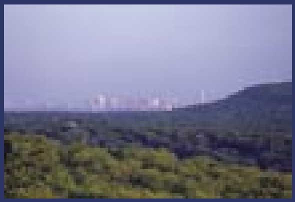


POSSIBLE CONSEQUENCES OF FUTURE CHANGE TO RESOURCES

CHANGES IN LAND USE AND LAND COVER

As continued human activity is the primary factor shaping the New York – New Jersey Highlands region, a better understanding of past and present trends in land use and land cover change was a critical component of this study. Accordingly, a land use and land cover analysis was undertaken with a twofold objective: (1) to provide a consistent assessment of present day (2000) land use and land cover across the two-State Highlands study area; and (2) to perform an analysis of land cover changes since 1972. A combination of Landsat Thematic Mapper and Multispectral Scanner satellite imagery, digital orthophotography, and existing State and county level data sets were used for the analysis. While the best possible effort was made to map land use and land cover with a high accuracy and consistent manner across the various time periods and entire study area, some error was inevitable. Due to the lesser reliability of the 1972 data set, more detailed change analyses excluded the 1972 data. Thus the land use and land cover data should be considered estimates with some margin of error. For more details of the analysis, see the New York – New Jersey Highlands Technical Report.

The Highlands contain a diversity of land uses and land covers. While extensive areas of the Highlands consist of large contiguous tracts of semiwilderness forest and watershed lands, the Highlands study area also contains other landscape types including river valley agricultural areas with scattered villages; rural areas with a mix of housing, woods, and fields; suburban towns; and small cities. The land use and land cover analysis shows that while forest land still dominates, human development has increased steadily from 1972 to 2000 (Table 3-5). Typical of the spatial patterns associated with urban sprawl, the tracts of new development are widely dispersed throughout the New York – New Jersey Highlands region (Figure 3-10). Both farm and forest land have been converted to residential and commercial land uses to meet the demands of a growing regional population. Analysis of the change during 1995 to 2000 indicates that the annual rate of forest loss to development is increasing, while the amount of farmland loss is decreasing (Table 3-6). This shift may reflect the amount of readily available land close to the New York City metropolitan area with farmland developed first and a more recent shifting to developing forested tracts.

Table 3-5. Land cover (acres) in the Highlands, 1972 to 2000

Land Cover	1972	1984	1995	2000
Developed	197,002	278,999	318,768	344,569
Farmland/Grassland	223,732	208,790	184,190	176,200
Forest	804,766	757,115	736,996	721,293
Wetland	127,312	100,309	103,556	102,254
Barren	3,201	10,069	10,262	9,652
Water	61,946	62,587	64,502	64,305
Total*	**1,417,959**	**1,417,869**	**1,418,273**	**1,418,273**

*Totals differ due to rounding.

Table 3-6. Rates of land cover change in the Highlands, 1984-2000

	1984-1995		1995-2000	
Land type	Area change	Percent change	Area change	Percent change
Developed*	+39,769 acres +3,615 acres/yr	+14.2 % +1.3 %/yr	25,801 acres 5,160 acres/yr	+8.1 % +1.6 %/yr
Forest/ Wetland**	-16,873 acres -1,534 acres/yr	-2.0 % -0.2 %/yr	-17,004 acres -3,400 acres/yr	-2.0 % -0.4 %/yr
Farmland/ Grassland***	-24,600 acres -2,236 acres/yr	-11.8 % -1.1 %/yr	-7,990 acres -1,598 acres/yr	-4.3 % -0.9 %/yr

*Developed land covers include impervious, bare, or partially vegetated land surfaces due to commercial, industrial, residential and transportation land uses.
**Forest/wetland land covers include upland and wetland forests, scrub/shrub and emergent vegetation communities.
***Farmland/Grassland includes agricultural lands (including cultivated land, pastures and hay fields), managed grasslands (e.g., large areas of mowed and irrigated/fertilized lawn and golf courses) and unmanaged grassland.

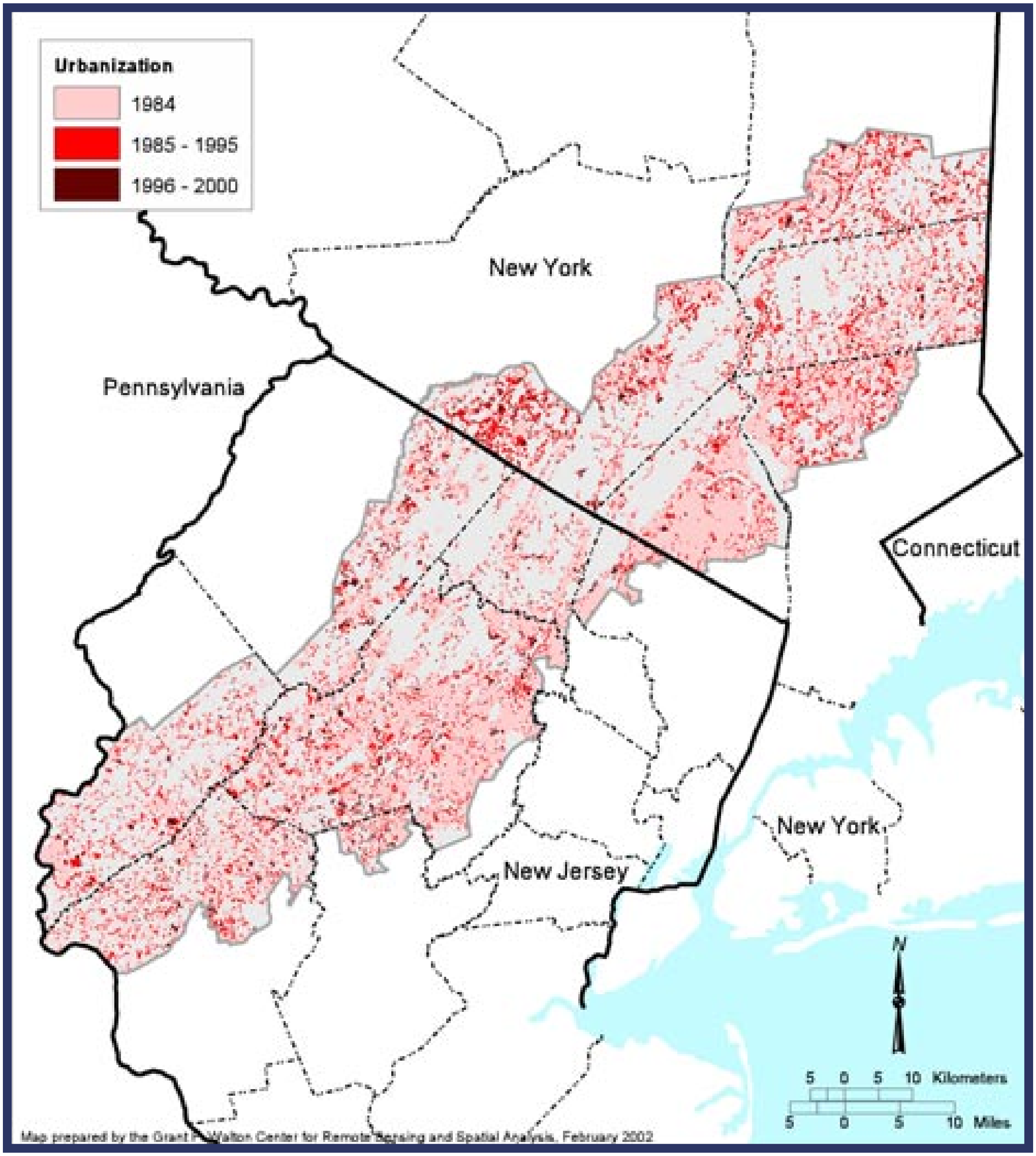
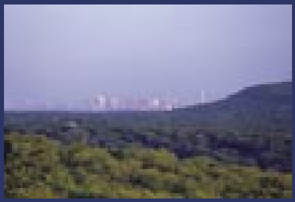


Figure 3-10. Urban development in the Highlands. Estimated land use and land cover in the New York – New Jersey Highlands show that development has increased steadily from 1984 to 2000. Typical of the spatial patterns associated with urban sprawl, the tracts of new development are widely dispersed throughout the Highlands region.

