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Agricultural Irrigation Reuse and Aquifer Recharge Options for Hebron

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Robert Kent
Nader Al-Khateeb
Said Assaf
Bruce Douglas
John Letey

Development Alternatives Inc
7250 Woodmont Ave Suite 200
Bethesda Maryland 20814

FORWARD

Collaborative Approaches for Resolving Water Issues

The FORWARD Team

Development Alternatives, Inc , Bethesda MD (Prime Contractor)
Arab Scientific Institute for Research and Transfer of Technology Ramallah West Bank/Gaza
Camp Dresser & McKee International Inc , Cambridge MA
CDR Associates, Boulder CO
Conflict Management Group, Cambridge MA
EnviroConsult Office, Amman Jordan
Environmental Quality International, Cairo Egypt
HDR Engineering, Inc , Austin TX
Jordan Institute of Public Administration Amman Jordan
Jouzy & Partners, Amman Jordan
Marketing Research Organization, Amman Jordan
Management, Planning and Research Consultants, Beirut Lebanon
National Center for Middle East Studies Cairo Egypt
RESOLVE, Inc , Washington D C
Training Resources Group, Alexandria VA
Water and Environment Research and Study Center, Amman Jordan

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LIST OF ABBREVIATIONS AND ACRONYMS

bgs	below ground surface
BOD5	five day biochemical oxygen demand
cm	centimeter
dS/m	deciSiemens per meter
du	dunum (1000 m2)
DWL	dynamic water level (pumping water level)
EC	electrical conductivity
Ep	pan evaporation
ha	hectare (10,000 m2)
IPCRI	Israel-Palestinian Center for Research Information
JWC	Joint Water Committee
kg	kilogram
km	kilometers
l/c/d	liters per capiti per day
l/s	liters per second
m	meters
m2	square meters
m2d	meters squared per day
m3	cubic meters
m3/d	cubic meters per day
m3/h	cubic meters per hour
m3/s	cubic meters per second
m3/y	cubic meters per year
masl	meters above sea level
mbsl	meters below sea level
MCM	million cubic meters
MCM/yr	million cubic meters per year
mg/l	milligrams per liter
ml	milliliters
mm/yr	millimeters per year
NIS	New Israel Sheqel
PWA	Palestinian Water Authority
RO	Reverse Osmosis
SAR	Sodium Absorption Ratio
SWL	Static Water Level
TDS	total dissolved solids
TSS	total suspended solids
USAID	The U S Agency for International Development
WHO	World Health Organization
WSSA	Water Supply and Sewerage Authority of Bethlehem, Beit Jala and Beit Sahour

Other Conventions

1 All dates are in the form day/month/year
2 Coordinates are Israel Survey Coordinates
3 Conversion rate is 3 5 NIS = $1 USD

EXECUTIVE SUMMARY

This report assesses the feasibility of reusing treated wastewater from the city of Hebron The study was funded by the U S Agency for International Development (USAID) as part of an Integrated Water Resource Management Program for the West Bank

The investigation explored the feasibility of agricultural reuse and/or artificial recharge with treated wastewater from Hebron It considered both water quantity and quality issues within the hydrological system without respect to political boundaries We interviewed many technical people both within and outside of government employment In addition, we visited several nearby areas where wastewater effluent is used for agricultural irrigation

Our study concludes that the reuse of treated wastewater for agricultural irrigation in the Hebron area is possible, although several issues must be resolved first We conclude that artificial recharge of treated wastewater should not be pursued because of the high quality of the existing groundwater (total dissolved salts less than 300 milligrams per liter) versus the high salt content of the treated wastewater, which is expected to exceed 900 milligrams per liter In addition, the great depth to the water table would make the cost to recover the water for agricultural reuse prohibitive

Additional investigations are necessary to evaluate the economic and political viability of an agricultural reuse option Necessary investigations include a detailed cost analysis, including crop pricing and marketing In addition, the ownership of the wastewater must be established Before an agricultural reuse program is implemented, the salinity of the wastewater must be decreased Our assessment suggests that various industries discharge wastewater having a high salt content to the sewer system Those wastewaters that are highly saline must be removed before they reach the treatment facility in order for an agricultural reuse project to be successful

CHAPTER 1

INTRODUCTION

The United States Agency for International Development (USAID) is funding an Integrated Water Resource Management Program for the West Bank One component of the program is to evaluate the feasibility of using treated wastewater effluent for direct application to agricultural crops and/or recharge of the "Upper" Aquifer of the Eastern Aquifer Basin in the general area of Hebron The statement of work for this project was developed by USAID Mission staff in Tel Aviv

The purpose of this study is to obtain information to support development of a conceptual design for wastewater reuse options for the Municipality of Hebron This study will build on data developed during a recent companion study "Industrial Wastewater Management Options Plan for Hebron" conducted by another FORWARD team

The scope of work consisted of the following ten specific tasks

1 Identify and assess potential irrigation sites,

2 Identify and assess potential recharge sites,

3 Study the range of wastewater effluent quality standards for irrigation and recharge applications,

4 Recommend two or more alternative areas for direct application of treated wastewater for irrigation,

5 Recommend three or more alternative areas for application of recharged (and then recovered) wastewater for irrigation,

6 Recommend four or more alternative areas for recharging the aquifer with treated wastewater,

7 Propose a recovery scheme for wastewater recharged to the aquifer,

8 Propose a plan for educating farmers on the use of treated wastewater,

9 Estimate capital and operation and maintenance (O&M) costs for irrigation and recharge alternatives, and

10 Prepare an action plan for the Agricultural and aquifer recharge options

The team assignment has two parts

- Identifying potential application areas for the use of treated wastewater from Hebron for agricultural irrigation and/or recharge of the Upper Cenomanian/Turonian Aquifer, and

- Preparing an agricultural irrigation and/or aquifer recharge option plan for treated wastewater effluent from a future wastewater treatment plant that will serve Hebron Municipality

We viewed our assignment as a significant component of an overall water resources management plan for an area of the world where water resources are scarce Consideration was given to both water quantity and quality issues within the hydrologic system Inasmuch as water moves in response to hydraulic head gradients, both above and below ground, without regard to political boundaries, our analyses were based on hydrologic features and ignored political boundaries The report will discuss several reuse options based on water quality and quantity within the hydrogeologic system Each option entails various costs and benefits, the magnitudes of which depend on other management decisions Therefore, an economic analysis will be required to identify the economically optimal management plan A successful water resource management plan must be scientifically and technically sound, economically feasible, and politically acceptable We are sensitive to political issues related to our assignment, but strove to restrict our analyses and report to scientific aspects from a politically neutral position

Unless otherwise noted, "Hebron" refers to the municipality of Hebron

Methodology and Report Organization

A general understanding of the natural environment, water resources, and wastewater characteristics was considered necessary to understand the options for wastewater reuse in the Hebron area To obtain this understanding, the project team met with a number of knowledgeable individuals and organizations to obtain background data on the study area In addition, the team spent considerable time observing firsthand the natural resources, water, wastewater, and agricultural practices in the area

This report first discusses the current status of the water supply and wastewater treatment system for the city of Hebron, then in general, the natural environment in which the project will occur Next we discuss the factors that will affect the successful outcome of wastewater reuse (water quality criteria, crop tolerance, etc) Then the results of each individual task outlined in the scope of work are addressed Lastly, we present conclusions and recommendations based on our study

CHAPTER 2

EXISTING CONDITIONS

The development of a wastewater reuse plan requires an understanding of the pertinent natural and man-made conditions that affect wastewater reuse Figure 1 is a map that shows the location of the project area All tables and figures are grouped together at the end of the report The following sections summarize the major areas we reviewed

Hebron City Water Supply

The total domestic and industrial supply to the Hebron area, including unpiped areas is reported to be 6 2 MCM/year (CDM/Morganti, 1997, Task 33) However, there is an overall loss of approximately 39 percent from the system The average per capita consumption for the combined piped and unpiped areas is approximately 35 liters per capiti per day (l/c/d) (CDM/Morganti, 1997 Task 33)

Hebron Municipality obtains 90 percent of its municipal water supply from two wells (Herodian Well Number 5 and the Beit Fajjar Well 1A) owned by the West Bank Water Department (WBWD) and the Water Supply and Sewage Authority of Bethlehem, Beit and Beit Sahour (WWSA) respectively, and 10 percent from two wells near Al Fawwar owned by Hebron Recently two new wells were drilled with funds from the German government but are not yet connected to the Hebron municipal system A third well (PWA-11) is being completed with funds from the USAID One additional USAID funded well was under construction at the time of our study

Currently the water supply for Hebron is inadequate, and water is distributed to consumers only intermittently The city charges for water on a sliding scale as follows

Volume	Rate
1-10 m3	3 2 NIS/ m3
11-20 m3	3 5 NIS/ m3
21 + m3	4 0 NIS/ m3

The city must pay 2 0 NIS/m3 for water delivered from the Herodian and Beit Fajjar wells Many residents supplement their water supplies by buying water from water tankers at a cost of approximately 18 NIS per cubic meter This water is stored in cisterns, which are also used to collect rainwater It has been estimated that as many as 75 percent of the households in Hebron have cisterns, for a combined storage capacity of 600,000 m3 (personal communication, Hebron, 1998)

Hebron City Wastewater System

Hebron has a combined sewer collection system for both domestic and industrial Wastewater According to CDM (CDM/Morganti, 1997, Task 33) the system serves only

50 percent of the households The system is projected to serve 95 percent of the population by the end of 1998 The existing sewer is old and has problems with leakage, blockages, and flooding Currently the wastewater is untreated, and raw wastewater is discharged to Wadi Alsemen, also referred to as Wadi Hebron, which flows south from the city toward Be'er Sheva Hebron does not charge for the collection of sewage The only cost to users from the City is a one-time connection fee of 10 NIS per square meter of floor space in the building

In 1988, a pumping station was installed south of the city to pump raw sewage to a system of lined ponds, located approximately 4 kilometers southeast of Hebron After settlement of the solids, wastewater effluent was drained from the ponds to a single, shallow subsurface drain line The system was undersized and poorly designed The pumping station rapidly clogged with waste and suspended solids from the stone-cutting industry The system was abandoned, and raw sewage continues to discharge to the Wadi Alsemen Photographs of the current raw sewage discharge and the abandoned pumping station and settling ponds are included in Appendix A Many of the villages or communities surrounding Hebron have no organized sewer system, using cesspools or discharging domestic or industrial wastewater untreated to the ground surface

The project team observed the discharge of the raw wastewater on several occasions The flow in the wadi appears variable, perhaps because water is delivered only intermittently and there may have been days that the only water in the wadi was coming from water either delivered in tankers or from cisterns, industrial wastewater discharges may be intermittent, and/or discharge may vary during the day due to water use patterns

FORWARD recently completed a study of the types of industries in Hebron that discharge to the sewer system (FORWARD, 1998) For that study, 31 individual site visits were conducted Based on our review of the types of industries examined in that study, we concluded that the effluent from several different industries would have a detrimental effect on either reuse for irrigation or aquifer recharge For example, tanneries, olive presses, ice cream factories, and sesame seed processing produce waste streams that are high in dissolved salts Samples of the raw wastewater discharge were collected for chemical analysis, as discussed in Chapter 6

Land Ownership

Either the agricultural or recharge option for wastewater reuse likely will require a significant investment in land Land in the Hebron area has been owned for centuries by private individuals, with ownership transferred to succeeding generations within a family Over the last century, people have been displaced, governments have changed, and registration of land did not always occur or in some cases was lost Acquiring even 5 hectares may require dealing with tens of owners Most of the agricultural operations the team observed in the Hebron area are small Individual plot sizes range from one to five dunum (du), although as many as 40 du under single ownership have been reported Large-scale farming, as practiced in other areas of the Middle East, does not exist in the Hebron area Any large-scale agricultural reuse would require buying land, forming a cooperative, or establishing an irrigation district to manage the infrastructure

Climate

The Hebron area has a Mediterranean-type climate with hot, dry summers and cool winters The eastern and southern parts of our study area have a semi-arid to arid climate Average rainfall decreases from west to east, ranging from approximately 600 mm/yr in the immediate vicinity of Hebron to less than 100 mm/yr near the Dead Sea The pattern and distribution of rainfall, temperature, and evaporation have a decided effect on the potential reuse of treated wastewater for agriculture These variables are discussed in more detail in Chapter 6

Surface Hydrology

The boundary between surface water catchments that flow to the Dead Sea and those that flow to the Mediterranean Sea runs through the study area This boundary, or watershed divide, is generally oriented north-south Halhul, Beni Ni'am, and Al Karmil are generally located on or east of the boundary, while Hebron, Yatta, and E'Sammu are in the western catchment Wadi Alsemen, where the treatment plant is proposed, is in the western catchment Both storm water and wastewater flow south from Hebron, then turn and flow southwest toward Be'er Sheva

Regional Geology

The regional geology of the West Bank has been extensively discussed in other documents prepared for USAID projects, (e g , see the various CDM/Morganti Reports in the references section) and will not be discussed in detail here The following discussion is considered appropriate for the scope of this project

Upper Cretaceous-age carbonate rocks crop out at the land surface along an asymmetric anticline that strikes in a approximately north/northeast direction and extends from Be'er Sheva in the south to Jerusalem The axis of this anticline lies west of Hebron These limestone and dolomitic rocks are primarily Cenomanian, Turonian, and Senonianin Age Figure 2 is a geologic map of the project area Figure 3 is a simplified structural map of the West Bank Figure 4 is a generalized cross section that shows the general west-east structure of the project area Figure 5 is a stratigraphic correlation chart In addition to the major anticline west of Hebron, the other major structural feature of the area is the Jordan Rift System located along the Dead Sea

Hydrogeology

The Mountain Aquifer system refers to the carbonate aquifers that crop out in the central anticline structure and discharge either to the Dead Sea on the east or the Mediterranean Sea on the west The Mountain Aquifer System can generally be divided into the Northeastern Aquifer, the Eastern Aquifer and the Western Aquifer Figure 6 is a general schematic representation of this aquifer system indicating the general directions of groundwater flow The Western Aquifer flows toward the Mediterranean Sea and discharges through a number of springs The Northeastern Aquifer flows to the northeast The Eastern Aquifer drains toward the Jordan Valley and the Dead Sea,

discharging through both fresh water and brackish water springs The Eastern Aquifer is of primary interest for this project The two major fresh water aquifers in the Eastern Aquifer are the "Lower" Cenomanian and the "Upper" Cenomanian aquifers These aquifers are generally considered to be separated by the "Middle " aquitard, which consists primarily of the Yatta Formation The low permeability of the Yatta Formation results in significant hydraulic head differences in the two aquifers On a regional basis, the head typically being higher in the upper aquifer However, locally, it is likely that the upper and lower aquifers are in hydraulic communication through fractures and faults Both aquifers consist of interbedded strata of different permeabilities, which, when combined with fractures and faults, produce a complex groundwater flow system Because of the depth to the water table, the high cost of drilling, and the sparse population in the downgradient areas, little is known about the direction and rate of movement of groundwater in the Eastern Aquifer except regionally

