Chapter 26

Water quality issues in the outer coastal plains: New Jersey

Tait Chirenje, Claude Epstein and Raymond Mueller

Abstract

New Jersey is the most densely populated state in the US and yet it is home to one of the most pristine groundwater resources in the country, the Kirkwood–Cohansey Aquifer System. This chapter discusses some of the activities that affect water quality in New Jersey's coastal plains. The most significant activities are human induced and they include excessive groundwater withdrawal and the addition of non-point and point source contaminants. The effects of those human activities that alter surface soils in ways that promote the movement of chemicals to streams and groundwater is included. The chemicals addressed include point source contaminants coming from superfund sites, landfills, underground storage tanks (USTs), sewage facilities, stormwater runoff facilities, storage lagoons, and other "state permitted" discharges. The contaminants include nitrates (NO_3^-), phosphates, pesticides, some chlorides and trace metals, and many volatile organic compounds (VOCs). Some of these come directly from their natural or human-induced deposition on the surface or come about because of the secondary impact of these deposited chemicals on surface soils and sediments. Well water withdrawals have also altered the pre-development groundwater and surface water flow patterns. Chlorides from brackish bays and tidal rivers and from the ocean itself have recharged coastal plain aquifers in Raritan Bay, Delaware and along the Atlantic Ocean. These pumping centers are also drawing chlorides and other ions from saline groundwater coming from deeper aquifers. In addition, VOCs and Fe have recharged underlying aquifers from contaminated rivers and point sources toward these pumping centers.

26.1. Introduction

Water supply and quality are among the most important environmental issues confronting us today, with most observers ranking them second only to overpopulation. Water touches every aspect of our lives including sanitation, health, agricultural production, and economic growth. It even poses national security risks in many countries (Lawford and Fort, 2003). Therefore, it should be no surprise that the use (or misuse) of water has long been the subject of passionate debate among various sections of civil society.

Lakes, rivers, and streams have long been viewed as cheap dependable sources of water. However, human activities have had significant impacts on them. For example, water bodies have been used for the disposal of waste materials, and where waste is not discharged directly, it eventually finds its way into waterways. Draining, channelization, paving land surfaces, agricultural, industrial and construction have resulted in the loading of many rivers and streams with sediment and other materials, thus altering their hydrology. Before it makes its way back into rivers, streams and lakes, water undergoes considerable changes in its chemistry, temperature, microbial populations and physical attributes due to both anthropogenic and natural causes. This chapter discusses water quality issues in the coastal plain, with specific emphasis on New Jersey. It does not go into water supply issues or riparian rights and/or the identification of specific culprits for contamination.

26.1.1. Water quality criteria

Through the years, the phrase "water quality" has been used to refer to those characteristics of water that make it suitable for a specific use. Overall water quality is determined by its thermal, physical, chemical, and biological integrity. However, rarely do we ever need water that meets the standards for all four criteria. The Clean Water Act (1972), which sets water quality standards for all contaminants in surface waters, takes the specific uses of a water body into account in regulating the quality of the nation's surface waters. The discrimination of water according to specific uses enables us to deem certain water suitable for use for a specific purpose, e.g., irrigation, while it may not be safe for other uses such as drinking or industrial purposes. In order to distinguish between water that is suitable for particular uses, e.g., irrigation and not drinking, the United States Environmental Protection Agency (USEPA), in conjunction with several industries, educational and private institutions, has developed measurable water quality indicators for each specific use. For

example, salinity, specific ion toxicity, and low infiltration (from high sodium [Na] and low calcium [Ca] in soil), make otherwise good quality water useless as irrigation water for agriculture (Ayers and Westcot, 1994).

The surface and groundwater quality of the New Jersey coastal plain has been the focus of much attention recently (Ayers et al., 2000; Fischer et al., 2004). Studies of specific chemical components have been undertaken in various counties of the New Jersey coastal plain to address issues of public health. These include chlorides (Cl^-), nitrates (NO_3^-), iron (Fe), mercury (Hg), radium (Ra), volatile organic compounds (VOCs) and pesticides.

In our discussion of water quality issues in the coastal plain, reference will be made to the United States Geological Survey (USGS) New Jersey well monitoring program which makes use of about 150 randomly sited shallow wells in the state (Fig. 26.1; USGS, 2004a, b). These wells are located in urban (60), agricultural (60), and undeveloped (30) areas. The parameters measured by these wells differ depending on their location (input factors). For example, the urban/suburban wells measure non-point source pollution coming from fertilizers and pesticides, septic tank discharges, leaky sewers, automobiles, VOCs, and other urban contaminants. The agricultural wells generally measure non-point source pollutants from agricultural fertilizers and pesticides, liming agents, mobilized metals, and others. The wells in undeveloped areas measure atmospheric discharges, e.g., Hg, acid deposition, NO_3^-, pesticides, VOCs, etc. Before we engage in detailed discussions about this study, we will discuss watersheds and their roles in surface and groundwater quality.

26.1.2. Watersheds

As far back as the late 1800s, John Wesley Powell described a watershed as "that area of land, a bounded hydrologic system, within which all living things are inextricably linked by their common water course and where, as humans settled, simple logic demanded that they become part of a community." In other words, a watershed is the area of land where all of the water that is under it or drains off of it goes into the same place (USEPA, 1995a). The USEPA adopted a watershed approach to address the problems associated with locating both point and non-point source discharges (Younos et al., 2003; USEPA, 1995a, b, c) because of challenges they were facing in the enforcement of the Clean Water Act in large watersheds.

The most fundamental processes and components in watersheds include (i) the chemical, mineralogical, and physical nature of the source
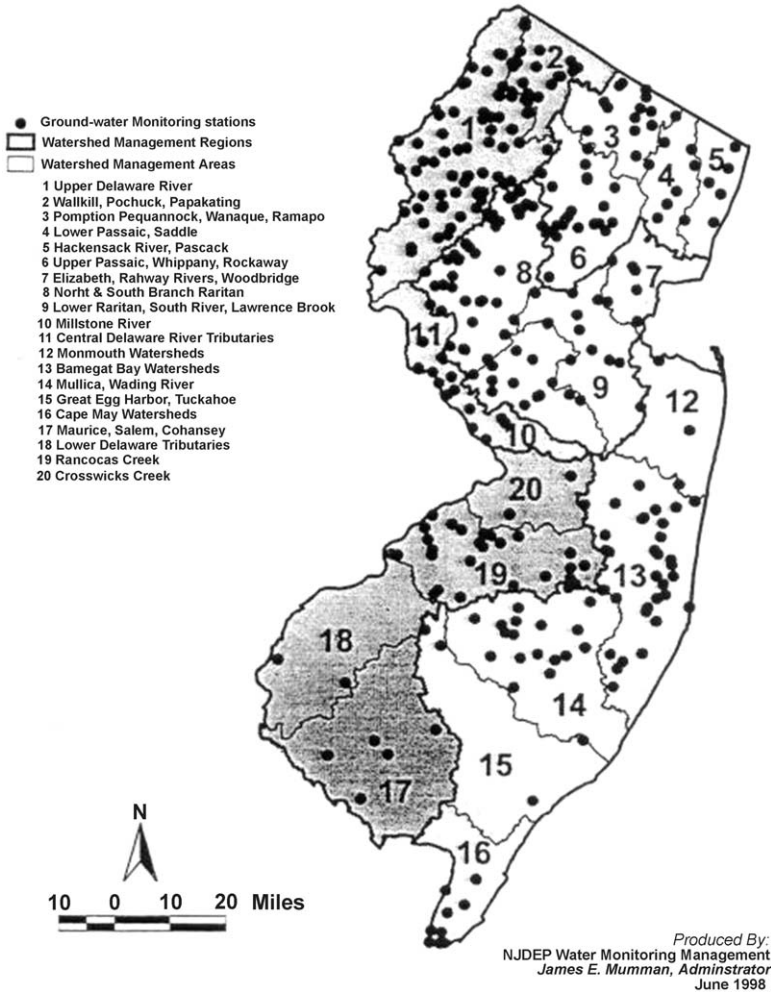
Ground-water Monitoring stations
Watershed Management Regions
Watershed Management Areas

1 Upper Delaware River
2 Wallkill, Pochuck, Papakating
3 Pomption Pequannock, Wanaque, Ramapo
4 Lower Passaic, Saddle
5 Hackensack River, Pascack
6 Upper Passaic, Whippany, Rockaway
7 Elizabeth, Rahway Rivers, Woodbridge
8 Norht & South Branch Raritan
9 Lower Raritan, South River, Lawrence Brook
10 Millstone River
11 Central Delaware River Tributaries
12 Monmouth Watersheds
13 Bamegat Bay Watersheds
14 Mullica, Wading River
15 Great Egg Harbor, Tuckahoe
16 Cape May Watersheds
17 Maurice, Salem, Cohansey
18 Lower Delaware Tributaries
19 Rancocas Creek
20 Crosswicks Creek

N

10   0   10   20 Miles

Produced By:
NJDEP Water Monitoring Management
James E. Mumman, Adminstrator
June 1998

Figure 26.1.   New Jersey groundwater monitoring program network.

