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# GROUNDWATER RECHARGE IN URBAN AREAS

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## ABSTRACT

The two interlinked networks of hydrological pathways in urban areas are described with particular reference to the links with groundwater. As well as reducing direct recharge, urbanization creates new pathways and sources of water for recharge, including leaking water mains, sewers, septic tanks and soakaways. The net effect is often to increase recharge to pre-urbanization rates, or higher in dry climates and cities with high densities and large imported water supplies.

## INTRODUCTION

Much of the surface of urban areas is rendered impermeable by buildings, roads and surface coverings. Because of this covering, the classical view of the effect of urbanization on groundwater is that recharge is reduced. For example,

> "... groundwater outflow ... decreases with urbanization, with direct runoff ... increasing." (Douglas, 1983)

and similarly from Lindh (1983)

> "Infiltration to the groundwater is markedly reduced ... with less water reaching the aquifer, wells may have to be deepened"

In fact urbanization alters all parts of the hydrological cycle so much that no simple analysis of the effects on groundwater is possible.

However, many of the alterations will increase recharge where there is permeable ground below the city. This has been recognised in principle by some writers, for example Gray & Foster (1972) and Monition (1977), but the increases have rarely been quantified. It has not been realised that urban recharge is often as high, of higher, than pre-urbanization rates (Lerner, 1986).

## URBAN HYDROLOGICAL PATHWAYS

Water does not often follow a cycle in the urban environment because it enters and leaves across the urban boundary. Rather it follows a network of pathways. There are two such networks of pathways in urban areas which are interlinked at many points. These are the (heavily modified) natural pathways and the water supply-sewage pathways. The principal pathways of the natural network are precipitation, evapotranspiration, runoff, infiltration, recharge and groundwater flow.

The principal paths of the water supply network are shown in Figure 1,

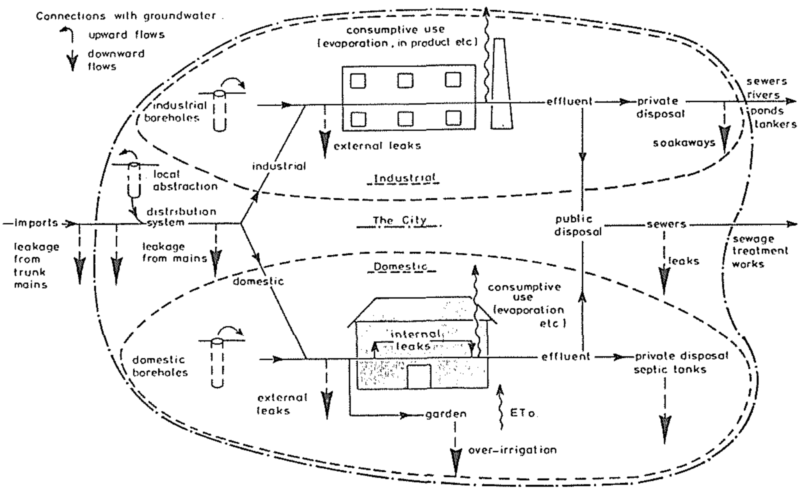


Figure 1. Flows of water and sewage in a city.

which particularly emphasises the interconnections with groundwater. Boreholes bring groundwater into the network; a variety of paths including leakage from pipes, over-irrigation and septic tanks carry water down to the groundwater system.

The water supply network carries large flows. Table 1 compares, for a number of major cities, precipitation - usually the main input to the natural network - with imports of water and local groundwater abstraction, which are the inputs to the water supply network. In highly urbanised areas, e.g. Hong Kong, and in arid or semi-arid climates, e.g. Doha and Lima, flows in the water supply network exceed those in the natural system. Even in temperate, moderate density cities (Vancouver, Birmingham) flows in the two systems are comparable in size.

## RECHARGE IN URBAN AREAS

### Recharge from the natural network

Large urban areas often have a micro-climate which may alter rainfall and evapotranspiration rates. These are probably second order effects on recharge when compared to the changes caused by surface coverings which generally reduce infiltration, and increase and accelerate runoff.

