Reestablishing Public Health and Land Use Planning to Protect Public Water Supplies

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Objectives. This study measured the extent to which land use, design, and engineering practices could reduce contamination of major public water supplies.

Methods. Key parcels of land were identified in New Jersey, and the potential uncontrolled loading of contaminants was estimated with the US Environmental Protection Agency's Long-Term Hydrologic Impact Assessment model for a variety of land use, design, and engineering scenarios.

Results. High-density per-acre development and engineering controls, along with housing and light commercial activity near main railroads, would substantially reduce runoff.

Conclusions. In New Jersey, government and purveyor action is being taken as a result of, and in support of, these findings. (*Am J Public Health.* 2003;93:1522–1526)

Since the beginning of the industrial revolution, inadequate treatment of human, animal, and industrial wastes has challenged those charged with providing potable water.[1–3] In 1993, more than 100 people in Milwaukee died from *Cryptosporidium,* which underscored the reality that our treatment technologies for water supplies are not foolproof.[3] Yet, leaking landfills, industrial lagoons, feedlots, and terrorists are perceived as greater threats to public health than runoff is.

Building on green lands leads to paving those lands. As a result, rain that would otherwise fall into streams and recharge an aquifer are diverted. The impact of diversion can be seen when the areas downstream become flooded after heavy storms. Water quality is affected by uncontrolled development that leads to runoff from cars, houses, shopping malls, gasoline stations, and the other accoutrements of urban development.[4] Water supplies can be damaged to the point of abandonment by residual debris, oil and grease, animal manure, tire residue, heavy metals, deicing compounds, and pesticides that are washed into watercourses during precipitation events.

Uncontrolled development has already threatened potable water supplies across the United States. The most prominent examples are New York City's 1900-square-mile Croton and Catskill watersheds. Research has found that the major reservoirs, once characterized as producing the best drinking water in the United States, are now threatened by the sprawl-related runoff of street salts, nutrients, and hazardous contaminants.[5]

A proactive policy option is to turn sensitive watershed land into a green buffer by purchasing it or by permitting the transfer of development rights to other less sensitive parcels. Building engineered structures that control runoff is another proactive policy option. We used an important public, potable, surface water supply in New Jersey to illustrate the need to proactively make land use, design, and engineering decisions in support of public health. Specifically, the research answered two questions: (1) What configurations of residential and light commercial land uses pose the most serious threat to water supplies? (2) What land use, design, and engineering options can be used to prevent degradation of water supplies?

METHODS

Study Area

The quality of drinking water is a major issue in New Jersey, as it is throughout the United States. For example, a 2000 poll of 800 New Jersey residents found that 40% believed that the quality of tap water coming into their homes was "only fair" or "poor." It is therefore not surprising that only 26% of New Jersey's residents reported that they drink tap water, compared with 53% of US residents.[6]

Within New Jersey, we focused on Hunterdon and Union Counties to illustrate the remarkably different conditions that call for thoughtful application of design, planning, and environmental health principles to support public health. Hunterdon County contains two major water supply reservoirs: Spruce Run and Round Valley. The Elizabethtown Water Company serves approximately 500 000 people with water from these reservoirs and the upstream areas that feed into them. Most of the shoreline of Spruce Run Reservoir is owned by the state, and thus forms a useful buffer strip. Buffer zones around reservoirs provide a good measure of protection for drinking water. However, most contamination is likely to come from streams and other tributaries feeding into the reservoir, and the lands adjacent to them are mostly privately owned.[7]

It is inevitable that developers will recognize the beauty of the area surrounding the Spruce Run Reservoir and its upstream areas and that they will propose building high-density condominiums, townhouses, or single-family houses along many of these streams. Unfortunately, zoning ordinances that should prevent such development often give way to money and political pressure.[8] In the event of residential development in this area, a local sewage treatment facility doubtless will be required to protect the reservoir and the other local wells from biological contaminants. But even under the best of conditions, it will be difficult to protect the reservoir from the runoff of gasoline, street salts, fertilizers, solvents, urban street wastes, pesticides, and other products of suburban development.