KEY FINDINGS:

- In 2000, **the Highlands study area was dominated by upland forest land cover types at 51 percent** of the total Highlands area, followed by developed land at 24 percent, farmland/grassland at 12 percent, and wetlands/water at 12 percent.
- **Developed land increased**, and conversion of forest/wetland and farmland/grassland continued from 1985 to 2000; however, **the rate of conversion of farmland/grassland slowed** during that time.



LANDSCAPE INDICATORS OF FOREST AND WATERSHED INTEGRITY

There has been a great push by Federal land-management agencies to develop land cover data sets and indicators that are suitable for measuring and monitoring land cover and associated environmental change across broad landscape regions. A suite of landscape-level indicators were chosen to quantify important components of the Highlands land use and land cover as one means of measuring the condition of the New York – New Jersey Highlands forests and watersheds:

1. Percentages of altered and unaltered land cover;
2. Indices of forest fragmentation;
3. Percentage of impervious surface cover; and
4. Percentage of the riparian areas of permanent streams that is in a vegetated, as compared to developed, condition.

The land use and land cover mapping, described under Changes in Land Use and Land Cover earlier in this section, served as the basis for the development of these landscape indicators. They were analyzed on a watershed basis, aggregating results to the level of Hydrologic Unit Code (HUC) 11 watersheds, which have an average area of about 50 square miles. There are 51 complete or partial HUC 11 watersheds within the New York – New Jersey Highlands study area. The four indicators were calculated for each of the 51 watersheds for each of the 3 years for which land use and land cover were established—1984, 1995, and 2000. This was done to permit analysis of existing trends and to estimate possible future conditions (low- and high-constraint buildout scenarios). The relationships between the selected landscape indicators and independently measured environmental parameters were examined to assist in identifying thresholds that may signify high potential for environmental degradation.

The amount of altered land within a watershed provides a useful indicator of watershed condition and the likelihood of degraded water quality. Altered land includes the following land use and land cover types that have minimal native vegetation (e.g., forest and wetlands): developed, farmland/grassland, and barren land cover types. Developed land represents land that is in some form of urban land use (i.e., commercial, industrial, residential). Developed land may actually have several different types of land covers, e.g., development or impervious surface (buildings, roads, driveways, parking lots, sidewalks), lawns, and bare soil.

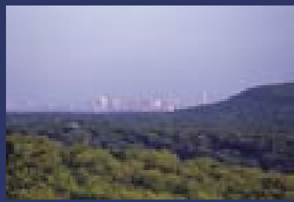
Analysis of altered versus unaltered land was conducted to evaluate the percentage of the watershed that is or might be in land cover types that would likely have a negative impact on water quality, due to factors such as point and nonpoint source pollution and soil erosion (see Changes in Water Resources later in this section). No watershed with more than 50 percent of its area in developed land had high quality surface waters, based on New Jersey Department of Environmental Protection and New York State Department of Environmental

Conservation State stream water classification data. The basins with the most degraded aquatic biological communities were those with approximately 50 percent developed land cover. The indicator analysis shows a general trend towards increasing altered land cover between 1984 and 2000 (Figure 3-11). Depending on the build-out scenario, the number of watersheds with more than 50 percent altered land cover could more than double (Figure 3-11). This increase in altered land indicates that threats to Highlands water quality are expected to increase. For more information, see the New York – New Jersey Highlands Technical Report.

Impervious surface cover is increasingly being used as a landscape level indicator of nonpoint source pollution and watershed health. Impervious surface cover reduces the amount of infiltration of water into the soil and increases runoff directly to stream systems, exacerbating stream "flashiness" and flooding problems. The amount of impervious surface within each HUC 11 watershed basin was estimated based on the land use and land cover data. Watersheds with more than 10 percent impervious surface were flagged as likely showing negative impacts on water quality and stream flashiness. A 10 percent impervious surface threshold is widely used in the water resources literature (Arnold and Gibbons 1996, Schueler 1998) and is backed up by our findings in the Highlands. The indicator analysis shows a general trend towards increasing impervious surface cover between 1984 and 2000 (Figure 3-12). Depending on the build-out scenario, the number of watersheds with greater than 10 percent impervious surface cover could more than triple or quadruple (Figure 3-12). This increase in impervious surface cover indicates that negative impacts to Highlands water quality are expected to increase. For more information, see the New York – New Jersey Highlands Technical Report.

Protecting wetlands and floodplains and establishing riparian buffer strips around lakes and streams where human development is excluded or minimized are "best management practices" that are often advocated as a means of reducing the impact of developed land uses on surface water quality. In addition to reducing nonpoint source pollution, soil erosion, and flooding impacts, riparian buffer zones serve as vital habitat for both upland and wetland-dependent species.

The percent of the riparian zones in altered and unaltered land covers was estimated on a HUC 11 watershed basis in the study area. The indicator analysis shows that alteration of riparian zones increased between 1984 and 2000 (Figure 3-13). The two build-out scenarios show a very different response in relation to riparian zone protection. The low-constraint scenario shows a large increase in riparian zone development and alteration, while the high-constraint scenario (which incorporates wider wetland buffers) remains largely unchanged from the present situation. The results of the high-constraint build-out scenario suggest that increasing the wetland buffer width will help to protect sensitive riparian zones (and thereby surface water quality), even with increasing development (Figure 3-13).



POSSIBLE CONSEQUENCES OF CHANGE: FOREST AND WATERSHED

Large expanses of contiguous forest are one of the notable characteristics of the Highlands. These upland and wetland forests serve to protect the integrity of ground water and surface water supplies as well as serve as critical habitat to a number of plant and animal species. Two parameters were analyzed as indicators of forest integrity: (1) the amount of interior or core forest habitat (i.e., the forest that is unfragmented with minimal "edge") in each watershed basin, and (2) the percent of overall forest cover by breeding bird atlas survey blocks (Andrle and Carroll 1988, Walsh and others 1999). The indicator analysis shows that the amount of overall forest and the unfragmented interior forest decreased between 1984 and 2000 (Figure 3-14). Under the build-out scenarios, the amounts of these indicators would continue to decline, suggesting that the integrity of the Highlands forests would be further compromised (Figure 3-14). For more information, see the New York – New Jersey Highlands Technical Report.

The analysis of landscape indicators coupled with the build-out analysis was developed to serve as a planning tool to provide a way to analyze "what if" scenarios. It is not an "absolute" prediction of future conditions at any particular point in time. Rather, it suggests what might be expected to happen based on existing patterns and trends and under the various assumptions contained in the build-out analyses.

The build-out scenarios suggest a very different picture of the Highlands region than what currently exists. After build-out, large areas of presently rural landscape would be replaced with tract-style development and dispersed large-lot housing, leading to a more suburban-mixed rural landscape. Extensive areas of river valley farms would be converted to large lot development and "farmettes," further isolating "working" farms that are presently part of New York and New Jersey's Farmland Preservation Programs (Appendix I). Existing public open space areas would provide a remnant core of forested upland in the north-central Highlands but would become further isolated as the existing forest matrix undergoes continued conversion and fragmentation.

