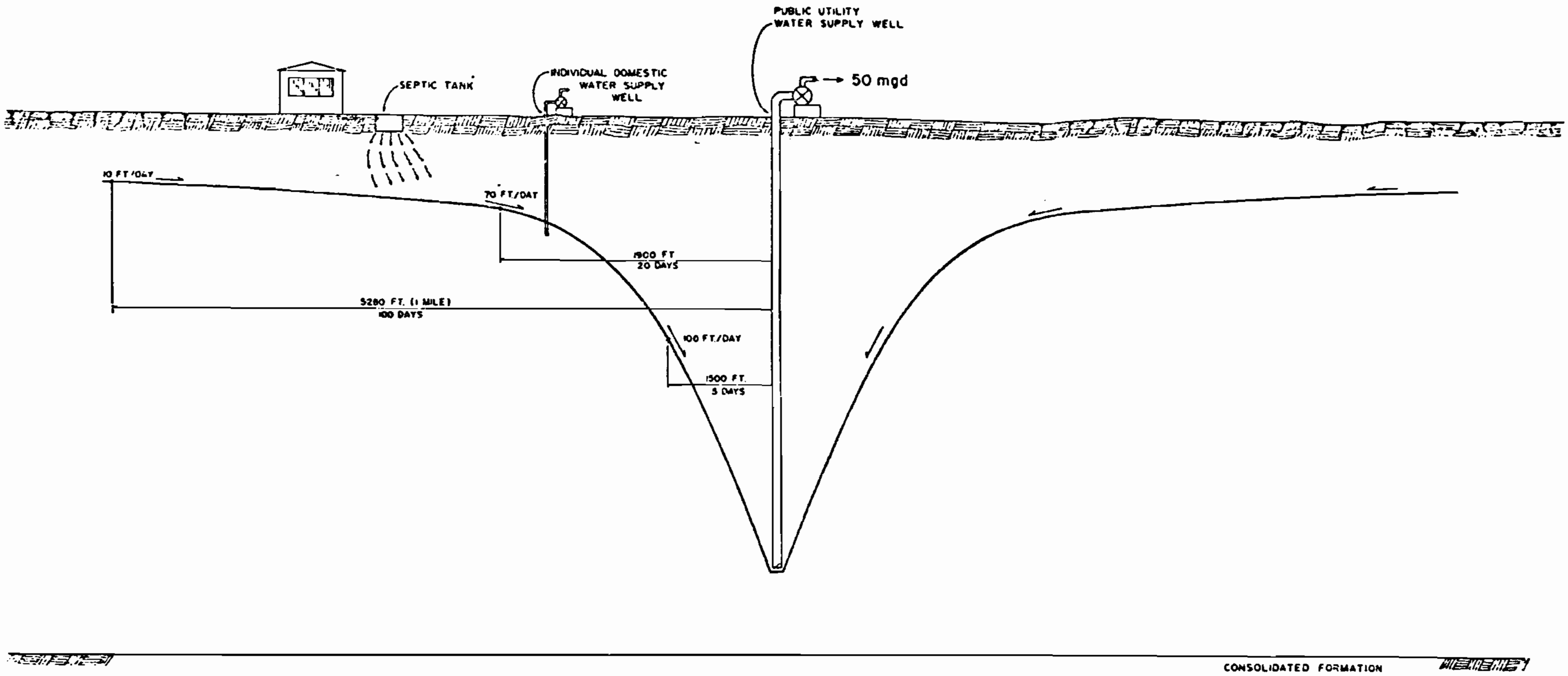
---

[5] *Department of Environmental Resources Management, Protection of Potable Water Supply Wells Program, Dade County, Fla., Dec. 30, 1980.*

Figure 4

CONE OF INFLUENCE

N.T.S.