Hunterdon County's population was 70 000 in 1970 and rose to 125 000 in 2001, an increase of 74%, and another 20 000 people and 11 000 jobs are expected by 2010.[9] Hunterdon is one of the most affluent counties in the United States and is a model of the kind of area that attracts people looking for an idealized rural setting in which to live and work.[9–10]

Union County is about 20 miles away from Hunterdon County and is connected via an interstate highway, but it is a very different environment. The population of Union County in 1970 was 543 000 and the population in 2000 was 506 000, a decrease of about 7%. With a population density of 4800 per square mile, compared with 260 in Hunterdon County, Union County is the very type of the postindustrial urban area that has lost most of its jobs, lost some of its population, became a home for recent immigrants, and was left with a legacy of contaminated sites, or brownfields.[10]

Union County is important in this case study, because it has the potential to host so-called "transit villages"—transit-oriented developments that have high-density housing and commercial settlements in close proximity to train stations for people who prefer to travel by train rather than automobile.[11] Auto-dependent sprawl could be reduced in such a setting.

Estimating Pollutant Loadings

We assessed uncontrolled nonpoint source pollution loads associated with different development densities to evaluate the impact of land use and engineering controls. This assessment required use of soil, geology, land use, and other local data sets.[12,13] We used the Long-Term Hydrologic Impact Assessment (LTHIA) model, which is highly recommended by the US Environmental Protection Agency (EPA) and is accessible via the Internet. The LTHIA model, which was developed in 1994 at Purdue University, has been improved over the years, most notably in 1998 (when nonpoint source pollution was added) and in 1999 (when it became accessible via the Internet).[14] The user provides input data on land use and hydrologic soil type for existing and planned/future conditions; LTHIA then combines this information with local precipitation data to calculate long-term average annual surface runoff.

Uncontrolled pollutant loadings are estimated in pounds per year (except for bacteria, which are estimated millions per 100 ml) for 14 water-quality variables: total nitrogen, total phosphate, suspended solids, lead, copper, zinc, cadmium, chromium, nickel, biochemical oxygen demand (BOD), chemical oxygen demand (COD), oil/grease, fecal coliform, and fecal strep. All of these substances are listed in the EPA's list of drinking-water contaminants (BOD and COD are caused by excess organic matter), and some are clearly hazardous to humans when consumed in fluids.[15] The model's land use categories include residential (various densities), commercial, industrial, parking, open space, water/wetlands, grass/pasture, agricultural, and forest. We compared the impact of current land uses with the results of 2 alternative residential development scenarios: single-family homes on half-acre lots or a density of 2 housing units per acre, and a more dense condominium development of 8 housing units per acre. Other simulations were run, but on the basis of our experience in New Jersey, 2 and 8 represented the range of densities that seemed suitable for this study area.

TABLE 1—Area of Residential and Commercial Land Use in Acres for 2 Residential Development Scenarios: Hunterdon County, NJ

Land Use Categories	Current Baseline	With 8 Housing Units per Acre	With 2 Housing Units per Acre
Forest	1755	865	368
Agricultural	1022	503	214
Grass/pasture	328	162	69
Residential	...	1000	1879
Commercial	...	575	575
Total	3105	3105	3105

Notably, our analysis did not include pesticides, although pesticides represent a threat to public health and ecological systems. We omitted pesticides because the study area has agricultural, grass/pasture, and other land uses that historically have been heavily treated with pesticides (Table 1). To make credible estimates of the impact of urban development on pesticides, we would need to know current pesticide use in the area and the likely pesticide use by residents of the new developments. Neither of these important facts was obtainable; indeed, the pesticide question is always difficult to answer whether the proposed development area is an active farm, pasture, or a forest. Urban development might increase or decrease pesticide runoff.

