The Geology of Water: *The* Limiting Factor in Urban Development

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Abstract

Of the several factors which bear on the initial establishment and later development of an urban center, the availability of an adequate *local* water supply is most important. The amount of available water includes that which is already obtained from both surface sources and underground aquifers plus the local reserves of water, which can readily be estimated from the geological setting. If any expanding urban area, such as Metropolitan Indianapolis, is to avoid major water crises and the certain deterioration of the quality of life, consideration must be given to setting a limit on population within the capacity of the *local* water resource, and directing "excess" population elsewhere.

Introduction

A number of factors have a bearing on the initial establishment and later growth of an urban center. Such factors include an advantageous geographic setting, the need for a regional supply center, favorable climate and vacation facilities, municipal services, employment opportunities, and intellectual and cultural exchange. But none is so important as the availability of an adequate water supply. As noted by Blake (1, p. 2), "Urban life . . . is peculiarly dependent upon water. Without it, cities simply could not exist."

Yet, the history of water needs in urban areas is the story of virtually continual crises. This is demonstrated so clearly by Blake (1) as, for city after city, he records an invariable and repetitive cycle of events: first, a slow realization that the water supply was inadequate in abundance and purity for the needs of the city; followed by a study of alternative solutions to the supply problem; followed by a reluctance to actually accept any of the alternatives because of the high cost; followed by a period of inactivity which ended with a calamity, such as fire or disease; followed finally by a burst of activity to construct the facilities for the needed additional supply of water; and too soon, the cycle began again.

It would seem proper, therefore, to consider the availability of water as a limiting parameter on the continued growth of any city. On the contrary, the adequacy of the water supply seems not to have been considered until some crisis made it impossible to ignore further. This is, partly, because of a tacit understanding by citizens that there is plenty of water, and partly, because of a more vocal assurance by "experts" that money and technology and careful planning can guarantee an adequate supply of water when it is needed.

As a result, considerations of the available water supply rarely interfere with the goal of trying to attract more industry, commerce, and people to a city, and then to expand the city boundaries to accommodate these increases. Thus, new sources of water eventually must be sought farther and farther from the city. In this respect, it is rather unsettling to think that southern California is seriously considering sources of water as far away as Canada.

This kind of thinking must, inevitably, lead to a deterioration in the quality of life in any major urban area. In the past several decades, such loss in quality of city life has been reflected by occasional water rationing in some cities (1, 4). When such rationing of water becomes commonplace and lasts for months or years instead of only a few weeks and occasionally, the decline in the quality of city life is clear and may even be symptomatic of a critical environmental deterioration.

Metropolitan Indianapolis: A Case In Point

The area around Indianapolis, which is representative of many growing centers of population, can serve to illustrate the premise: *local* available and potential water supplies should limit growth of urban areas. From a first-year population of 400-500 in 1821, Indianapolis has increased to about 450,000 people in 1970. As the city grew in population, it also grew in area from the original one square mile (2.59 sq. km) in 1821 to about half of the 402-square-mile (1372-sq. km) Marion County in 1970. The development of Indianapolis has become so interwoven with that of Marion County that in 1969 the city and county governments were combined into a single unit. The population of Metropolitan Indianapolis (*i.e.*, Marion County) was about 785,000 in 1970. Commuters from the adjoining seven counties (Fig. 1) increase the real population of the urban center to about 1,100,000 people within an area of about 3000 square miles (7770 sq. km).

Physical Setting of Metropolitan Indianapolis

Topography

The present topography of central Indiana reflects the fact that this area was covered by continental glaciers for significant intervals during the past 2 million years, the last ice withdrawing from the area only 18,000 years ago. The Indianapolis area is on the Tipton Till Plain, which is a flat to gently rolling terrain at elevations generally between 650 and 900 feet (200 and 275 m) above sea level in Marion County.

Drainage

Most of the Metropolitan Indianapolis area is drained by the (West Fork) White River, the principal stream in central Indiana, and its tributaries (Fig. 1). Fall Creek, the largest tributary on the east side, joins the White River near the center of the city of Indianapolis. In fact, the original site selected for Indianapolis in 1820 was on the east bank of the White River at the mouth of Fall Creek (2, p. 10). Of the western tributaries within Metropolitan Indianapolis, the most important is Eagle Creek, which joins White River in the southwestern part of the city.

