Groundwater in the Urban Environment: Problems, Processes and Management, Chilton et al. (eds)
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Water-sensitive urban planning: Concept and preliminary analysis

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ABSTRACT: In the context of sustainable development, there is a need to promulgate guidelines for urban planning which will consider the effects of the built environment on water resources. Our current work is a first step on the way towards Water-Sensitive Urban Planning (WSUP). It focuses on groundwater protection, and includes: a review of the state of knowledge regarding the effect of urban development on runoff and infiltration, assessment of these effects for the coastal aquifer in Israel, identification of relevant components of WSUP, preliminary practical proposals, and recommendations for further research.

1 INTRODUCTION

Water-Sensitive Urban Planning (WSUP) is an important component of sustainable development, whose goals, approaches, methods and results are predicated upon consideration and care for the long-term effects of development projects on the natural resources and on their usefulness to mankind, both now and in the future.

WSUP considers the effects of urban development on water resources. It has two aspects: the effects on the quantity and quality of water resources, and the effects on water use and on generation of wastewater. Our work relates to the first of these, and focuses on groundwater. In this context, the goal of WSUP is to increase the quantity of good quality water which infiltrates into the ground and eventually reaches the groundwater.

Rapid urban development over aquifers is occurring and is expected to grow in many places, including Israel's coastal plain. In view of this, we have posed three objectives for our work:

1. To review the current state of knowledge about the influence of urban development on groundwater;
2. To create the knowledge basis for WSUP, which relates to planning guidelines (including housing patterns) and to installation of facilities for mitigating potential negative effects;
3. To explore the application of the above to Israel's coastal plain, where extensive urban development is expected over the next two decades.

The research project is ongoing. In this paper we review the literature survey conducted, report interim results of the analysis carried out, propose some guidelines, and outline a plan for further research.

2 LITERATURE SURVEY

2.1 *Urban land use and the quantity of groundwater*

Common wisdom, reflected in publications on hydrology, is that urban construction of buildings, roads and parking areas increases surface runoff by creating more impervious surfaces, which translates into a reduction in infiltration and, therefore, less groundwater recharge (Maidment 1993; Harbor 1994; Singh 1995). However, several studies have indicated that the effect of urban development on the hydrological balance is not quite so pronounced, and that, in effect, the percentage of rainfall which infiltrates is greater than often thought (Van de Ven 1985; WAWA 1987; Ferguson 1994). This is particularly true if measures are taken to increase infiltration (Ishizaki et al. undated; Fujita 1992; Herath et al. 1993).

Hence, the first question we posed for this research was: is it correct that urban development reduces groundwater recharge? There are several ways to approach an answer. One is direct measurement of the effect on groundwater (Water Sensitive Urban Design Research Group 1989) and computation of the groundwater balance equation. This requires measurements which are difficult and computations which are error-prone, and hence is seldom done. An indirect way would be to measure rainfall, runoff and evaporation, and compute infiltration as the remaining unknown in the balance equation at the surface. Again, few measurements exist of the runoff in urban areas (Herath et al. 1993; Gerti et al. 1993). A third way is to use models which accept rainfall data and compute infiltration, evaporation and runoff, using a description of the watershed and the properties of soil and land cover (Singh 1995). This is the approach we have taken in the meantime, as long as measurements are not available.

2.2 *Urban land use and the quality of groundwater*

Land uses affect the quality of surface runoff and the water which infiltrates into the ground. Urban development is accompanied by an increase in the quantities of several pollutants, the ones of most concern include chloride, nitrate and heavy metals (Berry & Horton 1974; Atwood & Barder 1989; Christensen & Rea 1993; Kappen 1993; Pitt et al. 1994).

Assessing the effect of urban development on groundwater quality faces even more severe difficulties than those mentioned above for quantity. The processes are complex and diffuse, soil properties which are not readily measurable in situ have a significant influence, and, most important, the process may take several decades before the effects of land uses reach the groundwater (Ronen et al. 1986; Barringer et al. 1990). From the perspective of our work, it is quite certain that the cleanest water for infiltration is rain which falls on houses and their yards and gardens, in particular the water which can be collected directly from roofs.

3 ESTIMATING LOSSES TO GROUNDWATER RECHARGE DUE TO URBAN DEVELOPMENT: A CASE STUDY IN ISRAEL'S COASTAL PLAIN

The population growth and the rapidly rising standards of living in Israel have resulted in extensive urban growth. About half of the total increase has taken place, and is expected to take place in the future, in the coastal plain. The core of the accelerated development is in the metropolitan area of Tel Aviv, which lies above Israel's largest and most important multi-year reservoir of water, the coastal aquifer. The phreatic sandstone aquifer lies beneath an area of some 1900 square kilometers, with a thickness ranging from a few meters to about 200 m. The water table, below which the aquifer is saturated, lies 5 to 20 m below the land surface.

