NEW JERSEY GEOLOGICAL &
WATER SURVEY
Technical Memorandum 13-4

Changes in Groundwater Recharge Resulting from Development in Atlantic, Mercer, and Sussex Counties, New Jersey, 1995-2007

New Jersey Department of Environmental Protection

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Cover Photo

A bioretention basin at the Lawrence Nature Center in Lawrenceville, NJ. This basin receives stormwater runoff from neighboring areas and retains it for either recharge or evaporation. (Photo by C. Thompson)

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By

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Epigram

From Chapter III, The Woods (Marsh, 1864)

Influence of the Forest on the Flow of Springs
It is well established that the protection afforded by the forest against the escape of moisture from its soil, insures the permanence and regularity of natural springs, not only within the limits of the woods, but at some distance beyond their borders, and this contributes to the supply of an element essential to both vegetable and animal life. As the forests are destroyed, the springs which flowed from the woods, and, consequently, the greater water courses fed by them, diminish both in number and in volume.

General Consequences of the Destruction of the Forest
With the disappearance of the forest, all is changed. … The face of the earth no longer a sponge, but a dust heap, and the floods which the waters of the sky pour out hurry swiftly along its slopes, carrying in suspension vast quantities of earthy particles which increase the abrading power and mechanical force of the current, and augmented by the sand and gravel of falling banks, fill the beds of the streams, divert them into new channels and obstruct their outlets. The rivulets, wanting their former regularity of supply and deprived of the protecting shade of the woods, are heated, evaporated, and thus reduced in their summer currents, but swollen to raging torrents in autumn and in spring.

Contents

Figures

Tables

Appendices

Changes in Groundwater Recharge Resulting from Development in Atlantic, Mercer, and Sussex Counties, New Jersey, 1995-2007

Abstract

Precipitation generally runs off impervious surface and is not available to become groundwater recharge. Quantifying the change in impervious cover allows an estimate of the change in groundwater recharge. This paper is an analysis of changes in groundwater recharge for for three test counties in New Jersey -- Atlantic, Mercer and Sussex.

Geographic information system (GIS) coverages of New Jersey land uses are available for 1986, 1995, 2002 and 2007. Land use on each mapped parcel is characterized using a modified Anderson system and assigned to one of six categories -- agricultural, barren, forest, urban, water or wetlands. Comparing the area in each category in each county allows an estimate of changes. For example, Atlantic County had 152,721 acres of forest in 1986, which covered 39.1 percent of the county. This decreased to 138,231 acres in 2007.

Estimates of the percent impervious cover on each mapped parcel of land are available for the 1995 and later land use GIS coverages. Summing the estimated acres of county-wide impervious cover, and comparing from year to year, shows the impact of development. Atlantic County had 15,699 acres of impervious cover in 1995, 4.0 percent of the county. This increased to 19,003 acres in 2007. Impervious cover in Mercer County increased from 19,792 acres in 1995 (13.5 percent of the county) to 22,840 acres in 2007. In Sussex County impervious cover increased from 9,489 acres in 1994 (2.7% of the county) to 10,848 acres in 2007.

Estimates of groundwater recharge using parcel-specific characteristics are based on a methodology developed in New Jersey. One characteristic is the amount of impervious cover on each parcel. Estimated groundwater recharge in Atlantic county was 70,024 million gallons (mg) in 1995 and declined to 69,005 mg in 2007. In Mercer County the decline was from 28,209 mg to 27,506. In Sussex County the decline was from 86,543 to 86,277 mg. These estimates of groundwater recharge assume no recharge through wetlands, open water and hydric soil. It also does not account for any mitigation efforts made to reduce the impact on groundwater recharge.

New regulations in New Jersey require major developments (defined as on acre or larger) not create a net decline in groundwater recharge. The requirements were not fully implemented from 2002 through 2007. Atlantic County had an estimated decrease of 501 mgy of groundwater recharge from 2002 through 2007. Had the stormwater recharge requirements been fully implemented in 2002 this decline would have been only 157 mgy. In Mercer County this decrease would have been 40 mgy rather than the estimated 320 mgy. In Sussex County this decrease would have been 413 mgy rather than the estimated 640 mgy.

These impacts of infrastructure designed to maintain groundwater-recharge (known as best management practices or BMPs) on net changes in recharge in a county depend on how much of the

disturbed land occupies parcels exceeding one acre. In Mercer County 76 percent of the disturbed land from 2002 through 2007 was on parcels of land exceeding one acre, and thus would have been required to implement BMPs if the regulations had been fully implemented. These BMPs would have prevented 88 percent of the loss in recharge. In contrast, in Sussex County 61 percent of the disturbed land occupied parcels of land exceeding one acre. In this county the BMPs, had they been fully implemented, would have prevented 35 percent of the loss in groundwater recharge. The estimated impact in Atlantic County is midway between what is estimate for Mercer and Sussex Counties.