Groundwater flow in the project area is toward the east, southeast, and south-southwest (Figure 6) Locally, flow may be controlled by faults, fractures, permeability changes, and/or the dip of the geologic strata Static water levels range from 300 to 500 meters above sea level (masl) in the recharge area between Bethlehem and Hebron to 350 to 400 meters below sea level (mbsl) near the Dead Sea (CDM/Morganti, 1997, Task 33) Available measurements indicate water levels are declining in the Lower Aquifer near the recharge zone and in the Upper Aquifer near Al Fawwar During the 25 years from 1973 to 1998, the water level declined approximately 30 m in Herodian Well #2 (Lower Aquifer) El Fawwar Well No 1 is completed in the Upper Aquifer in the general area of several springs The water level was reported to be 13 m below ground surface (bgs) by Tahal in 1975 and to be approximately 40 m bgs in 1998 (City of Hebron Water Department personal communication, 1998)

Groundwater Recharge

Groundwater recharge derives from precipitation on the limestone and dolomite outcrops of the Upper and Lower Aquifers, losses from wadis during heavy rains, and leakage from sewers, cesspools, and water lines Rainfall in the recharge zone ranges from 500 to 700 mm/yr A portion of the rainfall is not recharged but is lost as evapotranspiration Recharge estimates for the Eastern Aquifer Basin range from 6 to 50 percent of rainfall This range of values reflects the relative scarcity of data for making this type of calculation A comprehensive discussion of the numerous studies completed to determine the amount of annual recharge is contained in the CDM/Morganti reports The reported recharge for the Eastern Aquifer Basin ranges from 100 to 175 MCM/yr The recharge rate specified in Article 40 in the Oslo Agreement is 172 MCM/yr

Aquifer Properties

Little information is available on aquifer properties for the Eastern Aquifer Transmissivity values ranging from 4 m2/d to 5,000 m2/d have been reported in various studies This range of reported transmissivity values suggests that groundwater flow occurs primarily in solution zones, karst features, and/or in fractures or fault zones This wide range in values makes it difficult or impossible to predict local well yields prior to drilling a test well One method of increasing the potential for drilling a higher-yield well

would be to locate the well near structural features that may have created fractures in the aquifer matrix

Wells and Springs

Only a few wells have been identified in the project area (Figure 7 and Table 1) Most wells completed in the Eastern Aquifer are located north and east of Jerusalem, and are not pertinent to our evaluation of wastewater reuse The immediate project area, where reuse or recharge of treated wastewater is contemplated, contains only a few known wells, for which well logs are not available Depths of wells located northeast of Hebron range from about 350 to 900 m The wells south or southeast of Hebron are reported to be from 100 to 500 m deep Springs are used extensively in the Hebron area for water supply and limited irrigation Selected spring locations are shown on Figure 7, and selected data on the springs is contained in Tables 2 and 3

Groundwater Quality

Generally, the Upper and Lower Aquifers contain water that has low total dissolved solids (TDS) Table 4 contains the results of historical chemical analyses of groundwater samples from wells in the area As groundwater flows from the recharge zone eastward toward the Dead Sea, the TDS probably increases In the Lower Aquifer, brackish springs discharge to the Dead Sea, however, it is not clear whether the springs are a mixture of water from the lower aquifer and deeper water sources of if the springs are derived solely from the Lower Aquifer The water quality of the springs at Ein Gedi, which discharges from the Upper Aquifer, is fresh (see Table 2) It is not clear whether the Upper Aquifer receives additional recharge between the outcrop area near Hebron and the discharge point at Ein Gedi According to Y Guttman of Tahal Consultants (personal communication, 1998), there is insufficient catchment area in the immediate drainage basin to support the flow of the Ein Gedi spring, therefore, the major portion of flow probably originates near Hebron The fact that the nitrate levels in the spring are higher than reported values in the recharge zone supports the theory of some local recharge The flow of water from Ein Geid springs is reported to be steady, showing only slight seasonal variations

Groundwater Contamination

The potential for groundwater pollution is very high in the recharge zone for the Upper and Lower Aquifers Pollution of springs by cesspools has been documented in the Hebron Area (Smith, 1985) In addition, the nitrate content of groundwater from the Al Fawwar wells is in excess of 50 mg/l The project team observed untreated sewage flowing in a small wadi approximately 50 m from Al Fawwar Well No 1 Reportedly, nitrate concentrations are high in most springs including the Ein Gedi spring near the Dead Sea Nitrate concentrations in the Herodion wells near the recharge zone range from 2 to 16 mg/l

Dr Uri Zoller at Haifa University-Oranim reported that water samples from many wells in both the Western and Eastern Aquifer Basins have detectable levels of surfactants,

demonstrating the impact of man's activities and the potential for contamination of even the deeper aquifers (personal communication, 1998)

Groundwater Safe Yield

The safe yield of the Eastern Aquifer is difficult to estimate because of the lack of data In practice, the sustainable yield of any aquifer is defined by the average recharge rate and the amount of water that can be withdrawn without causing an unwanted action, such as drying up springs or causing saltwater intrusion In an aquifer as complex as the Eastern Aquifer, for which few data are available, it is difficult to predict whether an unwanted action will occur, even if the recharge rate is known In this case, reported recharge rates range from 100 to 175 MCM/yr Recent modeling efforts by CDM suggest that pumping 79 MCM/yr under average recharge conditions will reduce discharges to the Dead Sea and will lower the regional water table in the southern part of the Eastern Aquifer (CDM/Morganti, 1997, Task 18)

Soils in the Hebron Area

In the Hebron area, soil associations were mapped at 1 500,000 scale in 1969, the text describing that map has been published only in Hebrew (Dan et al , 1977) We were able to obtain English-language copies of representative profiles for the soils found immediately south and east of Hebron from Dr Pinchas Fine at the Volcani Center, Institute of Soil and Water, Israeli Ministry of Agriculture According to Dr Fine, 1 50,000-scale mapping of soil types has been completed but has not been published and is not available in draft form

Terra Rosa, Brown Redzina, and Pale Redzina are the typical soil associations of the areas surrounding Hebron Chemical analyses and descriptions of representative profiles of these soils, collected in the West Bank, were reviewed (Table 5) The representative soil profiles indicate that the soil textures range from clay to loam Forty percent of the clay content in the Brown Redzina soil near Hebron was reported to be montmorillonitic The low exchangeable sodium percentages (Table 5) indicate that the soils are low in sodium relative to other cations, therefore sodicity will not limit their suitability for irrigation

CHAPTER 3

AGRICULTURAL PRACTICES IN THE HEBRON AREA

Agriculture presently is almost entirely rainfed and designed to maximize the use of precipitation Some irrigated crops such as cauliflower, squash, cucumbers, and tomatoes are grown near springs on flat or slightly sloped land Rainfed crops are grown mostly on terraced hillsides designed to capture and store runoff and in wadi bottoms The wadis are intermittently "dammed" using rocks, and the earth rearranged behind the dams to create flat plots of land for crops Plots of cultivated land reportedly are small, usually less than one to five dunum, although the project team observed some larger plots

Crops consist of grapes, olives, plums, various fruit trees, and some vegetables A few almond trees also were observed Olives, grapes, and plums are the major crops Some areas have been planted in wheat and barley The condition of the crops in late July, after several months of high evaporative demand and no precipitation, varied with location from no apparent water stress to obvious water stress Surprisingly, occasional plots of normally shallow-rooted vegetables were still producing, although they appeared water stressed Photographs of rainfed crop areas are contained in Appendix A

Nitrogen is applied sparingly to crops in the Hebron area because excessive vegetable growth early in the season would lead to high transpiration rates that could exhaust the soil water before the crop matures With low nitrogen input, very little nitrogen is left after the growing season Sheep manure is the major fertilizer used for rainfed crops Crop removal of water provides a storage capacity for rainfall in the soil, which is available for the next growing season Any precipitation greater than the storage capacity moves beyond the root zone Since rainfall is pure and nitrogen is applied sparingly, the water leaving the root zone would carry few chemicals However, because some residual nitrate always exists, the water moving through soil and bedrock to groundwater would be expected to be low in salinity but carry some nitrate

Present rainfed agricultural practices, which represent very efficient utilization of land and water resources have been adopted from centuries of experience surviving in the desert

CHAPTER 4

ALTERNATIVES FOR REUSE OF TREATED WASTEWATER

We evaluated two major alternatives for reuse of treated wastewater from Hebron aquifer recharge and agricultural reuse Agricultural reuse was considered the most viable alternative with aquifer recharge providing an alternative for storing treated wastewater during winter

To evaluate the types of wastewater irrigation practices that could be used in the Hebron area, we visited three agricultural reuse sites outside of the West Bank and reviewed operating reports on a fourth system Each site is discussed briefly below

Dan Regional Reclamation Project

The Dan Regional Reclamation Project consists of the treatment and recharge of municipal wastewater from the greater Tel Aviv area The treatment systems range from oxidation ponds to activated sludge The oxidation ponds were put into operation in 1970, and the activated sludge system began operation in 1987 Water from the treatment systems is recharged through flooding basins into a coastal alluvial aquifer where the water undergoes additional filtration through the aquifer matrix Since 1989, the recharged water has been recovered by a series of wells and then pumped to the Negev desert area for unrestricted irrigation use The operation and maintenance cost of the recharge project is 0 104 NIS/m3 (Mekorot, 1998)

The type of recharge and recovery system and agricultural reuse program practiced at the Dan Reclamation Project is not considered appropriate for the Hebron area, primarily because of the significant differences in the geology and hydrogeology of the two areas The Dan Project relies in part on the filtration of the wastewater through a sand aquifer and this type of aquifer does not exist in the Hebron area

Netanya Reuse Project

Secondary treated sewage effluent from Netanya is stored in a 3 8-MCM reservoir prior to reuse for irrigation of agricultural crops This reservoir does not store all of the effluent from Netanya During the irrigation season, some of the wastewater is taken by farmers before it reaches the reservoir In addition, if not all the effluent is needed and the reservoir is full, the excess effluent is discharged to a surface stream The appearance of the wastewater in the storage reservoir is good, and there is no odor The wastewater is pumped from the reservoir through automatic backwashing filters (185 micron) and then occasionally chlorinated prior to distribution The quality of the wastewater stored in the reservoir is such that algae and zooplankton can grow, plugging the drip irrigation systems, and it is not uncommon for extra chlorination to be required to prevent clogging Because this type of system could be used in the Hebron area, we suggest that for the next level of planning for this project, the design team visit this facility

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Be'er Sheva

Approximately 10000 m3/d of untreated raw sewage is delivered to a farming operation west of Be'er Sheva The sewage enters a series of small settling ponds, from which the liquid portion flows by gravity to a 1 1-MCM storage reservoir The stored effluent is dark and odorous The effluent is pumped through a continuous backwashing filter directly to the fields The farmer typically has two crops per year, cotton in the summer and wheat in the winter The effluent is applied to cotton using drip irrigation The farmer considers the poor quality of the raw sewage to be an advantage to the farming operation First, the cost is low Second, the quality is so poor that algae and zooplankton do not proliferate in the storage reservoir and do not plug the drip emitters (see appendix A for photographs of this operation) We do not recommend the use of raw sewage for irrigation in the Hebron area because the type of crops that can be grown would be restricted

Tal Shahar

We visited a private farm near Tal Shahar Abraham Sanati has operated this farm for a number of years At one time he used groundwater for irrigation, but changed to treated wastewater when his groundwater allocation was terminated The wastewater, from the city of Jerusalem, is reported to receive only primary treatment However, the sewage flows a considerable distance before reaching Mr Sanati's farm, then receives additional treatment in an on-site holding pond He does not take all of the wastewater flow, but only what he needs The water is stored in a 100,000 m3 clay-lined pond that he constructed at a cost of $300,000 Algae and duckweed grow in the pond The water is pumped from the pond through a two-stage filter system (a 200-micron followed by a 130-micron filter) and applied to crops through either a drip irrigation system (corn) or micro sprinkler (olives) Other crops are grown at the farm, but we did not inquire as to the irrigation methods Mr Sanati reported that he originally had problems with the drip emitters clogging, but through experimentation found a system that works satisfactorily Because this type of irrigation system could be used in the Hebron area, we suggest that the design team visit the site (Photographs of the operation are contained in Appendix A)

CHAPTER 5

RECHARGE OF AQUIFER WITH TREATED WASTEWATER

Task 4 (c) (6) in the statement of work requires the team to recommend four or more alternatives areas for the recharge of the upper Cenomanian /Turonian-age "Upper" aquifer of the Eastern Aquifer Basin with treated wastewater Task 4 (c) (7) requires the team to propose a well network or other scheme for recovering the recharged wastewater Three recharge methods were initially considered surface infiltration thorough constructed recharge basins, construction of dams across wadis, and injection/recovery wells After evaluating the probable wastewater quality after treatment and the geology and hydrogeology of the area, we concluded that artificial recharge is not likely to be a feasible option for reuse or storage of treated wastewater The following sections discuss the technical reasons that support dropping this option

Geology and Hydrogeology as Related to Artificial Recharge

Little is known about the path of migration that the wastewater would take after infiltration or injection Depending on the location, the injected water could move east toward the Dead Sea, southeast toward the desert, or southwest toward Be'er Sheva If the recharge site was selected near the proposed agricultural reuse area, the depth to the water table from the ground surface would be 250 to 350 m If recharge were via basins, the wastewater would need to travel through 250 to 350 feet of unsaturated carbonate rocks before encountering the water table from which it could be recovered It is impossible to predict the migration pathway in this type of geologic material It is also impossible to predict the size of the recharge basins because the infiltration rate is a function of permeability, which is unknown In most areas where artificial recharge via basins is practiced (such as the Dan Project near Tel Aviv), the geologic matrix is an unconsolidated material of sand or silt with known and/or predictable infiltration rates In this case, the basins would be constructed in a geologic matrix in which the primary zones of permeability are fractures or bedding planes Recharged water may migrate vertically downward if a fracture or fault is encountered, or it may migrate laterally and discharge prematurely as a spring near the recharge point In either case, the likelihood of recovering the recharged wastewater seems remote

We also reviewed the potential use of injection wells for recharge of the treated wastewater To estimate the number of injection wells necessary requires knowing typical values for the aquifer properties, including transmissivity Only a few production tests have been made on wells completed in the upper aquifer in the project area, and published results span a range of values Unpublished data for one well near Al Karmil suggest a production rate of 50 cubic meters per hour (m3/h) (Y Gutman, 1998, personal communication) Assuming that an injection well would have a recharge capacity similar to the production capacity of a water supply well it is possible to calculate the number of wells necessary to inject the anticipated wastewater flow rates Assuming an injection rate of 50 m3/h, 16 wells would be required in the year 2005, increasing to 38 wells by the year 2020 These wells would be used to inject the treated wastewater during the non-irrigation season and recover the water for irrigation in the summer

Injection wells are likely to cost the equivalent of production wells, resulting in construction costs of $16 million to $38 million based on the reported cost of water supply wells between Hebron and Bethlehem Recharge via injection wells would have significant operating cost due to clogging unless the water is treated to very high standards for both suspended solids and bacteria, or unless large fractures were encountered in the injection zone Recovery of this injected water would require high pumping cost and probably is uneconomical