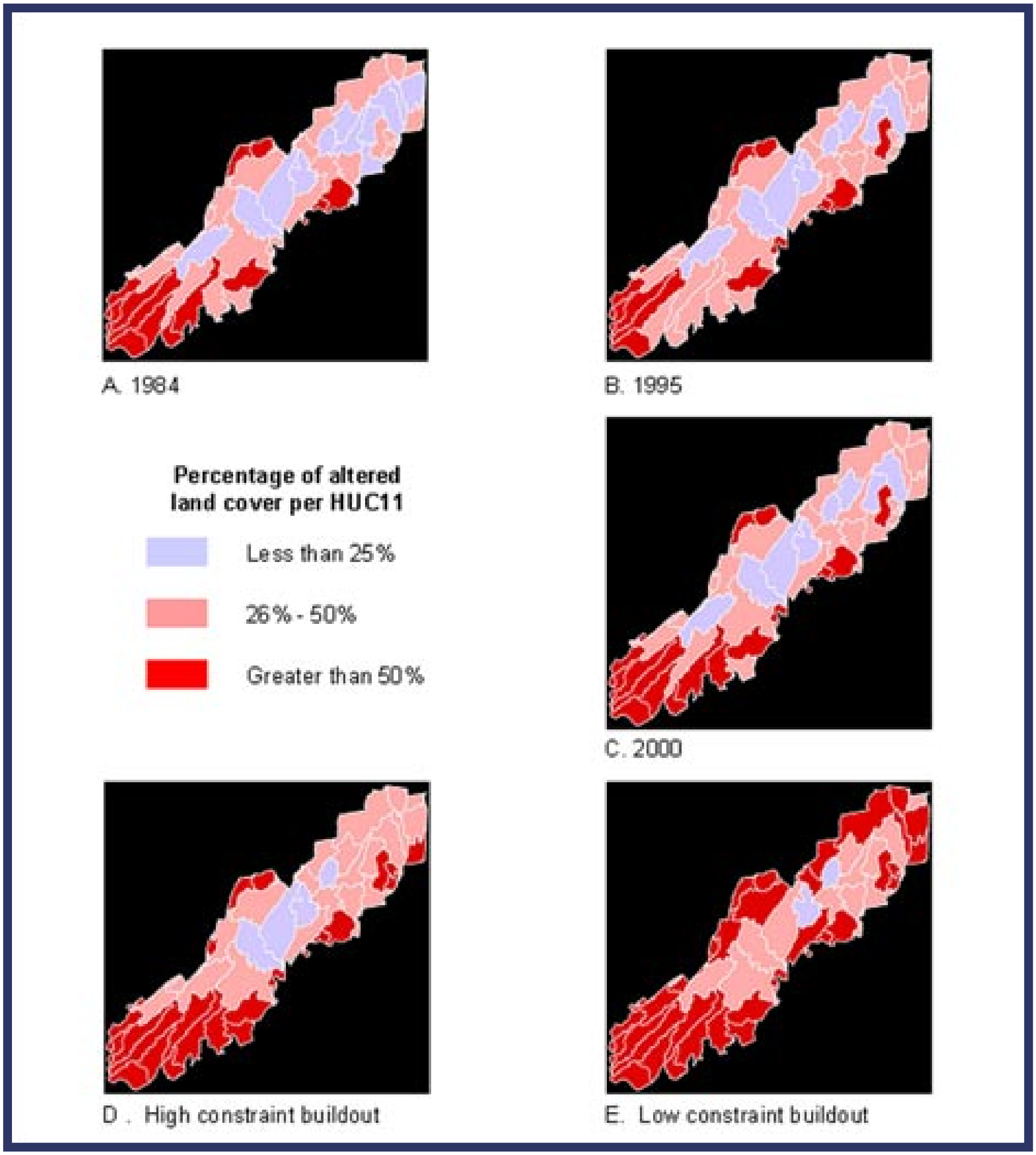
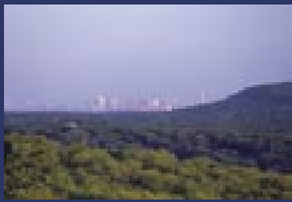


Figure 3-11. Change in land cover. Analysis of land cover in HUC 11 watersheds showed increasing altered land from 1984 to 2000 (A,B,C) and in the build-out analysis (D,E). Hydrologic Unit Code 11 refers to subwatersheds with an average area of about 50 square miles. Altered land greater than 50 percent has a negative effect on water quality.



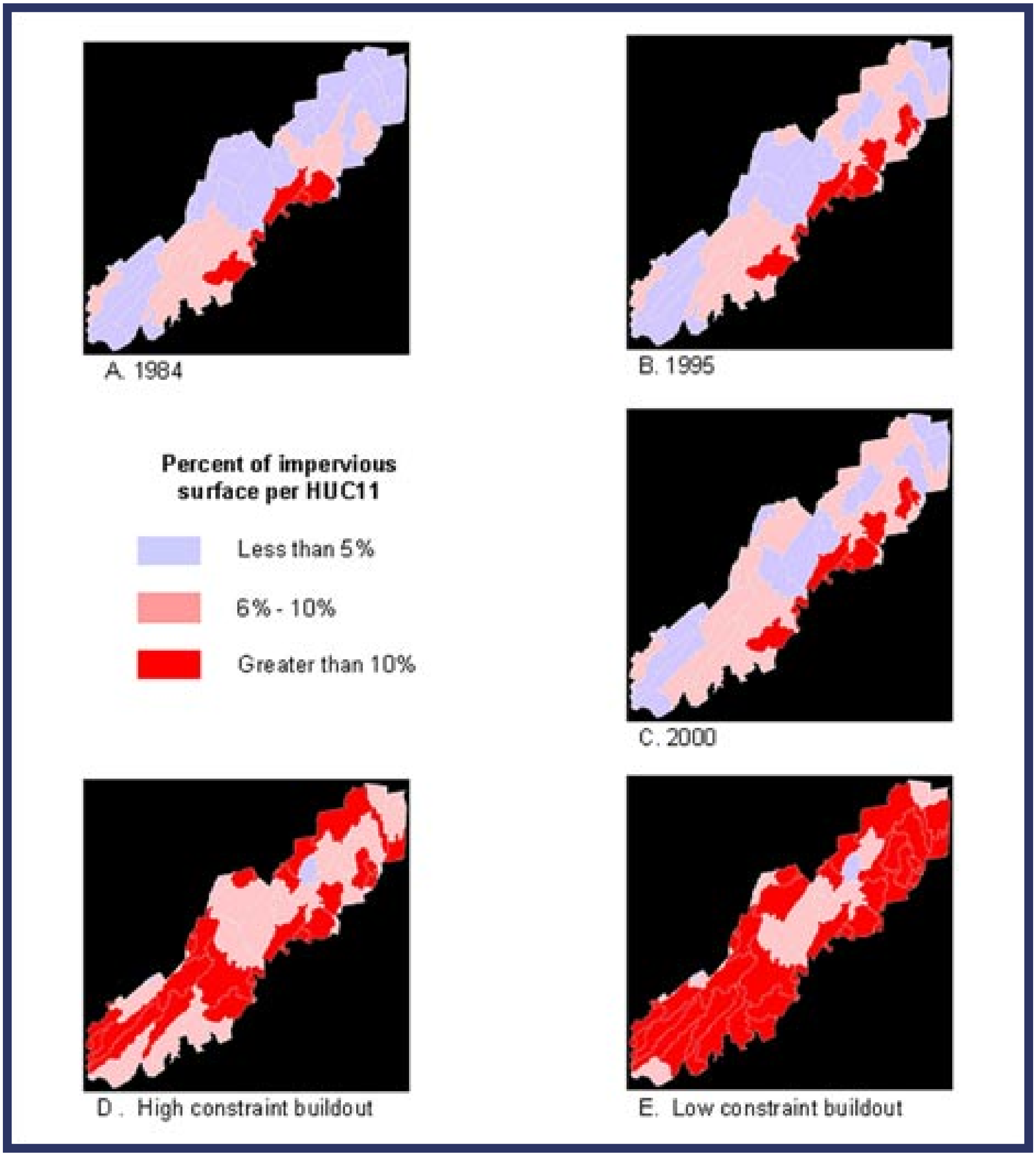


Figure 3-12. Change in impervious surface cover. Analysis of land cover in HUC 11 watersheds showed increasing impervious surface cover from 1984 to 2000 (A,B,C) and in the build-out analysis (D,E). Hydrologic Unit Code 11 refers to subwatersheds with an average area of about 50 square miles. Impervious cover greater than 10 percent is likely to be associated with negative impacts on water quality and stream "flashiness."

