Progressive development of water resources in the Middle East for sustainable water supply in a period of climate change

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The history of the Middle East has been influenced by past global climatic changes. Warm periods caused droughts, resulting in desertification, migration and war. Cold periods were humid and brought prosperity and agricultural settlement to the desert fringes. The forecast based on this correlation is that the present global warming will cause the drying up of the Middle East. As in the past, this negative impact should be mitigated by using the groundwater resources stored from past wetter times. This will involve deep drilling, pumping and modern irrigation methods within the framework of a new policy of ‘progressive development’, which will entail the use of currently undeveloped natural water resources beyond that of present water replenishment. While the use of the one-time groundwater reserves is taking place, a master long-term comprehensive progressive development plan for the Middle East will be prepared. This plan will include the step-by-step development of other water resources such as treated effluents, desalinated brackish groundwater and desalination of seawater.

Keywords: climate change; desertification; groundwater; irrigation; desalination

1. Introduction

The ‘Cradle of Civilization’ in the Middle East (also known as the Levant) is bounded on the south by the Syrian–Arabian Desert and on the north and northeast by the Taurus and Zagros mountain chains, while on the west stretches the Mediterranean Sea. The climate over this body of water, which extends between Europe to the north, Africa to the south and Asia to the east, is influenced by the large-scale mid-latitude atmospheric circulation of the North Atlantic Oscillation (NAO) and thus influences the cold-season precipitation over the margins of the three continents bordering this sea. The Mediterranean, which forms a corridor for the cyclonic low-pressure rain storms driven by the global westerlies storm system, is the source of the moisture. During the summer months, April–September, an arid to semi-arid dry climate prevails, while during most of the winter months, the weather is influenced by the marine system, which brings moisture and rainfall to the eastern Mediterranean. The frequency and intensity of the rain storms vary across the region and depend on the period

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under consideration. In the eastern part of the Mediterranean Sea, the climate system becomes rather complex, because it is there that the El Niño–Southern Oscillation (ENSO), namely the periodic change in surface water temperatures of the tropical central and eastern Pacific Ocean, has been found to play a role in winter rainfall as well as summer temperatures (Piero et al. 2006).

In this region, where long-term high-capacity water reservoirs are scarce, years of drought in which rain storms are rare and of low yield cause famine and even thirst in communities that are dependent on short-term storage of water in cisterns, pools or local springs. Such events are imprinted in the history of the Levant, when long and severe droughts caused migrations and wars, unsettling, resettling and even the disappearance of whole societies and cultures. Conversely, periods of abundant precipitation, which also occur in the region, left significant footprints of prosperity of local societies (Issar & Zohar 2007; Issar 2008a). The establishment and understanding of the correlation between these periods of calamity and abundance are essential for forecasting the impact of global climate changes (oscillations and variations) on the future availability of water resources in this region. Abundant historical evidence throughout the Levant can enable the development of a model that elaborates on the impact of climate change on sustainable water availability in the Middle East. Such a model can later serve as a platform for evaluating and assessing the possible impacts of climate change over similar regions with less adequate records and information.

2. The past

The present Mediterranean climate system, with its fluctuating magnitudes of annual precipitation, has prevailed since the end of the Last Glacial Maximum (LGM), which ended about 17 kyr BP. During that glacial period, the climate in the region was very humid, as evidenced by the existence of Lake Lisan (Bartov et al. 2002), which, at its highest level, reached approximately 148 m below MSL (mean sea level) ca 30.5 ± 0.22 kyr BP, concomitant with the coldest period in the NGRIP Greenland Ice Core record (Abu Ghazleh & Kempe 2009). Lake Lisan extended from the Sea of Galilee in the north to south of the Dead Sea of today, but as the LGM began to dwindle, ca 23 kyr BP, this lake began to dry up: by the end of the LGM, Lake Lisan had disappeared into the Dead Sea of today.

