PLANNING AND MANAGEMENT OF A SUSTAINABLE AND EQUITABLE WATER SUPPLY UNDER STRESS OF WATER SCARCITY AND QUALITY DETERIORATION AND THE CONSTRAINTS OF SOCIETAL AND POLITICAL DIVISIONS: THE CASE FOR A REGIONAL HOLISTIC APPROACH.

Joel R.Gat, Prof.Em.
Dpt of Environmental Science and Energy Research,
The Weizmann Institute of Science, 76100 Rehovot, Israel.
E-mail: Joel.Gat@weizmann.ac.il

ABSTRACT

The availability of adequate freshwater of appropriate quality has become a limiting factor for development, worldwide.. In the semi-arid and arid regions, where water scarcity was always a dominant problem, the interference with the natural system as a result of over-exploitation of both surface and ground waters and the effects of changes in land usage on the groundwater recharge and surface drainage fluxes resulted also in deterioration of the water quality. The water requirement of all users can be satisfied by proper technical means such as water imports or relocations, desalinization as well as proper prevention of pollution, remediation, clean-up and recycling; however, such measures if applied locally on an ad-hoc basis as an emergency procedure may impose an unbearable and unjust economic burden on some of the stakeholders and not necessarily those responsible for the problem. Such a situation is in all cases a pretext for discord and assignment of blame on those supposedly responsible for the deterioration of the water quality. The potential for friction is especially high under a trans-border situation, where one party controls the upstream recharge and the other the downstream discharge sites. It is now recognized that the rational, equitable and economically advantageous utilization of water resources must encompass the total watershed if not the whole regional water cycle. The common dependence on good and reliable water resources for all stakeholders, which cannot be subdivided, can then become an inducement for regional co-operation.

KEYWORDS: Groundwater; Surface water; Trans-border resources; Water Quality.

INTRODUCTION

The availability of adequate freshwater has become a limiting factor of the quality of life, worldwide. More than the water availability per-se, the issue is often the quality of the water resources for the supply of potable water.

In the semi-arid and arid regions water scarcity was always a dominant problem and thus a cause for rivalry. Moreover, the interference with the natural hydrologic cycle as a result of over-exploitation of both surface and ground waters and of changes in land usage resulted not only in the reduction of the available water amounts but also in the deterioration of the water quality due to pollution from urban, industrial and agricultural practices and salinity build-up in soil and water. One is concerned with the salinity buildup in the aquifers in general, the chemical composition of this salinity that limits the utilization of the water for specific uses, and moreover the presence of anthropogenic pollutants introduced by activities near the replenishment sites of the aquifers concerned. Such a situation is in all cases a pretext for discord and assignment of blame on those supposedly responsible for the deterioration of the water quality, especially in view of the possible high cost and technical complexity of the measures that need to be taken for remedying and alleviating the situation. Under a trans-boundary situation the potential for friction is especially high when one party controls the upstream recharge areas and the other the downstream discharge sites.

The optimal and sustainable exploitation of the natural water resource and the preservation of its quality under a regime of development, possibly also its amelioration by preventive measures and clean-up operations, all require the joint planning, management and operation of the water resource by all stakeholders in both the upstream recharge areas, the downstream discharge sites and by the population which utilizes the water (Haddad et al.,2000).

Obviously, the prerequisite for rational action, free of discord, is a scientifically sound analysis of the geo-hydrological and bio-geochemical structure of the water sources. This should be based on a detailed monitoring network and an accepted hydrological model that should also account for the pathways of the chemical components and possible pollutants in the system. Further, the options for remediation of the system and their economic evaluation need to be recognized. This will enable one to put into operation the required preventive measures and the cleanup operations for the continued sustainable operation of the water resources with an objective and clear understanding of the responsibilities and requirements of all partners with regards to the water resource and the economic burden imposed by the alternative management options.