SOURCE: Department Of Environmental Resources Management, Protection Of Potable Water Supply Wells Dade County, Florida, December 30, 1980.

quality water can be pumped from relatively shallow wells. As shown in two dimensions in Figure 4, the water level of an aquifer becomes most depressed at the point of extraction and gradually less depressed with increased distance from that point in any direction. The water in the aquifer moves toward the point of extraction at a rate which increases with decreasing distance. Therefore, the closer to the point of extraction that a potential pollutant enters the system, the greater the risk of it eventually contaminating the well. The relationship between the rate of water movement and the distance from the well or well field was translated into "critical zones of travel", which are based on travel time to the well and measured in days. Each one of these five zones has a set of restrictions on facility and zoning uses based upon acceptable pollutant loading. Because the water holding formation in this case is homogeneous throughout the area, the parameters determining the critical zones of travel can be uniformly applied to all public wells, no matter how they vary in size or yield.

In addition to causing a drawdown situation, over pumping lowers the volume of the existing water sometimes to the point that the concentration of natural salts becomes high enough to render the water undrinkable. Even the injection of considerable recharge may never restore the water quality in the aquifer system to its previous level. In addition, the unfortunate reality exists that if an aquifer is overtaxed, its potential as a long term water supply also becomes jeopardized. A vital component to managing groundwater systems, therefore, is the determination of and adherance to the "safe yield" of each specific aquifer. This is further described in the Chapters that follow.

Increasing Impervious Surface Cover

Another phenomenon that bears upon water quantity (and also water quality) is the prevention on recharge and promotion of runoff caused by covering the ground with impervious surfaces. This is an occurrence which is not specific to any particular land use, although they are all offenders to varying degrees. Generally speaking, a single family house built on a quarter acre lot covers 24% of the site with impervious surfaces.[6] Development at a higher density, such as with garden apartments, townhouses, or condominiums, covers 42% of the site with impervious surfaces. Commercial development covers around 85% of a typical site, while light industry covers 65%, and heavy industry covers 85%.[7] (See Chapter Five for a more detailed discussion of land uses and impervious surfaces.)

As indicated earlier, the ground surface area that is covered with impervious material, whether it be asphalt, concrete, or roofed structures, is removed from the reserve of land capable of directly recharging groundwater. In addition, because these surfaces are impermeable,

---

6. *Lower Raritan/Middlesex County Water Resources Management Program, Groundwater Recharge Management Handbook: Draft, Fy 1980 Output,*
7. *Ibid.*

water will accumulate and flow with greater velocity towards lower elevations where it is usually collected and channeled into streams, rivers, and lakes. Unfortunately this runoff, as discussed earlier, picks up the foreign matter that is deposited on the impervious surfaces between periods of precipitation. Thus, instead of becoming filtered and absorbed by the ground, the runoff produced by impervious surfaces becomes increasingly polluted as it interacts with parking lots, sidewalks, catch basins, and drain pipes. Many of the pollutants picked up and transported in this manner can eventually find their way to surface and/or groundwater and depreciate the entire system.

The parceling of farmland for residential subdivision increases net land coverage by impervious surfaces, concentrates residential wastes, and exacerbates the runoff problem. Therefore, water quality goals such as protecting aquifers and recharge areas can be congruous with goals aimed at keeping land in farming. Indeed, farming may be an ideal use for areas designated as sensitive to groundwater contamination as long as the proper BMP's are exercised. The land can be productive and still permit the normal process of the hydrologic cycle to function unimpeded.

It is sobering to think that land is continually being paved and built upon, but that the restoration of land back to recharge areas is a very rare circumstance. The writing on the wall says that there will be less water, it will be of lower quality, and more people will be using it. That is not a pleasant prospect for future generations.

Concentration of Natural Salts

In addition nitrate, which was discussed in detail earlier, the ions calcium (Ca), magnesium (Mg), potassium (K), and sulfate (SO_4) comprise the significant natural salts present in groundwater solutions. As with nitrates, these salts are picked up by recharging precipitation as it filters through the soil. Natural salts pose no threat to groundwater quality as long as the groundwater quantity is adequate to dilute it. Therefore, it is important that aquifers not be over pumped or "mined" to the extent that these salt concentrations reach the level where the water is unusable. In the same vein, it is important that excessive quantities of these salts not be added to the soil (e.g. fertilizer) where recharge occurs. The important relationship between groundwater quality and quantity becomes apparent in situations where significant accumulations of natural salts exist.