Groundwater Quality

Available water quality analysis of water samples from the Upper Aquifer suggest that the water produced from existing water supply wells is of very good quality, with TDS generally less than 250 to 300 mg/l Even assuming that the industrial waste containing high salt loads that currently discharges to the sewer can be removed, the treated domestic wastewater is expected to contain a dissolved solids content greater than 900 mg/l Thus, direct recharge would introduce poor-quality water into an aquifer of good quality In some cases this may not be a problem if it could be demonstrated that the recharged water could be recovered and used for irrigation However, given the relatively sparse data concerning the geology and groundwater flow paths, it is unlikely that the hoped-for recovery could be predicted or accomplished

Agency Acceptance

Given the high quality of water currently contained in the Upper Aquifer and the probable quality of the treated wastewater with respect to salts, it is unlikely that the Joint Water Committee (JWC) or other agencies would approve recharge of wastewater Based on our discussions, both government agencies and individuals in the private sector oppose artificial recharge in or near the recharge zone using treated wastewater

CHAPTER 6

AGRICULTURAL REUSE OPTION

Irrigation is one option for using treated wastewater Some basic principles related to irrigation will be presented as background for evaluating this option The purpose of irrigation is to provide water to meet crop evapotranspiration (ET) that is not met by rainfall The timing and amount of irrigation depends on the crop, rainfall distribution, soil water-holding capacity within the root zone, potential ET, water salinity, uniformity of water application, and crop yield In principle, irrigation water is applied before the soil dries to a level that decreases yield and in amounts that replace ET losses between irrigation When saline irrigation waters are used, additional water must occasionally be applied to leach salts from the root zone

Conceptual Framework

Whether to use wastewater for an irrigation project must be evaluated in the context of optimal water resource management in the Hebron region, which has some unique features Water balance in a geographic area is determined by net water inflow (precipitation, surface water inflow, and subsurface water inflow) minus net water outflow (ET, surface water outflow, and subsurface outflow) Because of its topographic location, the Hebron region's natural inflow is precipitation only, whereas outflows include ET and both surface and subsurface outflow

Except for what is captured in cisterns or stored in the soil, all of the precipitation leaves by surface and subsurface flows in directions away from the Hebron region Because precipitation is confined to the winter months, not enough can be captured and stored to meet water demands in the summer Summer supplies must be supplemented by pumping water from deep wells at high costs Wastewater therefore is a potentially valuable resource

In water resource management, a distinction is made between water use and water consumption Water use is removing water from the hydrologic cycle, using the water for some purpose, and returning it to the hydrologic cycle in liquid form The same amount of water exists For example, water can be used in the home to do laundry and then discharged to the sewer The water quality has been changed, but the water quantity has not Water is consumed when it is converted from liquid to vapor phase or placed in a location that is not economically retrievable for human utility Most irrigation water is lost through ET and therefore consumed

In general, domestic, commercial, and industrial activities use water while agriculture consumes water Therefore, in almost every economic analysis the monetary return per unit of water is less for irrigation than for other purposes Nevertheless, food and fiber are essential for sustaining human life, and irrigated agriculture contributes substantially to the total economic base of many societies of the world

Conjunctive use is another concept in water resource management Conjunctive use usually refers to a coordinated plan to use both surface and groundwater supplies Surface supplies are used preferentially during wet years, and groundwater during dry years The term could be broadened to refer to using water supplies conjunctively for urban and agricultural purposes The latter context is appropriate considering wastewater reuse When water is extracted from the same aquifer for both urban and agricultural purposes, the most efficient use of water would be to have the city use the high-quality aquifer water in exchange for lower-quality wastewater that could be used for agriculture In this case, approximately the same amount of water is consumed (ET), but because of differing water quality requirements the benefits of using the water conjunctively are optimized

Neither approach to conjunctive use is appropriate for the Hebron region There are essentially no surface water supplies, and except for the amount captured in cisterns, all of the domestic-use water is groundwater Furthermore, groundwater is not being pumped for agriculture (although a small amount of spring flow is utilized) Therefore, there is no opportunity for exchange between urban and agricultural uses of water in the immediate region

The high cost associated with pumping water from deep wells and raising it to high elevations calls for extracting the maximum economic use from the water Urban domestic and industrial use represent the highest economic use of the water After urban use, the water may provide additional economic value through agriculture The factor to be determined is whether the economic returns from agricultural use exceed the associated costs This report provides background information and a framework for doing the economic analysis, but lacks the scope of conclusively determining the economic feasibility of using wastewater for an irrigation project

Water Quality Criteria for Reuse of Treated Wastewater

The major concerns associated with the agricultural reuse of treated wastewater include exposure to pathogens and bioaccumulation of heavy metals Additional concerns are associated with plant toxicity to metals and/or salinity

Water quality criteria for the reuse of treated wastewater for agricultural irrigation were developed by the World Health Organization (WHO, 1989) for public health risks, metals, salinity, and public acceptance

The public health risks of using wastewater for crop irrigation relate to disease-causing microorganisms and parasites Public health criteria are needed to protect the health of farm workers, people living in the vicinity of the farm, food handlers, and consumers Dissolved metals in the wastewater may accumulate in soil and produce toxicity in plants Salinity is addressed from two perspectives crop tolerance of salinity in irrigation water, and the effects of increasing salinity of the groundwater by leaching of salts below the root zone Finally, the water quality criteria must be adequate to enable farm workers to safely utilize the treated wastewater, and to enable the public to accept and safely consume the crops grown with treated wastewater The WHO and Israel standards for wastewater reuse for agriculture are listed in Tables 6a & 6b

We recommend that the wastewater treatment facility for Hebron provide at a minimum, secondary treatment Secondary treatment of domestic wastewater provides for a significant reduction in biochemical oxygen demand (BOD) and total suspended solids (TSS) The degree of nutrient (nitrogen and phosphorus) and pathogen removal depends on the method chosen for secondary treatment (Metcalf and Eddy, 1991) An evaluation of treatment methods is outside the scope of this project

Public Health Risks

The greatest public health risks associated with agricultural reuse of treated wastewater are increased intestinal parasites and infectious diseases (WHO, 1989) The intestinal parasites of concern are nematodes (also called helminths), which can cause infections in field workers and consumers One of the most common of these nematodes is Trichuris (hookworm) Outbreaks of cholera, Ascaris infections, and Trichuris infections were documented in Jerusalem in farm workers and consumers in 1970 when vegetable crops were irrigated with untreated sewage (Shuval, 1986)

The public health risks can be minimized through (WHO, 1989)

1 Wastewater treatment
2 Method of Wastewater application /protection of farm workers
3 Crop restriction/consumer protection
4 Human exposure control (education)

Control of application methods, protection of farm workers, and public education include measures such as avoiding contact with the aerosol from a sprinkler irrigation system and requiring farm workers to wear boots These approaches and related measures are discussed in Chapter 7

Microbiological Issues

The World Health Organization (1989) established guidelines for acceptable levels of microorganisms in wastewater used for irrigation based on integrating the risks from specific crops and human exposure to disease-causing organisms (Table 6a) The highest quality of irrigation water established by the WHO, which is for crops consumed without cooking, relies on either disinfection or adequate retention time for pathogen die-off prior to application The WHO guidelines for cereal, fodder crops, pasture, and trees recommends an 8- to 10-day retention time in waste stabilization ponds prior to irrigation From a public health perspective, Israel's microbiological standards are concerned primarily with the level of coliform in treated wastewater (Table 6b)

Recommended Treatment Level for Protection (WHO, 1989) of Public Health

Two criteria are proposed for protecting public health if treated wastewater from Hebron is used for agriculture

- Reduce the fecal coliform concentration to less than 1000 counts per 100 ml (geometric mean), and

- Reduce intestinal parasites to less than 1 egg per liter (arithmetic mean)

Fecal coliform can be reduced by either sufficient retention time for die-off of the bacteria, or disinfection with chlorine A retention time of at least 60 days is recommended without disinfection (CDM, 1992) The intestinal nematodes can be controlled using at least 30 days of storage to reduce the nematode egg count to less than 1 per liter (CDM, 1992)

Salinity Factors Affecting Agricultural Reuse of Treated Wastewater

The salinity of water leaving a city is greater than when it enters The boron concentration and sodium adsorption ratio (SAR) are also increased These factors affect the usability of the water for irrigation, usually in a negative manner Salinity and boron have direct physiological effects on the plant, whereas SAR has effects on the soil physical conditions, which can indirectly affect plant growth

Irrigation water is lost through ET, leaving behind salts, including boron, which become concentrated in the soil solution When the concentration becomes excessive, plant growth is reduced To maintain yields, extra water must be applied to leach excess salts from the root zone The amount of water required for leaching depends on the salinity of the irrigation water and the crop tolerance to salinity

The relationship between the amount of applied water having various levels of salinity and relative yield of alfalfa, which is moderately sensitive to salinity, are illustrated in Figure 8 Each curve is for a water salinity represented by the electrical conductivity (EC) of the water in units of dS/m The applied water is scaled to pan evaporation (Ep) for translation to different climatic conditions These curves are for irrigation systems that apply the water uniformly across the field For a given water application, the yield decreases with increasing irrigation water salinity Expressed differently, greater quantities of saline water must be applied to achieve the same yield as with less saline water If the water salinity is too high, maximum yield cannot be achieved regardless of the amount of water applied

The relationship between relative yield and applied water having various levels of salinity for wheat are presented in Figure 9 Wheat is salt-tolerant, so yields are affected only when the salinity gets very high

Figures 8 and 9 illustrate the general effects using of saline waters to irrigate crops of different salt tolerances (Letey and Dinar, 1986) The results are for continuous irrigation with the water of a given salinity For a system in which irrigation with saline water is followed by a rainy season, such as in the Hebron region, a transient state model should be used to simulate the expected results

The consequences of irrigating with saline water go beyond the effects on crop yield Essentially all of the salts applied with irrigation water are transported below the root zone and migrate toward groundwater The salts leach from the root zone at a high

concentration For example, if 10 percent of the applied water leaches below the root zone, the salt concentration in the water leaving the root zone would be 10 times higher than in the irrigation water When irrigating with a water having EC equal to 1 dS/m, the EC of water moving to groundwater would be 10 dS/m The salinity of the water leaving the root zone can be approximated by dividing the concentration of the irrigation water by the leaching fraction The leaching fraction is the ratio of the amount of water moving below the root zone to the amount applied

Irrigation that leaches salts also leaches nitrate and other agrochemicals in the soil, creating two negative consequences 1) nitrates can degrade groundwater, and 2) additional nitrogen must be applied to the crop to compensate for the nitrogen that was leached This consequence can be partially mitigated by a drip system, fertilizer injection and precise fertilizer management

Water moving below the root zone may not always migrate to the aquifers Depending on the geology of the area, this water may discharge to the ground surface some place where the water evaporates, creating salinized zones

Waters having high SAR can cause soil dispersion and clay swelling, which produce dense soil crusts that do not transmit water very readily Divalent calcium and magnesium on the soil exchange sites become displaced by monovalent sodium when waters of high SAR are applied The consequences of sodium on the exchange sites become especially manifest when rainfall, which is almost like distilled water, penetrates the soil Soil sealing results in more runoff This negative effect can be mitigated by applying a calcium source, such as gypsum, before the rainy season This practice, however, represents a financial investment to offset the consequences of irrigating with a water of high SAR

In summary, some saline waters can be used for irrigation, but with several negative consequences Crop selection becomes restricted based on salinity tolerance Salts, nitrates, and other chemicals are transported below the root zone and can degrade aquifers or seep to land surfaces, inducing salinization of the land Additional nitrogen must be applied to replace the nitrates leached from the root zone A calcium material may be required to protect soil physical conditions if the water has a high SAR value

Uniformity of Irrigation

Uniformity of irrigation is important to irrigation management A perfectly uniform irrigation would be one in which the amount of water entering the soil is the same everywhere in a field With non-uniform irrigation, different parts of the field receive different amounts of water If one irrigates to produce the highest yield, enough water must be applied so that even the part of the field receiving the least amount of water will receive enough to produce maximum yield As a consequence, much leaching will occur on other parts of the field that receive excess water, increasing transport of nitrates and other chemicals to groundwater Additional nitrogen fertilizers will be required to maintain high yields On the other hand, if one irrigates to restrict leaching on those parts of the field which receive the most water, yields on other parts of the field will be reduced because of insufficient water If irrigation is not uniform, it is impossible to achieve both high yield and low chemical leaching

Well-designed and maintained drip systems provide the greatest opportunity for uniform irrigation and precise control over the amount of water applied These systems are also more expensive than sprinklers or furrow irrigation, but they minimize the negative consequences of irrigating with saline water

Utilization of Treated Wastewater for Irrigation in Hebron Region

The following sections discuss several issues regarding reuse of treated wastewater that are specific to the Hebron area

Irrigating Existing Agriculture Lands

One consideration is to use some of the treated wastewater to increase yields on existing agricultural plots of land that receive less than optimum amounts of water Although rainfed agriculture has been successful, crops are generally water stressed to some extent

Although yields could in most cases be increased by supplemental irrigation, this practice should not be the primary reuse option for several reasons based on economics, sustainability, and groundwater quality Many of the existing agricultural plots are small, highly dispersed, and located on "rough" topography The costs associated with a water delivery system would be high Furthermore, crop-water production functions are such that the increased yield per unit of additional water decreases as the yield increases Therefore, the marginal benefit from supplemental water is relatively low

Sustainability is a long term concern for supplementing present rainfed agricultural plots with treated wastewater The treated wastewater will contain salts at concentrations that are unknown at this time Regardless of the salt concentration, the consequences described below are valid Only the extent and timing of the consequences depend on the degree of salinity

In rainfed agriculture, the applied water is almost distilled Salts do not accumulate in the soil Irrigation with wastewater adds salts to the soil The salts in the soil solution create an osmotic potential that reduces water availability to the crop Irrigation can be managed to keep the salt concentration in the root zone at levels that would not reduce plant growth unless the salinity is excessive or the plant is overly sensitive to salt However, the solution leaving the root zone would be highly concentrated with salts This leachate may migrate to lower terraces and/or the wadi producing negative consequences The lower-lying fields could become salinized in a manner that would make them almost impossible to reclaim Presently rainfed agriculture is successful because the annual precipitation is about equal to crop ET As long as the soil has adequate storage capacity to retain water from the rain season to the crop season and salinity is not a factor, relatively good yields can be achieved Very little leaching occurs in this system If salts are added to the system by irrigation, and one wanted to revert to rainfed agriculture, much lower yields would be achieved because of salinity One option would be to leave the land uncropped for several years to achieve leaching from precipitation However, the lower lying areas may never be leached, at least in a reasonable time frame Therefore, for practical considerations, it would be impossible to

revert to completely rainfed agriculture in the future if irrigation with saline water is introduced to the area

Another consequence of irrigating the terraces and wadis with saline water is more nitrogen must be added to compensate for the nitrate leached with the salts This imposes an additional cost An added hazard of using saline water on rainfed agricultural areas is the deterioration of the soil physical condition Infiltration rates could be greatly reduced, causing the soil to become less effective at capturing and storing precipitation