THE WATER RESOURCES OF THE REGION AND THEIR CONSUMERS

In the area under discussion the climate ranges from semi-arid to arid, the latter extending over the southern (desert) regions and in the inland valleys, notably the southern Jordan valley. The region is characterized by large geographic and temporal disparities of the precipitation distribution, with relatively large annual amounts of precipitation in the higher mountain regions of the Galilee, Lebanon and Mt. Hermon and the longitudinal mountain chains of Samaria, Judea and (trans-) Jordan and much smaller amounts in the lowlands, rapidly decreasing towards the south. The Mediterranean climate further imposes a sharp seasonality in rainfall with a long rainless summer period devoid of any water inputs into the hydrologic systems, only slightly shortened by snowmelt waters in the northernmost part of the area. A relatively variable regime, with alternating drought and excessive rain periods further acerbates the situation.

The precipitation regime, coupled with the morphological structure of the area which is dominated by the feature of the Syrian – East Africa Rift, resulted in aquifers recharged predominantly at more elevated outcrops and draining to the west or east, discharging as small springs or subsurface outflow. The only major surface water system is presented by the Jordan River that channels the water excesses of the north southwards in the Rift Valley, finally to waste away in the Dead Sea under the beating sun in the arid desert.

From the dawn of history the pattern of human settlements was influenced by the availability of drinking water, with the location of preferred sites near the emergence of springs, along the course of a river or wherever shallow dug-wells encountered fresh underground water. As a rule, this dictated rather low-lying locations far away from the headwaters of the hydrological systems concerned, including places to which water could be conveyed by gravitational flow in aqueducts. The early settlements at higher elevations, which were preferred because of their security, milder climate and freedom from insect-borne diseases, had to rely on collected rainwater stored in cisterns or on small local springs. Such settlements were necessarily of limited size and extremely vulnerable in periods of drought.

The advent of mechanized pumping and deep drilling techniques made possible the increase and spread of anthropogenic activities further away from the visible sources of water. This enabled, on the one hand, the increase of the population in the mountainous areas, resulting in changes in land use and urbanization on or near the headwater of rivers and the sites of groundwater recharge; interference with the natural replenishment regime and the introduction of pollutants resulted. On the other hand, it encouraged the large-scale cultivation of the arable lands in the coastal plain and the inland valleys and of the more arid lands in the south. Since all of these are based on irrigated agriculture they required the supply of huge amounts of water; this then resulted in the increasing over-exploitation of the groundwater sources and the transport of water from the sources in the north, culminating in the so-called "National Water Carrier" which transports water from the Sea of Galilee to the coastal plain and the northern Negev.

These developments, often performed with the best of intentions but in violation of proper eco-hydrologic guidelines, resulted in widespread negative environmental impacts as described in Table #1.

The surface runoff systems

The Jordan River System (JRS) which includes the only fresh inland lakes, namely Lakes Kinneret and Hula (also known as Lake Tiberias or Sea of Galilee and Waters of Meron, respectively) is of an endorheic nature. Along the coast, rather short perennial rivers are fed primarily by springs draining the mountain aquifers and finally discharge into the Mediterranean Sea. In the arid regions of the inland valleys and the Negev, ephemeral flood-flows in dry-river beds (wadis) are the major surface water features; these play a crucial role in desert hydrology.

Apparently plentiful and immediately accessible, the perennial rivers are being exploited excessively both for activities along the banks of the rivers and lakes, but are also diverted to regions outside the natural borders of their respective watersheds. Common management concerns of river systems are the widely fluctuating nature of the discharge that require regulatory control measures (which in turn may affect the natural attenuation capacity of the overflow bank areas) and the construction of storage facilities. Of special concern is the extreme vulnerability of the river systems to the flushing of surface contamination into the river following strong rain events, acerbated by the release of sewage or irrigation return flow following utilization in domestic / industrial or agricultural activities, an effect seen even under humid conditions (e.g. Martinelli et al., 2004). The apparent excess of the running water feeds the illusion of quasi-infinite flushing capacity and encourages the lack of concern with adequate pollution control.

In the Jordan River basin a few additional factors were detrimental:

- the drainage of the Hula wetlands which resulted in the release of excess nutrients (especially of nitrates) and probably also further accentuated the seasonal fluctuations of the flow;
- the location in a deep Rift Valley with abundant remnant salinity, which results in increasing salinization of the waters along the river course;
- the damming of Lake Kinneret and curtailment of flow into the lower Jordan, especially during drought periods.