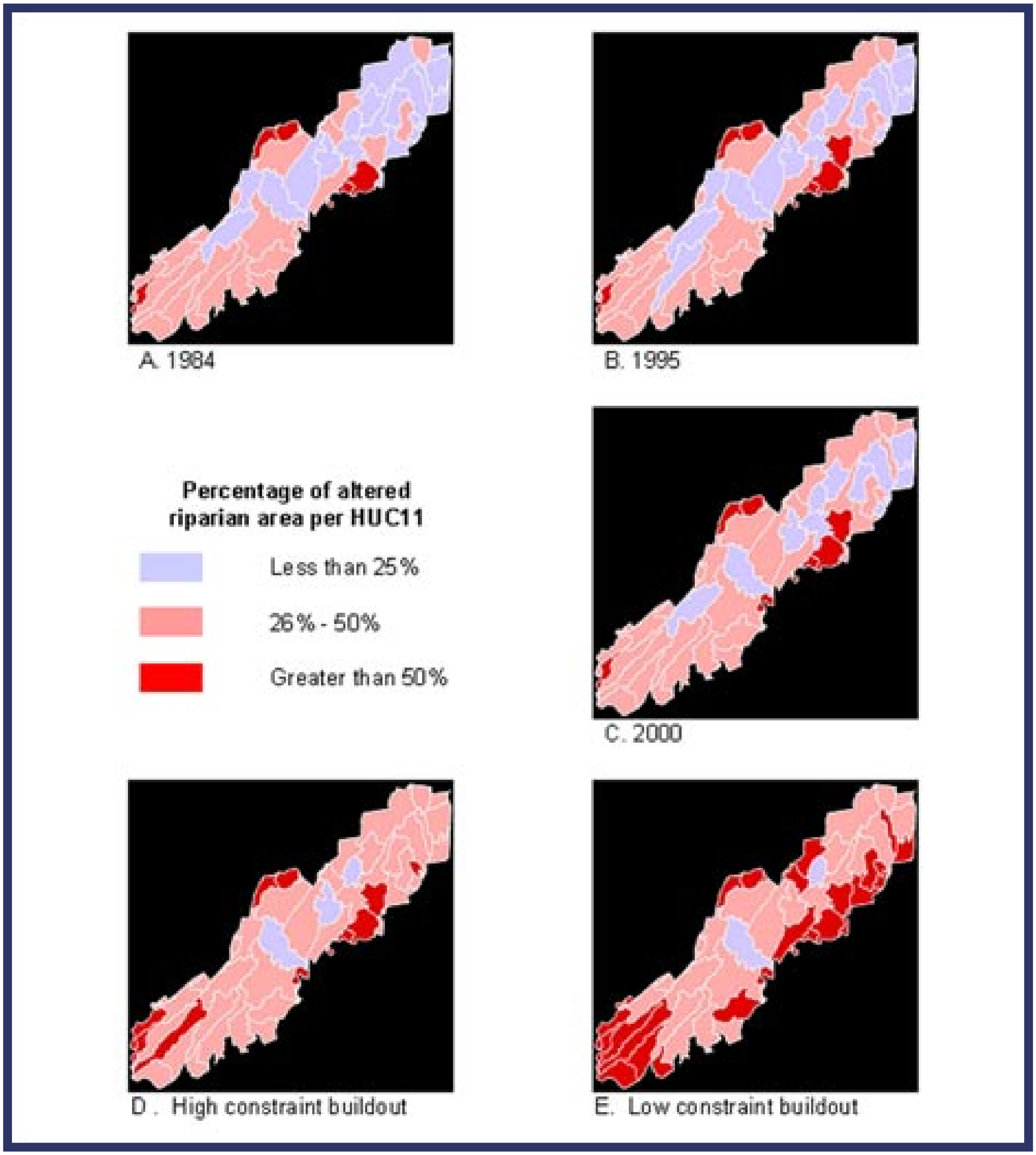


Figure 3-13. Change in riparian zones. Analysis of land cover in HUC 11 watersheds showed an increase in altered riparian zones from 1984 to 2000 (A,B,C) and a large increase in altered riparian zones under the low-constraint scenario of the build-out analysis (E). Under the high-constraint scenario (D), however, riparian zones show little change from 2000. Hydrologic Unit Code 11 refers to subwatersheds with an average area of about 50 square miles. Intact riparian zones reduce the impact of development on surface water quality.