Locating Sensitive Growth Areas

The Hunterdon County Planning Board provided us with existing land uses and zoning for the Spruce Run watershed area in a geographic information system (GIS) parcel-based format. We focused on the land within a quarter of a mile of the reservoir and its streams, because contamination of this land would have the greatest adverse impact on water quality. We then removed various lands from potential development, including a flood-zone buffer of 300 feet on each side of these waterways, state- or county-owned parks and open space, land located on steep slopes (greater than 15% grade), wetlands and other environmentally or culturally sensitive lands (as defined by the New Jersey Department of Environmental Protection), and lands already developed. Out of the total 25 035 acres (39.1 square miles) of land within the Spruce Run watershed area, we narrowed our focus to 3105 acres (4.9 square miles, or 12.4% of the watershed area) as our primary study area in Hunterdon County. These lands are currently categorized as forest, agricultural, and grass/pasture.

Our development scenarios are based on the assumption that 20 000 people will move into Hunterdon County over the next decade, with an average family size of 2.5 persons per dwelling unit. This population influx will require 8000 new residential units. We restricted commercial and retail development to areas already zoned for that purpose and to new areas that will naturally develop along major highways. A total of 1226 acres are assigned to these uses, including land that will not be covered by the footprints of buildings and associated parking areas and thus will be left in its current condition. We used various housing densities for residential land and calculated what proportion of the projected population increase could relocate on the 1879 remaining acres in this vulnerable area. We found insufficient land in the study area to house 20 000 people assuming that low-density single-family homes will be constructed. Only 3758 homes, at the rate of 2 units per acre, could

TABLE 2—Total Uncontrolled Nonpoint Source Pollution Loadings: Hunterdon County, NJ

	Baseline Pollution Loading	Change With 8 Housing Units per Acre	Change With 2 Housing Units per Acre
Contaminant, lb/y			
Total nitrogen	22 320	4 457	745
Total phosphate	5 447	1 771	1 048
Suspended solids	449 455	230 113	161 656
Lead	35	84	88
Copper	64	75	71
Zinc	100	1 133	1 219
Cadmium	9	2.5	1.1
Chromium	84	7	−14
Nickel	0	103	118
BOD	19 496	228 459	259 417
COD	0	752 091	822 891
Oil/grease	0	46 173	48 605
Bacteria, millions/100ml			
Fecal coliform	1.1	0.9	0.8
Fecal strep	0.0	3.9	4.7

BOD = biochemical oxygen demand; COD = chemical oxygen demand.
Note. The total area for each scenario is 3105 acres in Hunterdon County.

be constructed; however, 8000 condominium units could be built and 879 acres could be left in their current open-space condition. A comparison of these land use scenarios with current baseline conditions is shown in Table 1.

RESULTS

Estimated Impact

Estimates of total uncontrolled nonpoint source pollution loadings for 14 water-quality variables for these 2 development scenarios and existing baseline conditions are shown in Table 2. If either of these developments is built, we estimate substantial increases in the zinc, nickel, lead, BOD, COD, and oil/grease that will reach the nearby bodies of water. Notably, Table 2 also shows that the loadings do not vary much by residential-development density. Indeed, these density-related differences are within the expected predictive variance or error associated with the model. In essence, whereas pollution loadings did not differ for the various density options, loadings were vastly different for the development scenarios versus the baseline (undeveloped greenfields) condition.

Engineering Controls

Best management practices (BMPs) can mitigate the impact of development. The suitability of each BMP for a development is based on site considerations, such as slope, soil type, geology, water table depth, and development density. Each practice has certain advantages and disadvantages for each site. Nonstructural controls include zoning, open space retention, recharge-area protection, clustering, street sweeping, and public education. Structural (physical) controls include extended detention ponds (dry), wet ponds, infiltration trenches and basins, porous pavement, water-quality inlets, filter strips, and grassed swales. The most common structural control is either a wet or a dry pond; both have the potential for high pollutant removal if properly designed and maintained. Table 3 shows the potential for capturing unwanted contaminants across a variety of well-known BMPs. Individually or in combination, the BMPs have the potential to capture two thirds or more of the uncontrolled runoff. However, some BMPs could actually increase pollution. For example, nitrate nitrogen could increase with the application of surface sand filters and perimeter sand filters.