regions of chemicals and sediment, (ii) the nature of their transport and
the processes occurring along pathways, and, (iii) the identification
of, and chemical processes occurring within, sinks. While understanding
all these enables us to link all the processes that are occurring in
New Jersey's watersheds and come up with a full understanding of water
issues in this region, this discussion focuses on the source regions of
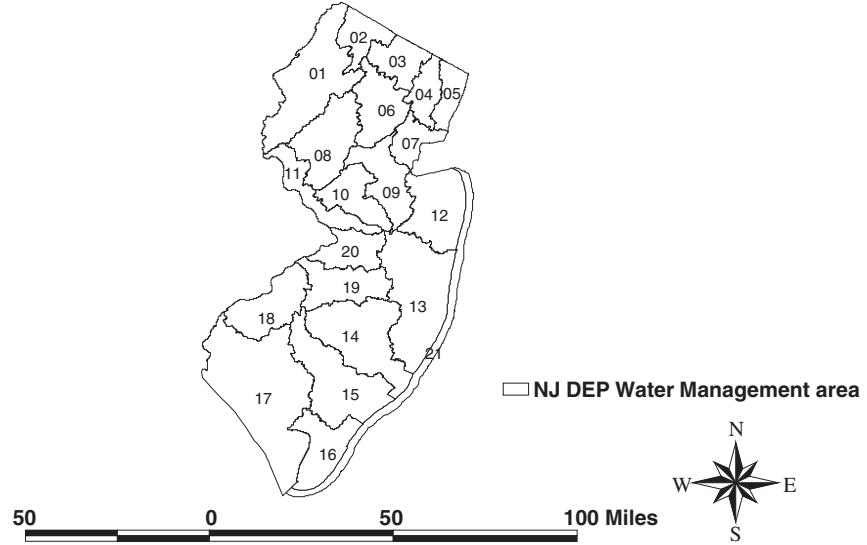chemicals and sediment and select processes occurring in the sink regions
(Fig. 26.2).

Figure 26.2. New Jersey water management areas.

26.2. Factors affecting water quality

Both surface and groundwater quality are affected by a multitude of
factors. Although both natural and anthropogenic factors are equally
important, in this discussion emphasis will be placed on how ant-
hropogenic factors alter the natural environment. Two such activities are
(i) the introduction of contaminants to the ground surface, leading to
polluted runoff into surface water bodies, and (ii) well water withdrawals,
which induce the infiltration of surface water and the intrusion of brack-
ish and saltwater. Well water withdrawals also draw in contaminated
groundwater from greater depths and distances within the aquifer or
adjacent aquifers. A few factors that are of most significance in the
coastal plain have been identified for this discussion. They include, but
are not limited to: land use changes (agriculture to urban) and, devel-
opment (increased urbanization and industrial activity), stormwater
management, and treated wastewater disposal.

26.2.1. *Application of contaminants to the surface of the New Jersey coastal plain*

Both point and non-point source pollution is significant in the coastal
plain. Point source discharges are carefully monitored by both the
NJDEP and USEPA. These include superfund sites (sites containing
contaminated groundwater or other releases that are a direct threat to
health and safety; USEPA, 2004a), landfills (NJDEP, 2004a), under-
ground storage tanks (USTs; NJDEP, 2004b, d), and sites of permitted
discharge (NJDEP, 2004c). Table 26.1 shows the distribution of such sites
in select counties in New Jersey.

   The kinds of facilities that have been given discharge permits by the
state include stormwater runoff systems, municipal solid waste plants,
infiltration lagoons, spray irrigation fields, dredge spoils, injection wells,
biosolid land applications, thermal waste water, sewer overflow, etc.
Table 26.2 presents the relative percentages of the areas where permitted
discharges are issued. In order to understand the full impact of these
discharges, a discussion on the hydrologic and geochemical setting of the
New Jersey coastal plain is necessary.

26.2.1.1. The hydrologic and geochemical setting of the New Jersey coastal plain

The New Jersey coastal plain is made up of a wedge of unconsolidated
sediments that thickened from the Delaware River Valley, which lies in
the western part of New Jersey, toward the Atlantic Ocean, which borders
the eastern side of the state. The northern and southern margins of the

Table 26.1. NJ point-source inventory

County	Landfills	Superfund sites	Registered underground storage tanks	NJPDES "discharge" permits
Atlantic	37	10	476	242
Burlington	37	14	800	420
Camden	33	10	801	707
Cape May	18	1	245	197
Cumberland	26	5	283	192
Gloucester	29	7	359	243
Monmouth	32	11	982	441
Ocean	36	12	825	313
Salem	16	1	164	131
Total	264	71	4935	2886

Table 26.2. Relative proportions of costal plain discharges

Discharged to:	% of Coastal plain permits
Surface runoff	31.3
Groundwater recharge	29.9
Surface water discharge	20.3
Storage	5.5
Rejuvenated and recycled	4.7
Combination	8.3

Atlantic coastal plain are bounded by the brackish waters of the Raritan and Delaware Bays, respectively. The coastal plain can be further divided into an inner and outer coastal plain. The inner coastal plain lies beneath the Delaware River Valley below Trenton, New Jersey, forming a northeast to southwest trending restricted belt of sand, clay, and greensand units whose geologic ages range from Lower Cretaceous to the lowermost Miocene. These units make up the base of the wedge overlying pre-Cretaceous bedrock. Except along the outcrop belts of these units, the aquifers within the inner coastal plain (the Potomac–Raritan–Magothy, the Englishtown, the Wenonah–Mt. Laurel, the Vincentown and the Piney Point Aquifer Systems) are confined. The outer coastal plain occupies most of the coastal plain by far and is commonly referred to as the "Pine Barrens." The outer coastal plain includes generally coarse textured sand and gravel units whose geologic age is younger (Miocene) than the inner coastal plain. The units of the outer coastal plain, overlying the units of the inner coastal plain, constitute an unconfined aquifer (the Kirkwood–Cohansey Aquifer System; Zapecza, 1989). This aquifer lies in the New

Jersey pine barrens and it contains about 17 trillion gallons of water. This water source is rated one of the cleanest in the United States (USEPA, 1995c).

26.2.1.2. Impact of development on the New Jersey coastal plain hydrology/ geochemistry

Rhodehamel (1970) defined the hydrologic cycle of the outer coastal plain as consisting of a single input (precipitation) and three outputs (evapotranspiration, groundwater recharge, and surface runoff). This also applies to the inner coastal plain although further refinement of the definition is necessary to account for the hydrologic and geochemical impact from human activities. Figures 26.3 and 26.4 are simplified schematics representing the pre-developed (without significant human settlement and construction) and developed hydrologic cycles of the New Jersey coastal plain.

The increase in well water withdrawals reversed the relationship between surface water and groundwater. In the pre-development condition, groundwater discharged from aquifers into the Raritan and Delaware Bays, the Delaware River, and the Atlantic Ocean. The increase in population and well water withdrawals formed massive cones of depression in some parts of the coastal plains. As a result, surface water recharges some parts of the coastal plain aquifers resulting in saltwater intrusion.

In addition, the cones of depression along the margins of the Delaware River have induced infiltration of river water into portions of the underlying aquifers. Moreover, since the rate of withdrawal from the New
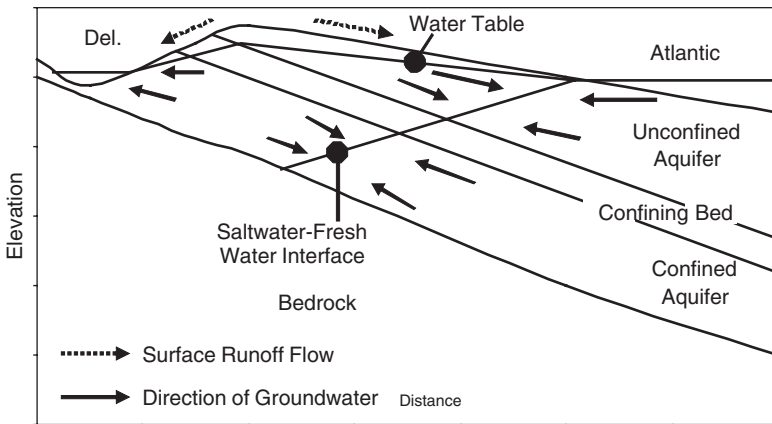

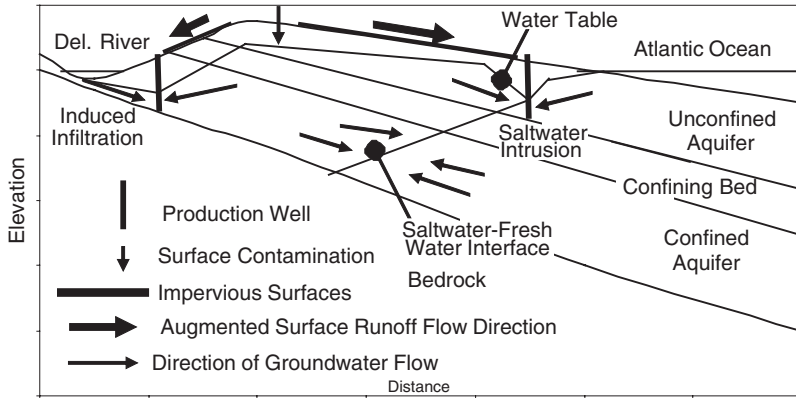*Figure 26.3.*   Pre-developed hydrologic cycles of the New Jersey coastal plain.