The fact that the LGM was a very humid period throughout the Levant is also evidenced by the deposits of a lake that existed in the Palmyra region in the Syrian Desert until 19–18 kyr BP (Sakaguchi 1987), as well as in the southernmost Sinai between 24 and 20 kyr BP (Issar & Eckstein 1969). It was during that same period that the sandy formations of the Nubian Sandstone aquifers prevailing under the Sinai and Negev deserts (Issar et al. 1972; Gat & Issar 1974; Issar 2003) were last massively recharged. Supporting evidence for a cold and humid climate comes from the isotope composition of the fossil groundwater of the Levant (Issar & Gat 1981). The issue of high humidity during the LGM and drying up during the post-glacial period is important for understanding the precipitation regime, which left a dramatic impact on the eastern Middle East during global cooling and warming periods. The equation ‘cold = humid while warm = dry’ disputes the conclusions of one of the eminent scholars of the prehistory of the Near East, Professor Ofer Bar-Yosef from Harvard University, Massachusetts, who claimed
that ‘during the Late Glacial Maximum, dated to ca 20 000 to 14 500 BP the entire region was cold and dry’ (Bar-Yosef 1998). As will be discussed below, the aforementioned equation has also been found to hold true for the Holocene and for the present, and most probably will also hold for the future as well.

From the end of the Last Glacial Period until the start of the agricultural era, i.e. for about 7000 years, Homo sapiens roamed the plains of the Levant as a hunter and gatherer. These methods of food supply were not sufficient to satisfy demand once the climate became drier, reducing the vegetal food resources for humans and wildlife. As the number of humans increased, as evidenced by the number of Epi-Palaeolithic sites in the Levant, the intensification of hunting no longer sufficed and the first steps in animal domestication, and probably also in sowing and planting, had to be taken.

The first farming settlement was in Jericho, north of the Dead Sea. This site is fed by a perennial spring issuing from the regional limestone–dolomite permeable rocks building the mountainous backbone of this region (Issar 2008b). Evidence from the Jericho Valley sheds light on an important hydrogeological feature characterizing the Levant, namely the dependence on perennial springs, fed by regional aquifers built from carbonate rocks of Mesozoic age. Such springs, fed by the mountainous carbonate aquifers issuing at the foothills of the mountain ranges bordering and crossing the Levant, form the longer-term water reserves of this region. The fact that the recharge zones stretch over the high-altitude areas where the water-bearing rocks are exposed guarantees that, even in years of drought, these areas will still get some rain, and because of the high infiltration and percolation capacities of these rocks, the aquifers will immediately be recharged. Moreover, at very high altitudes, winter snow supplies another volume of seasonal storage. Thus, during series of droughts, springs such as that of Jericho persist, although the quantity may decline.

The artificial mounds of anthropogenic sediments (tel) around these springs and the many layers of remnants of settlements, some destroyed by fire, are clear evidence of the importance of these springs in the history of the Levant. Yet the reader of archaeological reports describing the history of this region will seldom, if ever, find reference to climate change as an explanatory factor for the transformations evidenced by the archaeological findings. One has to admit that, owing to the perennial nature of the springs, the climate changes did not have a pronounced effect on their close natural environment. Nevertheless, one would expect archaeologists to ask what caused people to migrate from the far north or from the south, wage war in order to overtake this site, burn it to ashes and build it anew, awaiting its turnover.

While archaeologists may be excused for not referring to climate changes in the digs of mounds near the regional springs, such an omission by archaeologists investigating the abundance and resettling of ancient cities on the border of the desert is perplexing and less understandable. In searching for an explanation, one finds that this was not the case during the first half of the twentieth century when the deterministic paradigm, which claimed that climate changes played an important, if not decisive, role in the history of the Levant, was put forward by Yale University geographer Elsworth Huntington in his book Palestine and Its Transformation (Huntington 1911). He formulated this paradigm after visiting the abandoned cities all along the border of the Syrian–Arabian Desert. A few decades later, the archaeologists Thorkild Jacobsen and Robert M. Adams
rejected this paradigm after investigating the ancient Sumerian archives of clay tablets (Jacobsen 1958, 1960; Jacobsen & Adams 1958). They found that salt-resistant barley had replaced wheat as donations to the temples during the last centuries of the third millennium BC. Accordingly, they blamed the farmers of Sumer for over-irrigating and thus salinating their fields.