Many of the BMPs—especially ponds and detention basins—require substantial land. The 8-residential-units-per-acre option will accommodate them, but the lower-density configuration will not, because not enough land is available to fit in all the housing while preserving the acreage required for capturing the

TABLE 3—Estimated Pollutant Loading Reduction for Selected Best Management Practices

Best Management Practice	Total Phosphorus, %	Nitrate Nitrogen, %	Ammonia Nitrogen, %	Total Suspended Solids, %	Fecal Coliform, %	Metals, %
Extended detention basin	30	0	. . .	70	. . .	40
Wet pond	50	30	25	80	70[a]	60
Stormwater wetland	40	60	30	80	50[a]	60
Surface sand filter	50	Negative	. . .	80	40	40
Perimeter sand filter	60	Negative	70	80[b]	40	50
Bioretention system	60	. . .	50	80	. . .	80
Enhanced swale	30	50	50	60	. . .	40
Dry well	80	. . .	. . .	80	. . .	. . .
Pervious paving	50	. . .	. . .	60	. . .	60
Infiltration structure[c]	60	25	70	70	60	60
Filter strip	20	10	20	60	. . .	40
Riparian forest buffer	50	80	40	70	. . .	60

Source. Adapted from NJ Dept of Environmental Protection,[16] US Environmental Protection Agency,[17] and Scheuler.[18]
[a]If there is no resident waterfowl population.
[b]Needs pretreatment.
[c]With filter strip.

runoff. Hence, high density is required. Also, the BMPs' potential depends on proper maintenance and stewardship of the systems, which if not performed will quickly reduce the BMPs' effectiveness.

Institutional Smart Growth Options

Purchasing sensitive land or trading sensitive land for other land—especially if the redevelopable land can be part of a transit-oriented development—is desirable, because transit-oriented developments concentrate people and jobs around mass transit hubs rather than placing them on sensitive watershed lands. Our transit village proposal in Union County is not possible because of the county's already dense development. There is no single place where 8000 transit-oriented housing units can be placed. However, to illustrate the implications of what might be possible, we focused on 1 of Union County's larger and older cities—Plainfield—as a representative case study of the potential for residential redevelopment. Plainfield is an industrial suburb and commuter town that has suffered badly since the end of the World War II and has lost much of its middle-class population.[10]

We identified a 583-acre area along the rail corridor that is highly conducive to a mix of dense residential, small commercial, and retail redevelopment. The area is within walking distance of 2 train stations and thus would offer new residents an opportunity to reduce their reliance on automobiles to reach their jobs, the airport, and other conveniences. Our proposal includes redeveloping 15 of the 21 known brownfields within Plainfield.

If developed at the same density that we assumed in our Hunterdon County development scenario—8 units and 20 people per acre—the area could house about 11 600 people. If 30% of the land area used for parks and civic or community buildings were set aside to provide balance, this redevelopment zone could contain about 3265 new residential units and house about 8160 people. Allowing for some relocation of existing Plainfield residents into these new housing units would probably reduce the net impact to about 5000 to 6000 people, or about 25% to 30% of the expected population growth in Hunterdon County over the next 10 years.

Plainfield is only the eighth largest city in terms of land area and the third most populous in Union County. As such, it is reasonable to expect that redeveloping other brownfields and contiguous properties on a similar basis in multiple areas of the county could comfortably provide housing and services for more than half the people who might otherwise relocate on greenfields in Hunterdon County. In short, a series of transit-oriented, high-density developments in Union County would clean up brownfields, would not pollute public potable water supplies, and would help preserve open space around important reservoir and watershed areas in Hunterdon County.

DISCUSSION

Caveats regarding the Hunterdon County and Union County analyses must be noted. It is important to realize that the output of the Hunterdon County analysis is contaminant loadings. In other words, without water quality models, our results cannot be converted into concentrations of contaminants in the drinking-water supply, and our results certainly are not predictions of increased numbers of illnesses.