Figure 26.4. VOC concentrations in public supply wells (USGS, 2004b).

Jersey side of the coastal plain increased while that on the Pennsylvania side decreased, groundwater from Pennsylvania has been drawn under the river into New Jersey (Sloto, 2003).

Deeper within coastal plain aquifers, saline groundwater has been formed by the combination of saltwater recharge from the geologic past and the long-term accumulation of dissolved solids (Meisler, 1989). This deeper saline groundwater has been drawn westward toward pumping centers on the New Jersey side of the Delaware Valley.

Transfer of organic and inorganic materials from the atmosphere and the surface of the coastal plain, to the unconfined aquifers, adjacent streams, and the nearby coast has also increased with development. Superfund sites, landfills, septic systems, storage lagoons, leaky USTs, land application facilities, increased volumes of applied fertilizers and pesticides, deposition of air pollutants such as acid rain, heavy metals and organics, as well as accidental chemical spills and illegal dumping are all sources of these materials. Superfund sites are of particular interest. Although New Jersey is the fourth smallest state in the US, it is home to the largest number of superfund sites (114 in 2003), with Pennsylvania being the only other state to top 100 sites (NJDEP, 2003).

Finally, the construction of impervious surfaces (i.e., roads, buildings, industrial and commercial centers) and stormwater runoff facilities have altered two elements of the hydrologic cycle: sediment movement and chemical loss in runoff. Since most of the coastal plain surface is made up of unconsolidated sediments covered by forest or agriculture, groundwater recharge constituted a far greater percentage of hydrologic output than surface runoff during pre-development times (Rhodehamel, 1970).

The emplacement of impervious surface cover and the construction of
stormwater runoff networks have increased surface runoff while decreas-
ing groundwater recharge at the same time. Consequently, more organic
and inorganic materials make their way into streams and bays.

26.2.1.3. Sources of chemicals of concern to water quality

The chemicals affecting water quality by natural and human activities
include chlorides, NO_3^-, Fe, Hg, Ra, VOCs, fertilizers, and pesticides.
Their sources vary (Ervin et al., 1994).

  Chlorides: Coastal plain streams and aquifers are generally not con-
taminated with chlorides (Table 26.3; Watt and Johnson, 1992; Watt
et al., 1994, 2003; Lacombe and Rosman, 1995; Johnson and Watt, 1996;
Johnson and Charles, 1997). Stream concentrations, however, may be
elevated briefly in winter during periods of snow when salt is applied to
roadways. More long-term elevation results when contamination is by
other sources, e.g., saline groundwater drawn toward large cones of de-
pression, intrusion of brackish water from bays and ocean (and up
streams during times of drought; DeLuca et al., 2003).

  Saline groundwater underlies fresh groundwater in coastal plain aq-
uifers. A transition zone, called the saltwater–fresh water interface, marks
the boundary between these two water bodies. The depth of this bound-
ary can extend from sea level by the shore to a depth between a few
hundred to over a thousand feet beneath the surface of New Jersey. The

Table 26.3.   Chloride, nitrate & ammonia concentrations in coastal plain watershed

	Cl^-		$NO_3 + NO_2$		$NH_3 + Org\ N$	
	Min	Max	Min	Max	Min	Max
Streams						
Mullica	4.1	23	<0.05	4.18	<0.20	2.0
Great Egg Harbor	1.1	180	0.49	5.91	0.11	18
Upper Maurice	1.1	36	<0.05	3.70	<0.20	5.10
Toms, Meteconk. Kettle	6.4	12	<0.01	0.94	0.30	0.80
Rancocas, Assunpink, Blacks, Crafts	3.0	35	<0.01	3.10	0.30	4.80
Salem, Raccoon, Oldmans, Alloway, Stow	2.8	24	0.70	1.31	0.30	1.5
Aquifers						
Mullica	<0.10	16	<0.10	10	<0.20	0.90
Great Egg Harbor	2.3	16	<0.10	11	<0.20	0.80
Upper Maurice	2.2	35	<0.01	3.60	<0.20	1.00
Toms, Meteconk. Kettle	2.0	55	0.02	5.75	<0.05	0.52
Rancocas, Assunpink, Blacks, Crafts	2.8	35	<0.10	9.80	<0.20	2.10
Salem, Raccoon, Oldmans, Alloway, Stow	3.5	39	0.08	24	<0.20	2.60

distance inland to which this layer of salt water extends beneath the overlying freshwater increases with aquifer depth, and extends to within approximately 10 miles of the Delaware River for the deepest aquifer (the Potomac–Raritan–Magothy [PRM] Aquifer System, Meisler, 1989). Furthermore, the pumping center in the Camden vicinity has drawn the fresh water–saltwater interface to the northeast, thereby elevating chloride levels in parts of Gloucester and Salem counties. Saltwater contamination from surface saltwater bodies also induced by pumping centers has raised chloride levels in different aquifers in different parts of the coastal plain (Schaefer, 1983; Spitz and Barringer, 1992).

Iron: Iron enters surface and groundwater by the dissolution of iron-bearing minerals under anaerobic and low pH conditions. These conditions exist where the decomposition of organic matter (OM) consumes oxygen and generates acids in such settings such as muck soils, organic-rich sediments, accumulated organic wastes, leaky sewers and septic systems, landfills, and wastewater disposal systems. In addition, these conditions may occur under impervious surfaces such as clay or asphalt (Ervin et al., 1994).

Iron is common in both coastal plain surface water and groundwater. Near wetlands, Fe occurs in its lower oxidation state [Fe(II)] in the low pH, anaerobic conditions associated with elevated dissolved organic carbon (DOC) concentrations, especially during the summer (Johnson and Barringer, 1993). Once Fe(II) is recharged to underlying aquifers, it encounters oxygenated groundwater or atmospheric oxygen when it discharges at the surface. It then transforms into insoluble Fe(III) and precipitates as $Fe(OH)_3$ through processes often facilitated by iron bacteria (Zampella et al., 2001).

Many groundwater discharge sites on the coastal plain possess soils and surface deposits enriched in an Fe precipitate (i.e., limonite), locally called *bog iron*. Bog iron was heavily used in the late 18th and early 19th centuries for the production of Fe in the numerous iron furnaces built throughout the coastal plain (Pierce, 1957).

Iron concentrations above the National Secondary Drinking Water Standard (NSDWS, $300 \mu g \, l^{-1}$) occur in most coastal plain streams. The NSDWS is also exceeded in groundwater within and just down flow of the outcrop of the Potomac–Raritan–Magothy Aquifer System along the east side of the Delaware River. This region is highly urbanized (Lewis et al., 1991; Ervin et al., 1994). Iron also occurs in elevated concentrations in the other coastal plain aquifers (the Englishtown, Wenonah–Mt. Laurel, Vincentown, Piney Point, and Kirkwood–Cohansey Aquifer Systems, Watt and Johnson, 1992; Watt et al., 1994, 2003; Lacombe and Rosman, 1995; Johnson and Watt, 1996; Johnson and Charles, 1997; DeLuca et al., 2003).

The aforementioned situations represent generally "natural" groundwater flow conditions, but the direction of groundwater flow has been greatly altered by the massive pumping center near Camden. Groundwater, heavily enriched in Fe, has been drawn from old industrial sites in Philadelphia, under the Delaware River, to New Jersey by (a) the cessation of pumping on the Philadelphia side of the river, and (b) the progressive decrease in hydraulic head in the pumping center near Camden (Sloto, 2003).

Mercury: Mercury is a minor trace element in the sediments of the New Jersey coastal plain. The only mineral known to contain traces of Hg in this area is glauconite and it is mainly found in the inner coastal plain (Dooley, 1992). By far, the preponderant sources of Hg are aerial deposits. Other sources include geologic deposits, oceanic volatilization, and human sources (i.e., the processing of alkalis and metals and the incineration of medical wastes and fossil fuel combustion at electric plants). Once deposited, it may occur as the organic soluble complexes (e.g., methyl mercury, CH_3Hg) in ground and surface water. It is rarely found at toxic levels in surface and groundwater but it does become concentrated as CH_3Hg in fish and wildlife (USGS, 2000) through bioaccumulation and biomagnification, reaching toxic levels in some fish (NJDEP, 2002).

New Jersey DEP and USGS studies show mercury in the Kirkwood–Cohansey aquifer at levels above the national primary drinking water standard (NPDWS, $2\,\mu g\,l^{-1}$) in 265 of 2239 wells sampled (USGS, 1997). They identified four possible sources of the Hg, which include: atmospheric deposition from regional sources, historical land-applied mercurial pesticides, household contaminants, and point sources such as landfills and industries. Historical use of pesticides and Hg-based exterior paint were believed to be the more significant sources.

In terms of air emissions, NJDEP boasts the most stringent Hg regulations for municipal solid waste incinerators in the US. As a result, great strides have been made in reducing Hg emissions from municipal waste combustors, which includes a reduction from 2000 kg in 1993 to about 360 kg in 1996. This was achieved using both emission controls and source reduction. Approximately 90% of small facilities (notably, apartment complexes, which add about 65 kg per year) shut down their incinerators and are using alternate waste disposal options, resulting in cleaner air (NJDEP, 2002).