Even if the leachate did not migrate to degrade lower-lying terrace or wadis (which is unlikely), the leachate must go somewhere If the agricultural land overlies a useable aquifer, the aquifer water ultimately may become degraded The majority of the present agricultural lands in the Hebron region overlie the Upper or Lower Cenomanian Aquifers which are major suppliers of water for the area Therefore, even if one hazard of irrigating present agricultural land with wastewater could be mitigated, not all of the hazards could be mitigated

Quality of Hebron City Wastewater

The water delivered to Hebron is of high quality based on historical chemical analysis and on analyses of waters collected at three wells We are indebted to Dr M Ben-Hur of the Volcani Research Center for the analytical results The salinity is quite low for all three supply wells, having an average EC value of 0 67 dS/m (Table 7a)

Domestic and industrial use of water in the city degrades its quality Domestic use adds BOD, salts, and pathogens associated with human wastes Secondary sewage treatment does not remove salts from the water, so the treated wastewater will have the same salt concentration as the untreated water In the United States, domestic use increases the salt concentration in the range of 200 to 300 mg/l However, in Israel, where water is used more conservatively in the home, the concentration increases to approximately 600 mg/l Hebron would be expected to be similar to Israel or possibly have a greater increase in salinity

Although a wastewater survey was conducted of various industries in Hebron (FORWARD, 1998), few data were obtained on salinity A review of that report revealed that several industries could contribute significant salt loads to the sewer For example, the plant that processes sesame seeds reportedly discharges 800 kg of salt per day into the sewer If the sewer flow is 12 000 m3/day this discharge increases the salt concentration of the wastewater an average of 67 mg/l An ice cream factory reportedly was using 400 to 500 kg of 11 percent CaCl2 for coolant brine that was discharged to the sewer The raw water is softened with NaCl ion exchange, which presumably is recharged at the plant with a consequent discharge of salt A vegetable cannery also does water softening, but of the FORWARD report made no mention of the softening process The average EC of olive wastewater was measured at Hebron University to be 7 3 dS/m

The FORWARD report noted that the tanneries discharge waters highly concentrated with various chemicals We collected water sample from four processing steps and had

them analyzed by Dr Ben-Hur The EC values in dS/m were 48 for the washing vat (salt removal), 56 for chrome treatment, 9 5 for dehairing, and 17 4 for oil and dye (Table 7b) A water sample collected at the wastewater outfall had an EC of 3 28 dS/m (Table 7b) The boron concentration at the sewage outfall was 0 84 mg/l probably from domestic sources The boron concentration must be closely monitored if the water is to be used for irrigation, because boron is harmful to plants

A thorough evaluation of the wastewater salinity is essential for evaluating the option of agricultural reuse of the treated wastewater The EC is likely to change with time of day because daily industrial discharges change quickly, and change with time of year because of seasonality of some operations such as processing olives Dr Akrum Jalal Tamimi of Hebron University has indicated willingness to pursue this research in a detailed fashion

To allow agricultural reuse of the wastewater, the industrial wastewater from the tanneries must be kept out of the sewer system Likewise, water from the stone-cutting industry must be free of mineral particles (suspended solids) before discharge to the sewer The chemicals in the tannery wastes may negatively impact the effectiveness of the treatment plant as well as contribute undesirable chemicals to the treated water Pretreatment of the tannery wastes before discharge probably is not feasible Reverse osmosis (RO) treatment could provide a water suitable for sewer discharge, but the waste stream from the RO unit would require disposal

One possibility is to pipe the industrial wastewater and discharge it where there is no possibility for the chemicals to reach groundwater or have other negative impact Another possibility is to pipe or transport it by tanker truck to a lined pit where the water would evaporates and the salts accumulate Disposal of industrial waste is beyond the scope of our assignment, so the matter has not been thoroughly evaluated

Although the tanneries have been discussed specifically because of their potential impact to agriculture reuse, other industries that discharge massive amounts of salts to the sewer system should also be restricted For example, the discharge of 800 kg of salt from the ice cream plant should be restricted An alternative plan for disposing of highly concentrated industrial water must be developed If the wastewater is mostly domestic, and salt dumping into the sewer by industries is stopped, the wastewater could be used for irrigation in the Hebron region However, high salinity in the treated wastewater would jeopardize its economic utility for agriculture

Selection of Land Areas for Agricultural Reuse

The following criteria were established for identifying lands for potential irrigation by treated wastewater

1 The land must be in a location where the leachate would not flow unimpeded to the Upper or Lower Cenomanian aquifers

2 The topography should have gradual slopes that would not require extensive terracing

3 Preferably, the land would not presently be used for agriculture, if used, the present productivity would be low enough to economically justify irrigation or a shift in crops

Geographic areas overlying Turonian and Senomian geologic age strata with undulating topography best fit the above criteria Seven potential sites were identified (Table 8) Site locations are shown on Figure 10 The following is a brief description of each site

Wadi Alsemen

This area is downstream of the proposed wastewater treatment site It includes arable land along Wadi Alsemen and in tributaries to the wadi The land surface typically has slopes of less than 10 percent The area is located over Turonian-age strata The disadvantage to this site is that most of the land is already planted in olive trees, and existing rainfed agriculture is well established

Zif/Yatta

This area is located between the villages of Zif and Yatta on a plateau that has gently rolling topography, approximately 9 km south of Hebron There are approximately 1400 hectares of cultivated land located mostly on the west side of the surface water drainage divide The current crops appear to be primarily grapes and olives (see photograph in Appendix A) This area previously was identified as a potential site for irrigation with wastewater from Hebron (Plancenter, Ltd , 1997) The site is located primarily over Turonian-age strata, although the northern portion of the area may overlie upper Cenomanian-age geologic units The primary disadvantage to this site is that existing rainfed agriculture is well established

Al Karmil NE

This area is east of Yatta along the paved road between Zif and Al Karmel near the beginning of the access road to the Hebron Municipality Solid Waste Facility Potentially suitable areas are found on both sides of the road The area is located on the east side of the surface water divide, surface drainage is toward the Dead Sea The fields appear to be used to grow barley or similar grains There are stony areas between the fields The area overlies Turonion and Senonian-age geologic strata

Al Karmil E

This area, which is west of the village of Al Karmil, appears to be currently used to grow grain, such as barley The fields are on the east side of the surface water divide, and surface water drainage is toward the southeast Stony areas exist between the fields This area is potentially larger than indicated on Figure 10 and could extend a significant distance along both sides of the highway This area overlies Turonian and Senomian-age geologic strata

A Sammu' E

This area, which is approximately 3 km east of the village of E'Sammu and southwest of the village of Al Karmil, appears to be currently growing grain, such as barley The fields are on the east side of the surface water divide, and surface water drainage is toward the southeast The area is located over Senomian-age geologic strata

A Sammu' SE

This area, approximately 1 5 km southeast of the village of E'Sammu, appears to be used currently to grow grain, such as barley The fields are on the east side of the surface water divide, and surface water drainage is toward the southeast This area overlies Senomian-age geologic strata

Beni Ni'am

Located approximately 4 km southeast of Beni Ni'am, this area consists of a group of fields on the eastern foothills below Beni Ni'am The elevation of these fields is about 500 to 550 m The fields were observed from the 880-m high knoll south of the paved road that leads to Pene Hever This knoll is roughly 2 km from the fields The fields appeared to be cultivated with grain crops

Crop Water Demand

Crop water demand is driven largely by climate and the crop Crop ET is estimated by multiplying the pan evaporation (climatic variable) by a crop coefficient The crop coefficient varies with crop and time during the growing season Klein (1993) published a comprehensive analysis of ET for deciduous trees and grapes His report provides crop coefficients for peaches, nectarines, and table grapes for various harvest times (Figures 11 and 12) No crop coefficients were published for olives, but Isaac Klein (personal communication, 1998) indicated that they would increase linearly from about 0 3 in April to 0 6 at harvest time

Pan evaporation rates are presented on Figure 13 for the seven month growing period at Jordan Valley, South Hebron Hills, Upper Gallile, and the Coastal Plain The rate for the South Hebron Hills, located near Karmel, approximates the pan evaporation at our proposed potential irrigation sites identified as Al Karmil and A Sammu The Climatology Division of the Israel Meteorological Services provided us with pan evaporation for a pan located in Hebron City The pan evaporation at Hebron is identical to pan evaporation on the Coastal Plain, about 66 percent of the rate at Karmel The proposed potential irrigation site identified as Zif/Yatta probably has a pan evaporation intermediate between those of Hebron and Karmel

Klein (1993) conducted experiments on commercial orchards at Karmel on several cultivars of peach, nectarine, and prunes The amount of irrigation required ranged from 0 70 to 0 88 m We used the reported crop coefficients for grapes harvested on July 10,

August 10, and September 10 and the pan evaporation for Karmel to calculate a crop ET of 0 80, 0 89, and 0 93 m for the successive harvest dates

Land Area Requirements

The ET and crop coefficient data were used to estimate the land area that could be irrigated with various quantities of wastewater Our assignment was to recommend areas sufficient to handle wastewater quantities estimated for the year 2005 (19,000 m3/d), year 2010 (26,000 m3/d), year 2015 (34,000 m3/d), and year 2020 (46,000 m3/d) The calculation was done assuming an average crop ET of 0 85 m This value was selected based on measured ET values for various fruit trees at Karmel by Klein (1993) and computations for grapes using reported crop coefficients and pan evaporation for Karmel No adjustments were made for irrigation variability because we recommend the use of micro-irrigation systems which, when properly designed and maintained, apply water uniformly The land area can be scaled up or down if another ET value is used The results are presented in Table 9

The land areas presented in Table 9 are reasonable for planning purposes However, the assumptions must be recognized Irrigation was assumed to be uniform, typical of a well-designed and maintained microirrigation system No consideration was given to rainfall stored in the soil that could be carried over to supply part of the ET Salinity of water was assumed to be low Salinity is particularly troublesome because of the present uncertainty of the ultimate salinity of the treated wastewater The EC of 3 28 dS/m for the one combined wastewater sample we took is unacceptably high Almonds, peaches, and prunes are sensitive to salinity No data were available for nectarines, but they are probably sensitive Grapes are moderately sensitive, and olives are moderately tolerant

Water quantity and quality represent a dynamic, transient system The rain in winter is "pure," but the irrigation water used in the summer contains salts Thus soil salinity is a variable that depends on rain amount, irrigation amount, irrigation salinity, and ET, which will be related to both climate and crop tolerance to salinity A transient model is available (Pang and Letey, 1998) to simulate transitional soil salinity levels, but that refinement is not required at this stage of our investigation However, water applications could depend on whether the rain leaches all the salts and whether salts accumulate to detrimental levels during the growing season

Comparing the land requirements (Table 9) to potential land availability (Table 8) reveals that there should be adequate land to accommodate all anticipated wastewater production Note that the ET values assumed are for mature orchards ET values would be lower for young trees, and less irrigation water would be required

Wastewater Storage Considerations

Wastewater production does not temporally match crop ET requirements even during the growing season The mismatch is obvious in the winter, when crop irrigation is not required, but wastewater production continues To utilize all of the wastewater from Hebron, a water storage facility is a requirement

Theoretically, the required storage capacity is equal to approximately one-half of the annual wastewater flow given in Table 9 This theoretical value, which is based on completely emptying the storage once a year, does not allow for uncertainties and variable annual conditions The storage capacity should be higher than the theoretical value, a 10 percent increase is reasonable

Most of the land suitable for irrigation is at a higher elevation than the proposed sewage treatment plant Therefore, a reservoir must be at an elevation higher than the irrigated land Building a dam or series of dams in Wadi Alsemen below the treatment plant is an option for additional storage capacity and/or a reduction in the size of the reservoir required at the top of the drainage divide An economic analysis would identify the economically optimal combination of storage facility locations and sizes Construction of a dam(s) in the wadi has the added benefit of collecting runoff during the winter which would increase the supply of irrigation water and would dilute or decrease the salinity levels of the treated wastewater

Storage facilities provide an additional benefit to agricultural reuse Increased retention time contributes to water "purification" and possibly eliminates or reduces the requirement for disinfection

Perfectly matching irrigation water supply with water demand on an annual basis is unlikely Therefore, a storage facility in the wadi should be designed to release water into the wadi as required Various reservoir options are discussed in Chapter 8 of this report

Methods for Applying Irrigation Water

Treated wastewater would be pumped from the treatment plant area to a reservoir above the agricultural land Mainlines would run from the reservoir to the agricultural area, with a distribution network to be developed through a future study The requirements for irrigation uniformity and precise control on water application suggest the use of a microirrigation system, which includes drip emitters or spray nozzles and fertilizer injection This irrigation system provides precise water and nutrient management, which allows for minimizing the negative aspects of irrigating with waters that contain dissolved salts

This system allows maximum production per unit of water with minimum environmental consequences The undulating topography eliminates the possibility of using low-cost surface irrigation system Large nozzle sprinklers do not provide the uniformity required Furthermore, the health hazards associated with using treated wastewater are greater with a sprinkler system

Emitter clogging can be a problem for drip systems Causes of clogging can be broadly categorized as chemical, physical, or biological Chemical clogging is associated with the chemical composition of the water, with hardness and iron and magnesium concentrations being important factors Adjusting the pH can control the hardness effect Physical effects are controlled by filtration The biological factors may require chlorination However, the chlorination level should be set to prevent emitter clogging and not to provide disinfection unless the organisms in the water require it

Water treatment to prevent clogging is most economically done as water is removed from the storage reservoir and introduced to the distribution system Depending on the types of emitters and other factors, the farmers may have to provide some final filtering

As discussed in Chapter 4, wastewater from the city of Netanya is used for irrigation Part of the wastewater is stored in a reservoir prior to delivery The Israel Water Works Association conducts research and tests filter systems to prevent emitter clogging by wastewater They have several publications that should be consulted during the final design of the wastewater reuse plan for Hebron

Future Requirements for Developing the Irrigation Project

Our analysis has established that the development of an irrigation project is potentially feasible for utilization of treated wastewater from Hebron However, the ultimate success of an irrigation project is dependent on several factors that go beyond the scope of and time allotted to our study Described below are future detailed studies that must be completed to allow final conclusions to be drawn

1 A plan must be developed and implemented to keep industrial discharge of salt and toxic chemicals from the sewer system In the absence of this accomplishment, our judgment is that a wastewater reuse project will fail Profitability of the project is very sensitive to the salinity of the wastewater An early, thorough evaluation of the wastewater salinity and its sources is required as base information The most relevant parameters to be measured are electrical conductivity, calcium, magnesium, sodium, and boron

2 Although general land areas have been identified for irrigation, a detailed land survey is required to accurately determine the amount and location of appropriate land The criteria for selecting land for irrigation should include potential productivity, existing land use, and potential hazards to groundwater contamination from the irrigation

3 Landowners of the identified appropriate lands must be identified Their willingness to invest in an irrigation system and pay for irrigation water must be established The project must be established on a firm economic basis, and farmers' willingness to invest is essential