In the arid drylands the ephemeral flows are an integral link in the chain of formation of the local groundwater, as discussed below. Any interference with these flows thus affects not only the downstream users of the surface water but also the groundwater resources. Due to the episodic and intermittent nature of the phenomenon it serves to flush all surface accumulated materials, including saline residues of evaporation ponds, and thus these flows have a high pollution potential (Gat, 1980).

Groundwater systems

Groundwater is the major resource of fresh water in the region, serving the double function of water conduit and storage reservoir, compensating for the seasonality of the precipitation input. Groundwater was once thought to be relatively immune to deterioration by anthropogenic activities when compared to surface waters, based on its natural remediation capacity, thus constituting a safe reserve for freshwater supply. One is learning, however, that it takes just a little longer before the full impact of the deterioration of the overtaxed aquifers becomes apparent.

Four different aquifer types are discussed:

- the mountain aquifers, recharged at the higher elevations of the mountainous backbone in Judea, Samaria, the Galilee and the Carmel Ridge and then draining in a confined manner through limestone layers to the lower elevations in the east, south or west (cf. for example Harpaz et al. 2000);
- the phreatic coastal aquifer, that underlies the coastal plain extending from the Lebanon to the Sinai coast. This aquifer drains naturally underground into the Mediterranean Sea;
- the deep Nubian sandstone aquifers of the Negev and Sinai, filled with palaeo-water.
- aquifers recharged along the river beds, especially by the flashfloods in the arid zone.

The mountain aquifers

One is faced with the following facies of man's interference with the mountain aquifers,

- an over-exploitation resulting in salinization by enabling encroachment of adjacent saline water bodies and in the curtailment of spring discharges which affect the flow in the rivers, especially their supposedly-stable base-flow component;
- widespread contamination of the headwaters of the aquifers as a result of the appreciable urban development on the mountainous recharge areas of the main groundwater aquifers of Judea and Samaria,

mostly without an adequate infrastructure for effluent treatment.

The interference occurred both in the headwater region of the aquifer in the mountains through hindrance of the natural recharge pathways and the exploitation of the water table region, as well as excessive pumping from deep wells in the downstream locations. Attempts to make up for the incurred water deficit by recharge of intercepted surface waters during the rainy season improved the water balance to some extent, but resulted at times in water quality problems. Artificial recharge of imported waters from the National Water Carrier as a means to utilize the aquifer as a seasonal storage reservoir also affected the water quality of the aquifers due to the higher salinity of the extraneous waters.

The coastal aquifer

Situated beneath the most populated and intensively cultivated portion of the region and being of a phreatic nature, it is not surprising that the coastal aquifer shows the most severe environmental impacts. These range from widespread salinization due to water extraction by pumping in excess of the natural recharge resulting in the lowering of the water table, thus enabling encroachment of either seawater from the west or of saline groundwater from the east, to the contamination of the recharge flux by both industrial, domestic and agricultural practices. Further, the blocking of much of the surface for infiltration by urbanization adds to the negative water balance.

The steps taken for making up for the water deficiency and for correcting this situation over the years consisted at first of channeling excess water into the region and recycling of treated urban effluents, mainly for irrigation purposes and only secondarily as a recharge flux to the over-exploited system. An ambitious recharge scheme of creating an artificial water mound along the coast in order to prevent the seawater incursions necessarily resulted in stopping the natural underground discharge of the aquifer into the sea and thus created in practice a semi-closed hydrologic system without outflow in which the salinity accumulates in the soil zone under the irrigated fields from year to year, to be flushed into the aquifer during the occasional wet rain-year. The saving grace of the coastal aquifer is that water flow in it proceeds along relatively short parallel paths, more or less perpendicular to the shoreline, so that there is little interference and cross-contamination in the north-to-south direction. This results in a situation in which parts of the aquifer were preserved in a reasonably pristine state.

The arid zone aquifers

The hydrology of arid areas (drylands) differs considerably from that of more humid environments (CWST, 2000). Due to a negative water balance the precipitation amount is usually not sufficient to overcome the water deficit in the surface that results from evaporation during the dry periods, so that direct infiltration and local groundwater recharge is a rarity. Any substantial groundwater recharge can materialize only following the accumulation of an appreciable water depth by means of surface runoff at a potential infiltration site (Schoeller, 1959) and by bank infiltration from rivers originating outside the arid region. The most important aquifer systems in the Negev and Sinai Desert were recharged in the past during wetter periods (paleo-waters) and their utilization constitutes a "mining" operation since replenishment by recent recharge is minimal.