This blame became the trumpet call for a generation of archaeologists and historians to follow in procession and, since then, most historians of this region have dispensed with the role of climate changes, preferring to put the blame for its calamities on its inhabitants. No subversive doubt was raised as to whether climate might not be to blame for dryness, and thus not enough water being available to wash out the salts. Indeed, the period when this happened, namely the end of the third millennium BC, was one of the driest in the history of the region. This is evidenced by the disappearance of agricultural settlements all along the southern border of the Levant, the decline of the ancient levels of the Dead Sea, and the oxygen and carbon isotopes composition of the stalagmites of Soreq Cave in the Jerusalem mountains (Bar-Matthews et al. 1998).

Thus, in view of all the evidence of dryness, putting the blame on the farmers of Sumer, for over-irrigating and thus causing the soils to become saline, is beside the point. Moreover, taking into account that this region is arid and the only source of water is that brought by the Euphrates and Tigris rivers, the fall in the level of these rivers during this period meant lack of water for irrigation rather than over-irrigation (Thompson 2004).

The global rise in ocean and sea levels and the flooding of coastal areas worldwide during this same period hints at a correlation of global warm climate and melting of glaciers with the rise in ocean and sea levels and droughts in the Mediterranean region (Issar 2003). A good correlation was also found between these data and those on the movement of the Scandinavian glaciers (Issar 2008c). Thus, with all due respect to the learned and meticulous research of Jacobsen & Adams (1958), their vastly articulated findings may, rather, reflect solid evidence supporting the significant impact of climate change. Unfortunately, the archaeologists, historians and environmentalists who followed in their footsteps are still not aware that blaming human society rather than climate change is ill advised to the point of absurdity in a region bordering a desert.

Archaeological evidence from numerous sites in presently desolate areas reveals flourishing habitats of vegetation, wildlife and humans. In today’s deserts, deposits of ancient lakes are found, while cores of sea and lake sediments reveal sediments that were deposited under different, wetter or drier, climate regimes. As long as they occurred during prehistoric times, not to mention geological eras, archaeologists and geologists do not hesitate to blame climate changes for these abrupt alterations. Yet, when it comes to historical times, the finger is pointed at human misconduct. As already mentioned, the responsibility for shifting the blame onto humanity should be attributed to the Sumerian archaeologists Jacobsen & Adams (1958). Their accusations were contrived in a period when the ‘Dust Bowl’ disaster, which devastated the Great Plains in the central states region of the USA during the early 1930s, had not yet been forgotten. At that time, the sole blame for that disaster was placed on the shoulders of the local farmers who had farmed extensively without taking any measures to prevent soil erosion. Public opinion was therefore ready to adopt the explanations of Jacobsen and Adams and put all the blame on the heads of the poor Sumerians. Today it is
clear that the Dust Bowl crisis was first of all triggered by a major drought event (Schubert et al. 2004), although in that case man was not totally blameless, as poor land-use practices facilitated wind erosion and dust storms. With the new information available from various data, it can also be concluded that the main reason for the salt crisis of ancient Sumer was a major climate change of global warming, which caused the drying up of the whole region and the lack of water to flush the salts from the soil (Thompson 2004; Issar 2008a).

One can find a similar accusation of man over climate in the case of the desertification of the Negev, Israel. In this case, the blame was thrown on the Arab invaders for the decline and desertion of the sophisticated Byzantine flood-harvesting irrigation system (Evenari et al. 1971).