4 Assuming that landowners are willing to invest, a cooperative organization must be established among them The following is a proposed structure patterned after irrigation districts in California All of the farmers are members of the district They elect representatives to serve on a Board of Directors The district also has a paid technical and administrative staff, which works under the direction of the Board of Directors The district purchases the water and sells it to the farmer members The difference between purchase and sale price provides the budget for district operations such as maintenance of the reservoir, treatment of water delivered to the major distribution pipes, technical advise to the farmers, etc

5 A way should be developed to take advantage of economy of scale in designing the irrigation system for several small land parcels This might involve owners of adjacent lands agreeing to grow the same crop with a common irrigation system that is jointly operated In other words, smaller cooperatives could be established within the irrigation district and behave as if they were individual large landowners Another alternative is to have an individual, corporation, or organization obtain a long-term lease agreement with the landowners The landowners benefit from receiving rent and the corporation can efficiently manage the project on a larger scale

6 The irrigation project can be sustainable only under the condition that ownership and rights to the treated wastewater are firmly established Hebron City must have the right to sell the water to the Irrigation District Returns from the sale would be used to operate the treatment plant, maintain the irrigation reservoir(s), distribution network, and future expansion

7 An economic optimization analysis will be required The analysis should identify optimal siting and size of the holding reservoirs It should identity the appropriate price the city should charge the district for the wastewater, and then the price the district should charge the farmers To accomplish these tasks, responsibilities would have to be delineated Who pays for maintenance of the storage facilities? Who pays to pump the water from the treatment plant to the upper reservoir? What costs does the district adsorb, and what costs are imposed on the individual farmers? The optimization would be based on net societal benefits and would indicate whether the irrigation project is economically feasible In effect, can the income from the sale of crops pay for the capital investment and operational cost of the project? If not, an alternative such as finding another purchaser of the wastewater or some type of subsidy would be required

8 Conclusions from any analysis will depend on the level of capital investment by USAID We were told that for the irrigation reuse project for wastewater from Be'er Sheva, the Israel government paid 70 percent of the reservoir costs and 30 percent of the irrigation system costs (Netafim, 1998 personal communication) USAID should evaluate the merits of investing capital in the irrigation system to establish a sustainable economic project

9 If the project is judged to be economically feasible, detailed planning on all aspects of the project should proceed in a coordinated manner Coordinated planning would include the treatment plant, wastewater storage facilities, wastewater pumping facilities, and the delivery system to the farms An environmental assessment of the feasibility of wastewater storage facilities, is also required The types of crops and economic return on each crop should be determined The plan should allow the efficient increase in size of the total project as increasing amounts of treated wastewater are produced

CHAPTER 7

EDUCATION PLAN FOR FARMERS AND LOCAL POPULATION

The education of the farmers, neighbors, and consumers regarding the use of treated wastewater for agricultural irrigation needs to begin with enabling the stakeholders to accept and become a part of planning the reuse approach Ultimately, the farmers will be the operators of the irrigation systems The initial success of the project depends on local acceptance and willingness to participate in, and pay for, the irrigation water The long-term success of the project depends on an ongoing education program for the farmers, farm workers, and consumers The success of wastewater reuse in the Hebron area will depend on the farmers' willingness to use the effluent for irrigation and the public's willingness to consume the farmers' products A planning program to ensure success of the project can be implemented in two phases

- Phase 1 – A short-term public acceptance program, including small-scale demonstrations for reuse of treated wastewater, can be established in Hebron

- Phase 2 – In the long term, an irrigation extension program and an on-going irrigation/reuse education program must be established

There are two critical aspects to the timing of these phases Phase 1 should begin early, because the farmers and the consumers must gain confidence that the project is being developed to meet their needs The chances of gaining this confidence are greatest early in the decision-making process and decrease as decisions are made regarding the reuse program If the farmers are expected to use the wastewater for irrigation, their needs must be considered in the planning, design, implementation, and operation and maintenance processes Secondly, the education programs in Phase 2 must be designed and implemented as a continuous process that will last as long as the wastewater is used for agricultural irrigation or, until the reuse practice is so well established that the need for public education no longer exists

Public Acceptance/Demonstration Project (Phase 1)

Gaining public acceptance should involve the farmers and consumers in the decisions that affect them so they have an appropriate degree of responsibility for their role in the project Health education and promotion of wastewater reuse are more effective when conducted by people in the community than through mass media or outside trainers This can be accomplished through a network of community workers and extension agents Females typically are more effective for information dissemination on food safety because women in the area are in charge of the food purchasing There will be a need for a program to train local trainers In addition, the Muslim clergy should have an important role in the educational program and should be included in the train-the-trainer program The following steps can be incorporated into the public acceptance process

1 Train-the-trainer program,
2 Clergy education program,

3 Publicity and promotion of the reuse project,
4 Farmer survey of willingness to use treated wastewater,
5 Evaluation of willingness of farmer to pay for wastewater,
6 Discussion of religious issues
   a) working with treated wastewater,
   b) handling crops irrigated with treated wastewater,
   c) consumption of crops irrigated with treated wastewater,
7 Small-scale pilot treatment facility and irrigation/reuse demonstration plot(s),
8 Tours of demonstration facility and other irrigation/reuse operations in the region,
9 Publicity regarding the benefits of wastewater reuse in arid climates, and
10 Publicity about other areas in Muslim countries where wastewater is reused

Farmer Education/Irrigation Extension Program (Phase 2)

The goals of the irrigation management and farmer education are to enable the successful use of treated wastewater for crop production, protect the health of the workers, people living near the farms, and consumers of the crops, and to demonstrate the safety of the use of treated wastewater so there is no decline in the market value of crops To provide maximum effectiveness, these two components should be interwoven into a comprehensive irrigation management program

These programs are best managed at a local level, perhaps by the Hebron Directorate of the Palestinian Ministry of Agriculture, Hebron University, or other local group In addition, the resources of Hebron's Health Engineering Department, which is responsible for the wastewater system, could be used It would be appropriate to develop a local wastewater treatment and reuse/irrigation demonstration center/field station where hands-on irrigation training can be given and data can be collected on meteorological factors and crop response to irrigation with treated wastewater Based on reported operating problems with treated wastewater, several Middle Eastern countries have established full-time irrigation specialists as a trainers and advisors, and in some cases have established experimental field stations

The following units could be incorporated into a farmer education program

- Crop selection,
- Selection of an irrigation system ,
- Financial management for purchase, installation, operation, and maintenance of an irrigation system,
- Installing irrigation equipment,
- Operating and maintaining irrigation equipment,
- Safety issues for workers who contact irrigation water,
- Monitoring crop water needs and irrigation timing ,
- Optimizing irrigation to benefit yields and profits,
- Consumer education, and
- Crop safety

CHAPTER 8

ESTIMATED CAPITAL AND OPERATION AND MAINTENANCE COSTS ASSOCIATED WITH AGRICULTURAL REUSE

The capital and operating costs associated with this project have a number of variables that cannot be accurately defined within the scope of this project As discussed in Chapter 6, a complete economic optimization analysis is required However, we have developed preliminary cost for wastewater storage options, irrigation system costs, and operation and maintenance cost Potential income from the sale of treated wastewater also is discussed

Storage Reservoir Costs

Four wastewater storage options were developed and costed The capital and operating costs for the selected options are outlined in Tables 10 through 13 None of the estimates include the cost of distribution pipes from the reservoir to individual fields Assumptions used in developing these costs are contained in Appendix B The locations of a potential storage reservoir and a dam site are shown on Figure 10 The cost estimates do not include characterization of the sites for geotechnical, hydrogeological, and air quality issues

Option One

Option one would utilize Hebron's wastewater for irrigation in the Zif, Yatta, Al Karmel/E, or Sammu areas This option includes pumping the treated wastewater from the proposed treatment plant to a storage reservoir(s) near the top of the east-west drainage divide The storage reservoir would be designed to hold approximately one-half of the yearly flow of wastewater (irrigation will not occur in winter) The initial storage reservoir would be sufficient to hold the flow through the year 2005 The size of the reservoir would have to be increased or additional reservoirs constructed to contain the increased flows expected in 2010, 2015, and 2020

Option Two

Option two is similar to option one except the reservoir near the top of the east-west drainage divide is designed to hold only a few days of flow The major storage reservoirs would be constructed in the Wadi Aisemen, possibly as dams Dams across Wadi Aisemen could serve the additional purpose of collecting storm water, which could also be used to increase the area irrigated

Option Three

Option three is not designed to collect or use all of the wastewater generated by Hebron The water would be used only during the irrigation season, and only a small (30-day) holding basin would be necessary near the top of the drainage divide This option would provide for holding the wastewater for sufficient time to allow for pathogenic purification, and chlorination would not be required During the non-irrigation season, the treated wastewater would be allowed to flow down the Wadi Aisemen

Option Four

Option four does not consider the reuse of the wastewater in the Hebron area In this option, all of the treated wastewater would be collected and allowed to gravity-flow to the Be'er Sheva area It is likely that farmers in the Be'er Sheva area would be willing to pay for the water The city could negotiate both the quality and price of delivered water

Cost of Installing Irrigation Systems

The cost of an irrigation system depends on the type of system Based on our evaluation, we recommend a microirrigation system (drip or mini-sprinkler) for delivering treated wastewater

The cost of purchasing and installing the irrigation systems will vary with the quality of the system and the type of crops selected for irrigation Typically, drip systems for orchards cost less than for row corps, because fewer lines are required To develop cost estimates for this study, we contacted Netifam, an international manufacturer of drip irrigation systems We examined a drip system that has been used for more than 15 years to carry raw wastewater This system had preformed satisfactorily with minimal maintenance Netifam quoted a cost of 8000 to 10000 NIS per hectare for fruit crops and 15000 to 20000 NIS per hectare for row crops These costs translate into a range of approximately $2500 to $5700 per hectare These estimates are similar to those developed by the University of California, Division of Agricultural Sciences (UC, 1981) Using these costs and the land estimates required for irrigation in 2005 and 2020, we estimate the cost of a drip system (purchase and installation) to range from $2 million to $4 6 million in 2005, increasing to $5 million to $11 3 million to accommodate the volume of treated wastewater in 2020 These costs assume the water will be delivered to the head of a field under 7 meters of pressure The cost of pipelines from the storage reservoir to the fields is not included in this estimate

Cost of O&M Irrigation System

The cost of operating an irrigation system can be divided into two components, the cost of pumping water from the treatment plant to the irrigation storage reservoir, and the cost of operating the individual farmer's drip irrigation system, which will be paid for by the individual farmer The O&M cost has been estimated for each reuse option (see Tables 10 through 13) The cost of operating an individual farmer's irrigation system will vary

The primary costs are associated with labor, power for pumps, system repairs (or replacement), and the price of water Excluding water costs, operating costs for drip irrigation in the US have been estimated at $225/hectare/year (UC, 1981) Costs for labor (primarily family members) will probably be less in the Hebron area than in the U S

Income from the Sale of Treated Wastewater

The price the city can obtain for treated wastewater is impossible to determine until an economic analysis of the irrigation reuse option is completed and the farmers' willingness to pay determined However, for planning purposes, the Netanya reuse project charges $0 65 NIS per cubic meter for secondary treated wastewater If the entire volume of Hebron's treated wastewater were sold, this would produce an income of approximately $1 3 million in the year 2005, increasing to $3 1 million in 2020

CHAPTER 9

DISCUSSION OF SCOPE OF WORK TASKS

The following discussion of each individual task forms the general conclusion of our report Task numbers refer to the original scope of work developed by USAID

- **Identify and Assess Potential Irrigation Sites (Task 4 c 1)**

  We have identified seven sites for potential irrigation with treated wastewater from Hebron A total of 3090 hectares were identified, although they are generally not contiguous The individual sites are indicated on Figure 10 Based on our review of irrigation methods and our discussions with research institutions, irrigation cooperatives, and individual farmers, drip irrigation appears to be the irrigation method of choice for treated wastewater We identified a number of suitable crops that can be grown locally The crops selected will depend on the individual farmer and the local, regional, or international market for these crops The amount of treated wastewater that can be applied to each site will vary based on the crops and natural rainfall Priority areas should not include the areas with well-developed rainfed crops (Zif/Yatta area)

- **Identify and Assess Potential Recharge Sites (Task 4 c 2)**

  Based on the information we reviewed on the geology and hydrogeology of the area, water quality in the Upper Aquifer, and the expected quality of the treated wastewater from Hebron, we believe that artificial recharge should not be considered for wastewater reuse This conclusion is consistent with the conclusion in the Integrated Water Resources Management Plan for the Hebron-Bethlehem area (CDM/Morganti, 1997 Task 33)

- **Study Range of Wastewater Effluent Quality Standards for Irrigation and Recharge Applications (Task 4 c 3)**

  We evaluated the basic water quality requirements for both irrigation and recharge The expected concentration of dissolved salts in the treated wastewater compared to the quality of water in the upper aquifer suggests that none of the typical treatment methods can produce wastewater suitable for recharge Our evaluation of the treatment level necessary for irrigation suggests that secondary treatment is preferred, followed by a minimum of 30 days storage or chlorination prior to reuse on agricultural crops This treatment level is consistent with the levels outlined by CDM (CDM/Morganti, 1997 Task 33) These recommended levels were

  - Total BOD 15 mg/l
  - Dissolved BOD 10 mg/l
  - Suspended Solids 15 mg/l
  - Fecal Coliform <200/100 ml
  - Nematodes <0 1/ml

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- **Recommend Two or More Alternative Areas for Direct Application of Treated Wastewater for Irrigation (Task 4 c 4)**

  We identified seven potential areas for irrigation with treated effluent The areas can be or expanded as the volume of wastewater increases These areas are identified on Figure 10 and Table 8 Our first priority would be to irrigate areas not currently used for rainfed agriculture

- **Recommend Three or More Alternative Areas for Application of Recharged Wastewater for Irrigation (Task 4 c 5)**

  We believe that recharge of wastewater is not a viable option, therefore, we did not identify any specific area that could be irrigated with recovered, recharged wastewater Instead, we developed options to store treated water during the winter for later use in irrigation, that is, we have substituted surface storage for subsurface storage

- **Recommend Four or More Alternative Areas for Recharge of the Aquifer with Treated Wastewater (Task 4 c 6)**

  We believe that recharge of the aquifer with treated wastewater is not a viable option in the Hebron area Accordingly, areas for artificial recharge were not identified

- **Propose a Recovery Scheme for Wastewater Recharged to the Aquifer (Task 4c 7)**

  Because we are not recommending recharge to the aquifer, no recovery scheme is recommended

- **Propose a Plan for Educating Farmers on the Use of Treated Wastewater Effluent (Task 4 c 8)**

  We developed a plan for educating farmers and consumers on the use and safety of treated wastewater for irrigation (Chapter 7) Based on our evaluation, this type of program can best be operated as an extension service associated with Hebron Agriculture Department, Hebron University, or Non-Governmental Organizations (NGOs) Based on our review of the operational problems encountered with the use of treated wastewater at other locations, the education and training program should be ongoing and given in conjunction with a research program A train-the-trainer program would be developed initially to allow local people to serve as the primary trainers

- **Estimate Associated Capital and O&M Cost for Irrigation and Recharge Alternatives (Task 4 c 9)**