Introduction

As New Jersey becomes more developed the percentage of the land surface that is covered by impervious cover increases. Groundwater recharge then decreases unless the runoff from the impervious cover that had previously infiltrated is captured and infiltrates elsewhere.

Groundwater recharge is a component of the water cycle. Rainfall that does not run off the land surface, does not evaporate, and is not taken up by plants infiltrates the land surface and becomes groundwater. A methodology developed and widely used in New Jersey (Charles and others, 1993) enables estimation of the average annual amount of water that infiltrates below the root zone and becomes groundwater recharge.

Groundwater recharge supports wells and stream base flow. Reductions in recharge can affect groundwater levels and limit water available to support stream ecology in dry times (Winters and others, 1998). Impervious cover on the land surface may redirect water that would otherwise have become groundwater recharge. This redirected water may increase storm runoff (Watson and others, 2005; Frazer, 2005).

This study looks at three counties spanning the state from south to north – Atlantic, Mercer and Sussex (fig. 1). Atlantic is a developing coastal county in southeastern New Jersey. Mercer is a developed county in west central New Jersey with significant urban and suburban areas. Sussex is a predominately rural and wooded county in northwestern New Jersey.

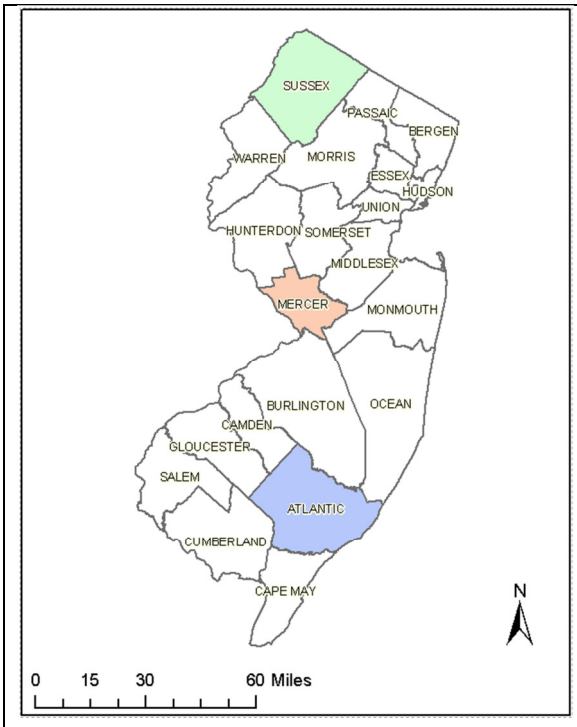

Figure 1. Location of Atlantic, Mercer and Sussex Counties, New Jersey

This report estimates the impact of increased impervious cover on groundwater recharge in Atlantic, Mercer, and Sussex Counties, from 1995 through 2007. It also considers the potential mit-

igation of this impact if recharge on disturbed parcels of land exceeding one acre in size were to be maintained using engineered solutions.

Acknowledgements
This report has benefited from the comments of Mark French and Sandy Blick, both of the New Jersey Department of Environmental Protection.

Land Use and Impervious Cover

State-wide land use in New Jersey is monitored at regular intervals (NJDEP, 2013). The most recent aerial photographs are of conditions in 1986, 1995, 2002 and 2007. These photographs are the basis for an analysis of land use changes (Office of Science and Research, 2013). These analyses enable insight into the impacts of development in New Jersey. Evaluation of development impacts makes possible a prioritization of remediation efforts.

NJDEP summarizes land use into six general categories based on a modified Anderson land-use-classification system -- agriculture, barren land, forest, urban, water, and wetlands (NJDEP, 2007; Anderson and others, 1976). Table 1 lists total areas of each county. Table 2 and figure 2 show estimated land uses in Atlantic, Mercer and Sussex Counties in 1986, 1995, 2002 and 2007. Figure 3 shows 2007 land use in each county based on these categories.

Table 1. County Size and Acreage.

County	Area	
	$miles^2$	acres
Atlantic	610.6	390,814
Mercer	228.6	146,328
Sussex	535.1	342,479

Comparing mapped land use in different years enables evaluation of land-use changes. Hasse and Lathrop (2010) quantified the increases in urban areas and decreases in open space from 1986 to 2007. All three of the counties studied here showed an increase in urban areas during the 21-year-span 1986-2007. The percentage of Atlantic County covered by the urban land use increased from 12.1 percent to 16.7 percent from 1986 to 2007. Mercer County increased from 35.9 percent to 47.7 percent and Sussex County from 10.3 percent to 15.6 percent in the same time period.

The amount of impervious cover is a critical factor in environmental analysis. Impervious cover is defined as material which is waterproof enough to divert quick runoff of rainfall and snowmelt. It also generally does not allow groundwater recharge. Increased runoff rates and decreased recharge correlate with degraded environmental conditions (Arnold and Gibbons, 1996; Frazer, 2005; Schueler and others, 2009).