We decided to concentrate on the main bulk of urban development: the residential area including the associated services (social services, commercial areas, local roads, parking spaces and small open spaces). We left out industrial areas and main transportation corridors.

The first objective of the case study was to provide initial estimation of the losses to groundwater recharge, resulting from the pattern of urban construction which is typical of Israel of the 1990s. Another objective was to identify the components of urban planning that seem to directly influence groundwater recharge.

3.1 *The Test Location - Kiryat Ganim*

The neighborhood of Kiryat Ganim, a newly constructed urban area on the coastal plain of Israel, was selected for our case study (Meiron-Pistiner 1995). Its construction began in 1991. By 1994 its population reached about 6,400 residents in 1,770 households. The neighborhood is part of Rishon Le-Zion, a city south of Tel Aviv that has grown from about 50,000 in the early 1970's to 100,000 ten years later, and to more than 150,000 inhabitants in the early 1990's. The population of the area and the physical plan of the neighborhood are typical of the urban sprawl at the heart of the State of Israel, the core that spreads above the coastal aquifer.

The climate in the area is Mediterranean, mild, with an average of 58 days of rainfall (over 0.1 mm) a year, from about October to April, dry the rest of the year. The annual rainfall averages 536 mm (maximum 912 mm, minimum 312 mm. The highest monthly rainfall is in December, with an average of 146 mm.

The soil on which Kiryat Ganim was constructed is primarily sandy, about 160-180 m thick to the impervious layer below. The groundwater in this area shows concentrations of chloride in the range of 110 to 230 mg/1, and nitrate (as $N0_3$) in the range of 40 to 75 mg/1 (the acceptable concentrations are: CI", 250 mg/1 for potable and unrestricted agricultural use; $N0_3$, 45 mg/1 for unrestricted potable use, with an upper limit of 90 mg/1). Hence, the groundwater in this area is suitable for most uses, but the concentrations are approaching critical limits.

Kiryat Ganim has an area of 560 dunams (560,000 m^2) with 57% covered by residential buildings and their yards; the remaining 43% include: 21% open space, 10% roads (those not within the residential area), 9% public and commercial services, and 3%

undeveloped open spaces.

The building patterns of Kiryat Ganim are typical of the recent (1990s) urban sprawl above the coastal aquifer of Israel. Out of the average area per person in the housing area (without public services, main roads, neighborhood open spaces, etc.), about one quarter is covered by roofs, 40% (!) are paved areas, and the remainder (about one third) is green (mostly private gardens). As can be expected, the lower the density of housing units per dunam, the higher the total area per person (2.5 times higher in low density than in high density). It might be expected that in lower densities, a larger percentage of the area per person will be open and green, but this is not the case in Kiryat Ganim; the percentage of green areas is the same in higher and lower densities, and hence, the impervious area per person in low density is 2.5 times larger than in high density.

3.2 *Computational Methods*

Because of the difficulties in field measurements, as discussed above, we used two methods to estimate the loss of infiltration due to the construction of Kiryat Ganim: the Soil Conservation Service (SCS) method (SCS 1975; Harbor 1994; Ferguson 1996) and the Storm Water Management Model (SWMM) (Huber & Dickinson 1988; Huber 1995).

According to the SCS method, the volume of runoff from each storm is a function of a Curve Number (CN), taken from tables. The CN value is assigned according to the land uses on the watershed. The more impervious the area, the higher its CN value, and the larger the runoff volume. The computation is carried out for each rainstorm, and the runoff from all storms is totalled over the year. It is then assumed that the increase in runoff translates into an equal reduction in infiltration.

SWMM performs a continuous simulation, using sub-models of the hydrologic processes in the watershed (evaporation, infiltration and runoff) with parameters assigned to each sub-model according to watershed shape and area, soil properties, and evaporation rates. The computed values of each variable are totalled over a year's simulation period, to yield the annual volumes of runoff and infiltration. SWMM uses variable time intervals in the computations: a short interval (typically five minutes) during rainfall, and longer intervals corresponding to the time between storms.

3.3 *Data and Results*

Rainfall records from the nearby Beit Dagan meteorological station were examined, and five years were selected, according to their total rainfall amount: one close to the long term average, two close to the upper and lower extremes, and two more in between.

For the SCS method, eight land uses were identified in Kiryat Ganim, and for each of them the total area and the division into pervious (CN=49), cultivated (CN=39) and impervious (CN=98) areas were measured on a detailed map. The impervious area is further separated into roofs and paved surfaces, as required for a later analysis.

SWMM was run for the same years. The area was divided into six sub-basins, the Green-Ampt model was used for infiltration, and parameter values were taken from the manual (Huber & Dickinson 1988).