  We developed capital costs associated with construction of storage reservoirs, pumping stations, pipelines, and irrigation reservoirs for four irrigation alternatives Costs were not developed for the recharge option The operating cost for

delivering treated wastewater to storage reservoirs also was developed We estimated the cost of preparing the land for irrigation, and we talked with farmers about the capital and operating costs of their individual irrigation systems We also estimated the price that the city could charge for the treated wastewater on the open market However, these costs are for preliminary planning purposes, and a through cost/benefit analysis of the agricultural reuse option is required These costs are discussed in Chapter 8

The capital costs for constructing pipelines and holding reservoirs range from $7 5 million to $29 million to accommodate the expected wastewater flow of 19,000 m3/d in the year 2005 The capital costs for a flow of 46,000 m3/d in 2020 range from $19 7 million to $78 million

Operating costs of maintaining the reservoir and piping systems are estimated at less than $1 million per year in 2005 Operating costs for the year 2020 range from $1 million to $3 million

None of the costs discussed in this Chapter have been adjusted for inflation and are in present day dollars

- **Prepare an Action Plan for Agricultural and Aquifer Recharge Options (Task 4 c 10)**

  We prepared a plan of action for integrating an agricultural reuse program into the overall conceptual design for the proposed wastewater treatment plan for the Hebron area The plan, which includes a general scope of work covering the planning, design, and implementation of the irrigation program, can be used in the Request for Proposal for Package 2 of the Integrated Water Resources Management Program The plan is contained in Appendix C

CHAPTER 10

CONCLUSIONS AND RECOMMENDATIONS

The following conclusions and recommendations are offered for consideration in the future planning for the Integrated Water Resources Management Program for the West Bank

1 Data concerning the natural environment of the Hebron area is scarce and often unreliable Data are difficult to obtain from either the Palestinian or Israeli authorities The general distrust of both sides in providing data to the other (because of political differences) will make implementing a scientific, technical, environmentally acceptable, and cost-effective reuse program difficult The existing studies that we reviewed frequently use data collected in the 1960s and in most cases is only suitable for general planning purposes Before implementing a reuse project, site-specific data will be necessary to understand the consequences of any specific action The high cost of implementing these detailed studies probably means that decisions will be made with inadequate data

2 While agricultural reuse of treated wastewater currently is in vogue and is used increasingly in arid climates, the full environmental consequences of reuse have not been fully recognized, especially as regards to the leaching of salts and pesticides into groundwater

3 Most major artificial recharge projects using treated wastewater are located over unconsolidated sediments, which have some filtration capacity to remove bacteria and suspended solids, and some adsorption capacity for metals and other contaminants In addition, these unconsolidated sediments are generally considered homogeneous when modeling groundwater flow, and predictions of flow paths, flow rates, and water quality can be made Artificial recharge and recovery of treated wastewater in fractured carbonate strata have not been documented in the literature Although not necessarily considered, irrigation with treated wastewater may result in unintended recharge to aquifers, without a complete geologic investigation in the immediate area where irrigation is proposed, impact to the upper aquifer is unknown

4 At least one previous evaluation of irrigation using treated wastewater from Hebron recommended that the wastewater be applied to a 1200-hectare section of land east of Yatta, which currently is under cultivation under rainfed conditions (Zif/Yatta site in this report) This rainfed agricultural practice has developed over the centuries and is generally in balance with nature The rain used to grow crops has very few dissolved salts, and few chemical fertilizers or pesticides are applied to the land Irrigation of this land with treated wastewater ultimately could produce all of the problems that many countries are now experiencing with irrigated agriculture (soil salinity, contamination of soil, and groundwater, etc) We conclude that it would be preferable to select land that historically has not been used for intensive agriculture Therefore, the land near Zif/Yatta would be our last choice to be developed into irrigated land

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5 The practice of combining industrial and domestic waste into a single sewer must be ended prior to implementing a treatment and reuse program for the wastewater from Hebron A large number of industries and potentially many home industries discharge waste with high concentrations of dissolved salts into the sewer Because they cannot be removed with conventional primary or secondary treatment methods, these salts will pass through the treatment system and undermine agricultural reuse One option would be to install a separate sewer for industrial waste A second option would be to install holding tanks at each industrial facility and truck the liquid waste to a disposal site Given the concentrations of salts and volumes of waste anticipated, some type of evaporation system may be appropriate

6 The practice of disposing of waste slurry from the stone-cutting industry to the sewer system should be discontinued prior to the construction of any waste treatment system, since the suspended solids will clog collection lines and/or the treatment system components Currently some stone-cutting slurry is dumped directly into the sewer In some cases, the slurry is transported by tanker to Wadi-Alsemen, downstream where raw sewage currently is being discharged

7 At a minimum, secondary treatment should be required if the agricultural reuse option is selected The final water quality (i e , suitable for restricted or unrestricted crops) should be established through a joint planning committee made up of the various agencies that will review the project From a public health and environmental point of view, treatment for unrestricted use would be preferable if the wastewater is reused in the Hebron area

8 A complete economic optimization analysis is required to evaluate the economic feasibility of the reuse of treated wastewater from Hebron The analysis should identify the appropriate price the city should charge for the wastewater and should determine whether the income from the sale of crops can pay for the capital investment and operational costs that each farmer will incur

9 The right of Hebron to sell the wastewater should be established in the early stages of this project

10 A more detailed evaluation of the types of crops that can be grown with treated wastewater should be conducted as part of the overall economic analysis This analysis should include crop salinity tolerance, available markets and farmer/consumer preferences

11 The potential environmental impacts of wastewater storage facilities must be evaluated and assessed to determine the overall feasibility of large-scale wastewater reservoirs in the Hebron area Geotechnical issues such as dam and abutment foundation stability and availability of fill material, hydrogeological issues, such as potential leakage and short-circuiting to groundwater, as well as the impact on surface water hydrology must be addressed Air quality issues, such as the direction of prevailing winds and probable odor dispersion plumes, also need to be evaluated The current ownership and availability of lands for the wastewater storage facilities, including dams, reservoirs and appurtenant structures, will also have to be determined

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TABLES

TABLE 2
DATA FOR SELECTED INDIVIDUAL SPRINGS IN THE HEBRON AREA

Map ID No	Name	Elevaton	Coordinates	Flow Rate (L/sec)	CI (mg/l)[1]	NO^3 (mg/l)	Aquifer	Comments
S-1	Ein Um Eddaraj	680	172 50/131	12-22	187	153		
S-2	Ein Aytan	775	166 48/121 55	1-2	42	40		
S-3	Ein Irtas	725	167 60/121 70	5-20			Upper Cenomanian	
S-4	Arrub	940	163 5/115				Upper Cenomanian	Near Agricultural Station
S-5	Ein Si'ir	860	163 90/110 18	1-9				
S-6	Hebron Bypass Spring **	900	160 9/111 3				Upper Cenomanian ?	
S-7	Wadi Aquf	580	153 5/110		Sweet		Upper/Lower Cenomanian Contact	Water Used for Tree Nursery
S-8	Al Fawwar	750	154 8/98 2					
S-9	Yatta ** Pool	800	162 8/92 4				Upper Cenomanian	Renovated by USAID (Domestic Use)
S-10	Ein Fashkha * (4 Springs)	390	192 78/124 70	1700	1230-4250		Lower Cenomanian ?	Feeds Marsh Near Dead Sea
S-11	Ein Gedi ** ***	-300	187/97	677	81	27	Upper Cenomanian ?	Nature Preserve & Bottled Watersource

Notes

1 mg/l = milligrams per liter

* Blake & Goldschmidt

** Identified by Project Team elevation and coordinates are estimated

*** Analysis from Bottle Label

Map ID numbers refers to numbers on Figure 7

Source Mustafa Nuseibeh & Taber Nasser Eddin, 1995 unless noted

TABLE 3

DATA FOR SPRINGS NOT SPECIFICALLY LOCATED

Village	Spring	Summer- Flow		Winter-Flow		Flow	Average
		L/sec	M^3/day	L/sec	M^3/day	L/sec	M^3/day
TARQOUMIAH	MUSSALLAM	1 00	86 40	1 88	162 69	1 442	124 546
	AL-SUFLIE	0 10	8 64	0 30	25 92	0 200	17 250
	ALI TAHA	0 20	17 28	0 40	34 56	0 300	25 920
BEIT OOLA	AL ZEER	0 50	43 20	2 20	190 08	1 350	116 640
	AL QAWS	0 30	25 92	0 30	25 92	0 300	25 920
	AL SHA'RAWI	0 20	17 28	0 52	44 93	0 360	31 104
	M YOUSEF	0 30	25 92	0 85	73 44	0 575	49 650
	M ABD GHANIE	0 30	25 92	1 20	103 68	0 750	64 800
IZNA	AL-BUS	0 60	51 84	2 00	172 80	1 300	112 320
	AL-NAQIAH	0 10	8 64	0 30	25 92	0 200	17 280
	AL-BALAD	0 20	17 28	0 30	25 92	0 250	21 600
	FIR'AH	0 80	69 12	1 00	86 40	0 900	77 760
SUREEF	AL-KASSEH	0 10	8 64	0 03	25 92	0 200	17 250
	HILWAS	0 10	8 64	0 30	25 92	0 200	17 250
	AL-KHNZEER	0 01	0 52	0 05	4 32	0 028	2 419
SA'EER	AL-BALAD	0 25	21 60	9 00	777 60	4 625	399 600
	KWAZEEBA	0 35	30 24	7 00	604 80	3 675	317 520
	KWAZEEBA2	0 15	12 96	4 60	397 44	2 375	205 200
TAFOUH	ISTAS	0 30	25 92	0 30	25 92	0 300	25 920
	AL-SIT	0 20	17 28	0 20	17 28	0 200	17 250
	AL-MA'MOODIAH	0 20	17 28	1 50	129 60	0 850	73 440
	AL-HAWOOZ	0 20	17 28	1 00	86 40	0 600	51 840
	AL-BUSTAN	0 05	4 32	0 10	8 64	0 075	6 450
BEIT OMMAR	AL-BALAD	0 50	43 20	0 50	43 20	0 500	43 200
	AL-JINAN			0 60	51 84	0 300	25 920
	JUTHOOR	0 08	6 91	0 55	47 52	0 315	27 216
HEBRON	IM SALEEM	0 20	17 28	0 20	17 25	0 200	17 280
	ARAB			1 00	56 40	0 500	43 200
	SARAH	0 50	43 20			0 250	21 600
	KHEIR AL-DEEN	0 80	69 12			0 400	34 560
AL'AROOB	AL-FAWWAR			1 70	146 88	0 850	73 440
	HAJ HAMED	0 30	25 92	0 40	34 56	0 850	80 240
	HAJ HAMED 2	0 25	21 60	0 29	25 06	0 270	23 825
AL-JAB'AH	AL-HIJRI	0 50	43 20	0 50	43 20	0 500	43 200
DOORA	AL-DILBI	0 30	25 92	2 00	172 80	1 150	99 360
	AL-MAJNOON	1 00	56 40	10 00	864 00	5 500	475 200
	AL-BAIARAH	0 60	51 84	5 00	432 00	2 600	241 920
	NADER SHAREEF	0 20	17 28	1 10	95 04	0 650	56 160
	HAJ AMER	0 50	43 20	4 00	345 60	2 250	194 400
	KANNAR	0 80	69 12	6 00	518 40	3 400	293 760
	KANNAR 2	0 10	8 64	0 30	25 92	0 200	17 280
	LUNQOR	0 10	8 64	1 70	146 88	0 900	77 760
	AL-HIJRI	0 40	34 56	2 50	216 00	1 450	125 280
	IMRAN	0 01	0 66	0 50	43 20	0 255	22 032

TABLE 4
HISTORICAL WATER QUALITY ANALYSES FOR WELLS IN THE HEBRON AREA

Map ID No	Well's Name	Date	Ca	Mg	Na	K	CL	SO4	HCO3	NO3	TDS
W-1	Herodıan No 1A 17-11/1	4/1/91	66	21	20	1 3	27	8 5	262	11	
		10/31/95	44	22	17	1	31	5	218	16	243 3
W-2	Herodıan No 2 17-11/2	10/1/89	62	27	14 5	1 2	28	8 5	284	7	
		4/1/91	65 5	27 5	17 4	2	23	9 5	303	2	
		10/1/93	40	26	15 6	1 4	26	9 5	225	11	
		10/31/95	28	22	15	2	25	6	195	7	200 9
W-3	Herodıan No 3 17-11/3	10/1/89	66	32	14	1 3	28	10 5	332	4	
		4/1/91	68 5	31 5	17 4	2 2	24	11	329	2	
		10/1/93	31	29	15 6	1 5	26	11 5	216	12	
		10/31/95	31	27	15	2	27	7	233	5	228 6
W-4	Herodıan No 4 16-11/6	10/1/89	68	34	14 5	1 6	28	13 5	326	4	
		4/1/91	68	31	20	2 6	24	13 5	333	2	
		10/1/93	45	31	16 9	1 6	27	15 5	251	8 5	
		10/31/95	47	29	15	2	29	10	278	6	274 8
W-5	Herodıan No 5 16-11/7	10/31/95	44	27	34	1	36	7	243	13	281 6
W-6	Beıt Faıjar 16-11/1A	10/1/89	58	25	18 5	0 8	35	7 5	262	11	
		4/1/91	57 5	24	22 5	1 1	30	9 5	262	12	
		10/1/93	36	27	20	1 2	32	9	212	15	
		10/31/95	46	27	18	1	33	5	257	13	269 4
W-7	Rıhıya /Yatta 15-09/13	10/1/93	43	28	29	1 5	49	11 5	244	10 5	
		10/31/95	46	28	25	2	49	8	257	7	291 4
		10/1/96	47	38	23	2	46	46	285	7	

TABLE 4 (continued)
HISTORICAL WATER QUALITY ANALYSIS FOR WELLS IN THE HEBRON AREA

Well ID No	Well's Name	Date	Ca	Mg	Na	K	CL	SO4	HCO3	NO3	TDS
W-8	Samu' No 1 15-09/1	10/1/93	65	24	36 3	2	72	17	208	46	
		10/31/95	52	24	35	3	78	16	189	35	336
		10/1/96	63	34	32	2	75	12	282	36	
W-9	Fawwar 1 15-09/10	10/1/93	35	28	37 5	6 9	71	34	118	81	
		10/31/95	62 8	34 6	33 3	7 42	68	31	303	65 2	451 4
		10/1/96	53	37	30	8	68	23	218	63	
W-10	Fawwar 2 15-09/12	10/1/93	43	29	36 3	4 9	64	30	140	74	
		10/31/95	72	31 9	33 7	1 29	58 1	28 4	312	56 3	435 2
		10/1/96	72	34	36	1	59	20	265	64	
W-15	Ein Gedi No 2*	8/7/97	15030	21830	55765	**	175620	400	230		

Notes

All analysis in mg/l

** Included in Na analysis

* Oil test well

Source of Data Palestinian Water Authority

TABLE 5
TYPICAL CHARACTERISTICS OF SOILS IN THE HEBRON AREA

Brown Redzina								
Depth (mm)	Texture		Clay Fraction Mineralogy (%)[1]				ESP	SAR
		% Clay	Mont	Kaol	Illite + Palyg	Calc		
0-40	Loam	19 2	n/a	N/a	n/a	n/a	2 4	1 1
40-120	Loam	26 4	40	30	15	10	1 8	0 9