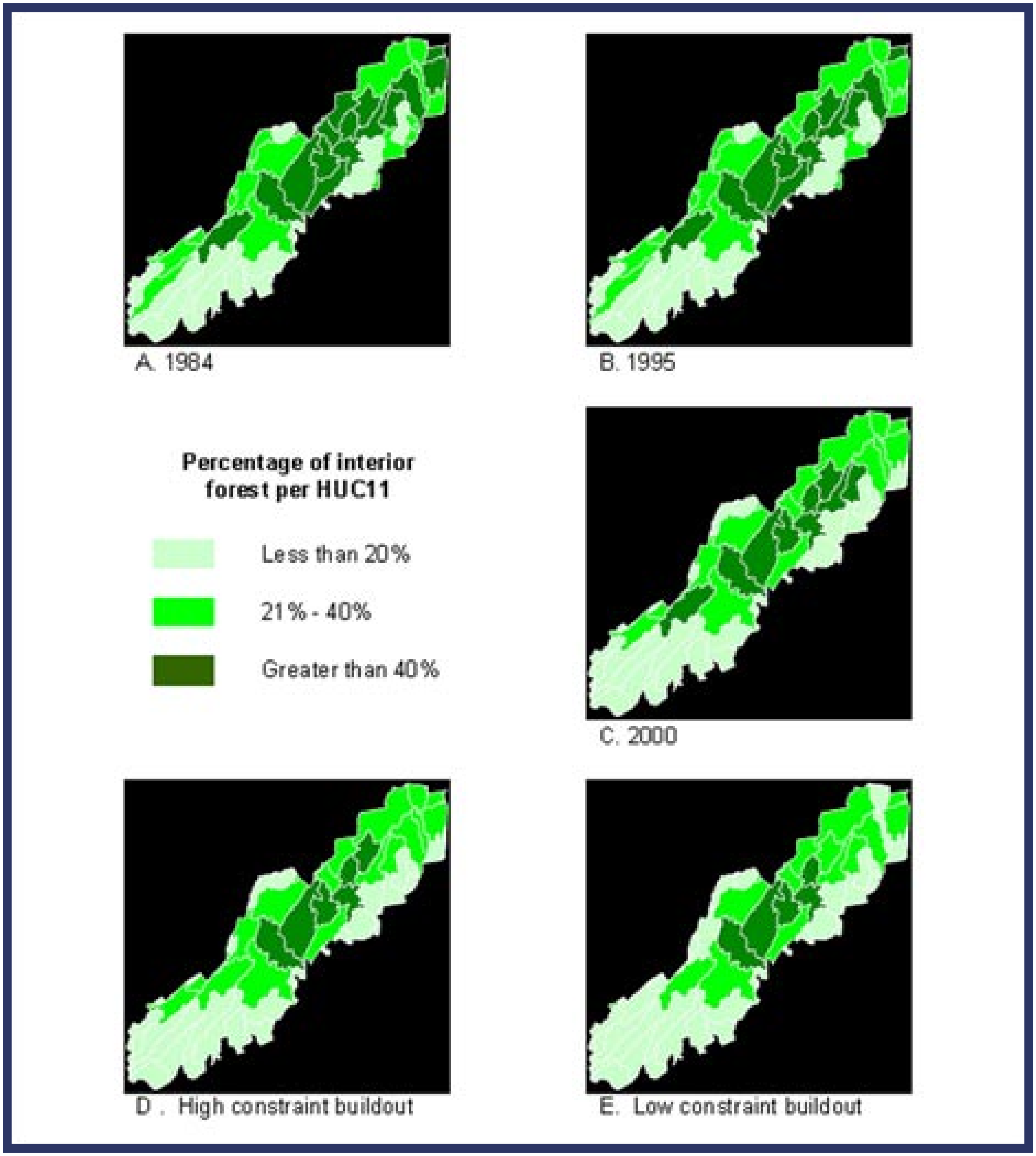


Figure 3-14. Change in interior forest. Analysis of land cover in HUC 11 watersheds showed a decrease in unfragmented forest from 1984 to 2000 (A,B,C) and in the build-out analysis (D,E). Hydrologic Unit Code 11 refers to subwatersheds with an average area of about 50 square miles. Loss of unfragmented forest compromises forest integrity and wildlife habitat.

KEY FINDINGS:

- The analysis of Highlands watersheds by the U.S. Geological Survey demonstrates that **watersheds with more than 50 percent altered land show compromised water quality.**
- **The number of watersheds with more than 50 percent altered land cover could more than double in the future.** There was a general trend toward increasing altered land cover during the 1980s and 1990s, with a third of watershed basins dominated by altered land covers (i.e., greater than 50 percent developed, cultivated, or barren land) in the year 2000. Approximately 50 percent of basins in the high-constraint scenario and more than 70 percent of basins in the low-constraint scenario have more than 50 percent altered land cover.
- **As impervious surface cover increased above 10 percent, the overall stream water quality fell from a high water quality standard.** A comparison of stream water quality classification and the percentage of impervious surface cover on a HUC-11 watershed basis for New Jersey basins showed that those basins that were ranked as having the highest water quality had an impervious surface cover of 10 percent or less.
- **The number of watersheds with more than 10 percent impervious surface cover could more than triple to quadruple.** Analysis shows a general trend towards increasing impervious surface cover, with more than 15 percent of the watershed basins in the year 2000 surpassing the 10 percent threshold. More than 50 percent of basins in the high-constraint scenario to more than 70 percent of basins in the low-constraint scenario had more than 10 percent impervious surface cover.
- **The alteration of riparian zones increased between 1984 and 2000. In 2000 approximately 75 percent of watersheds had riparian zones with more than 25 percent altered land cover.** A smaller subset of watersheds (approximately 13 percent), primarily those in agriculture-dominated landscapes, had more than 50 percent of the riparian zone in altered land covers.
- **The two build-out scenarios show different responses in relation to riparian zone protection.** In the high-constraint scenario (which incorporated wider wetland buffers), riparian zone development and alteration increased only slightly (to 20 percent) from the situation in 2000, while the low-constraint scenario showed a large increase (to 47 percent). The results of the high-constraint build-out scenario suggest that increasing the buffer distance will help to protect sensitive riparian zones and thereby enhance surface water quality.
- **A threshold of 70 percent or more forest cover was identified as prime habitat for interior nesting birds and raptor species.** Analysis of the 1995 New Jersey breeding bird atlas survey block data in relation to the Highlands land use and land cover indicates a significant decline

in the number of observed forest interior species at both the 70 percent and 25 percent levels of forest cover. In the year 2000, 22 percent of the survey blocks were considered prime forest habitat for forest interior nesting birds or raptors. Under the low-constraint scenario, the number of prime forest habitat blocks decreased by 38 percent to where only 13 percent of the Highlands were considered prime forest habitat.

- **Analysis of interior forest cover shows a steady decline** from 15 watersheds in 1984 to only 9 watersheds in 2000 that have more than 40 percent interior forest cover. **Under the build-out scenarios, the amount of interior forest habitat further decreased**, especially in the low-constraint scenario, in which only 5 watersheds had more than 40 percent interior forest.

CHANGES IN WATER RESOURCES

Land use can affect the quality, quantity, and distribution of water recharging an aquifer or running overland to streams. An increase in impervious surfaces, such as parking lots, buildings, and roads, decreases the amount of land through which precipitation can infiltrate and recharge an aquifer. Water that does not infiltrate the ground increases the amount of runoff, with potential increases in soil erosion, flooding, and surface-water contamination. The loss of recharge water also changes the timing of streamflow. Less ground water flows to streams as baseflow during dry periods and more surface water flows to streams as immediate runoff during wet periods. These changes in the hydrology of a watershed are accompanied by ecological and hydrological impacts: increased flooding during high-intensity rain storms, stressed ecosystems, decreased water-supply storage during droughts, and degraded water quality.

WATER BUDGET

The effect of the high- and low-constraint scenarios on Highlands water budgets were evaluated using the watershed model described in this section. In this model, projected increases in impervious surfaces and ground water withdrawals drive the change in water budget components between 1995 and the build-out scenarios. Model simulations show little change in water budgets between high- and low-constraint scenarios. Therefore, the low-constraint scenario was used because it represents the worst-case conditions.

Model-simulated differences in runoff, baseflow, total streamflow, and evapotranspiration between 1995 conditions and the low-constraint scenario are shown in Figure 3-15 for 182 HUC 14 subwatersheds plotted in order of increasing impervious surface cover. (Subwatersheds that are designated by HUC 14 have an average area of about 8 square miles.) Trend lines clearly show the relationship of increasing impervious surface to each water budget component. As the percentage of impervious surface in a subwatershed increases, direct runoff increases, baseflow decreases, total streamflow increases (runoff increases more than baseflow decreases), and evapotranspiration decreases.

The increased rate at which the components deviate from 1995 conditions for watersheds with a projected increase of 15 percent or more impervious surface cover is also significant. The degree of change is measured in inches per year over a drainage area. To bring this into perspective, note that average mean annual streamflow for Highlands watersheds is about 25 inches per year, average baseflow is about 18.5 inches per year, and average runoff is about 6.75 inches per year. Figure 3-15 suggests a potential 50 percent or more increase in runoff in watersheds that are projected to have an increase in impervious surface of 15 percent or greater. The trend line for baseflow suggests about a 10 percent decrease in baseflow.

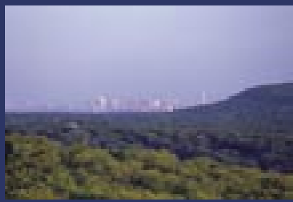


Figure 3-16 shows the degree to which streamflow characteristics of runoff and baseflow are predicted to change at the subwatershed scale based on the change between the simulated water budgets for 1995 and the low-constraint scenario. The areas of moderate and greatest change are directly related to the increase in impervious surface (Figure 3-15) and water withdrawals. These areas include subwatersheds drained by the Wallkill, Lamington, Musconetcong, Pequest, Rockaway, Pequannock, Ramapo, and Pompton Rivers, and Lopatcong and Pohatcong Creeks. The greater the degree of change in streamflow characteristics, the more these watersheds would show increases in runoff, decreases in ground water recharge, and decreases in stream baseflow. Increased monitoring of ground- and surface-water quality and quantity is warranted in areas expected to undergo significant development, particularly in areas where there is little existing data.