More recent investigations based on proxy data, such as changes in the level of the Dead Sea (Frumkin 1997; Frumkin & Elitzur 2002; Bookman (Ken-or) et al. 2006) and in the isotopic composition of cave stalagmites and lake deposits (Bar-Matthews et al. 1998), led Issar & Zohar (2007) to correlate major climate changes with major events in the history of the countries bordering the eastern Mediterranean (including Egypt), emphasizing the role of climate changes on the history of the Levant. At the same time, Issar & Zohar (2007) also substantiated the argument that failure to understand the role of climate change in the history of the Levant not only is a theoretical issue but also has important practical implications for the following question: What will be the impact of the present climate change on the hydrological regime of the Levant? In view of the discussion herein, the answer, unfortunately, is that this region will become drier. In other words, the borders of the deserts in the Middle East region will move northwards.

Although the reasons for the cold and warm periods during the Holocene are still under debate, the aforementioned equation for the Levant (cold = wet, warm = dry) has been found to persist throughout history. Thus, while the hypothesis of Milankovitch cycles (Hays et al. 1976) explains the mechanism of global glacial and inter-glacial periods during the Pleistocene, and the recent strong correlation between the curves of global warming and industrial gases in the atmosphere explains the warming of the globe at present, the question of historical climate changes remains open.

3. The present

While archaeologists and historians of the Levant overlook the impact of climate changes in the past, today’s geographers, ecologists, politicians and even climatologists are ignoring the connection between global warming and the most recent series of dry years. The prevailing opinion is that this region is characterized by droughts, which come and go—this despite information that shows that there has been an increase in the frequency of severe droughts during the last two decades (Israel Ministry of Foreign Affairs 2002; Yakin 2006; Israel Ministry of Environmental Protection 2009). The recent drought of 1998–2001 in northern Israel was the most extreme drought in the last 130 years. It affected the water flow of the Jordan River and brought the level of the Sea of Galilee, which is the only natural freshwater reservoir in Israel and, in fact, in the entire Middle East, to its lowest point in all historical periods (Inbar 2007). According to data
from the Israel Water Authority, mean annual precipitation for the last 5 years has been below average and 2008 was extremely dry, with about 50 per cent of the average precipitation in many basins (Israel Ministry of Environmental Protection 2009).

A group of climatologists from the universities of Tel Aviv and Haifa analysed temperature and rainfall changes from 1961 to 1990 over the eastern Mediterranean, specifically the Jordan River basin, using regional climate models (RCM), and projected these changes to 2071–2100. The climate models showed that the average temperature over the Mediterranean region has increased by 1.5°C to 4°C in the last 100 years, while the precipitation over most of the Mediterranean has shown a dominant negative trend in the last 50 years. Observations made over the last few decades confirm the results of the models, as the observed reduction in precipitation can indeed be linked directly to global warming (Alpert 2004; Alpert et al. 2008). The use of these models is elucidated in ‘Future predictions of moisture budget over the eastern Mediterranean based on super-high-resolution global model’ (Alpert & Jin 2009). Yet, while the total amount of precipitation over the eastern Mediterranean is decreasing, the occurrence of extreme events is on the rise (Morin et al. 2007).

Although, when the present paper is finalized, rain events may still occur and thus there is not yet an official report on the annual amounts of rain during the winter of 2009–2010, from the press reports it can be concluded that the annual rainfall was around, and in a few regions even above, the annual average. The same reports tell that this period was the hottest winter in Israel since orderly temperature recording began in 1942.