Notes Elevation 750 m above sea level
Location 4 km south of Teqoa, coordinates 1715/1120 (15 km east/northeast of Hebron)
Bedrock Turonian Limestone

Terra Rosa								
Depth (mm)	Texture	% Clay	Clay Fraction Mineralogy (%)[1]				ESP	SAR
			Mont	Kaol	Illite + Palyg	Calc		
0-20	Clay	58	n/a	N/a	n/a	n/a	2 33	0 34
20-50	Clay	55	n/a	N/a	n/a	n/a	1 85	0 41
50-95	Clay	62	n/a	N/a	n/a	n/a	1 67	0 37
95-150	Loam	13	n/a	N/a	n/a	n/a	1 54	0 38
150-200	Clay	72	n/a	N/a	n/a	n/a	1 60	1 07
200-250	Clay	73	n/a	N/a	n/a	n/a	2 21	0 49
250-300	Clay	73	n/a	N/a	n/a	n/a	2 40	1 95

Notes Location One km northeast of Emmanuael, coordinates 1647/1752 (13 km southwest of Nablus)
Climate Subhumid Mediterranean, average annual precipitation 650 mm
Bedrock Dolomite

Noncalcareous Brown Redzina								
Depth (mm)	Texture	% Clay	Clay Fraction Mineralogy (%)[1]				ESP	SAR
			Mont	Kaol	Illite + Palyg	Calc		
0-150	Clay	46 5					1 0	0 48
150-260	Clay	47 9					1 5	1 03
260+	Bedrock							

Note Parent material is aeolian dust, location not specified

[1] Mont = Montmorillonite, Kaol = Kaolinite, Palyg = Palygorskite, Calc = Calcite

Source Draft English-language revisions to Dan et al (1978)

TABLE 6A
WORLD HEALTH ORGANIZATION GUIDELINES FOR REUSE OF WASTEWATER IN AGRICULTURE

Category	A	B	C
Conditions and Crops	Crops likely to be eaten uncooked (grapes, olives, tomatoes, lettuce, celery, cucumbers etc)	Cereal, industrial and fodder crops, pastures and trees (reforestation, wheat, barley cotton, hemp, etc)	No worker or public exposure (e g , subsurface irrigation)
Group Exposed	Workers consumers, public	Workers	Workers
Intestinal Nematodes (arithmetic mean of number of eggs/liter)	≤ 1	≤ 1	N/A
Fecal Coliforms (geometric mean of number per 100 ml)	≤ 1000	No standard recommended	N/A
Wastewater Treatment Expected to Achieve Required Microbial quality	Series of stabilization ponds or disinfection	8-10 days retention in stabilization ponds	Pretreatment dependant on requirements of irrigation technology

Source Adapted from WHO, 1989

TABLE 6B
ISRAEL STANDARDS FOR REUSE OF WASTEWATER IN AGRICULTURE

Group of Crops	D	C	B	A
Principal Crops	Unrestricted Crops	Deciduous fruits[a], conserved vegetables, cooked and peeled vegetables, green belts, football fields, and golf courses	Green fodder, olives, peanuts, citrus, bananas, almond, nuts, etc	Cotton, sugar beets, cereals, dry fodder seeds, forest
Effluent Quality,				
BOD_5 total (mg/l)	15	35	45[b]	60[b]
BOD_5 dissolved (mg/l)	10	20	--	--
Suspended Solids (mg/l)	15	30	40[b]	50[b]
Dissolved Oxygen (mg/l)	0 5	0 5	0 5	0 5
Coliform counts/100 m	12 (80%) 2 2 (50%)	250	--	--
Residual available chlorine (mg/l)	0 5	0 15	--	--
Mandatory Treatment				
Sand filtration or Equivalent	Required	--	-	--
Chlorination, minimum contact time (minutes)	120	60	--	--
Distances				
From residential areas (m)	--	-	250	300
From paved road (m)	--	-	25	30

[a]Irrigation must stop 2 weeks before fruit picking no fruit should be picked from the ground
[b]Different standard will be set for stabilization ponds that provide a retention time of at least 15 days
Source USEPA, 1992

TABLE 7a

ANALYSIS OF SPRINGS AND WATER WELLS
City of Hebron

Sample No	Sample Location	Date	pH	E C (dS/M)[1]	Boron
267-01	Bypass spring	26/7/98	8 24	0 703	BDV
267-02	Al Fawwar #1	26/7/98	7 32	0 691	BDV
267-03	Ein El Dilbih Spring	26/7/98	7 83	0 578	BDV
267-10	Herodian (lower aquifer)	26/7/98	7 38	0 667	BDV
267-11	Herodian (upper aquifer)	26/7/98	7 61	0 651	BDV

TABLE 7b

ANALYSIS OF WASTEWATER
City of Hebron

Sample No	Sample Location	Date	pH	E C (dS/M)[1]	Boron
267-04	Sewage outfall	26/7/98	7 11	2 28	0 935
267-05	Tannery (chrome waste)	26/7/98	3 37	56 1	--
267-06	Tannery (salt waste)	26/7/98	6 27	48 2	0 055
267-07	Tannery (oil and dye)	26/7/98	5 01	17 4	--
267-08	Tannery (dehairing)	26/7/98	10 1	9 46	0 062
267-09	Sewer break	26/7/98	7 54	2 74	0 191

Notes

1 dS/M=decSiemens per meter

All analysis performed by the Volcani Institute under the direction of Dr M Ben Hur
BDV = below detectable value (not specified)

TABLE 8
POTENTIAL SITES FOR AGRICULTURAL IRRIGATION/ WASTEWATER REUSE

Site No	Site Name	Coordinates of Center of Area	Horizontal Distance to WWTP (km)	Approximate Area (ha)	Range in Elevation (m)
1	Wadi Alsemen	096N, 156E	3-4	240	700-630
2	Zif/Yatta	096 2N,162 5E	3	1400	780-860
3	Al Karmil NE	94 4N, 166E	7-8	300	650-710
4	Al Karmil E	92 5N, 165 5E	7-8	350	700-770
5	A Sammu' E	090N, 161 5 E	9-10	300	800-830
6	A Sammu' SE	087 5N, 160 5E	11	200	760-810
7	Beni Ni'am	100N, 169W	7-10	300	520-720

Notes
1) Elevation of wastewater treatment plant (WWTP) is approximately 760 m above mean sea level
2) Coordinates, distances and elevations are approximated from 1 50,000 topographic maps

TABLE 9
ESTIMATED LAND AREA REQUIRED FOR IRRIGATION

Year	Daily flow (m^3/d)	Annual flow (Mcm/yr)	Land Area (ha)
2005	19000	6 9	812
2010	26000	9 5	1118
2015	34000	12 4	1460
2020	46000	16 6	1997

TABLE 10
Option One

COST ESTIMATES FOR EFFLUENT STORAGE IN ZIF, YATTA

Year	2005	2010	2015	2020
Flow (m^3/d)	19,000	26,000	34,000	46,000
Reservoir Size (MCM)	3 8	5 2	6 8	9 1
Land Requirement, dunum (1000 m^2)	525	700	900	1250
Land Price	2 63	5 6	9	18 75
Construction Costs				
Reservoir Earth Works	11 5	21	27	36
Mechanical Works and Control Room	0 5	1 0	1 5	2
Conveyance Pipeline (5 km and 50-m head)	1 75	1 88	3	3 5
Pumping Station	0 65	0 9	1 2	1 5
Engineering Design and Supervision (10%)	1 7	3 04	4 17	6 18
Contingencies (15%)	2 81	5	6 88	10 2
Total Capital Costs, $ million	21 54	38 42	49 2	78 13
Operation and Maintenance Cost, 4% of Construction Cost	0 86	1 54	2 11	3 13

Notes

Reservoir sized to hold 6 months of flow
Reservoir is 8 meters deep
Land requirements include reservoir site and 10% for roads buildings etc
Reservoir is lined with compacted local soil

TABLE 11
Option Two

COST ESTIMATES FOR EFFLUENT STORAGE IN A DAM DOWNSTREAM OF TREATMENT PLANT AND AN IRRIGATION RESERVOIR TO HOLD A ONE-WEEK EFFLUENT AT ZIF-YATTA

Year	2005	2010	2015	2020
Flow (m^3/d)	19,000	26,000	34,000	46,000
Reservoir Size (MCM) (Dam)	3 8	5 2	6 8	9 1
Land Requirement, dunum (1000 m^2)	400	570	750	910
Land Price	2	4 6	7 5	13 65
Construction Costs				
Construction of Dam Wall	5	6	8	10
Mechanical Works and Control Room	0 5	0 6	0 8	1
Irrigation Storage Reservoir (One-week Flow Storage Capacity), Earthwork	0 65	1 1	1 85	2 6
Conveyance Pipeline (5 km and 50-m head)	1 75	1 88	3	3 5
Pumping Station	0 65	0 9	1 2	1 5
Engineering Design and Supervision (10%)	1 1	1 5	2 2	3 2
Contingencies (15%)	1 75	2 5	3 7	5 3
Total Capital Costs, $ million	13 4	19 08	20 75	60 75
Operation and Maintenance Cost, 4% of total Construction Cost	0 64	0 76	1 13	1 63

Notes

Dam size was assumed to hold 6 month flow
Reservoir depth is assumed to be 8 meters at deepest point
Operation cost includes cost of pumping from treatment plant to reservoir

TABLE 12
Option Three

COST ESTIMATES FOR PARTIAL EFFLUENT STORAGE IN AN IRRIGATION RESERVOIR AT ZIF YATTA WITH 30-DAY FLOW CAPACITY

Year	2005	2010	2015	2020
Flow (m^3/d)	19,000	26,000	34,000	46,000
Reservoir Size (MCM)	0 63	0 86	1 1	1 5
Land Requirement, dunum (1000 m^2)	90	120	150	210
Land Price	0 45	0 96	1 5	3 15
Construction Costs				
Reservoir Earth Works	2 52	3 44	4 4	6
Mechanical Works and Control Room	0 2	0 3	0 4	0 5
Conveyance Pipeline (5km and 50 m head)	1 75	1 88	3	3 5
Pumping Station	0 65	0 9	1 2	1 5
Engineering Design and Supervision (12%)	0 67	0 9	1 26	1 76
Contingencies (20%)	1 25	1 7	2 35	3 28
Total Capital Costs, $ million	7 49	10 08	14 11	19 69
Operation and Maintenance Cost, 4% of total Construction Cost	0 3	0 4	0 56	0 70

Notes

Reservoir sized for 30 days of storage
Any excess wastewater continues to flow in Wadi Al Samen

TABLE 13
Option Four

COST ESTIMATES FOR EFFLUENT CONVEYANCE BY GRAVITY TO THE SOUTH AND SELLING TO BEERSHEVA

Year	2005	2010	2015	2020
Flow (m^3/d)	19,000	26,000	34,000	46,000
Construction Costs				
Precast Concrete Pipes, 1500 mm diameter, length 35km	10 5	10 5	10 5	10 5
Installation of Pipes, 35-km length	12 5	12 5	12 5	12 5
Engineering Design and Supervision (10%)	2 3	2 3	2 3	2 3
Contingencies (15%)	3 8	3 8	3 8	3 8
Total Capital Costs, $ million	29 1	29 1	29 1	29 1
Operation and Maintenance Cost, 0 0	0 0	0 0	0 0	0 0

Note

Assumes that pipe for the flow in 2020 is installed in 2005

Table 1

DATA FOR WELLS IN THE HEBRON AREA

Well Name	Herodian 1 A	Herodian 2	Herodian 3	Herodian 4	Herodian 5	Beit Fajr 1A	Rihiya (Yatta)	Samu 1	Fawwar 1	Fawwar 2	F wwar 3	Fawv r 4	H bron # 1	Hebron # 2	Ma on	PWA #11	Ein Gedi #2
Map ID No	W 1	W 2	W 3	W-4	W 5	W-6	W 7	W 8	W 9	W 10	W 11	W 12	W 13	W 16	W 17	W 14	W 15
Coordinates	170 90/118 30	170 92/119 33	170 85/117 22	169 46/114 08	169 46/114 12	169 60/115 10	157 20/096 25	153 46/092 2	156 20/098 15	156/098	156 20/098 15	156/098	169 10/113 25	168 35/113 10	173 10/094 00	169 3/116 9	186 82/08928
Surf Elevation	574	562 93		684 5									700	700	459 70		372 8
Date Drilled or Op ratng Year		1973	1981	1990	1994	1987	1985	1967	1960s	1960s	1960	1960s	1998	1996	1981	1998	1957
Total Depth (m)	350	770	800	691	350	305	495	191 29	100	40	150	125	704 5	387	678	851	2571
Size of Hole or Casing and Casing Depth		(9 5/8) 394 4m		(9 5/8) 691m		(13 3/8) 305m		(10) 191 29									
Aquifer	U Cen manian	L Cenoman an	L C n m n n	L C nomam n	U Cenomanian	U C noma i n	Turom n	Turonian	Turonian U Cenomanian ?		Turom n U Cenomanian ?		L Cenom ian	U C noman an	L Cenomam n	L C nom nian	
St ti Water Le l (mbgs)[1]		257 7	305 35	326 4		159 18	317	158 5	40	13		11	358 26	103		464	
Safe Yield (m /hr)	120	336	400	249	78	230	34	50	69	25	48	5		100	40		
Dyn mic W t L v l f th Safe Yield							355		** 80	28							
Water Usage	Domestic	Domesti	Domestic	Dom stic	Domestic	Domestic	Domesti	Domestic	Domestic		Domestic		Domestic	Domestic		Domestic	Oil Test
Owner	WBWD	WBWD	WBWD	WBWD	WBWD	WSSA	WBWD	WBWD	Hebron City	Hebron City	Hebron City	Hebron City	Hebron City	Hebron City	Israeli Army	Hebron City	
W t r Pump d in 1995 (m^3)	946 9	2803 4	3433 9	1817 3	613 5	1879 9	301 5	423 7	527 9		191						
Log A ailable	N	N	Yes ?	No	No	N	No	No	No	No	No	No	Ye	No	No	Yes	Yes
Chemical Analysis	Yes	Yes	Y s	Y	Y	Y	Y s	Ye	Y s	N	Y s	No	Y	N	N	No	Y
Operating Status	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Y s	Abandoned	Yes	Abandoned	Waiting on Pump	Not Yet Operating	In Use	Not Completed	Ab ndoned Oil Test Well