The land-use evaluations of 1995, 2002 and 2007 included an estimate of the percentage of impervious cover on each mapped parcel of land. The data enable an analysis of the total amount of impervious cover in these years. Multiplying the area of each parcel by its percentage of imper-

vious cover provides an estimate of the net area of impervious cover on that parcel. Summing the area of impervious cover for all parcels yields an estimate of total impervious cover.

Table 2. Land uses, by county and year, in acres and percent of county.

County	Land Use	Year							
		1986		1995		2002		2007	
		Acres	%	Acres	%	Acres	%	Acres	%
Atlantic	agriculture	26,402	6.80	25,289	6.50	24,457	6.30	23,460	6.00
	barren	4,205	1.10	3,724	1.00	4,283	1.10	2,900	0.70
	forest	152,721	39.10	147,699	37.80	142,752	36.50	138,231	35.40
	urban	47,478	12.10	53,633	13.70	59,133	15.10	65,553	16.80
	water	36,157	9.30	37,689	9.60	37,391	9.60	39,078	10.00
	wetlands	123,850	31.70	122,781	31.40	122,798	31.40	121,593	31.10
Mercer	agriculture	37,548	25.70	29,202	20.00	24,687	16.90	22,465	15.40
	barren	1,528	1.00	1,490	1.00	1,973	1.30	1,420	1.00
	forest	26,484	18.10	27,611	18.90	27,080	18.50	26,309	18.00
	urban	52,497	35.90	60,286	41.20	65,732	44.90	69,805	47.70
	water	2,761	1.90	3,137	2.10	3,265	2.20	3,373	2.30
	wetlands	25,510	17.40	24,603	16.80	23,591	16.10	22,956	15.70
Sussex	agriculture	50,499	14.70	43,250	12.60	38,443	11.20	37,067	10.80
	barren	1,828	0.50	2,196	0.60	2,400	0.70	2,097	0.60
	forest	194,295	56.70	194,321	56.70	193,597	56.50	190,063	55.50
	urban	35,341	10.30	42,372	12.40	48,005	14.00	53,331	15.60
	water	12,681	3.70	12,656	3.70	12,489	3.60	13,188	3.90
	wetlands	47,835	14.00	47,684	13.90	47,544	13.90	46,736	13.60

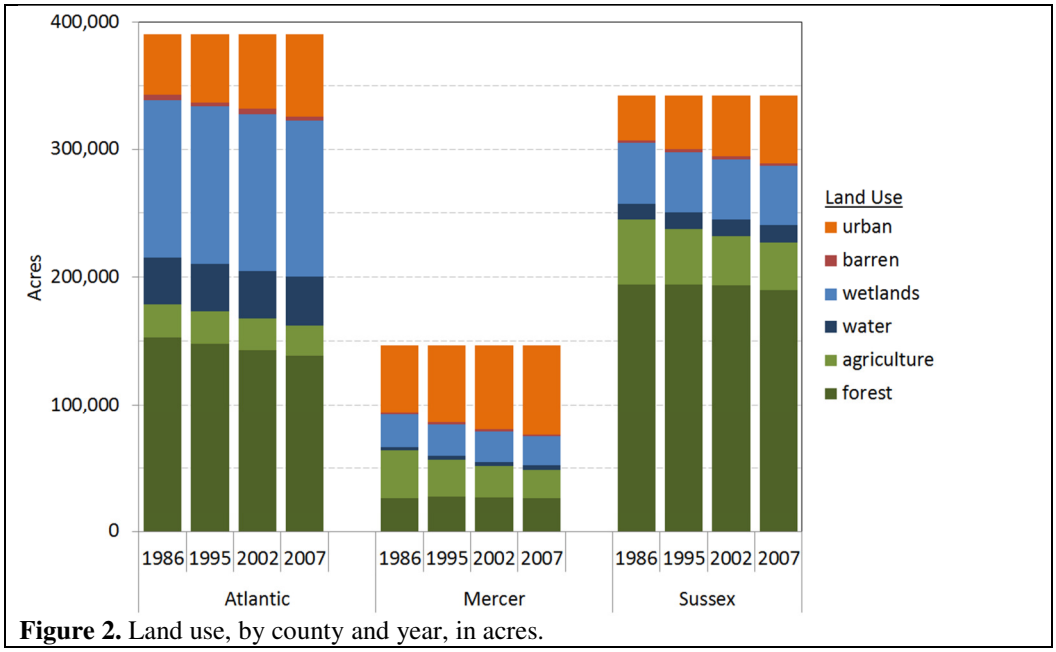

Figure 2. Land use, by county and year, in acres.