The impact of increasing temperatures and decreasing precipitation, as shown by the RCM, is manifested by a series of years of drought and thus water crises throughout the Levant. Over the mountainous terrains in Samaria and Judea (West Bank Palestinian territories), water shortages are felt by the rural as well as the urban populations. A large part of the shortage is due to the outmoded and badly maintained water supply system, and part is due to restrictions imposed by the Israeli Government on uncontrolled drilling and pumping of wells in the regions in which the limestone–dolomite aquifers are recharged. Nevertheless, beyond these constraints, the impact of drought years is being felt in the decreasing discharge of springs and wells fed by the diminishing, yet over-exploited, shallow aquifers. The mountainous aquifers, like all the major water resources in the Middle East, are cross-border groundwater reservoirs that are heavily used by both Israel and Palestine. Unfortunately, the flinging of accusations between the Palestinian and Israeli parties, based on political disagreements, are over-shadowing the important issue of the impact of recurring drought years.

According to the UN and International Federation of Red Cross and Red Crescent Societies (IFRC), in Syria the drought, which is now in its second year, is affecting farming regions mainly in the north and east of the country where dry farming of grains has been suffering from the scarcity of rainfall. Blamed on a combination of climate change, man-made desertification and lack of irrigation, up to 60 per cent of Syria’s land and 1.3 million people (of a population of 22 million) are being affected. Just over 800 000 people have lost their entire livelihood, according to the UN and IFRC (IRIN 2009).
The same drought has also affected Turkey’s mega-project of dams and reservoirs on the Euphrates–Tigris rivers, leading to a reduction in the quantity of water released to Iraq and Syria and to complaints from the water ministers of those countries at a ministerial meeting. Iraqi Water Minister, Latif Rashid, claimed that, while rainfall had decreased by 40 per cent, leading to drought and a serious reduction in agricultural activity, it had also led to mass migration in the south of the country. The quantity of water released from the Euphrates by Turkey between August 2008 and August 2009 was reduced by 30 per cent. Turkey’s Environment Minister, Veysel Ergolu, argued that, during 2006 and 2008, rainfall had decreased by 24 per cent in the Tigris river basin and by 46 per cent in the Euphrates river basin (Culpan 2009).

Generally speaking, all surface-water resources of the Levant are close to being fully exploited (except for the rivers of southern Anatolia, which flow and discharge into the Mediterranean Sea) and the water quality has deteriorated dramatically over time, while most of the small rivers are already heavily contaminated owing to the discharge of effluents aggravated by the limited natural discharge of water.

Finding a solution to the problem, as exemplified by the Euphrates–Tigris case, is complicated by the fact that all major water resources (rivers and groundwater reservoirs) are trans-boundary water bodies. In general, the riparian (downstream) users depend on upper basin activities for the availability of both adequate quantities and quality of water.

4. The future—progressive development

Investigations into the impact of past climate changes on the history of the natural environment and water resources, and thus on human society, and observations on the present impact of global warming predict a rather gloomy future. This prediction is backed by computerized climate model projections, including the most recent (2007) AR4 models from the Intergovernmental Panel on Climate Change (IPCC 2007), which also give negative forecasts, namely, that the precipitation regime of the ‘Fertile Crescent’ may abate rather seriously due to global warming, to such a negative level that this region may even lose the basis for its historical epithet (Kitoh et al. 2008a,b). Based on historical records, Issar forecasts a 20 to 40 per cent decrease in average annual precipitation (Issar 2008a,c). Water shortages in the Levant will worsen in the very near future, owing to an anticipated massive increase in population as well as hopefully elevated living standards, which will increase the demand for additional water for domestic use and food production. Nevertheless, an important lesson can be drawn from the history of this region: crises resulting from a shortage of water resources have been averted or mitigated in the past by human resourcefulness and innovations that led to sophisticated water production, distribution and use. In the Levant, this was mainly effected by the development of tools for the use of groundwater resources and methods for the diversion and storage of spring flows, by the excavation and later drilling of wells, or by the invention and development of pumping technologies. Past reliance on groundwater points to the fact that this resource is more reliable than surface water, a fact that was recognized by past generations, owing to its long-term storage character and its better protection from negative anthropogenic impacts.
Thus, the increasing reliance on and consequent exploitation of groundwater in periods of diminishing precipitation imply use of reserves, and as the periods of drought lengthen, such use involves interference with long-term groundwater balance, which has been established over many generations (hundreds and even thousands of years). This policy of survival, not to mention development, raises doubt as to whether the principles of sustainable development of existing (and future) water resources will be able to avert the forthcoming catastrophes associated with water scarcity in these regions, especially in developing societies in dry land basins with limited and rather scarce water resources. The accelerating socio-economic crises in the developing world and the still looming negative impacts of global climate change on already thirsty and hungry societies strengthen the conclusion of the present authors that a new policy of development has to be considered, namely one that will ensure progress towards a safer and sustainable life, while averting irreversible environmental catastrophes.