MANAGERIAL CONSIDERATIONS FOR PROVIDING A SUSTAINABLE WATER SUPPLY (based in part on an unpublished lecture: Gat, 2003)

Due to the long period of uncontrolled operation and development, the occurrence of accidental spills as well as natural calamities such as a period of drought years, many of the water resources have deteriorated to an extent that their utilization is curtailed as a source of potable waters or for indiscriminate use for irrigating sensitive crops. In dealing with the situation for optimal benefits of all, one must distinguish between:

1. the present state of the aquifers and the measures to be taken for their remediation;
2. the operational changes to be introduced into the present system in order to prevent further harmful effects;
3. the planning of future developments in a sustainable manner.

All of these require, first of all, a detailed monitoring of the "health" of the aquifers (a baseline study) in order to identify the problem sites. Further, as complete as possible a hydrological model of the aquifers has to be provided that spells out the transit times, mixing and flow patterns, in order to be able to predict the future dissemination of the salinity or pollutants under different operational scenarios.

Possible strategies for dealing with the deterioration of the water quality and the continuing supply of fresh water can then be considered. These are

- Prevention of release of contaminated water to the environment;
- Clean-up of effluents before discharge;
- Separation of "clean" and "dirty" pathways of recharge (distinguish between protected and sacrificial systems;
- In-situ natural or enforced remediation (e.g. by reactive barriers);
- Pump, treat and recharge of treated water;
- Treatment and cleanup at pump head prior to distribution to consumers;
- Replacement, dilution or flushing by imported water.

Choice of the options adopted is dictated by the nature of the pollutant, its dissemination or containability, economic consideration as well as societal and ethical concerns. As an example of the latter, the choice of sacrificial aquifers (which is often the cheapest and easiest one to take) is unacceptable when both possible impacts on natural systems and the interest of future generations are taken into account.

The management options in each of the stages of development and planning are summarized in Table #2. The water requirement of all users can obviously be satisfied by proper technical means such as water imports or relocations, desalinization, as well as proper prevention of pollution, remediation, clean-up and recycling. However these measures, if applied locally on an ad-hoc basis as an emergency procedure, may impose an unbearable and unjust economic burden on some of the stakeholders (not necessarily those responsible for the problem), one which could be reduced by the equitable planning and sharing of the local and regional water resources, based on an optimal hydro-economic scenario. In order to do this properly, a clear definition of the water requirements must be first established, followed by the recognition that the basic “Water Right” entitles everybody to an adequate supply of clean water for legitimate uses (Annex 1 of the memorandum of the Green Cross International, March 2000), rather than the conventional approach based on historical rights or location within the watershed (upstream vs. downstream location). Obviously, the effort and cost of supplying the water will differ for various segments of the population depending on their location relative to the sources of supply, and the nature of their requirement (in terms of quantity and quality of the water). Further, the “nuisance value” as far as the nature of the effluents produced and their effect on the natural water cycle must be taken into account. Depending on the degree of “legitimacy” of the water use, a pricing index (or penalty) may be imposed The decision on the legitimacy of the water use is usually the most difficult one to take as it is not subject to objective criteria but involves value judgments, cultural and historical considerations as well as social concerns (Dooge, 2000).

These are the types of discussions relative to the distributions and pricing of the commodity that apply in any dispute between the stakeholders.. If one accepts such an approach also in the case of a trans-boundary situation, the political discussion is reduced to one relating to the onus of payment for the commodity, whether it should be based on the equal sharing of costs or a penalty to polluter (“polluter pays” policy), a discrimination between existing and new activities, etc. Prudence would then dictate that following the screening of all available options the economically most conservative scenario of water supply be adopted, certainly on the scale of the watershed and possibly within the whole regional context, where those who benefit from this scenario are expected to share in the cost of supplying water to more unfavorably located consumers. The full cooperation of all stakeholders in the adoption of the development plans is obviously mandatory.