This runoff is often carried in storm sewers, drains, or other artificial waterways. Thus it is probable that direct recharge is reduced in urban areas. It should be noted in passing that permeable pavements are sometimes used to reduce runoff, and these will increase recharge by allowing infiltration while reducing vegetation cover and so reducing evapotranspiration (van Dam & van der Ven, 1984).

There is potential for recharge from storm sewers and drains, even when these are designed to carry water out of the city. Aside from the well known tendency for sewers to leak, Lerner (1986) presents evidence that such recharge occurs in Hong Kong. In a water resources study of Liverpool, the University of Birmingham (1984) concluded that significant amounts of storm water leaked from sewers into the groundwater systems.

Storm water is often deliberately recharged. In the U.K. for example, soakaways are commonly used to dispose of runoff from domestic roofs, and for road runoff from some motorways and in some cities. Recharge basins for storm water are used, for example, on Long Island and are thought to bring recharge up to pre-urbanization rates (Seaburn & Aronson, 1974). In arid climates there is often no provision for storm runoff, and the (rare) increased runoff from impermeable surfaces will infiltrate into the permeable surroundings.

Table 1. Relative sizes of inputs to the urban hydrological networks

| City | Area[1] ($km^2$) | Date | Precipitation | Imports | Local g'water | Units |
|---|---|---|---|---|---|---|
| Urban Sweden[2] | 4024 | c.1970 | 701 | 235 | nd[3] | mm |
| Mexico City[2] | nd[3] | 1980 | 86 | 14 | nd[3] | % |
| Hong Kong[2,4] | 1046 | 1971 | 1912 | 1310 | 64 | mm |
| Hong Kong[5,6] | 0.61-0.35 | 1980 | 2000 | 650-7500[7] | 0 | mm |
| Sydney[2] | 1035 | 1962-71 | 1150 | 333 | 16 | mm |
| Vancouver[2] | 0.21 | 1982 | 1215 | 576 | 0 | mm |
| Lima[8] | 400 | 1978 | 10 | 1650[9] | 950[9] | mm |
| Doha, Qatar[10] | 294 | 1981/82 | 167 | 175 | 27 | mm |
| Birmingham[11] | 500 | 1985 | 730 | 675 | 30[12] | mm |

1 Many of the areas are for a supply zone and include rural and semi-rural land
2 Grimmond and Oke, 1986
3 nd - no data given in source document
4 Whole city
5 Lerner, 1986; Geotechnical Control Office, 1982

6 Thirteen districts on Hong Kong Island
7 Assuming minimum night flows are 40% of supply
8 Lerner et al, 1982
9 Includes agricultural use
10 Pencol, John Taylor & sons, 1985
11 Written communications, Severn Trent Water Authority
12 Local groundwater only used by industry

**Recharge from the water supply network**

All water supply networks leak. Few authorities claim to be able to reduce leakage below 10% of supply, and rates of 50% have been reported. This sources alone can generate a potential recharge of up to 3000 mm/yr, although rates of 100-300 mm/yr are more common (Lerner, 1986). Sewers leak, as shown by the many examples of groundwater pollution below cities sewage. Many urban areas do not have sewers, relying on septic tanks and soakaways to dispose of effluents - this water must recharge groundwater. For example in Bermuda, with an average rainfall of 1460 mm/yr, water supply is from roof catchments and sewage is disposed of to septic tanks. These, and soakaways for storm drainage, increase recharge from 365 mm/yr in rural areas to 575 mm/yr in the urban area (Thompson & Foster, 1986).

The third main source of recharge from the water supply network is over-irrigation of parks and gardens. These are irrigated for aesthetic rather than commercial reasons. Application is often by unskilled labour. The amount of water applied rarely depends on plant water needs, but on the affluence of consumers, pricing policies for water supplies and, in the case of municipal parks, on bureaucratic procedures. For these reasons over-irrigation is normal with many multiples of the potential evapotranspiration being applied. Excess water percolates deep to recharge groundwater. An example is Doha in Qatar where over-irrigation has raised groundwater levels to the surface in many low lying areas.