Radium: Radium reaches groundwater through dissolution from radium-bearing minerals in soils and aquifers under similar conditions. The source of the Ra found in the surface and groundwater of the coastal plain is probably from the decay products of impurities in minerals

present in coastal plain sediments. These minerals, making up minute percentages of coastal plain sediments, include ilmenite, monazite, rutile, sphene, tourmaline, zircon, glauconite, and muscovite (Dooley, 1992).

Radium concentrations exceeding the USEPA NPDWS have been reported from Kirkwood–Cohansey wells in the outer coastal plain (Szabo et al., 1997). Three isotopes of Ra (Ra-224, Ra-226, and Ra-228) have been identified in the coastal plain by the USGS (Szabo et al., 1997; Szabo and DePaul, 1998). These studies report that 33% of the 170 Kirkwood–Cohansey wells exceeded the USEPA maximum contamination level (MCL, 5pCi/L) for the combined concentration of Ra-226 and Ra-228. But this elevation was most common in agricultural areas situated on the Bridgeton Formation. The Bridgeton Formation is made up of radioactive minerals transported from northern New Jersey, Pennsylvania and New York. The normally low pH of the outer coastal plain is made more acidic by the application of fertilizers, thereby leaching Ra from these minerals into the underlying unconfined aquifer.

Zapecza and Szabo (1986) reported elevated Ra concentrations in parts of the coastal plain adjacent to the fall line in the southeastern United States. This would be equivalent to the concentration level in the inner coastal plain of New Jersey. Table 26.4 shows the metal results of the New Jersey surface water monitoring program.

Volatile Organic Compounds: Volatile organic compounds are considered the third major threat to groundwater quality behind pesticides and nitrates (USEPA, 1988). They come from various point sources such as landfills, spills, leaky USTs and above-ground storage tanks (ASTs),

Table 26.4. Trace metal results from the New Jersey surface water monitoring study

Detectable trace elements	N	Number of wells in which trace elements detected by land use			Maximum value detected ($\mu g\,l^{-1}$)	NJ drinking water MCL ($\mu g\,l^{-1}$) 1996
		Agricultural ($N = 31$)	Urban ($N = 22$)	Undeveloped ($N = 22$)		
Arsenic	70	9	5	7	112	501
Barium	70	30	22	18	1180	2000
Cadmium	69	6	7	1	16	5
Chromium	69	13	10	4	3.6	100
Copper	70	20	14	7	38	1300AL
Lead	70	8	8	2	11	15AL
Mercury	70	2	1	0	1.7	2
Selenium	70	13	10	4	13.1	50
Total Detections	–	101	77	43	–	–

After Serfes (2004).

and waste lagoons, landfills and contaminated runoff and recharge. They occur in highest concentrations in urbanized areas. In the inner coastal plain, they occur largely in the outcrop area of the Potomac–Raritan–Magothy (PRM) aquifer system (Ervin et al., 1994), with higher occurrence in the more urbanized lower aquifer. They are also found in the outer coastal plain in the Kirkwood–Cohansey aquifer system. Withdrawals from public supply wells, having large radii of influence, tend to intensify VOC concentrations by intercepting recharge from many point sources (Ervin et al., 1994). In such cases, monitoring wells could underrepresent VOC exposure in drinking water due to their small radii of influence. Common organic chemicals found in the New Jersey surface water monitoring study (Serfes, 2004) were methyl tertiary butyl ether (MTBE, detected in 4 and 10 out of 31 and 22 agricultural and urban wells, respectively), chloroform (detected in 7, 8, and 9 out of 31, 22, and 18 wells in agricultural, urban, and undeveloped land, respectively), perchloroethylene (detected in 4, 3, and 0 out of 31, 22, and 18 wells in agricultural, urban, and undeveloped land, respectively), and toluene (detected in 4, 2, and 1 out of 31, 22, and 18 wells in agricultural, urban and undeveloped land, respectively).

Nitrates reach surface and groundwater largely from precipitation, fossil fuel combustion, agricultural and residential fertilizers, and wastewater. Pesticides and herbicides generally come from agriculture, but also from residential neighborhoods, gardens, lawns, golf courses, parks, and landfills. Both nitrates and pesticides are discussed in more detail in later sections.

26.2.1.3.1. Impact of well water withdrawal on water quality
The population of the New Jersey coastal plain has increased rapidly over the last century, with the state having a population of 8,700,000 in 2005 (US Census Bureau, 2005). One consequence has been the increase in groundwater withdrawal through production wells. Pumping centers of various sizes in aquifers have altered the pre-development groundwater flow pattern, drawing contamination from water overlying unconfined aquifers and from nearby streams, bays, and coastal waters (Ervin et al., 1994).

26.2.2. Retention basins, stream hydrology and pollutant load

Retention or detention basins are used to delay, capture, store, treat, or infiltrate stormwater runoff so it does not discharge directly into a surface water body. Under perfect conditions, the retained or detained water is only discharged from the basin either by infiltration or evaporation. In

reality, stormwater basins are only effective in reducing on-site and downstream flooding by controlling the rate of stormwater discharge. Good stormwater management practices (SMPs) take the watershed approach, i.e., stormwater management in sub-watersheds must take into account the changes caused by new and existing development in the whole watershed.

Other benefits from stormwater basins include water quality improvement such as sediment removal, aesthetics and recreational opportunities. Although stormwater basins also remove sediments, most of them are not designed for that purpose. Specific sedimentation basins, used during construction, are used for this purpose, i.e., to control off-site migration of sediment. This helps preserve the capacity of downstream reservoirs, ditches, diversions, waterways, and streams. Sometimes sedimentation basins are converted to stormwater basins at the end of the construction period.

26.2.2.1. Stormwater management and coastal water quality

Increased development and urbanization has led to an increase in paved and impervious areas leading to an increase in stormwater runoff volume and non-point source pollution in New Jersey. Contrary to the popular belief that stormwater runoff is natural and harmless, urban stormwater is the second largest source of water quality damage in estuaries (USEPA, 1995a, b). It is also a substantial contributor to the damage of other water bodies. The decrease in trees, grasses, and other plants that normally serve as filters has led to less filtration of the even higher pollutant loads in many urban areas. The long list of potential pollutants in urban stormwater includes nutrients (e.g., NO_3^- and phosphates), heavy metals (e.g., chromium [Cr], copper [Cu], lead [Pb], and zinc [Zn]), microbial contamination (bacteria and fungi), organic materials (oil, grease, pesticides, plasticizers, and flame retardants) and sediment and litter (Table 26.5). Sources of these pollutants include streets, parking lots, driveways, golf courses and lawns, leaking sewers and septic tanks, pet wastes, and construction sites (Oberts and Osgood, 1991).

Urban stormwater quality issues are particularly important in New Jersey because it is the most urbanized state in the United States. Currently, 15% of the total land area in New Jersey is considered urbanized (Nizeyimana et al., 2001) and this urbanization trend continues to increase (national urbanization average ∼3%; Obarska-Pempkowiak, 2001). Because stormwater basins are not designed to handle 100-year floods, stormwater quality is often closely related to surface water quality. Increased urbanization and paving has led many stormwater basins to fail

Table 26.5. Common pollutant load in stormwater

Pollutant	Typical concentration
Total suspended solids	$80\,\mathrm{mg\,l^{-1}}$
Total phosphorus	$0.30\,\mathrm{mg\,l^{-1}}$
Total nitrogen	$2.0\,\mathrm{mg\,l^{-1}}$
Total organic carbon	$12.7\,\mathrm{mg\,l^{-1}}$
Fecal coliform bacteria	3600 MPN/100 ml
E. Coli bacteria	1450 MPN/100 ml
Petroleum hydrocarbons	$3.5\,\mathrm{mg\,l^{-1}}$
Cadmium	$2\,\mathrm{\mu g\,l^{-1}}$
Copper	$10\,\mathrm{\mu g\,l^{-1}}$
Lead	$18\,\mathrm{\mu g\,l^{-1}}$
Zinc	$140\,\mathrm{\mu g\,l^{-1}}$
Chlorides (winter only)	$230\,\mathrm{mg\,l^{-1}}$
Insecticides	$0.1\text{--}0.2\,\mathrm{\mu g\,l^{-1}}$
Herbicides	$\leqslant 5\,\mathrm{\mu g\,l^{-1}}$

From Schueler (1987, 1995, 1996, 1997); Rabbanal and Grizzard (1996), USEPA (1983) and Oberts and Osgood (1991).

even with rain events below the 10-year floods, exacerbating the situation. A national survey of waterways in 1998 found that 65% of New Jersey's assessed waterways failed to meet water quality standards (USEPA, 1998). Cahill Associates (1993) demonstrated that a typical suburban-density development with 23% impervious cover would deprive groundwater aquifers of over 40 million gallons of recharge per square mile annually. Even more alarming is the fact that it is estimated that 100-year floods would occur at a frequency of 5 years if impervious cover increases beyond 65% (Hollis, 1999). Barringer et al. (1994) observed that as development occurred, there were increases in flow and flow variability in two streams in New Jersey, although it was difficult to attribute the increase to specific causes. Table 26.6 shows the effect of development on the area of impervious surface.