AVAILABLE WATER

A water budget analysis provides an estimate of how water moves through a watershed, but cannot directly determine the amount of water available to meet increased water-supply needs without overstressing the resource. Safe yield, which indicates how much water a surface water reservoir can provide based on the drought of record, has been calculated for all surface water reservoirs in the Highlands, as was discussed in Section 2 under Surface Water—Streams, Rivers, and Reservoirs. Ground water resources also have sustainable or dependable yields (New Jersey Department of Environmental Protection and Energy 1992). Continuous declines in ground water levels, adverse impacts upon other wells, and unacceptable depletion of streamflow within a watershed are indicators that the sustainable yield of ground water is being exceeded.

Quantifying the sustainable yield from a ground water source is difficult. For planning purposes, the New Jersey Statewide Water Supply Plan (New Jersey Department of Environmental Protection 1996) assumed that 20 percent of ground water recharge is available for human use with no acceptable regional impacts in noncoastal plain aquifers. There are concerns, however, with using the 20 percent threshold for watershed-specific management decisions (New Jersey Water Supply Authority 2000). Taking these concerns into account, and for the purpose of analysis, both a 20 percent and 10 percent threshold of ground water recharge was used to determine Highlands watersheds that are the most sensitive to current and forecasted increases in ground water withdrawals.

Model-calculated baseflow within a HUC 11 watershed was assumed to equal ground water recharge within that watershed. Ground water withdrawals from the 1995 and the low-constraint development simulations were subtracted from 20 percent and 10 percent of the total ground water recharge for each watershed. The results are displayed for 1995 in Figure 3-17 and for the low-constraint scenario in Figure 3-18. For 1995 conditions, ground water withdrawals exceeded 20 percent of ground water recharge in the HUC 11 watershed drained by the Whippany

River. This result is consistent with long-term water-level declines in the Whippany River basin that indicate ground water withdrawals are exceeding the rate of recharge to the aquifer (Illustration 2-2B, page 18). Using the 10 percent threshold of ground water recharge to represent sustainable yields, HUC 11 watersheds drained by the Ramapo River in New York and New Jersey, the upper Musconetcong River, the Pequest River, and tributaries of the upper Delaware River in Warren County, New Jersey—in addition to the Whippany—are the most sensitive to ground water withdrawals.

Based on the predicted population increase for the low-constraint scenario and water use of 85 gallons per day per person, an estimated additional 52.4 million gallons per day of ground water was assumed to be withdrawn from aquifers underlying the watersheds in the modeled area. The results of taking the difference of the total withdrawals from 20 percent and 10 percent of model calculated baseflow for the low-constraint scenario is shown in Figure 3-18. Ground water withdrawals exceeded 20 percent of aquifer recharge for this scenario in watersheds drained by the Ramapo, Whippany, and Pequest Rivers, upper Delaware tributaries, and Lopatcong Creek. Using a sustainable yield threshold of 10 percent, watersheds drained by the Rockaway and Upper Musconetcong Rivers were added to the watersheds previously mentioned as being the most sensitive to ground water withdrawals.

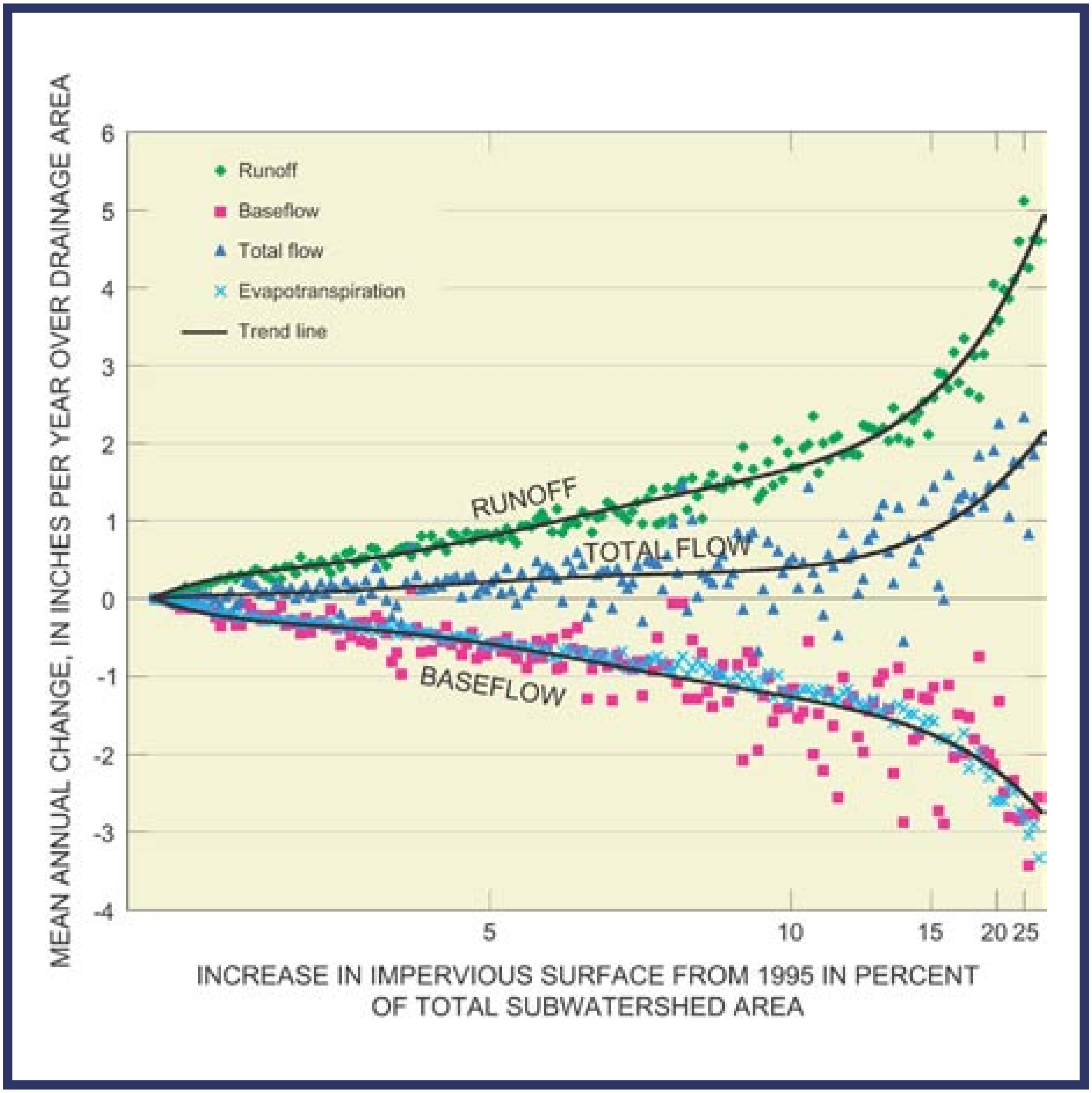


Figure 3-15. Effect of impervious surfaces on streamflow. Changes in streamflow characteristics and evapotranspiration are directly related to increasing impervious surface area, as shown here for 182 HUC 14 subwatersheds in the Highlands. Hydrologic Unit Code 14 refers to subwatersheds with an average area of about 8 square miles.