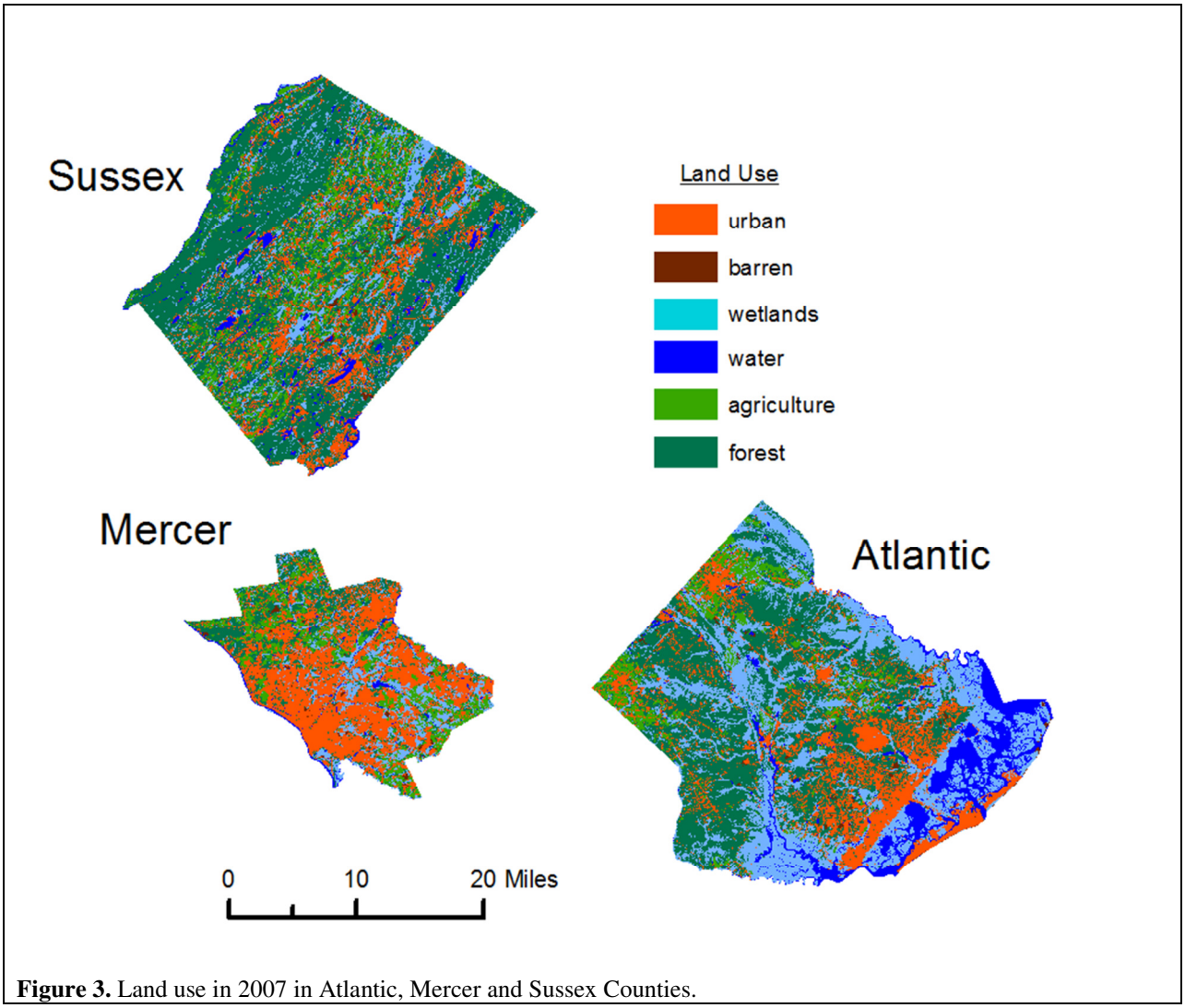

Figure 3. Land use in 2007 in Atlantic, Mercer and Sussex Counties.

Table 3 and figure 4 show estimated impervious area in the three counties for 1995, 2002 and 2007. In Atlantic County the acres of impervious cover grew from 15,699 in 1995 to 19,003 in 2007. In Mercer County the increase was from 19,792 to 22,840 acres and in Sussex County the increase was from 9,489 to 10,848 acres. Of the three counties studied, Mercer is the most urbanized and this is reflected in the percent of the county covered by impervious surfaces in 2007 – 15.6 percent. Atlantic and Sussex are much less urbanized with an estimated 4.9 percent and 3.1percent, respectively, covered by impervious surfaces in 2007.