Although efforts to control soil erosion and sediment control date as far back as 1975, when the New Jersey Soil and Sediment Control Act was enacted (N.J.S.A. 4:24–3 and 4:24–42) and the Standards for Soil Erosion and Sediment Control in New Jersey (N.J.A.C. 2:90–1.1), municipalities were only required to condition development approvals from the local Soil Conservation District for projects disturbing more than 5000 square feet of land. The recently published New Jersey stormwater rules (NJDEP, 2004 c, d) require counties, through municipalities, to develop stormwater plans in their jurisdiction and submit them to the state for approval. This will go a long way in addressing stormwater quality in the state.

Table 26.6. Typical impervious surface coverages for common land uses

Surface cover	Impervious surface (% of total site)
Forest	5
Parks	15
Lawns/pastures	20
Playgrounds	25
Residential (units/acre)	
1	15
2	25
3	34
4	42
5	48
6	52
7	56
Business district or surgical center	95

Adapted from Wells (1994).

26.2.3. Treated wastewater disposal and coastal water quality

Our success in protecting and improving coastal water quality largely depends on our ability to treat urban wastewater and manage stormwater. Under provisions of the Clean Water Act, the USEPA has the authority to implement pollution control programs such as setting wastewater standards for industry, fund the construction of sewage treatment plants under the construction grants program, and address the critical problems posed by non-point source pollution.

The main objectives of wastewater treatment are to convert sewage into suitable end products that can be discharged into any environmental media (e.g., waterways) economically and efficiently. This is done through a set of treatment procedures that include: (a) preliminary treatment (screening for large objects), (b) primary treatment (sedimentation), (c) secondary (biological) treatment, and (d) tertiary treatment. The extent of each treatment is dependent on the quality requirements of the receiving streams.

Since 1972, the federal government has invested over $84 billion dollars in improving wastewater treatment plants, with the private sector investing more than double that amount (Association of State and Interstate Water Pollution Control Administrators, AWPCA, 1992). This has led to a significant reduction of pollution in discharge zones of treated sewage effluent. For example, the number of people served by municipal systems that provided no wastewater treatment or had only primary treatment decreased from 34 million to 1.15 million from 1972 to 1992. At the same

time, the number of people on systems with advanced treatment increased from about 6 million to more than 60 million. New Jersey benefited immensely from these investments by improving the water quality on its coastal areas substantially, and beach and bay closings have been dramatically reduced since 1988.

26.2.3.1. Septic tanks, USTs and landfills

The Barnegat Bay watershed is one of New Jersey's 96 watersheds. It comprises a 1700 square kilometer area encompassing all of the land and water in Ocean County, as well as parts of Monmouth County. More than 500,000 people live within the Barnegat Bay Watershed, and that population doubles in the summer with an influx of visitors from Philadelphia, New York, and other parts of New Jersey. Studies by the Barnegat Bay National Estuary Program (BBNEP) Scientific and Technical Advisory Committee (2001) identified nutrient and pathogen pollution as high priority management areas in the watershed. Most of the nutrient flow and pathogens were attributed to urban land uses, especially the use of septic tanks and other effluent discharges. For example, the BBNEP estimated that the amount of septic effluent flow that recharged the groundwater table in Ocean County amounted to 1,330,000 gal day^{-1} (5,030,000 l day^{-1}). They arrived at this value by multiplying the total of 8437 septic systems within the Barnegat Bay watershed by 3.5 persons per system, and 45 gal (170 l) per person per day (USEPA, 1980). Nitrate loadings from all septic systems were estimated to range from 216,930 to 295,300 kg year^{-1}.

Septic tanks do considerable damage due to the relatively short distance between the bottom of the septic system and the sandy texture of the Cohansey sands, which comprise most of the Barnegat Bay watershed. Sometimes homeowners, unaware of the harmful effect of their actions, flush paint thinners, degreasers, cleaners, and detergents into septic systems, exacerbating the problem.

Underground storage tanks are another source of pollutants in the Barnegat Bay watershed. They include USTs for storing gasoline, cleaning fluids, farm chemicals, and/or home heating oil. In New Jersey, tanks with a capacity of 2000 gal (7570 l) must be periodically tested and to have leak detection measures, but there are no such requirements for the homeowner (NJDEP, 2004c). Homeowners only have to worry about USTs when there is change of ownership. The NJDEP now maintains a database of USTs in every county.

Landfills are another significant source of pollutants in this watershed. Landfills that were constructed in the past were a little more than dump

sites (Hill, 2004). They were constructed without liners or caps so that rainwater percolated through the garbage, concentrated sewage and chemical wastes and, ultimately drained down into underlying soils and groundwater. This problem has since been solved for new landfills by requiring liners, leachate collection systems, and methane capturing devices. Although old landfills still contribute to the problem (Hill, 2004), many of these sites have found their way on the national priority list (NPL) to accelerate remediation.

26.2.4. Agricultural nutrients and pesticides

Agricultural runoff (non-point source pollution) carries sediment, nutrients, salts, pesticides, and fertilizers, which threaten both groundwater and surface water. The discussion of agricultural input in New Jersey should be concentrated in the agricultural south, which is, coincidentally, located in the New Jersey Pinelands. A New Jersey Pinelands Commission study by Zampella (1994) demonstrated that land-use related disturbance had a substantial effect on the natural water chemistry of Pinelands streams. He demonstrated a gradient of increasing pH, specific conductance, and concentrations of soluble Ca, Mg, total nitrite plus NO_3^-, ammonia (NH_3) and phosphate that correlated with watershed disturbance (increasing urban and agricultural land-use intensity and wastewater flow). However, NO_3^- and phosphates in many of the 14 sites sampled were traced back to wastewater treatment plants rather than agricultural areas. Nonetheless, agricultural areas still contribute a considerable amount of nutrients, salts, pesticides, and sediment to waterways.

26.2.4.1. Sediment and salts

Sediments have been discussed under urban stormwater. This section discusses agricultural stormwater and runoff. In New Jersey, agricultural stormwater is regulated under Tier 2 municipalities (NJDEP, 2004c, d).

Agricultural activities contribute much of the global sediment supply to rivers, lakes, estuaries, and the world's oceans (Milliman and Syvitski, 1992). Sediment pollution affects water bodies in many ways such as: through excessive turbidity, reducing photosynthesis, increasing temperature in the water column, and deposition in river and lake beds, leading to ecological and physical changes of the water bodies. Sediments may also cover fish eggs and prevent spawning in some lakes. The fine fraction of eroded soils also carries adsorbed chemicals, e.g. NO_3^-, phosphates, chlorinated pesticides, VOCs, and metals, which alter stream or lake chemistry, hence affecting aquatic biota. The presence of NO_3^- and

phosphates in waterways leads to eutrophication (the excessive promulgation of aquatic vegetation, notably algae, due to nutrient enrichment in waterways), which leads to decreased dissolved oxygen (DO) levels as the same aquatic vegetation decompose.

Livestock acreage in New Jersey predominantly consists of small equestrian enterprises. The often barren exercise lots and paddocks possess compacted soils. These impervious soils generate sediment and excess runoff that picks up animal wastes releasing not only sediment, but also NO_3^-, phosphates, OM, and pathogens to surface waters. This is a significant problem in some counties where horse farms comprise half the acreage of all agricultural land, e.g., Ocean County.

Zampella et al. (2001) showed that developed land and upland agriculture explained 84–89% of the variability in pH, EC, Ca, Mg, and Cl^-, with agriculture accounting for a greater percentage of the variation in Ca and Mg concentrations. Agriculture also accounted for 53% of the variability in sulfate concentrations. Developed urban land explained 84% of the variability in Cl^- concentrations, possibly from deicing salts (Zampella et al., 2001). The elevated levels of Ca and Mg were associated with land-use related watershed disturbance, with liming being cited as a possible culprit (Johnson and Watt, 1996).

26.2.4.2. Nitrates and phosphates

Nutrients from fertilizers play a significant role in eutrophication of water bodies in New Jersey. Although adults are less susceptible, NO_3^- in excess of $10 \, mg \, l^{-1}$ can cause human infant methemoglobinemia (blue baby syndrome), which can be fatal (USEPA, 1988). Although excessive phosphates have not been linked to any physiological problems in humans, they are often the limiting nutrient for eutrophication to occur in water bodies. For this reason, activities that release phosphates tend to correlate very well with eutrophication.

Due to the diverse land uses in New Jersey, it is difficult to attribute the sources of nutrients to one specific land use activity. Nitrates and phosphates may originate from a variety of activities including: inorganic fertilizers used in agricultural, residential or commercial areas, wastewater discharges, septic tanks, pet wastes, other land-applied animal wastes, or from other organic residuals such as sludge.

Because New Jersey is highly urbanized, it is prudent to also consider the contribution of urban areas to nutrient pollution. Applying loading rates given by Palone and Todd (1997) to the Barnegat Bay watershed, lawn fertilizers contribute $5–10 \, kg \, ha^{-1} \, year^{-1}$ of nitrates from typical residential lots. This means that there is the potential for $286{,}580–573{,}200 \, kg \, year^{-1}$ of

NO_3^- wash off from lawns in the Barnegat Bay watershed if you take the 1997 residential population and divide it by 3.5 persons per household and multiplying by application rates for NO_3^- on lawn fertilizers.