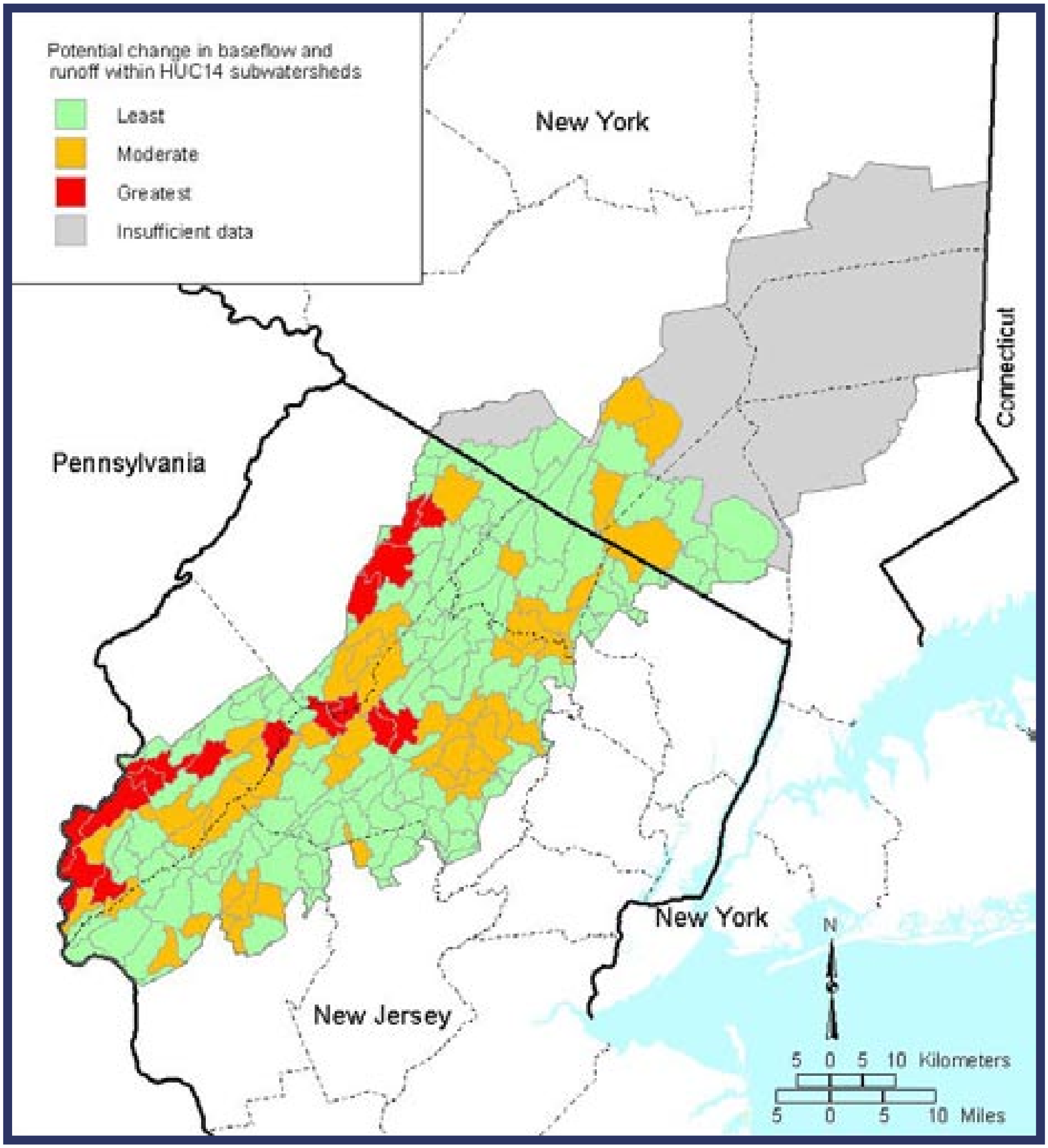
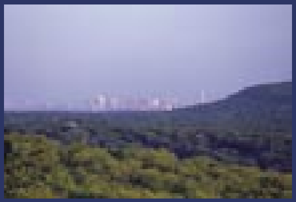


Figure 3-16. Predicted changes in streamflow. Different degrees of change in streamflow characteristics are predicted for HUC 14 subwatersheds under the low-constraint scenario of the build-out analysis, depending on the amount of impervious surface and water withdrawals in an area. Increased surface runoff, decreased ground water recharge, and decreased ground water discharge to streams are associated with greater degrees of predicted change. Hydrologic Unit Code 14 refers to subwatersheds with an average area of about 8 square miles.



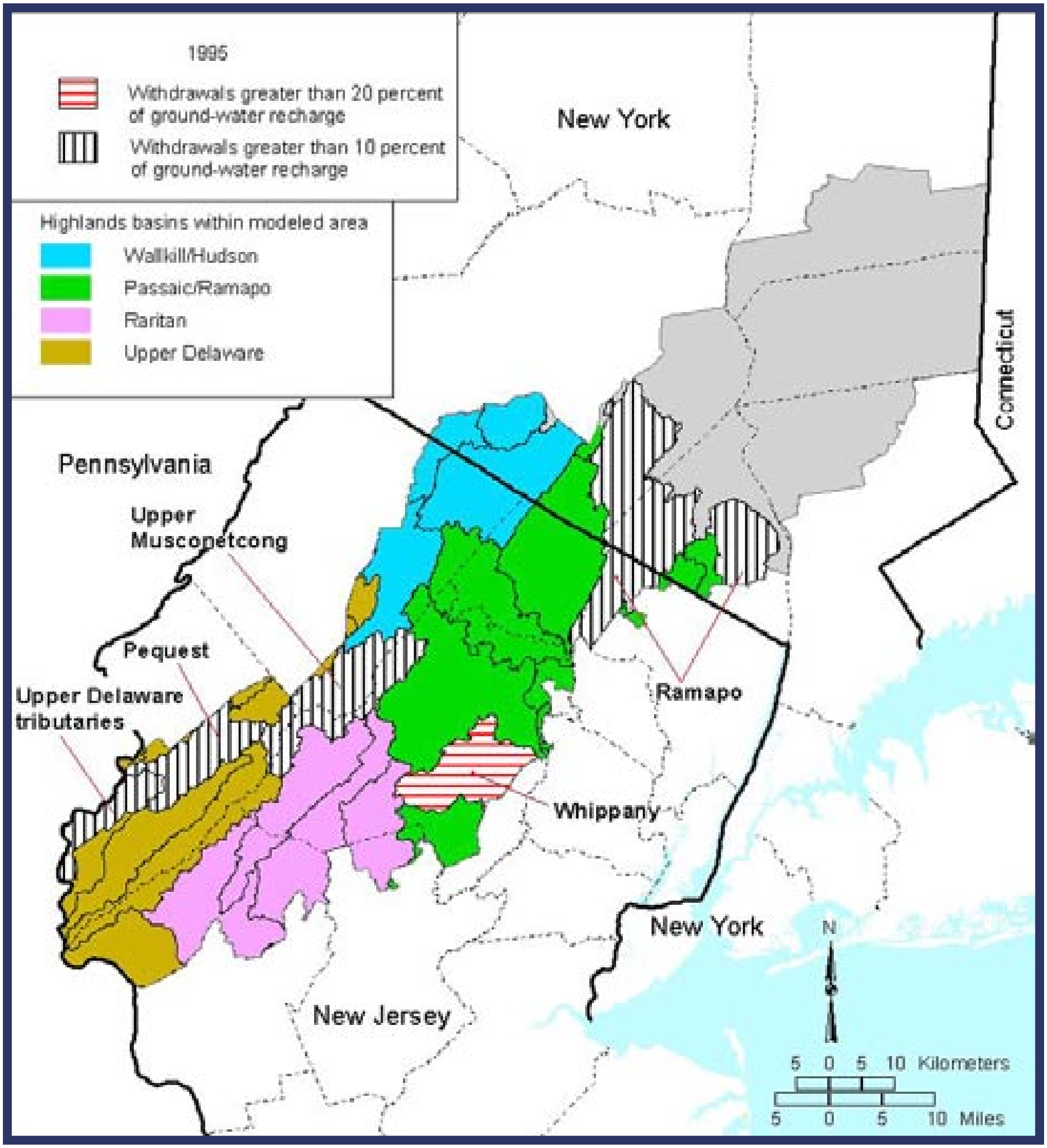


Figure 3-17. Sustainable water yield, 1995. This map shows HUC 11 watersheds where ground water withdrawals exceeded 20 percent and 10 percent of the estimated ground water recharge in 1995. Thresholds of 20 percent and 10 percent of estimated recharge were used to determine watersheds most sensitive to 1995 ground water withdrawals. Hydrologic Unit Code 11 refers to subwatersheds with an average area of about 50 square miles. Compare Figure 3-18.