It is suggested that this new policy be called ‘progressive development’ (Issar 2009), as it entails, first and foremost, profound and sweeping changes in attitude on the development approach towards natural environmental resources in arid and semi-arid zones. These changes will use the as-yet undeveloped natural water resources without being bound to the common environmental definition of ‘sustainability’, namely controlled water use beyond the present or current rate of water replenishment.

Needless to say, the application of the policy of progressive development is vital also beyond the borders of the Fertile Crescent. The special issue of Science on 12 February 2010 (vol. 327, no. 5967, p. 797) focuses on the global challenge of ensuring a secure food supply for the nine billion people expected to inhabit Earth by 2050. In the various articles published in that issue, the experts agree that, in order to answer this challenge, agriculture all over the world has to supply more food per square metre of land and per cubic metre of water. At present about one billion people are undernourished, and this number is forecast to increase owing to the rise in global temperature and the further aridization of many regions. Yet, none of the articles consider an important fact that about a third of the continents of our globe is covered by arid and semi-arid regions, a big part of which is forecast to become even drier. At the same time, beneath these vast areas exist tremendous quantities of fossil water. Moreover, along their borders big rivers annually take to the sea billions of cubic metres of fresh water (Forkasiewicz & Margat 1982; Issar & Nativ 1988; Salem & Pallas 2004). Progressive development suggests a policy of using these vast areas and these quantities of water in order to supply water and thus food to future generations. This new policy entails using water resources, especially groundwater, including one-time reserves and intensive use of soil and marginal land resources. Progressive development comes instead of sustainable development in the arid and semi-arid regions as it is impossible to sustain resources that diminish due to ongoing climate change.

In terms of natural resources, progressive development will aim for the comprehensive development of soil and water resources, including one-time water reserves and marginal land resources. Such projects will include deep drilling and pumping, modern irrigation and agricultural methods with highly efficient irrigation. Water development projects will plan ahead for the diversion of rivers from regions of excessive water resources to regions of need. For providing food
for the increasing world population, new land that is adequate for intensive
cultivation will have to be developed, even in arid basins. This will not be
possible without the creation of additional ‘new’ water for planting the deserts.
Thus the main goal and target must be to produce food, but at the same time,
it should also be to sequester atmospheric carbon and thus help to mitigate
global warming.

In a nutshell, progressive development aims to guarantee the survival and well
being of future generations of the developing world in arid and semi-arid zones,
by prioritizing investment in the advanced planning and development of new
and even marginal water resources, step by step, while observing and assessing
the current and possible future impact on man, nature and the environment.
Almost 100 years of intensive, yet successful, development of the agriculture
industry in the dry lands of Israel have been associated with the simultaneous
development of the most sophisticated water resources and water technologies.
In some cases, water exploitation has led to significant, albeit temporary,
environmental stress; however, in most cases, massive interference with the long-
term natural groundwater balance has not revealed any substantial negative
impact on nature—nevertheless water development projects are under continuous
investigation for potential negative environmental impact. Massive diversion of
water from the upper Jordan Valley by Israel, Jordan and Syria has deprived
the Dead Sea of a substantial input of water. Its current low level and its dried-
up southern end are frequently cited by the media as examples of the negative
impact of development on a natural resource. Seldom, if ever, does one find the
information that during historical warm and dry periods, such as for example
the Moslem warm period in around 800 AD, the level of the Dead Sea was
almost as low as it is today (Issar & Zohar 2007). The various solutions to
changing the present situation, by bringing water from either the Red Sea or the
Mediterranean, should be examined, while taking into consideration the numerous
components (human, natural environments, energy, economy, etc.) that make up
the holistic approach.