Less than 25% of New Jersey residents test their soils before applying fertilizers and even fewer use slow release fertilizers (Grandin, 1993). Even professional lawn service companies surveyed at the same time did not regularly test lawn before applying fertilizer. This contributes to increased NO_3^- and phosphate losses through leaching and erosion. In fact, studies done by the BBNEP Scientific and Technical Advisory Committee showed that urban areas contributed more NO_3^- and phosphates to the watershed than agricultural areas (BBNEP Scientific and Technical Advisory Committee, 2001).

Generally NO_3^- is not a significant aquifer contaminant, but some trends in NO_3^- concentrations have been reported. Nitrate concentrations in aquifers decrease with depth (MacLeod et al., 1995). In the outer coastal plain, NO_3^- concentrations are higher in the Kirkwood–Cohansey aquifer system beneath agricultural land than other types of land use (MacLeod et al., 1995; Szabo et al., 1997). In the inner coastal plain, NO_3^- is generally low in aquifers but in the outcrop of the Middle and Upper Aquifers (PRM), both NO_3^- and NH_3 are elevated especially beneath the urban areas around the City of Camden and adjacent parts of Gloucester County (Ervin et al., 1994). Ammonia has been reported at or above the New Jersey Secondary Standard (i.e., $0.5 \, mg \, l^{-1}$) in several urbanized streams in the inner coastal plain (DeLuca et al., 2003). Figure 26.5 shows the distribution of NO_3^- in groundwater (U.S. Geological Survey, 2004a).

26.2.4.3. Pesticides

Pesticides tend to be applied to large areas, thus they are considered non-point source contaminants. Both the United States Department of Agriculture (USDA) and the New Jersey Experimental Station have been recommending different types of pesticides since the late 1800s. This long-term use has resulted in pesticide residues of certain persistent pesticides in soil at concentrations that exceed the NJDEP residential soil cleanup criteria and may pose risk especially to children who ingest these soils. For example, up to 5% (240,000 acres) of the total area of New Jersey (5 million acres) may be impacted by the historical use of arsenical pesticides. Cheaper, relatively safer and more effective pesticides, e.g., organochlorines, were only developed in the late 1960s (Hayes and Laws, 1991; NJDEP, 1999). Lead arsenate was the pesticide of choice for apple (and other fruit) orchards, golf courses, turf farms and vegetable fields, and was usually applied at several pounds per acre. Calcium arsenate was
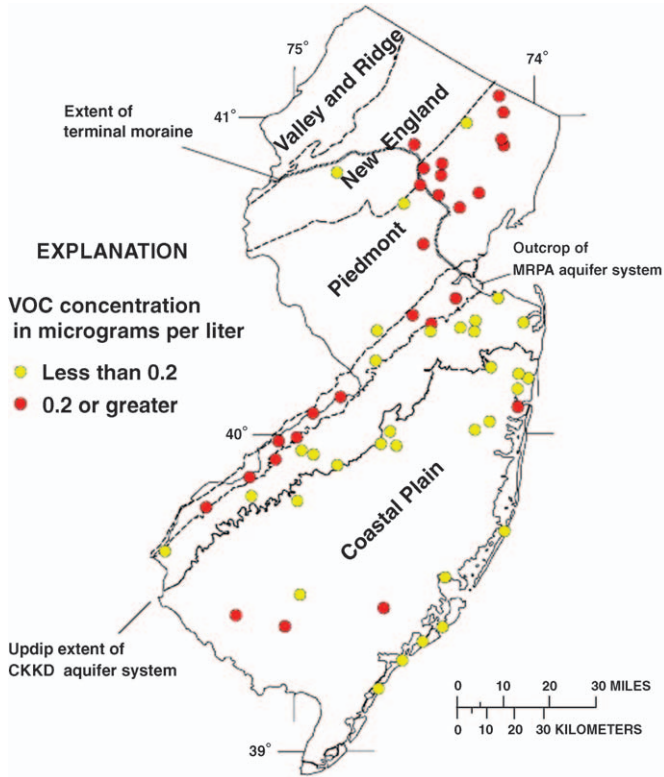
Figure 26.5.   Nitrates in water from wells sampled by the USGS.

used on white potato farms (Murphy and Aucott, 1998). Lead arsenate
contamination is suspected predominantly in six counties (Burlington,
Cumberland, Gloucester, Hunterdon, Monmouth and Salem) because
they account for most of the fruit production over the last 90 years, with
Burlington and Gloucester being the largest producers.

Interestingly, arsenical pesticides use was reduced mainly due to its cost
and effectiveness rather than health and safety considerations. The or-
ganochlorines, dichlorodiphenyl trichloroethane (DDT), Aldrin and Die-
ldrin, were applied in varying proportions on different crops. Hence, it is
difficult to predict where they are likely to be found in the state. However,
the USEPA banned the use of DDT in 1972 and that of Dieldrin and
Aldrin on foodstuffs in 1974 and on all products in 1987 (USEPA, 1990).
All three chemicals have made the dirty dozen list, a list of 12 of the most
dangerous organic chemicals to be phased out from use internationally,
developed at the Stockholm Convention in 1998.

As agricultural land is converted to other land uses, developers, municipal officials, homebuyers, and even lending agencies are inquiring and even testing for pesticide residues in soils. It is not unusual for some municipalities to require environmental assessments of land as part of their site approval process.

Ayers et al. (2000) studied the nature of pesticides in coastal plain surface water and shallow groundwater. In almost all streams and 63% of the groundwater samples tested pesticides were detected below NPDWS standards. Four herbicides (atrazine, metachlor, prometon, simazine) and some of their metabolites occur commonly. Atrazine and metolachlor are found in streams and shallow groundwater in agricultural areas, and are applied largely by licensed applicators. Prometon and simazine, also found in streams and shallow groundwater, are commonly used by non-licensed applicators such as homeowners and occur in urban areas. Prometon is used to clear roadways, railroad beds, and other right of ways. Consequently, it may also occur in areas of mixed land use. Simazine is found in streams and shallow groundwater in both agricultural and urban areas.

Ayers et al. (2000) reported that the insecticide carbaryl was rarely found in groundwater samples in spite of its common usage. Carbonates generally have a short half life and are easily metabolized by plants. They further reported that many organochlorine insecticides were commonly detected in low concentrations. Dieldrin, used in residential areas for termite control and in agricultural areas for insect control, has been detected in stream sediments. It was also detected in 24–27% of the monitoring and production wells sampled in their study and in 20% of the streams draining agricultural areas. The use of dieldrin was discontinued for agricultural use in the 1970s and for termite control in the 1980s. The fact that it is still being detected is testimony to the stability of organochlorines in the environment.

Results from the New Jersey surface water monitoring study showed a preponderance of pesticides and herbicides in wells in agricultural areas. Wells in undeveloped land, typically had concentrations below detection level (Serfes, 2004). Common pesticides and herbicides were atrazine (detected in 14 and 5 out of 31 and 22 agricultural and urban wells, respectively), deethylatrazine (detected in 15 and 4 out of 31 and 22 wells in agricultural and urban land, respectively), dieldrin (detected in 2 wells in both agricultural and urban land, respectively). Others that were detected include metolachlor (detected in 16 and 3 wells in agricultural and urban land, respectively), DDE (detected in 4 and 1 well in agricultural and urban land, respectively), prometone (detected in 4 and 7 wells in agricultural and urban land, respectively), and simazine (detected in 10

and 3 wells out of 31 and 22 wells in agricultural and urban land, respectively; Serfes, 2004).

26.2.5. *Trace metals and their effects on stream geochemistry*

Iron occurs in its soluble ferrous state in low pH, anaerobic conditions. However, streams in the New Jersey Pinelands are characterized by an unusual reddish brown color, as a result of decomposed plant material and dissolved Fe(III). Due to the underlying parent material, groundwater in the Coastal Plain area contains large concentrations of dissolved Fe(II) and Mn(II). These metals are oxidized under oxic environments such as grottos, springs, and swamps, a process often facilitated by Fe bacteria (e.g., Lepothrix), causing the chemical reactions that precipitate the ore masses. A thin film of rust forms on its surface and floats. The iron oxide combines with sand and gravel to form a low-grade iron ore that includes siderite (iron carbonate, a white ore) and other iron oxides (red ores) that are deposited along stream banks.

Both hydrous ions of Fe and Mn affect chemical reactions in surface waters due to their ion exchange capacities derived from pH-dependent surface charge (Parks, 1967). This means that the hydrous metal oxides are anion and cation exchangers in acid and alkaline solutions, respectively. There is limited exchange under neutral conditions. Manganese is generally oxidized to Mn(II) oxide in oxic and alkaline conditions, leading to greatest adsorption under oxidized alkaline conditions when it changes to Mn(IV) [insoluble] (Parks, 1967). On the other hand, Stumm and Lee (1960, 1961) found that Fe(III) was the only species found in slightly acidic to alkaline conditions under oxidizing conditions. They noted that Fe(II) was stable in oxic conditions only under highly acidic conditions, e.g., acid mine drainage. Thus Fe(II) would precipitate out as a hydroxide or carbonate under conditions of moderate to high carbonate alkalinity. Ferric iron hydroxide precipitates in an amorphous form, giving it unique absorption properties. Freshly precipitated Fe(III) hydroxide exhibits high sorption compared to aged Fe(III) hydroxide, possibly due to the rearrangement of the structure, tending to a more crystalline form (Morgan and Stumm, 1965). It is important to understand boundary conditions that lead to formation of precipitates, e.g., change in pH and redox, because metal-facilitated transport and sequestration takes place at the same time.