Three development conditions were considered: before development; after development, where all roofs and paved areas are impervious; and after development but with the roof drains connected to the garden/yard, adding their area to that of the pervious area.

Detailed results for SCS have been reported in Carmon & Shamir (1997a), and those for SWMM in Carmon & Shamir (1997b). Table 1 presents a summary of the average results for the five years: the lost infiltration per square kilometer due to urban development according to current practice, and the percentage of that loss which can be saved by connecting roof drains to the ground.

Table 1. Loss of infiltration due to urban development, and percent saved by connecting roof drains to the ground.

	Computation by the SCS model	Computation by the SWMM model
Increased runoff per km^2 due to urban development	71,000 m^3/year (14 % of the rain)	240,000 m^3/year (47 % of the rain)
Percent saved by connecting roof drains to the ground	35%	32%

4 TOWARDS WATER-SENSITIVE URBAN PLANNING

A planning team has been preparing, since 1990, a master plan for Israel into the 21st century. It includes forecasts of population and the built areas, to the year 2020 (Mazor & Trop 1994). According to these forecasts, the urban area in Israel's coastal plain in 2020 will be double its value in 1990 (from about 650 km^2 to 1275 km^2). Taking the results computed for Kiryat Ganim and projecting them to the entire area of the coastal aquifer according to these forecasts indicates that the lost infiltration will be (by the two computational methods) between 90 and 300 million m^3/year, half from existing urban areas and the other half from new ones. This is a very significant amount of water, in particular in the Middle East, where water shortage may have to be alleviated through expensive desalination.

Reducing this amount by WSUP will yield other benefits, especially a decrease in surface runoff which will enable reduction in the size and cost of the drainage systems. Other potential benefits would be reduction in the magnitude and severity of flooding in the urban area itself, and in the waterways and coastal waters to which the drainage is directed. Needless to say, consideration must be given to the effect on groundwater quality of changing from the conventional to the proposed urban development scheme.

Our conclusion is that sustainable development and preservation of the water resources require a joint effort by researchers and planners to develop and implement guidelines for WSUP. In this concluding section of the paper, we propose to contribute in this effort, by: (a) identifying the relevant components of urban planning, (b) providing preliminary practical suggestions for planners, and (c) proposing a plan for further research.

4.1 *Relevant Components of Urban Planning*

Based on the work conducted so far, i.e. study of the literature and the investigation of Kiryat Ganim, we identify five components of urban planning which should be considered in connection with their effect on runoff and infiltration:

1. The proportion of built and paved areas versus open spaces (impervious versus pervious land cover), in common building patterns.
2. The distribution of open (pervious) spaces over the area. There are ways to "break" the impervious area by patches and strips of pervious area, where water accumulated over the impervious part has a chance to penetrate into the ground.
3. Pervious paving materials for sidewalks, parking areas, paths, squares, and interior roads. Water quality has to be considered when dealing with roads and parking lots, but paved areas in yards, gardens and sidewalks are probably safe from the point of view of quality.
4. Sub-division of the area into small "micro" catchments. Each building, with its small yard/garden and a low stone wall around it, can become an infiltration basin.
5. Incorporation into the urban fabric facilities designed to intercept, detain and infiltrate water from precipitation. Such facilities may be at several scales: the individual lot and building, the urban cluster (urban block), and the larger urban area and region.

Information about the effectiveness and cost of several facilities and means to reduce urban runoff and increase infiltration is available in the literature (Schueler et al. 1992; Kennedy Engineers 1992; Ishizaki et al. undated; Fujita 1993; Ferguson 1994; Konrad et al. 1995).

4.2 *Preliminary Practical Proposals*

Urban development is expected to continue, even over aquifers whose waters are important, because of the economic pressures which are usually much more powerful than the forces of preservation. Still, we hope that by identifying actions for preserving groundwater quantity and quality, which can be harmonized with urban development, the goal of sustainable development will be served.

Given the state of knowledge at this time, as revealed in our study, we cannot as yet provide well founded recommendations, even though such are urgently needed. We can, however, already make the following initial proposals:

1. The public, relevant authorities, urban planners and designers should be made aware of the opportunities for reducing the negative effects of urban development on groundwater quantity and quality;
2. Open spaces, especially green tracts, should be interspersed in the area to be developed, in a manner which will allow as much of the surface runoff to be intercepted by pervious areas as possible;
3. Wherever possible, rainwater should be captured on site, before it flows and becomes polluted; special attention should be paid to using yards as micro-catchments;
4. In the first stage of planning of an urban area, the sensitivity of the area in terms of potential damage to groundwater should be assessed. The

sensitivity assessment is intended:
- to identify small areas above phreatic aquifers which serve as important natural infiltration basins, due to specific topographical or geological structure, and to inhibit or limit construction above them;
- to identify larger vulnerable areas above phreatic aquifers, the soil of which is permeable and the quality of groundwater underneath them is high, and to direct planners to use the best knowledge available to them in order to increase infiltration and care for the quality of the infiltrated water.