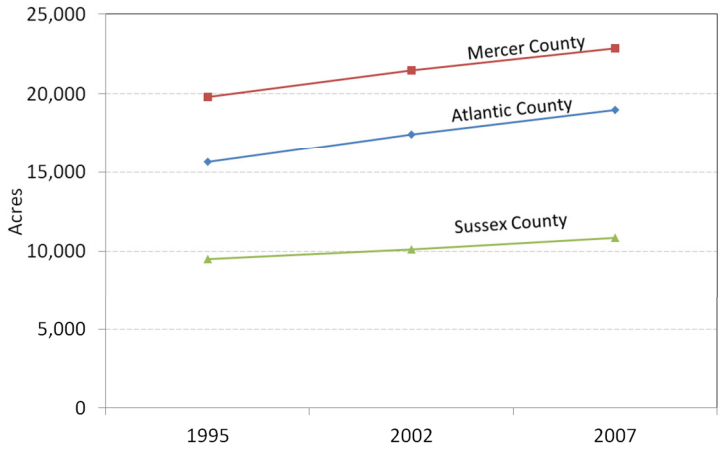

Figure 4. The rise of impervious cover from 1995 to 2007

Table 3. Acreage and percentage of impervious cover in 1995, 2002, and 2007.

County	1995		2002		2007	
	acres	% of county	acres	% of county	acres	% of county
Atlantic	15,699	4.0%	17,459	4.5%	19,003	4.9%
Mercer	19,792	13.5%	21,487	14.7%	22,840	15.6%
Sussex	9,489	2.7%	10,101	2.9%	10,848	3.1%

Groundwater Recharge

Groundwater is a vital resource for New Jersey. Groundwater withdrawals for human and agricultural use are about 250 billion gallons annually (Hoffman, 2002). Groundwater discharge to surface water also helps to maintain stream base flow, contributes to ponds and wetlands, and sustains aquatic ecology between rainfalls (Alley and others, 1999). Maintaining groundwater recharge is thus an important step towards maintaining the aquatic environment.

Groundwater recharge is that portion of precipitation which does not run off, is not evaporated or transpired, and moves vertically downward through the soil to become groundwater. It can be

measured directly using soil moisture probes at various depths, or estimated using a water-budget approach, or inferred from stream base flow.

Charles and others (1993) developed a water-budget approach for estimating groundwater recharge in New Jersey. This approach estimates annual average recharge based on parameterized estimates of soil unit, land use, climate and evapotranspiration. It assumes that all precipitation on impervious surfaces is redirected to a stormwater drain and does not become groundwater recharge. It estimates groundwater recharge for a specified location, soil type, and vegetation cover, assuming no impervious cover. For land uses partially covered by an impervious surface the groundwater recharge is reduced by a corresponding percentage.

The method of Charles and others (1993) has been applied numerous times in New Jersey (for example, French and Hoffman, 2000; Hoffman and French, 2000). French (2002) provides spatial geographic information system (GIS) coverages of groundwater recharge using 1995-1997 land use.

This approach does not estimate groundwater recharge under wetlands, surface-water bodies, or hydric soils. Wetlands and open water may be recharge or discharge areas. Recharge (or discharge) at these locations must be evaluated using site-specific techniques and thus are not addressed. Hydric soils tend to be nearly saturated or have a very shallow water table (Charles and others, 2003). These soils are also excluded from this evaluation methodology. One complication is that the area mapped as water and wetlands changes slightly from one evaluation cycle to the next. This is due to slight changes in photointerpretation technique in addition to development-related changes (for example, building on wetlands or creation of new ponds).

Table 4 lists the area of water and wetlands in the three selected counties in 1995, 2002 and 2007. It also gives the area of hydric soils that are not covered by water or wetlands. Table 4 also lists the area of each county for which the methodology of Charles and others (1993) is applicable. The groundwater recharge volume in each county is calculated as having been recharged in these areas.

Figure 5 shows the extent of water and wetlands (as mapped in 2007) and hydric soils in the three counties. In 2007, the areas for which groundwater recharge may be estimated covered 48.9 percent of Atlantic County, 67.2 percent of Mercer County, and 78.1 percent of Sussex County.

Groundwater recharge estimates for the three test counties, based on the methodology of Charles and others (1993), for the years 1995, 2002 and 2007 are in table 5. The combination of increased impervious cover and changes in land use resulted in decreasing groundwater recharge in each county with time. Estimated groundwater recharge dropped from 70,024 to 69,512 mgy (a decline of 0.7 percent) in Atlantic County from 1995 to 2007. In Mercer County the change was from 28,209 to 27,506 mgy (2.6 percent decline) and from 86,543 to 86,277 mgy (0.3 percent decline) in Sussex County during the same period.

Table 4. Areas of hydric soils, water, wetlands and recharging areas in 1995, 2002, and 2007.