**Net effect of urbanization**

Figure 2 summarises the changes in recharge that urbanization can cause. With so many changes, and with different conditions in every city, it is difficult to generalise about the net effect. However it is clear that there will be always be man-made sources of recharge. In drier climates, or with large imported supplies, or with poor maintenance of piped systems, recharge in urban areas is likely to exceed that in rural areas. Table 2 gives some examples of water balances for urbanised aquifers.

Table 2. Example water balances of urbanised aquifers ($10^3 m^3/d$)

| City | Lima | Doha | Bermuda |
|---|---|---|---|
| Area ($km^2$) | 400 | 294 | 6.3 |
| Recharge from: | | | |
| precipitation | 0 | 11.5 | 4.83 |
| rivers | 280 | 0 | 0 |
| Agricultural irrigation | | 0 | 0 |
| park irrigation | 390 | 37.6 | 0 |
| leaking mains | 340 | 25.3 | 0 |
| sewers and septic tanks | 0? | 17.6 | 3.13 |
| soakaways | 0 | - | |

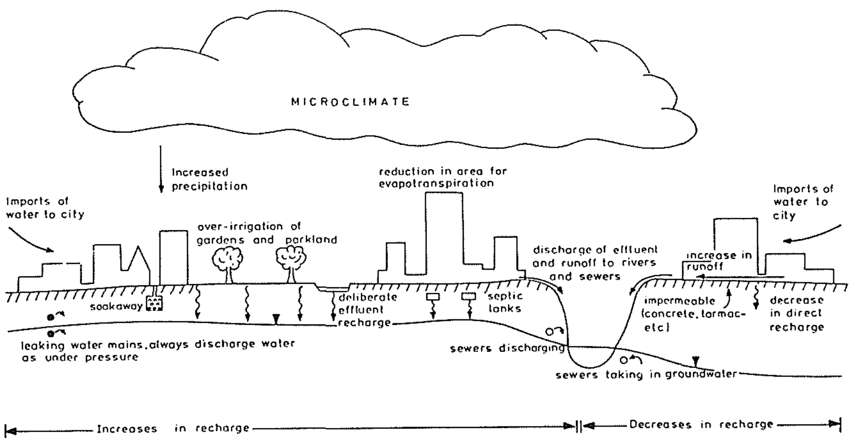


Figure 2. Urban effects on groundwater recharge.

## ESTIMATING RECHARGE IN URBAN AREAS

The multiplicity of recharge sources and complexity of landuse and surface cover, make it extremely difficult to estimate recharge in urban areas. For example, consider the possible sources of recharge from the water supply network:

recharge = leakage from water mains
+ external losses from consumers' properties
+ leakage from sewers
+ flow to septic tanks
+ deep percolation from domestic irrigation
+ deep percolation from municipal irrigation (1)

Considering all these components individually, with their associated errors, can lead to a large accumulated error in the recharge estimate. To reduce errors, it is preferable to consider the overall balance and estimate recharge as follows:

net recharge = imports of water
+ local abstractions of groundwater
- consumptive use
- effluent leaving area (2)
+ increase in water table

Methods of using both equations are discussed by Lerner (1988). Estimating recharge from the natural network presents even greater problems, the most difficult of which is losses from storm sewers. All studies of leaking sewers have been those which collect water, not lose it, because this is an important factor in design. Except in research studies, water balance over individual storms is unlikely to be accurate enough because of the uncertainties in both measurement of precipitation and runoff, and in estimates of detention and evaporation. Field tests in combined sewers at times of low flow, or injecting and tracking known flows or tracers, or analysis of groundwater responses may provide more accurate estimates for small parts of a city, but are impractical for the whole system. The best approach will be to set upper and lower bounds on recharge by water balance methods. These estimates can then be refined by calibration of a groundwater flow model against groundwater responses and outflows.

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