Nevertheless, it is appropriate to suggest what might happen in a worst-case scenario for public health and for better outcomes. Under the worst possible circumstance, even in this relatively pristine area, the runoff from an uncontrolled urban development, such as the scenarios we simulated, could lead to acute and chronic illnesses through drinking water, contact recreation, and fish consumption.[3,19] Pathogens, and hence serious waterborne outbreaks, could increase, as could less serious gastrointestinal infections, ear and eye infections, and skin rashes. With respect to chronic diseases, runoff could increase the carcinogenic, toxic metal, and hormonal disrupter burden in the exposed population. In short, without attempting to overamplify the risk, we consider it fair to say that this combination of acute and chronic public threats from uncontrolled runoff is a major challenge to our water supplies.[19,20] Perhaps we are engaging in wishful thinking, but we do not believe that the worst-case scenario will materialize in this watershed.

We brought our results to the attention of senior state officials and water purveyors whom we have known for many years. They were distressed; as a result, they have begun to increase sampling, and they will build a set of water quality models so that contaminant-loading estimates can be converted to concentrations in the water supply. More important, rather than wait for more data, they have begun to use their financial and political resources to preserve the parcels we have identified as highly sensitive. This action includes arguing that land-preservation funds should be prioritized for sensitive watersheds. Indeed, making the protection of these sensitive areas a priority was a recommendation given to Governor-elect James E. McGreevey by his Smart-Growth Transition Team, which M.G. cochaired. In short, the best public health outcome is that the land will be protected by the state and its local governments and that some of the people who would have moved to this area will relocate to transit-oriented developments.

A less favorable but plausible outcome is that the smart growth policies will fail, and much of the sensitive land will not be preserved. If this happens, we hope that engineering controls will be effectively deployed to control runoff. According to the New Jersey Department of Environmental Protection, treating stormwater runoff is estimated to cost between $2000 and $50 000 per water-impervious developed acre. The BMP costs are higher for small developments and decrease rapidly for larger areas.[16] Water purveyors should expect additional costs. For example, Oleg Kostin, superintendent of plant operations for the Elizabethtown Water Company, estimated that it would cost his company 5% to 10% more per year if the company's current raw water were to be degraded. The current cost for chemicals is about $1 million a year (personal communication, February 24, 2003).

With regard to the transit-oriented development part of smart growth, we have no incontrovertible data to show that people or businesses that would otherwise move to Hunterdon County would be willing to live in Union County on former brownfield sites. Yet, a recent survey of 800 New Jersey residents shows that this scenario is not implausible.[21] Specifically, 14% of New Jersey residents said they both planned to move during the next 5 years and would move to a cleaned-up former brownfield site. Those who seem most likely to move to a transit-oriented development on a former brownfield site are young (average age=35 years), currently live in apartments, and want to improve the quality of their residences and their neighborhoods. Typically, their next move would be to a suburb like Hunterdon County. But many of the interested parties said that they already lived near a brownfield, and they perceived a cleaned-up site with brand-new housing as an opportunity to improve the quality of their lives without moving out of the area. Hence, our assumption that people who otherwise would move to sprawling suburbs might be willing to stay in new housing built on former brownfield sites is not far-fetched.

Environmental health and planning have a long and joint history of gathering data and then advocating action to protect public health on the basis of that data. Our study calls for the reappearance of "the ghost of urban redevelopment past" that resulted in the institution of zoning, the building of New York City's Central Park, the understanding that unbridled industrial growth in Pittsburgh was having a serious impact on the health of immigrant populations, and other urban policies of the late-19th and early-20th centuries that recognized that many design, planning, and public health problems are inexorably linked.[22] Environmental health must be a major consideration in land use and engineering decisions, in regional development planning, and in transportation planning. We need to act on the emerging evidence of environmental health benefits. ■

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This article was accepted April 8, 2003.

Contributors

M. Greenberg organized and directed the study and prepared the article. H. Mayer co-directed the research and directed the Plainfield study. K.T. Miller obtained field data from Hunterdon County and performed the housing density computations. R. Hordon performed the runoff computations. D. Knee performed the GIS work for Hunterdon County.

Acknowledgments

This project was supported by a cooperative grant from the Development, Community and Environment Division of the US Environmental Protection Agency (R–82861901).

Human Participant Protection

No protocol approval was needed for this study.

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