County	Soil or Land Use	Estimated ground-water recharge*	Year							
			1995		2002			2007		
			area (acres)	% of total	area (acres)	% of total	change (acres)	area (acres)	% of total	change (acres)
Atlantic	hydric soils+	None	39,771	10.20	39,530	10.1	-241	39,103	10.0	-426
	water+	None	36,130	9.30	37,787	9.7	1,657	38,852	10.0	1,065
	wetlands+	None	123,536	31.60	122,164	31.3	-1,372	121,593	31.1	-571
	all others	Estimated	191,151	48.90	191,108	48.9	-44	191,040	48.9	-68
Mercer	hydric soils+	None	20,901	14.30	21,462	14.7	560	21,672	14.8	210
	water+	None	2,864	2.00	3,343	2.3	480	3,359	2.3	16
	wetlands+	None	24,750	16.90	23,308	15.9	-1,442	22,952	15.7	-356
	all others	Estimated	97,796	66.80	98,198	67.1	402	98,329	67.2	130
Sussex	hydric soils+	None	15,164	4.40	15,078	4.4	-86	15,069	4.4	-9
	water+	None	12,786	3.70	12,718	3.7	-68	13,169	3.8	452
	wetlands+	None	47,473	13.90	47,129	13.8	-344	46,739	13.7	-390
	all others	estimated	267,044	78.00	267,546	78.1	502	267,493	78.1	-53

* Using the methodology of Charles and others (1993).

\+ Areas not included in estimated groundwater recharge.

Table 5. Estimated groundwater recharge in Atlantic, Mercer and Sussex Counties, 1995, 2002, and 2007 (millions of gallons per year)

county	1995	2002	2007
Atlantic	70,024	69,506	69,005
Mercer	28,209	27,825	27,506
Sussex	86,543	86,918	86,277

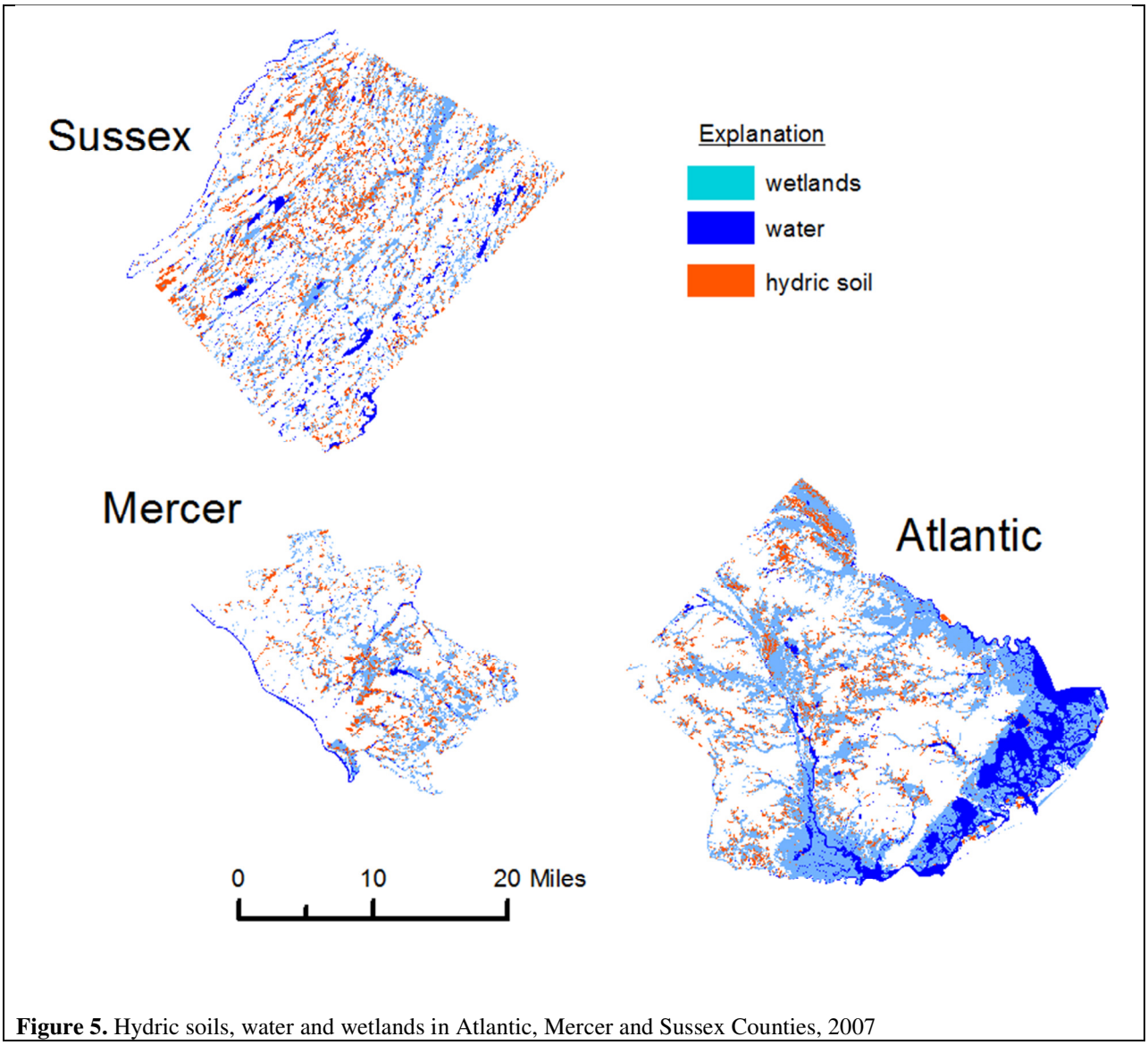

Figure 5. Hydric soils, water and wetlands in Atlantic, Mercer and Sussex Counties, 2007