Apart from their economic importance, both dissolved and suspended Fe are important in colloid generation and transport (in conjunction with suspended organics). These colloids play a significant role in the retention, mobility, and availability of various trace elements and nutrients, as

well as the degradability of various xenobiotics (e.g., pesticides). For example, several workers have reported that adsorption (or co-precipitation) of As on Fe oxides is a major factor in determining the concentration of dissolved and suspended As in groundwater (Welch and Lico, 1998), rivers (Johnson and Thornton, 1987; Fuller and Davis, 1989), pore waters (Masscheleyn et al., 1991), lake water (Belzile and Tessier, 1990; DeVitre et al., 1991; Moncure et al., 1992), and in estuaries. Work done by Welch et al. (2000) provided evidence of Fe oxides affecting As in water, including: (1) correlation between Fe and As in sediments and sediment extracts, (2) observations that As concentrations vary with diel pH cycles, and (3) laboratory column studies.

The adsorption of trace elements, e.g., As, by $Fe(OH)_3$ depends on pH, the concentration of $Fe(OH)_3$ and competing ions. Co-precipitated As is released from iron oxide as the crystalline growth of the oxide proceeds. Although As(III) is adsorbed faster than As(V), adsorption proceeds very quickly for both species, with 90% of total As being adsorbed within $24\,h^{-1}$ (Raven et al., 1998).

Iron compounds can also release As into the environment. For example, Lovley (1991) showed a biologically mediated reaction (dissimilatory Fe reduction) that releases As from Fe oxide using OC. In fact, the high concentrations of As in some groundwater can be attributed solely to the dissolution of Fe compounds (Nagorski and Moore, 1999). Shapiro (1964) found that some natural water organics reduced the size of ferric hydrous oxide precipitates to between 0.1–0.45 μm in the presence of natural OM. This enhanced colloid-facilitated transport of other metals through the peptization of the Fe species. In the absence of natural OM, ferric hydrous precipitates were larger than 0.45 μm and were filtered out by standard membrane filters. Since organics by themselves exhibit ion exchange, their interaction with hydrous ferric oxides may affect their adsorption of and/or complexation with metals such as Cu, Cd, and Cr. This has profound effects on the aquatic chemistry of streams.

26.3. Conclusion

We discussed water quality issues in the Coastal Plains of New Jersey. Human activity considerably influences water quality in the coastal plain by applying chemicals or altering surface soils in ways that promote the movement of chemicals to streams and groundwater. Some of these are point-source contaminants coming from superfund sites, landfills, USTs, sewage facilities, stormwater runoff facilities, storage lagoons, and other "state permitted" discharges. The contaminants include NO_3^-, phosphates, pesticides,

some chlorides and trace metals, and many VOCs. Some of these are non-point source contaminants coming directly from their natural or human-induced deposition on the surface or come about because of the secondary impact of these deposited chemicals on surface soils and sediments.

However, a second human activity that has had a great deal of impact indirectly comes from well water withdrawals, which have progressively risen with population growth. Pumping centers in various parts of the coastal plain have altered the pre-development groundwater and surface water flow patterns. Chlorides from brackish bays and tidal rivers and from the ocean itself have recharged coastal plain aquifers in Raritan Bay, Delaware, and along the Atlantic Ocean. These pumping centers are also drawing chlorides and other ions from saline groundwater coming from deeper aquifers. In addition, VOCs and Fe have recharged underlying aquifers from contaminated rivers and point sources toward these pumping centers.

REFERENCES

Association of State and Interstate Water Pollution Control Administrators, 1992. America's Clean Water: The States' Evaluation of Progress 1972–1992.

Ayers, R.S., Westcot., D.W., 1994. Water Quality for Agriculture. UNFAO Publication, pp. 24–64.

Ayers, M.A., Kennen, J. G., Stackelberg, P.E.,. 2000. Water Quality in the Long Island-New Jersey Coastal Drainages, New York and New Jersey, 1996–98: U.S. Geological Survey Circular 1201, p. 40.

Barnegat Bay National Estuary Program (BBNEP) Scientific and Technical Advisory Committee, 2001. Barnegat Bay National Estuary Program Characterization Report.

Barringer, T.H., Reiser, R.G., Price., C.V., 1994. Potential effects of development of flow characteristics of two New Jersey streams. Water Resour. Bull. 30(2), 6–40.

Belzile, N., Tessier, A., 1990. Interactions between arsenic and iron oxyhydroxides in lacustrine sediments. Geochim. Cosmochim. Acta 54, 103–109.

Cahill Associates, 1993. Stormwater Management Systems, Porous Pavement System with Underground Recharge Beds, Engineering Design Report, Cahill Associates.

DeLuca, M.J., Hoppe, H.L., Heckathorn, H.A., Riskin, M.L., Gray, B.J., Melvin, E., Liu, N.A., 2003. Water Resources Data New Jersey 2003. Volume 3. Water-Quality Data: U.S. Geological Survey Water-Data Report NJ-03-3, p. 668.

DeVitre, R., Belzile, N., Tessier, A., 1991. Speciation and adsorption of arsenic on diagenetic iron oxides. Limnol. Oceanogr. 36(7), 1480–1485.

Dooley, J.H., 1992. Natural Sources of Mercury in the Kirkwood-Cohansey Aquifer System of the New Jersey Coastal Plain. New Jersey Geological Survey Report 27, p. 17.

Ervin, E.M., Voronin, L.M., Fusillo, T.V., 1994. Water Quality of the Potomac-Raritan-Magothy Aquifer System in the Coastal Plain, West-Central New Jersey. U.S. Geological Survey Water-Resources Investigations Report 94–4113, p. 114.

Fischer, J.M., Riva-Murray, K., Hickman, R.E., Chichester, D.C., Brightbill, R.A., Romanok, K.M., Bilger, M.D., 2004. Water Quality in the Delaware Basin, Pennsylvania, New Jersey, New York & Delaware, 1998–2001. U.S. Geological Survey Circular 1227, p. 38.

Fuller, C.C., Davis, J.A., 1989. Influence of coupling of sorption and photosynthetic processes on trace element cycles in natural waters. Nature 340, 152–154.

Grandin, B. A., 1993. Exploring householder's use of lawn and garden chemicals in a subwatershed of the Great Swamp: Preliminary findings. Technical Report, Department of Human Ecology, Cook College, Rutgers University, New Brunswick, New Jersey.

Hayes, Laws, 1991. Handbook of Pesticide Toxicology. Academic Press, San Diego, CA.

Hill, M.K., 2004. Understanding Environmental Pollution, second ed.. Cambridge University Press, Cambridge, UK.

Hollis, G.E., 1999. The effect of urbanization on floods of different recurrence interval. Water Resour. Res. 11(3), 434.

Johnson, C.A., Thornton, I., 1987. Hydrological and chemical factors controlling the concentrations of Fe, Cu, Zn and As in a river system contaminated by acid mine drainage. Water Res. 21(3), 359–365.

Johnson, M.L., Charles, E.G., 1997. Hydrology of the unconfined aquifer system, Salem River area: Salem River and Raccoon, Oldmans, Alloway, and Stow Creek basins, New Jersey 1993–94. U.S. Geological Survey Water-Resources Investigations Report 96–4195, 5 sheets.

Johnson, M.L., Watt, M.K., 1996. Hydrology of unconfined aquifer system, Mullica River basin, New Jersey, 1991–92. U.S. Geological Survey Water-Resources Investigations Report 94–4234, 6 sheets.

Lacombe, P.J., Rosman, R., 1995. Hydrology of the unconfined aquifer system in the Upper Maurice River basin and adjacent areas in Gloucester County, New Jersey 1986–87. U.S. Geological Survey Water-Resources Investigations Report 92–4128, 5 sheets.

Lawford, R., Fort, D., 2003. Introduction. In: Water: Science, Policy and Management. Water Resources Monograph 16. American Geophysical Union. 10.1029/016WM01. p. 1.

Lewis, J.C., Hochreiter Jr., J.J., Barton, G.J., Kozinski, J., Spitz, F.J., 1991. Hydrogeology of, and Ground-Water Quality in, the Potomac-Raritan-Magothy Aquifer System in the Logan Township Region, Gloucester and Salem Counties, New Jersey. U.S. Geological Survey: Water-Resources Investigations Report 90–4142, p. 92.

MacLeod, C.L., Barringer, T.H., Vowinkel, E.F., Price, C.V., 1995. Relation of nitrate concentrations in groundwater to well depth, well use, and land use in Franklin Township, Gloucester County, New Jersey, 1970–85. U.S. Geological Survey Water-Resources Investigations Report 94–4174, p. 29.