The comprehensive progressive development of various integrated water
resources, such as one-time groundwater reservoirs, marginal aquifers, treated
effluents, desalinated seawater and brackish groundwater, has provided Israel with
sustainable water distribution systems: fresh potable, and brackish and treated
effluents. This serves as the most solid foundation for the reclamation of desert
basins by turning them into productive land.

In applying this conceptual model to the Levant, the first priority is the capture
and use of water emerging from the mountains’ carbonate aquifers of south-
eastern Antalya, or flowing in the subsurface to the sea. The water may be
diverted to the Euphrates–Tigris basin, which, as discussed earlier, is already
suffering from water shortages, which are forecast to worsen. The surface flow
alone, most of which at present flows into the sea, is of the order of 15 billion
cubic metres per year. This flow is additional to the direct subsurface flow to the
sea, which can be tapped by belts of wells along the seashore or in the upstream
basins. The impact of future climate change on flow during a series of drought
years may result in an up to 50 per cent decrease in discharge production, yet, even
in this case, enough water will remain for piping to the Euphrates–Tigris basin
to mitigate the impact of these rivers’ diminishing flow (Rende 2007). Another
source to be considered for mitigating the reduction in these rivers’ flow is use
of the groundwater reserves underlying the Syrian Desert, which contain low or even non-replenished (fossil) water (Khouri 1982), namely mining of groundwater from slowly replenished one-time subsurface reservoirs.

The progressive development of these one-time reserves of groundwater, as well as of those in other parts of the Levant, such as southern Jordan and Israel, should be carried out simultaneously with the introduction of advanced methods of cultivation and irrigation, under the motto of ‘more crop per drop’. The know-how for irrigating plants, rather than the soil, with 90 per cent irrigation efficiency is already available. The water is applied in a pulse subsurface drip-irrigation system, injecting water only when optimal micro-climate conditions prevail for maximum photosynthetic rate. These measures should be taken and adopted on a national and regional basis. However, this calls for national programmes of education and investment, especially in the rural sector. Farmers in the agricultural sectors must be able to understand, and then operate, the most sophisticated agricultural technologies in order to achieve high production with low water application in marginal dry land basins. Encouraging examples of the introduction of sophisticated water-saving irrigation technologies can be observed in arid basins around the world. In the Jordan Valley, traditional irrigation methods have been replaced by drip irrigation and cultivation in greenhouses, doubling the amount of cultivatable land with the same amount of water.

The more progressive stages will include integrated projects of seawater and brackish groundwater desalination for urban centres. In modern large desalination plants, the energy component is about 3.75 kWs m$^{-3}$, less than 20 per cent of the total cost of desalination but nevertheless substantial. Approximately one billion cubic metres per year of treated water will be produced by desalination and other water-treatment technologies in less than two decades in the Middle East alone, and the negative impact of energy on the environment will be noticeable. Therefore, following the progressive development methodology, alternative sources of energy should be explored, such as solar and wind-driven desalination plants. The subsurface storage of desalinated water during hours and seasons of minimum demand should be examined. As about 40 per cent of consumption in urban centres returns as sewage, the reclaiming of this water for its reuse for irrigation has to become part of the local and national plan. The reclaimed sewage may be stored during seasons of low demand in either the subsurface, as in the case of the Coastal Plain of Israel, or in artificial lakes.

Progressive development projects should adopt a comprehensive holistic approach, namely one that explores all technical, natural and human implications, in order to guarantee minimal negative impact on the global environment.

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