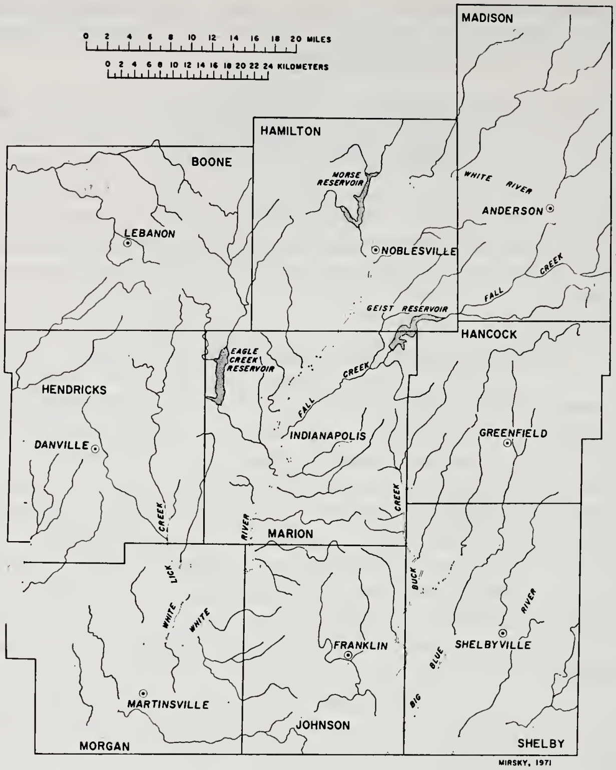

FIGURE 1. *Surface drainage in central Indiana and the three principal reservoirs for the Metropolitan Indianapolis area.*

Surficial Geology

Perhaps the most important aspect of the physical setting is the surficial geology (Fig. 2), because the surficial materials are the raw materials on which other factors act or depend. Thus, the surficial materials are the parent materials for the soils which have supported agriculture from the beginning, as well as being a prime source of sand and gravel for the construction industry as central Indiana becomes more urban and less rural, and even contain significant amounts of potable water.

Most of the surficial materials in Marion County consist of Pleistocene glacial deposits, which range in thickness from 15 to about 350 feet (5-107 m). These deposits are related to the Kansan, Illinoian, and Wisconsinan glaciations, though only the Winconsinan deposits occur at the surface within Marion County. The chief glacial deposit is a widespread till which blankets the upland surfaces between major streams. The second most widespread glacial material is outwash, consisting of sand and sandy gravel, which characteristically occurs along the major streams as terraces. The original site of Indianapolis was on such a terrace, as is much of the downtown area of the modern city. Ice-contact deposits of sand and gravel are present as generally small and isolated kames, occurring mostly in the southern area, with till either within or overlying (2). Relatively minor amounts of generally thin alluvial sand, silt, and clay, which occur along the major streams, are underlain by outwash.

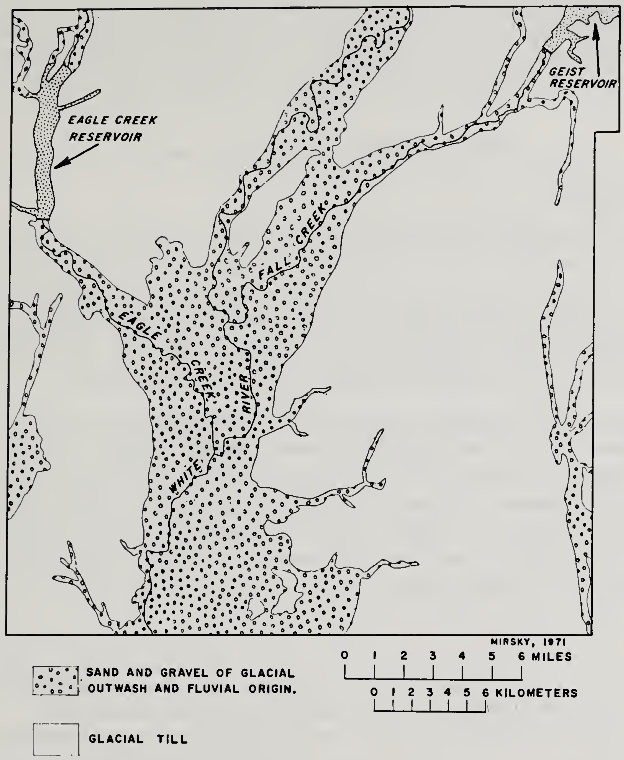

FIGURE 2. *Generalized Map showing the surficial geology of Marion County (Metropolitan Indianapolis), central Indiana (2).*

Bedrock Geology

The bedrock geology of Indiana is relatively simple: from a positive axis trending across the state from northwest to southeast, Paleozoic rocks dip gently westward into the Illinois Basin or northward into the Michigan Basin. Nowhere in the Metropolitan Indianapolis area is there any bedrock exposed at the surface, because of the glacial cover.