Masscheleyn, P.H., Delaune, R.D., Patrick, W.H. Jr., 1991. Arsenic and selenium chemistry as affected by sediment redox potential and pH. J. Environ. Qual. 20(4), 446–456.

Meisler, H., 1989. The occurrence and geochemistry of salty groundwater in the northern Atlantic coastal plain. U.S. Geological Survey Professional Paper-1404-D.

Milliman, J.D., Syvitski, 1992. Geomorphic/tectonic control of sediment discharge to the ocean: The importance of small mountain rivers. J. Geol. 100, 525–544.

Moncure, G., Jankowski, P.A., Drever, J.I., 1992. The hydrochemistry of arsenic in reservoir sediments, Milltown, Montana. In: Kharaka, Y.K., Maest, A.S. (Eds.), Water-Rock Interaction. Rotterdam, Balkema, pp. 513–516.

Morgan, J., Stumm, W., 1965. Role of multivalent hydrous metal oxides on limnological transformations. Proceedings 2nd International Conference of Water Pollution Research, Pergamon Press, New York, NY.

New Jersey Department of Environmental Protection (NJDEP), 1999. Findings and recommendations for the remediation of historic pesticide contamination. http://www.state.nj.us/dep/special/hpctf/final/hpctf99.pdf

New Jersey Department of Environmental Protection (NJDEP), 2002. New Jersey Mercury Task Force, Volume III: Sources of Mercury in New Jersey, p. 21.

New Jersey Department of Environmental Protection (NJDEP), 2003. Publicly funded clean-up site status report. http://www.nj.gov/dep/srp/publications/site_status/2003/pdf

New Jersey Department of Environmental Protection (NJDEP). Division of Surface Water, 2004a. Landfill Information: http://www.state.nj.us/dep/dshw/lrm/landinfo.htm (updated 5/29/02).

New Jersey Department of Environmental Protection, (NJDEP) Division of Water Quality, 2004b. Database: http://www.state.nj.us/dep/dwq/database.htm (updated 6/2/04).

New Jersey Department of Environmental Protection (NJDEP). Bureau of Underground Storage Tanks, 2004c. Underground Storage Tank Inventory: http://www.nj.gov/dep/srp/bust/ustri.htm (updated 3/5/04).

New Jersey Department of Environmental Protection (NJDEP), 2004d. Municipal Stormwater General Permit Guidance Materials. http://www.nj.gov/dep/stormwater/sw_guidance.htm (updated 5/3/05).

Obarska-Pempkowiak, H., 2001. Retention of selected heavy metals: Cd, Cu, and Pb in a hybrid wetland system. Water Sci. Technol. 44(11-12), 463–468.

Oberts, G.L., Osgood, R.A., 1991. Water quality effectiveness of a detention/wetland treatment system and its effect on an urban lake. Environ. Manage. 15(1), 131–138.

Palone, R., Todd, A., 1997. Chesapeake Bay riparian handbook: A guide for establishing and maintaining riparian forest buffers. USDA, Forest Service, NA-TP-02.97, Radnor, Pennsylvania.

Parks, G.A., 1967. Aqueous surface chemistry of oxides and complex oxides minerals, in Equilibrium Concepts in Natural Water Systems, Advances in Chemistry Series 67. American Chemical Society, Washington, DC, pp. 121–160.

Pierce, A.D., 1957. Iron in the Pines: The Story of New Jersey's Ghost Towns and Bog Iron. Rutgers University Press, New Brunswick, NJ.

Rhodehamel, E.C., 1970. A hydrologic analysis of the New Jersey Pine Barrens Region. New Jersey Department of Environmental Protection Water-Resources Circular 22, p. 35.

Schaefer, F.L., 1983. Distribution of chloride concentrations in the principal aquifers of the New Jersey coastal plain, 1977–1981. U.S. Geological Survey Water-Resources Investigations Report 83–4061, p. 56.

Serfes, M., 2004. New Jersey's Ambient Groundwater Monitoring Network . New Jersey Water Monitoring Council Meeting Presentation (09/24/04).

Shapiro, J., 1964. The effect of yellow organic acids on iron and other metals in water. J. Am. Wat. Wks. Ass. 56, 1062–1082.

Sloto, R.A., 2003. Historical ground-water-flow patterns and trends in iron concentrations in the Potomac-Rarirtan-Magothy aquifer system, in parts of Philadelphia, Pennsylvania and Camden and Gloucester Counties, New Jersey: U.S. Geological Survey Water-Resources Investigations Report 03–4255, p. 37.

Spitz, F.J., Barringer, T.H., 1992. Ground-water hydrology and simulation of saltwater encroachment, shallow aquifer system of southern Cape May County. New Jersey. U.S. Geological Survey Water-Resources Investigations Report 91–4191, p. 87.

Stumm, W., Lee, G.F., 1960. The chemistry of aqueous iron. Schweizerische Zeitschruft fur Hydrology XXI, 295–319.

Stumm, W., Lee, G.F., 1961. Oxygenation of ferrous iron. Ind. Eng. Chem. 53, 143–146.

Szabo, Z., DePaul, V., 1998. Radium-226 and radium-228 in shallow groundwater. U.S. Geological Survey Fact Sheet FS-062-98, Southern New Jersey, p. 6.

Szabo, Z., Rice, D.E., McLeod, C.L., Barringer, T.H., 1997. Relation of distribution of radium, nitrates and pesticides to agricultural land use and depth. U.S. Geological Survey Water-Resources Investigations Report 96-4165A, p. 107.

United States Census Bureau, 2005. New Jersey Quick Facts. http://quickfacts.census.gov/qfd/states/34000.html (updated 11/16/05).

U.S. Environmental Protection Agency (USEPA), 1988. National Water Quality Inventory: 1988 Report to Congress.

U.S. Environmental Protection Agency (USEPA), 1990. Chemical Information Fact Sheets. U.S. Environmental Protection Agency, Office of Pesticide Programs, Special Review Branch, Washington, D.C.

United States Environmental Protection Agency (USEPA), 1995a. Watershed protection. A project focus. EPA841-R-95-003.

United States Environmental Protection Agency (USEPA), 1995b. Watershed protection. A statewide approach. EPA841-R-95-004.

United States Environmental Protection Agency (USEPA), 1995c. Watershed protection. A watershed approach framework: People working together to protect public health and the environment—community by community, watershed by watershed. http://www.epa.gov/owow/watershed/framework

USEPA Office of Water, National Water Quality Inventory, 1998. Report to Congress, www.epa.gov/305b/98report/nj.html; Widener Environmental and Natural Resources Law Clinic analysis, 1999.

U.S. Geological Survey, 1997. Mercury in groundwater, soils and sediments of the Kirkwood-Cohansey Aquifer in the New Jersey Coastal Plain. USGS Open File 95–475.

U.S. Geological Survey, 2000. Mercury in the Environment. U.S. Geological Survey Fact Sheet 146–00.

U.S. Geological Survey, 2004a. Nitrate in water from wells sampled by USGS, http://nj.usgs.gov/gw/maps/nitrate.gif

U.S. Geological Survey, 2004b. Total VOCs in water from wells sampled by USGS, http://nj.usgs.gov/gw/maps/voc.gif

Watt, M.K., Johnson, M.L., 1992. Water resources of the unconfined aquifer system of the Great Egg Harbor River Basin, New Jersey 1989–90. U.S. Geological Survey Water-Resources Investigations Report 91-4126, 5 sheets.

Watt, M.K., Johnson, M.L., Lacombe, P.J., 1994. Hydrology of the unconfined aquifer system, Toms River, Metedeconk River, and Kettle Creek Basins, New Jersey, 1987–90, 5 sheets.

Watt, M.K., Kane, A.C., Charles, E.G., Storck, D.A., 2003. Hydrology of unconfined aquifer system, Rancocas Creek area: Rancocas, Assunpink, Blacks, and Crafts Creek basins, New Jersey 1996, 5 sheets.

Welch, A.H., Lico, M.S., 1998. Factors controlling As and U in shallow groundwater, southern Carson Desert, Nevada. Appl. Geochem. 13(4), 521–539.

Welch, A.H., Westjohn, D.B., Helsel, D.R., Wanty, R.B., 2000. Arsenic in groundwater of the United States: Occurrence and geochemistry. Groundwater 38(4), 589–604.

Wells, C., 1994. Skinny streets and one sided sidewalks: A strategy for not paving paradise. Technical Note 38: Watershed Protection Techniques 1(3), 135–137.

Younos, T., de Leon, R., Lewicki, C., 2003. Integrating service learning into watershed management programs: Opportunities and challenges. J. Am. Water Res. Ass. Paper # 01243.

Zampella, R.A., 1994. Characterization of surface water quality along a watershed disturbance gradient. JAWRA 30(4), 605–611.

Zampella, R.A., Bunnell, J.F., Laidig, K.J., Dow, C., 2001. The Mullica River Basin. A report to the Pinelands Commission on the status of the landscape and selected aquatic and wetland resources. Pinelands Commission, New Lisbon, New Jersey.

Zapecza, O.S., 1989. Hydrogeologic framework of the New Jersey coastal plain. U.S. Geological Survey Professional Paper1404-B, p. 49.