4.3 *Recommendations for Further Research*

To establish planning guidelines for WSUP on a sound basis, much more research is required. Assembly of an adequate information and knowledge base requires years of field measurements and analytical studies. We should, however, not wait for these to be completed before issuing some recommendations which seem justified on the basis of what we can conclude in a shorter period of time. Urban development is progressing rapidly in many areas underlain by groundwater aquifers, and we must try to protect their waters while we continue to conduct further studies.

Hence, a two-phase strategy is proposed. The goal of the short-term phase is to issue recommendations for WSUP based on knowledge obtained from the studies already conducted and elicited from experts. The goal of the long-term phase is to issue affirmative planning guidelines, based on valid and reliable empirical research that explains cause and effect relationships between urban land uses and groundwater quantity and quality, in addition to investigation of the technical, economic, social and administrative feasibility and effectiveness of the proposed guidelines.

The short-term effort is based on existing knowledge; the assembly of information, summary, analysis and conclusions on:

1. The effect of different ratios of pervious areas in an urban zone, and their spatial distribution (few and large or small and many), on the quantity and quality of surface runoff infiltrating into the ground;
2. The effects of devices and facilities designed to increase infiltration of surface runoff, including: stone walls around gardens that create a micro-detention and recharge basin; roof drains connected to the surface of the yard or garden, or to an underground "recharge well"; pervious paving materials; pervious ("leaking") drainage pipes; small detention ponds (temporary or permanent); temporary use of playgrounds as detention and recharge facilities.

For each one of these, the analysis should address two aspects:

1. The physical consequences - effects on the water resource, on the drainage system, on the environment, and on the urban landscape. These conclusions should be relevant to other regions and countries, with similar conditions;
2. Feasibility of implementation - technical, economic, administrative and social considerations of introducing planning guidelines, installing devices or facilities, and maintaining them. Some of the conclusions may be specific to the location, while others may be more universal.

Our current work focuses on these short-term tasks. In parallel with the above plan for the short-term, there is need for a concerted long-term effort to improve knowledge and generate the information upon which policies can be based, with confidence. Empirical investigations must be a central element of this effort The objective is to collect and analyze field data on the relationships between tractable (independent) variables (land uses, building types, and facilities installed in the urban area) and the dependent variables (quantity and quality of runoff and groundwater), with appropriate attention to intervening variables such as meteorology and soil types. These tests must be conducted over periods of years.

Measurement facilities for surface runoff and its quality should be installed at the micro scale (house with yard/garden), at the meso scale (urban block) and at the macro scale (large sections of a city). Location of the measuring stations and the frequency of measurement need careful planning, to maximize the benefit of the data gathered. Some information of this type has been collected in several places in the world; it should be assembled and analyzed to provide the initial basis for the data collection effort. Groundwater quantity and especially quality should be measured directly by observation wells, in the unsaturated and saturated zones of aquifers to detect the influence of land uses and activities at the surface. Such monitoring systems require a dense network of wells, because of the local nature of the pollution, but do not need frequent measurements in time, since the processes are usually quite slow.

Models of urban hydrology should be modified to incorporate knowledge generated by field studies. Most existing models have concentrated on surface runoff, and even those which compute infiltration directly (for example SWMM) do not deal fully with the effect of the spatial distribution of pervious and impervious sub-areas and the effect of the temporal and spatial variability of rainfall on infiltration.

5 CONCLUDING REMARKS

In this paper, we have concentrated on one main aspect of WSUP, namely its effect on groundwater, in particular the quantity of infiltration. Other important aspects include: groundwater quality, effects on other water resources, water consumption in the area, effects on the drainage system and impacts on the downstream environment.

We believe it is feasible to reduce substantially the negative effects of urban development on the quantity and quality of groundwater in underlying aquifers, and maybe even bring about an improvement relative to conditions prior to urban construction. This leads to a new paradigm: urban runoff is a resource, not a nuisance.

Groundwater recharge is one aspect of WSUP. We believe that in its broadest sense WSUP has the potential to be viable technically, economically and socially, and contribute to sustainable development We have examined some of the other aspects, are continuing the study, and seek to cooperate with researchers and practitioners who see the benefit in promoting Water-Sensitive Urban Planning.

ACKNOWLEDGEMENT

The work was carried out under contract to the Water Commission and the Ministry for Environmental Protection, and supported in part by the Fund for the Promotion of Research at the Technion. We are grateful to many who have worked on the project or helped in advice and data: Sigalit Meiron-Pistiner, Lea Kroneveter, Avner Kessler, Aryeh Ben-Zvi, Rami Gerti, Moshe Getker, Shmuel Arbel, Israel Gev.

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