In Marion County, immediately under the surficial materials, bedrock includes from northeast to southwest Late Ordovician shaly limestone; Silurian limestone, dolomite, and shale; Middle Devonian dolomitic limestone; Late Devonian to Early Mississippian black shale; and Early Mississippian shale and sandstone (Fig. 3).

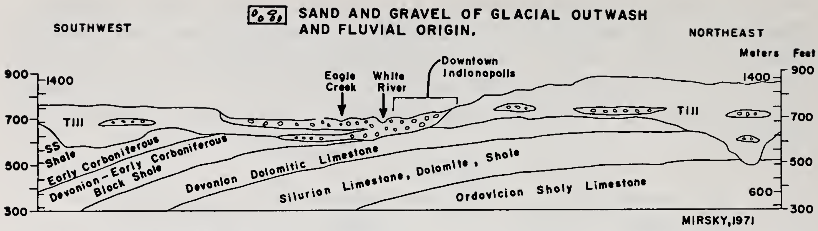

FIGURE 3. *Generalized geologic cross-section of Marion County (Metropolitan Indianapolis), central Indiana (2). (See text for identification of water-bearing units.)*

Water In Metropolitan Indianapolis

Source of Water

The water used by Indianapolis is derived from both surface and underground sources. The acquisition, treatment, and distribution of most of this water is through a private firm, the Indianapolis Water Company, which utilizes surface water primarily. Underground water, only a minor source for the Water Company, is much more important as a source for use by industry and by outlying communities.

Surface water. Surface water used by Indianapolis is obtained from White River (74%) and from Fall Creek (26%) (Fig. 1; Table 1); no surface water is derived from Eagle Creek, although the small community of Speedway in west-central Marion County does obtain about 2.4 mgd (9 mld) of water from this stream. None of the other streams in Marion County has sufficient flow to be seriously considered as a source for surface water.

TABLE 1. *Source and Average Daily Use of Water in Million Gallons (Liters) per Day, in Metropolitan Indianapolis, 1971 (Preliminary Estimates by William C. Herring, Indiana Department of Natural Resources, Division of Water).*

	Use in Million gallon/day		
	Non-industry	Industry	Total
Surface Water	63.2 (239.4)[1]	22.0 (83.3)	85.2 (322.7)
White River			74%
Fall Creek			26%
Eagle Creek			0%
Underground Water	22.8 (86.4)	37.0 (140.2)	59.8 (226.6)
Sand & Gravel (Outwash, Kames, Fluvial)			33.0 (125.0)
Sand & Gravel (Lenses in Till)			8.6 (32.6)
Limestone Bedrock			18.1 (68.6)
Other (SS, Sh)			0.1 (.38)
Total	86.0 (325.8)	59.0 (223.5)	145.0 (549.3)

[1]Figures in parentheses indicate water use in millions of liters per day.

The availability of the surface water supply is controlled through reservoirs on each of the main streams (Fig. 1). In 1942, the Indianapolis Water Company completed Geist Reservoir in northeastern Marion County, making the water supply from Fall Creek dependable at about 25 mgd (94.7 mld). Similarly, Morse Reservoir, about 10 miles (18.5 km) north of the Marion County Line, was completed in 1956 with a capacity of about 6,900 million gal. (261 billion l), and has assured a dependable water supply from White River at about 75 mgd (284 mld). Although Indianapolis does not yet use surface water from Eagle Creek, the city-owned Eagle Creek Reservoir in northwestern Marion County, which was completed in 1971 for recreational and flood-control purposes, will be a future source of some surface water.

Underground water: The principal sources for underground water (Table 1) are the sand and gravel deposits of Pleistocene glacial and recent fluvial origin and the underlying Middle Devonian Jeffersonville Limestone and Geneva Dolomite and the Middle Silurian Niagaran Limestone (2, p. 49).

The sand and gravel deposits occur as a more or less continuous tongue which underlies and flanks the principal stream valleys to a thickness of up to 100 feet (30 m), or as isolated thin lenticular bodies enclosed within the clayey glacial till which blankets the county (Fig. 3). The rocks of Silurian age are about 180 feet (55 m) thick and consist of interbeds of fine-grained crystalline to silty to argillaceous limestone (2, p. 74-75) with the upper half being the main aquifer. The Devonian aquifers include the 23-foot (7-m) thick massive to granular Geneva Dolomite and the overlying 60-foot (18-m) thick thin-bedded chalky to crystalline to locally brecciated and sandy Jeffersonville Limestone. Less than 1% of underground water is obtained from sandstone and shale of Mississippian age, which occur directly under the glacial till in the southwestern corner of Metropolitan Indianapolis.