REFERENCES

CWST (2000). The management of water supply and effluent discharge for urban development in the arid zone. *Report on a workshop organized by the Center For Water Science and Hydrology of Ben-Gurion University.*

Dooge J.C.J. (2000). Water and Environment in Dry Land Development: Socio-Economic and Ethical Aspects of Water Management. In: *International Conference on "Water and Environment,- Resolving conflicts in the development of Drylands,* Center of Water Science and Technology of the Ben-Gurion Univ. of the Negev, Abstract Booklet.

Haddad M., Feitelson E. and Arlosoroff Sh. (2000). The management of shared aquifers. In: *Management of Shared groundwater Resources; the Israeli-Palestinian case with an International Perspective,* E.Feitelson and M.Haddad (edtrs), Kluwer Academic Publishers, pp.3-24.

Harpaz Y., Haddad M. and Arlosoroff Sh. (2000). Overview of the mountain aquifer. In: *Management of Shared groundwater Resources; the Israeli-Palestinian case with an International Perspective,* E.Feitelson and M.Haddad (edtrs), Kluwer Academic Publishers, pp.43-56.

Gat J.R. (1980). The relationship between surface and subsurface waters: water quality aspects in areas of low precipitation. *Hydr. Sciences Bull.***25**, 257-267.

Gat J.R. (2003). Water for the future; Planning a sustainable and equitable water supply for an expanding economy under stress of water scarcity and quality deterioration; - the case of water for a developing Middle East. *Unpublished lecture at the IBERDROLA symposium on "Water and Sustainable Development",* Hotel Villa Real, Madrid.

Martinelli L.A., Gat J.R., De Camargo P.B., Lara L.L. and Ometto P.H.B. (2004). The Piracicaba River Basin: Isotope Hydrology of a tropical river basin under anthropogenic stress. *Isotopes in Environmental and Health Studies,* **40**(1), 45-46.

Schoeller H. (1959). Arid Zone Hydrology; recent developments. *UNESCO series on Arid Zone Research*, **No.12.**

Table 1. ANTHROPOGENIC EFFECTS ON AQUIFER QUALITY

1. Land use changes that affect the natural water balance and the rate and location of the groundwater recharge flux;
2. Introduction of chemical and other noxious materials on the surface or into the subsurface, in the pathway of the recharge waters;
3. Water extraction that affects the pressure distribution, flow rates and pathways in the aquifer;
4. The application of water inputs additional to the precipitation, such as irrigation water, sewage effluents or water imports, especially during the dry season;
5. Changes in the microclimate, affecting the water balance and/or the precipitation regime.
6. Effects on the self-cleaning capability of the system by microbial or chemical remediation processes.

Table 2 Actions to guarantee a sustainable supply of clean water

Evaluation of existing situation:
Survey of existing supply, requirements and effluents (quantity/lity); Estimating the "safe yield, (quantity/lity)" of the water sources; Monitoring the "health" of available aquifers and future projection based on hydrological models; Consideration of potential alternative water resources.

Actions to be undertaken for *immediate* amelioration:
Clean-up or desalination prior to distribution to supply system; Education for improved "water culture"; Prevention of effluent release or clean-up prior to recharge; Local "pump & treat".

Improvement in the water supply system for sustainability under a regime of growth and expansion [moderate expense]:
Separation of "clean" and "dirty" recharge pathways (protected and sacrificial aquifers); Establishment of sewage treatment plants and recycling of water for operations requiring marginal water quality; Increased exploitation of local water resources (flood interception, deepening of drillings, dew and fog harvesting, brackish water sanitation).

Planning of new developments:

- Provide detailed hydro-geological model and its eco-hydrological links;
- Establishment of “clean water protection zones” and natural refugios;
- Educated siting of development projects in relation to recharge pathways
- Regionally optimized water supply and discharge scheme;

Management strategies for continued safe operation under both routine and unexpected climate scenarios:

- Provide reserve supply and discharge options and storage capacity;
- Flexibility in infrastructure with inbuilt controllable redundancy;
- Preference of regionally integrated varied local schemes to grandiose projects (which are less adaptable to changes in climate and technological advances);
- Operate detailed monitoring regime for “advance warning”.