Simulated Impact of Groundwater Recharge BMPs

The impact of increased development on groundwater recharge is well documented (Winters and others, 1998; Watson and others, 2005; Frazer, 2005). In an effort to minimize this impact the New Jersey Department of Environment Protection published in 2004 a set of regulations (N.J.A.C. 7:8) which require major developments to implement 'best management practices' (BMPs) that preserve groundwater recharge (NJDEP, 2004). Meeting this regulation requires that a part of the runoff from impervious areas must be captured and recharged. This is accomplished by constructing devices usually referred to as best management practices (BMPs). BMPs may include bioretention systems, stormwater wetlands, dry wells, extended basins, manufactured treatment devices, pervious paving systems, rooftop vegetated cover, sand filters, vegetative filters and wet ponds (NJDEP, 2004). The BMP must be designed and built with the express purpose of infiltrating water.

Major developments are generally defined as those which disturb one or more acres of land. The goal of these new regulations is to minimize the loss of groundwater recharge resulting from an increase in impervious cover and to avoid net change in groundwater recharge due to major developments. The groundwater-recharge part of these stormwater management rules were first applied in 2004 to residential developments and those requiring a NJDEP Division of Land Use permit.[1] The regulations started to apply to commercial and industrial developments in 2006 but delays occurred and they were not fully implemented until 2007.

If this regulation had been fully in effect from 2002 to 2007, the decline in groundwater recharge resulting from development would have been smaller. The amount of loss is related to the size of the disturbed land. If all development had been on parcels larger than one acre there would have been no decline in groundwater recharge had the new regulations had been in effect. If all development had disturbed less than one acre of land, no stormwater BMPs would have been required and there would have been no change in the estimated decline of groundwater recharge resulting from development.

Table 6 lists the change in land generating groundwater recharge in each of the three counties by size of disturbance. This analysis excludes water, wetlands, and areas underlain by hydric soil. In Atlantic County a total of 1,315 acres had a land use change from 2002 to 2007. A total of 366 acres (27.8 percent) of this disturbed land occurred on parcels less than an acre in size. The remainder, 949 acres (72.7 percent), occurred on parcels of land larger than 1 acre. Of the 1,085 acres with a land use change in Mercer County, 261 acres (24.0 percent) were on parcels smaller than 1 acre and 824 acres (76.0 percent) of disturbance was on parcels larger than 1 acre in size. In Sussex County a total of 685 acres show a land use change, and 261 acres (38.15 percent) were on parcels of land smaller than 1 acre, whereas 424 acres (61.9 percent) were on parcels larger than 1 acre.

[1] Sandra Blick, NJDEP, personal communication, 2013.

Table 6. Comparison of disturbed groundwater recharges areas based on parcel size

County	Total disturbed area (acres)	Disturbed area, by parcel size			
		<1 acre		>1 acre	
		acres	% of total	acres	% of total
Atlantic	1,315	366	27.83	949	72.17
Mercer	1,085	261	24.06	824	75.94
Sussex	685	261	38.10	424	61.90

As land use changed the amount of impervious surface grew. Table 7 lists the increases in impervious surface from 2002 to 2007 by size of disturbance. This analysis excludes areas mapped as water and wetlands but includes areas underlain by hydric soils. It is based on a comparison of 2007 to 2002 land use, listing parcels for all areas that changed, and calculating the area of each parcel. Each parcel in the underlying data base also lists an estimate of the percentage of impervious cover. These data are summarized by county for 2002 and 2007 (table 7). Impervious surface increased by 1,544 acres in Atlantic County. There was an increase of 426 acres of impervious surface on disturbed parcels of less than 1 acre in size. The remainder (1,121 acres or 73 percent of the increased impervious surface) occurred on disturbed parcels larger than 1 acre in size and, had the stormwater regulations been fully implemented, would have been required to install BMPs to preserve groundwater recharge. In Mercer County an increase of 1,021 acres of impervious surface (76 percent of the total increase) occurred on parcels larger than 1 acre. In Sussex County an increase of 457 acres of impervious surface (61 percent) occurred on parcels greater than 1 acre in size.

Table 7. Changes in impervious surface by county and parcel size, 2002-2007.