Use of Water

The average daily use of water in Metropolitan Indianapolis for 1971 is shown in Table 1. Of 86 mgd (325.8 mld) used by non-industry (mostly residential and commercial), 74% is obtained from surface water and 26% from underground water. By contrast, industry obtains only 37% of the 59 mgd (223.5 mld) it uses from surface water but 63% from underground sources.

The Indianapolis Water Company is the chief supplier for non-industrial users, as well as furnishing industry's surface water needs. The Water Company obtains only about 7.2 mgd (27.3 mld) from its own wells, mostly to supplement the surface water supply in times of emergencies (such as during a drought or when a water treatment plant or water main is being repaired or to "heat" surface water in winter).

With 37 mgd (140.2 mld), industry is the main user of underground water, and has its own wells for this purpose. The remainder of the underground water is used as follows: 9 mgd (34.1 mld) by towns in Marion County other than Indianapolis proper, 6 mgd (22.7 mld) by commercial businesses, 5 mgd (18.9 mld) by domestic users (that is, home owners with private wells), 1.8 mgd (6.8 mld) by institutions, and 1 mgd (3.8 mld) for agricultural-irrigation purposes (W.C. Herring, personal communication).

Discussion

At the beginning of the 1970's, Indianapolis has sufficient water of acceptable quality available for all domestic, commercial, and industrial needs. The Indianapolis Water Company, however, recognizes that present usage is approaching the existing capacity, so it expects by 1975 to have to purchase from the city-owned Eagle Creek Reservoir up to 12.4 mgd (47 mld) to meet the anticipated increased demand by the continually growing city. Moreover, the Water Company is now planning to expand its Geist Reservoir so that an additional 57 mgd (216 mld) will become available by 1978.

Local surface water reserves in the Indianapolise area could become inadequate within a few years after Geist Reservoir is enlarged. Underground reserves are not known, but a reasonable estimate by adding more wells is 30 to 60 mgd (113-227 mld), perhaps as much as 140 mgd (530 mld) more with artificial re-charging, giving a potential total of 200 mgd (757 mld) (W. G. Herring, personal communication). Thus, the total local surface and underground water supply would be about 330 mgd (1249 mld), an amount sufficient for a maximum population of about 1¾ million people at the 1970 per capita use of 185 gal (700 l) per day. A report by the U. S. Army Corps of Engineers estimates that water needs in the Indianapolis area will be about 177 mgd (670 mld) in 1980 and 360 mgd (1364 mld) in 2020 (3). If the expected population increase is valid and only local water sources are utilized, a water shortage in the year 2000 is a real possibility. In recognition of this eventuality, and to prevent it, consideration is even now being given to sources of surface water outside the Indianapolis area.

The municipal officials and the citizens should resist all pressures to expand beyond the population which can be served by *local* water supplies, thereby ensuring a high quality of city life, at least in those aspects involving water. If this optimum population is exceeded, then a number of water problems which are now only minor nuisances from time to time will assume major proportions and adversely affect the quality of life in Indianapolis. These problems include those which touch on health, pollution, disagreeable taste and smell, increased treatment and re-cycling costs, shortages and consequent rationing. If it seems necessary to transport water from more distant sources, then there are problems related to the construction and maintenance of the aqueduct, and the postponed but nevertheless eventual problem of shortages at the distant source.

Conclusions

There is a curious optimism in many recent reports which simultaneously warn on the one hand of impending critical water crises resulting from increased use, tremendous waste, and overtaxed collection-storage-distribution systems and, on the other, of resolution of these problems through proper regional water resources management (*e.g.*, 5). The emphasis for the cure is misplaced, however: instead of devising ways to locate distant sources of water and to bring it to the expanding urban center, means should be sought to re-direct population in excess of that sufficient for *local* water supplies to other places where new sources of water can be tapped and used locally. Another city, comparable in size to Indianapolis, has recently decided to limit its growth (4). Bologna, the seventh largest city in Italy, is planning to stabilize its population at about 600,000 people in the city itself, and to direct any further influx of people to one of 17 surrounding communities, each of which will stabilize at 50,000 inhabitants. This "blueprint," properly modified to take into account local geologic and other physical details, should be applicable to any expanding metropolitan area.

Acknowledgments

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