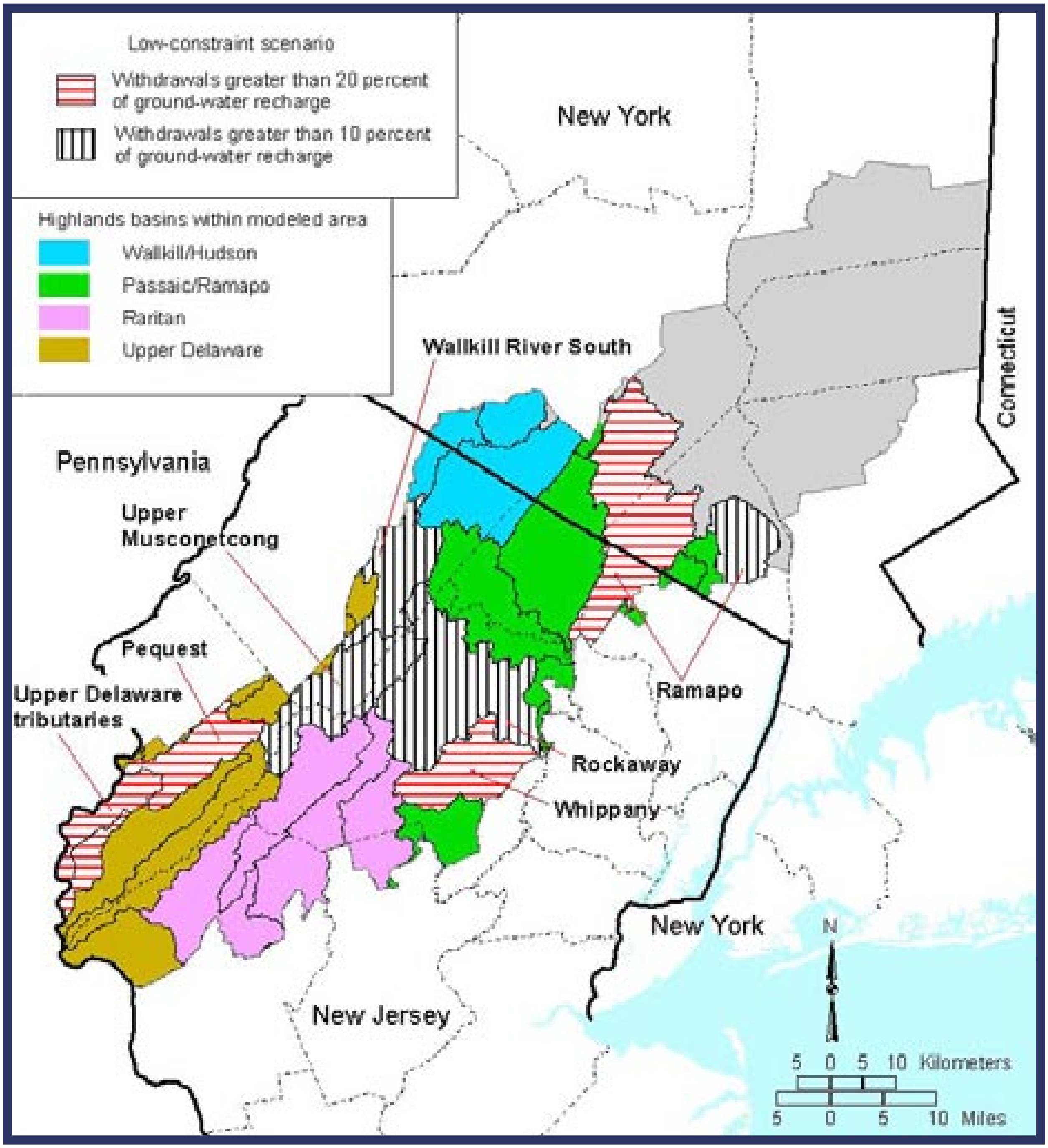
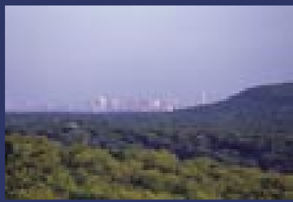


Figure 3-18. Sustainable water yield, low-constraint scenario. This map shows HUC 11 watersheds where ground water withdrawals exceeded 20 percent and 10 percent of the estimated ground water recharge under the low-constraint scenario of the build-out analysis. Thresholds of 20 percent and 10 percent of estimated recharge were used to determine watersheds most sensitive to increased ground water withdrawals under the low-constraint scenario. Hydrologic Unit Code 11 refers to subwatersheds with an average area of about 50 square miles. Compare Figure 3-17.



POSSIBLE CONSEQUENCES OF CHANGE: WATER RESOURCES

KEY FINDINGS:

- Water budget analysis of 182 Highlands subwatersheds shows that **as impervious surface cover increases, direct-runoff increases, baseflow decreases, and evapotranspiration decreases.**
- **The predicted rate of change in runoff, baseflow, and evapotranspiration increased significantly for subwatersheds with a projected increase of 15 percent or more impervious surface cover over conditions existing in 1995.**
- **Water budget calculations indicate a potential 50 percent or more increase in runoff, and a 10 percent or more decrease in baseflow, in subwatersheds with increases of impervious surface greater than 15 percent.**
- **The increase in impervious surface, as projected by the high- and low-constraint build-out scenarios, had a greater impact on changing Highlands water budgets than did the estimated increase in ground water withdrawals by the projected larger population.** However, both were predominant factors driving the change in water budgets.
- **Streamflow characteristics would be most affected in HUC 14 subwatersheds drained by the Wallkill, Lamington, Musconetcong, Pequest, Rockaway, Pequannock, Ramapo, and Pompton Rivers, and Lopatcong and Pohatcong Creeks**, owing to the increase in impervious surface cover and water withdrawals projected by the future development and population growth scenarios.
- **Loss of recharge water for aquifers, increased flooding during high-intensity rain storms, stressed ecosystems, decreased water-supply storage during droughts, and degraded water quality have been attributed to increases in impervious surface cover.** Increased monitoring of ground and surface water quality and quantity is warranted in areas expected to undergo significant development particularly in areas where there may be little existing data.
- **For 1995 conditions, ground water withdrawals exceeded 20 percent of ground water recharge only in the HUC 11 watersheds drained by the Whippany River.** Using the 10 percent threshold to represent sustainable yields, HUC 11 watersheds drained by the Ramapo River in New York and New Jersey, the upper Musconetcong River, the Pequest River, and tributaries of the upper Delaware River in Warren County, New Jersey—in addition to the Whippany—are the most sensitive to ground water withdrawals.
- **Based on the predicted population increase in the low-constraint scenario, and water use of 85 gallons per day per person, an estimated additional withdrawal of 52.4 million gallons per day was assumed from aquifers underlying the watersheds within the watershed model area.** Ground water withdrawals exceed 20 percent of aquifer recharge for this scenario in watersheds drained by the Ramapo, Whippany, and Pequest Rivers, upper Delaware tributaries, and Lopatcong Creek. Using a sustainable yield threshold of 10 percent, watersheds drained by the Rockaway and Upper Musconetcong Rivers are added to the watersheds previously mentioned.