County	Impervious Surface (acres)			Change in impervious surface, by parcel size			
	Year		change	<1 acre		>1 acre	
	2002	2007		acres	%	acres	%
Atlantic	17,459	19,003	1,544	426	28%	1,121	73%
Mercer	21,487	22,840	1,352	332	25%	1,021	75%
Sussex	10,101	10,848	746	288	39%	457	61%

Table 8 lists the simulated impact of groundwater recharge BMPs in the three test counties had the stormwater regulations been fully implemented from 2002 to 2007. In Atlantic County the estimated decline in groundwater recharge was 501 mgy, from 69,506 mgy to 69,005 mgy. Had stormwater BMPs been fully implemented and had there been no change in groundwater recharge on parcels larger than one acre the recharge would have been 69,349 mgy. If BMPs had

been fully implemented and had prevented all loss of groundwater recharge from disturbed parcels larger than one acre the BMPs would have prevented the loss of 344 mgy of recharge. This is a reduction of 69 percent in the estimated loss of groundwater recharge.

This analysis assumes that the stormwater BMPs are applied only to disturbed parcels greater than one acre in size. Some municipalities in New Jersey are implementing regulations that require stormwater infiltration on smaller size parcels.[2]

In Mercer County the estimated decline of 320 mg in groundwater recharge from 2002 to 2007 would only have been 40 mgy had groundwater BMPs been fully implemented, a difference of 280 mgy. Thus there would have been a 88 percent reduction in the loss of groundwater recharge if BMPs had been implemented. In Sussex County the estimated decline of 640 mg would have been 413 mgy had groundwater BMPs been implemented, a difference of 227 mgy. The BMPs would have reduced groundwater recharge loss by 35 percent.

Table 8. Impact of groundwater-recharge BMPs on estimated 2007 recharge, by county

County	2002 recharge (mgy)	2007 recharge, no BMPs		2007 recharge w/ BMPs		Reduction in groundwater recharge loss	
		mgy	decrease from 2002 (mgy)	mgy	decrease from 2002 (mgy)	mgy	%
Atlantic	69,506	69,005	501	69,349	157	344	69
Mercer	27,825	27,506	320	27,785	40	280	88
Sussex	86,918	86,277	640	86,504	413	227	35

Figure 6 shows, for the test counties, the percentage of groundwater loss from 2002-2007 that would have been prevented if BMPs has been applied to disturbed parcels larger than 1 acre versus the percentage of disturbed land larger than 1 acre. Because the BMPs are designed to prevent any groundwater loss, if 100 percent of the disturbed land were on parcels larger than 1 acre there would be no groundwater loss. Mercer County had the greatest percentage of disturbed land on parcels larger than 1 acre, thus the BMPs had the greatest effect there on reducing groundwater loss. Sussex County had the smallest percentage of disturbed land on parcels larger than 1 acre and thus the BMPs had the smallest effect therein reducing groundwater loss.

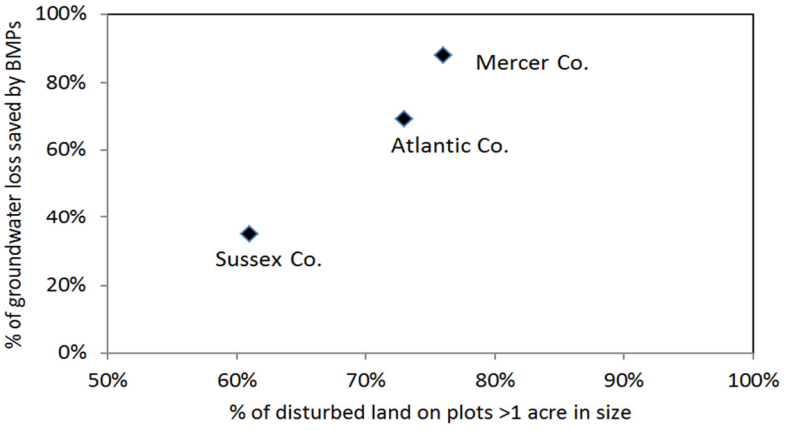

Figure 6. Reductions in groundwater loss vs. size of disturbed land.

[2] Sandy Blick, NJDEP, written communication, 2013.

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Appendix A Relevant Internet Links

Programs	
New Jersey Department of Environmental Protection	www.state.nj.us/dep/
New Jersey Geological and Water Survey	www.njgeology.org
New Jersey Stormwater	www.njstormwater.org/
Rutgers University rain garden resources	www.water.rutgers.edu/Rain_Gardens/RGWebsite/rginfo.html
General Data Repositories	
New Jersey Department of Environmental Protection GIS coverages	www.nj.gov/dep/gis/lists.html
New Jersey Geological and Water Survey Digital Geodata Series	www.njgeology.org/geodata/index.htm#list
New Jersey Geographical Information Network	https://njgin.state.nj.us/NJ_NJGINExplorer/index.jsp
Specific GIS Data Sets	
groundwater recharge in New Jersey, by county	www.njgeology.org/geodata/dgs02-3.htm
New Jersey 1995/1997 land use	www.state.nj.us/dep/gis/lulc95shp.html
New Jersey 2002 land use	www.state.nj.us/dep/gis/lulc02cshp.html
New Jersey 2007 land use	www.state.nj.us/dep/gis/lulc07cshp.html