N tes

1 mbgs m ters b l w gr und surf ce

Tahal 1975

C ty f H b W t Department

SOURCE PWA unless noted

BEST AVAILABLE COPY

FIGURES

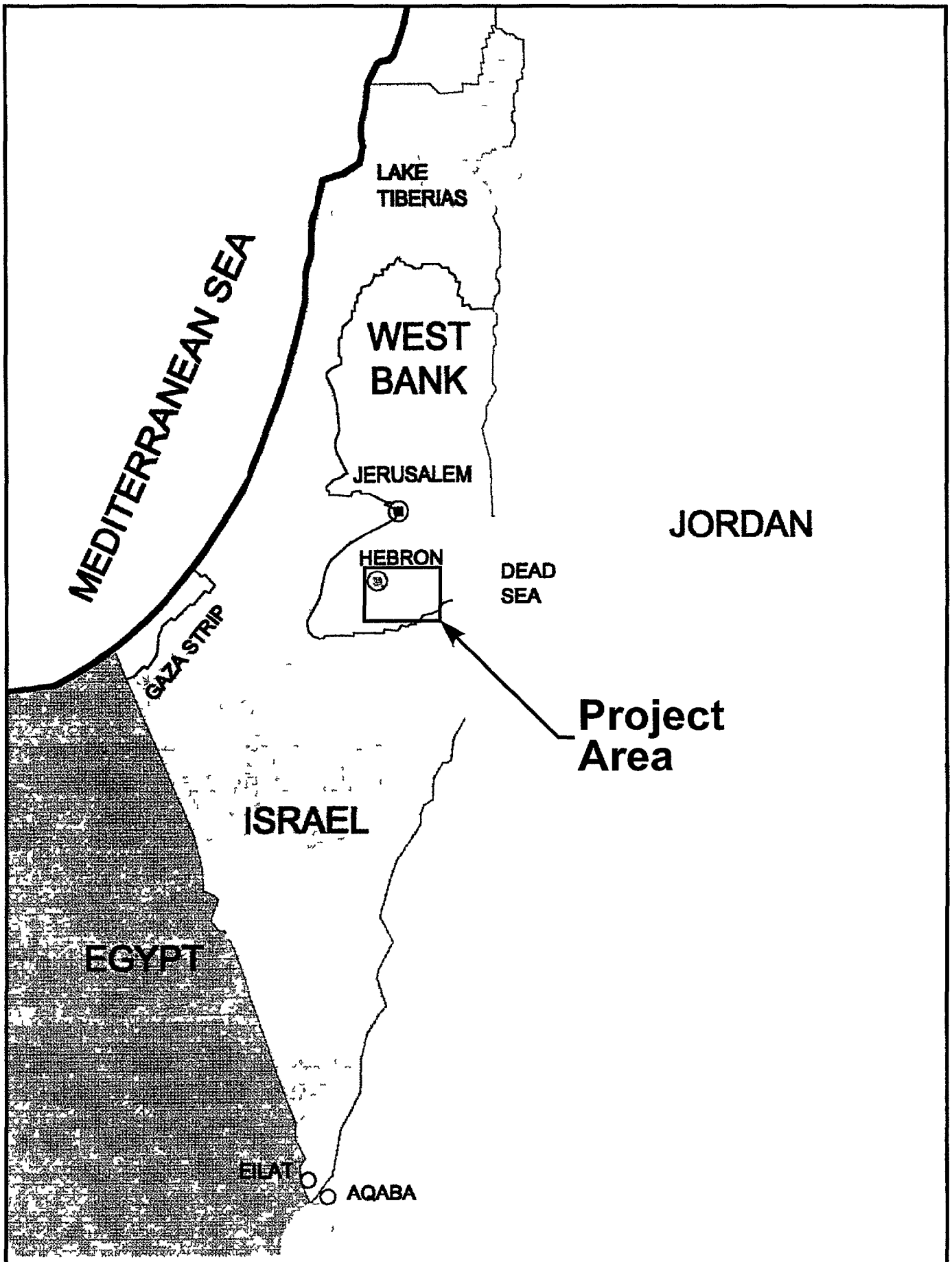
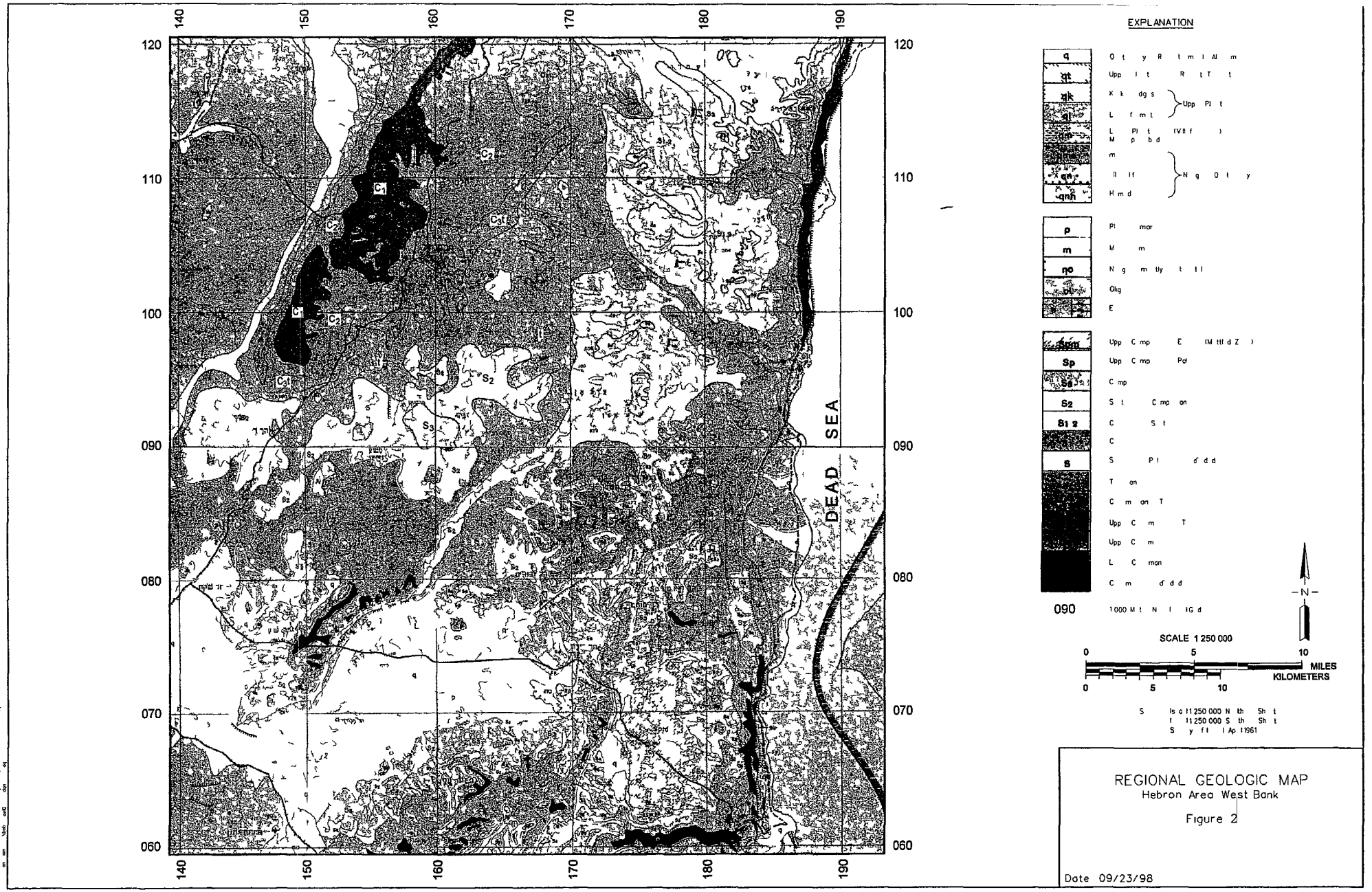


Figure 1: Study Area Location

Source
Montgomery Watson
Arabtech Jardeneh

Privapps\Presentations\DK\Bob\Israel 07 98\Figs_01 cdr

62



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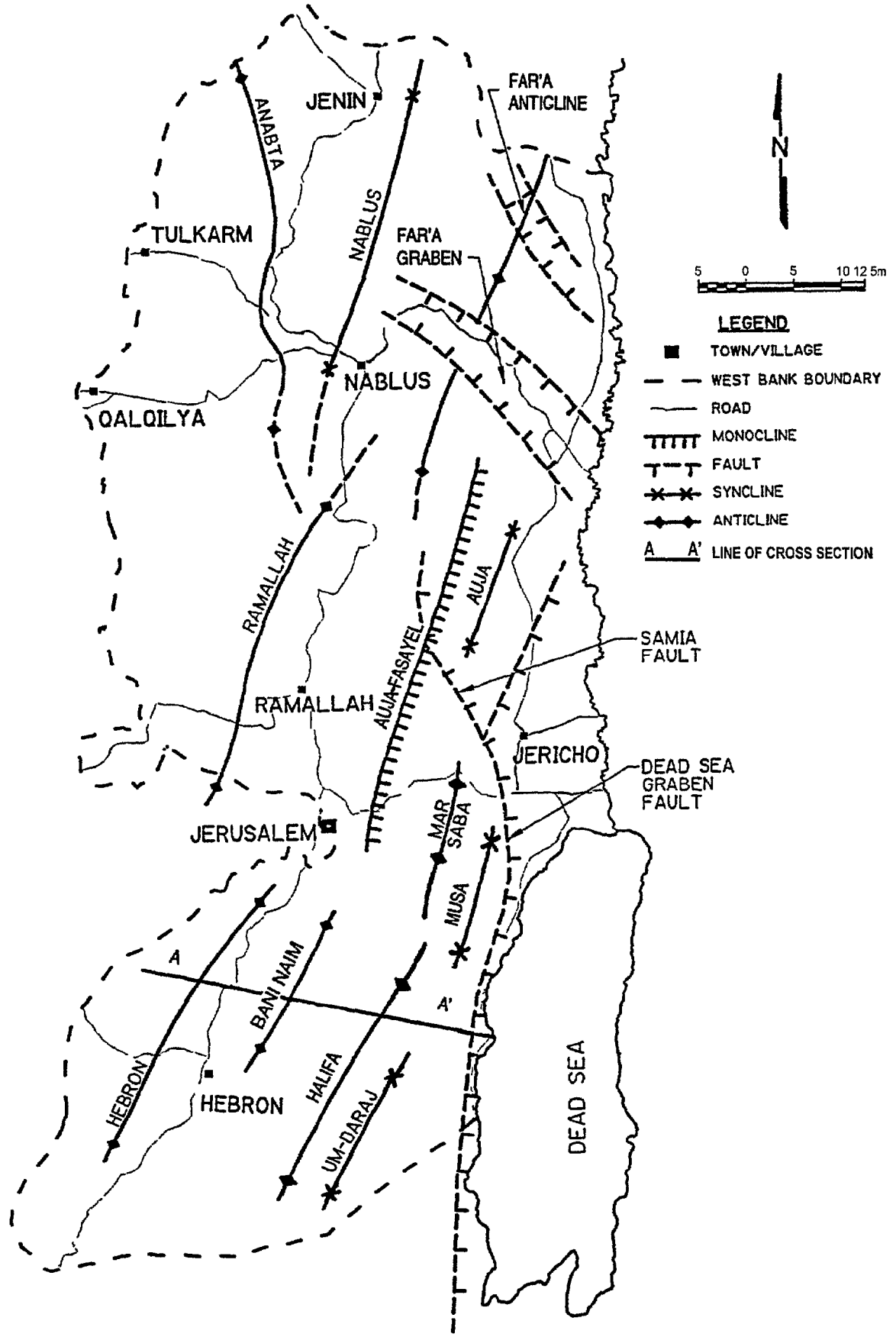


Figure 3: Simplified Structural Map

Source
CDM/Morganti

Privapps\Presentations\DK\Bob\Israel 07 98\Figs_01 cdr

64

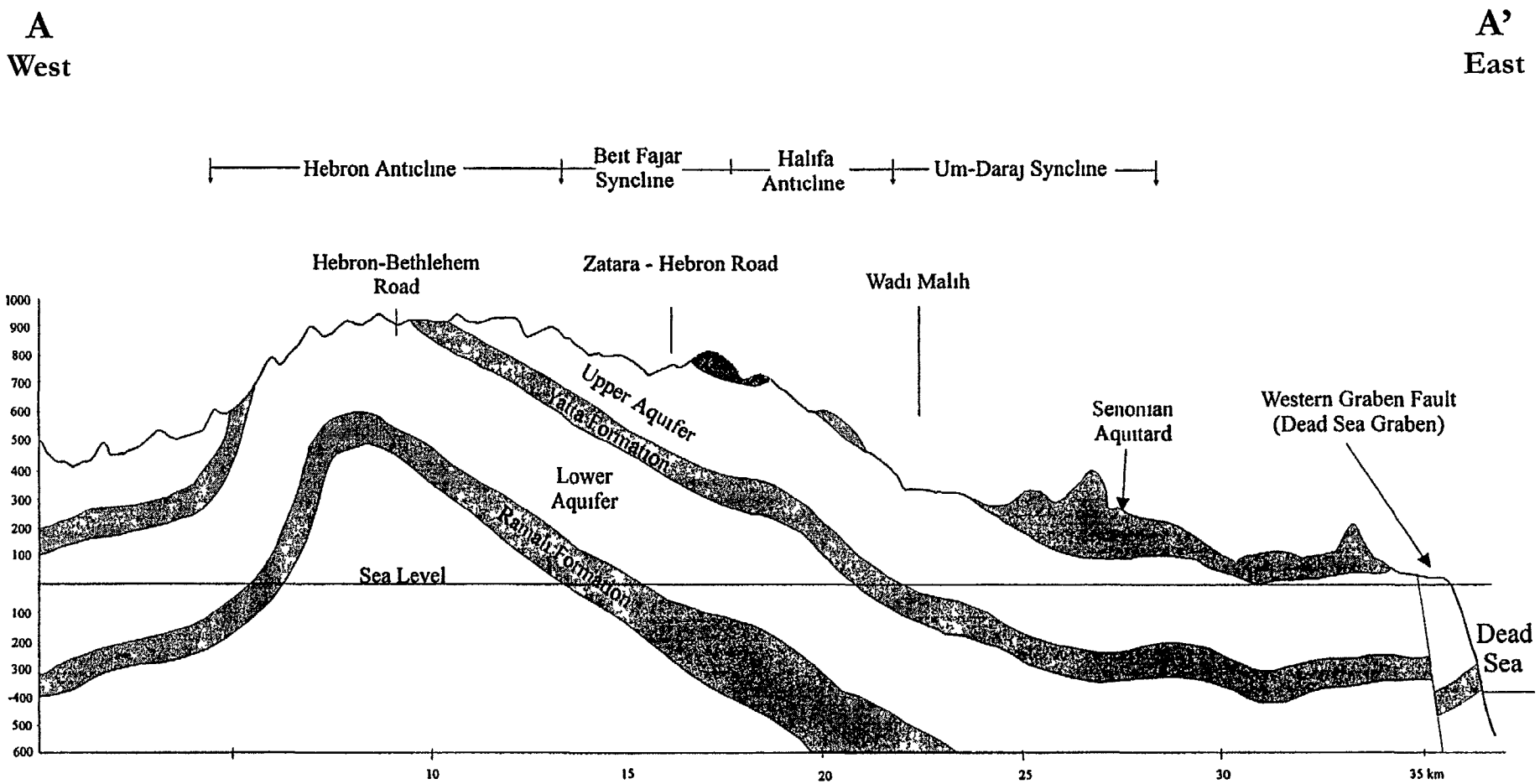
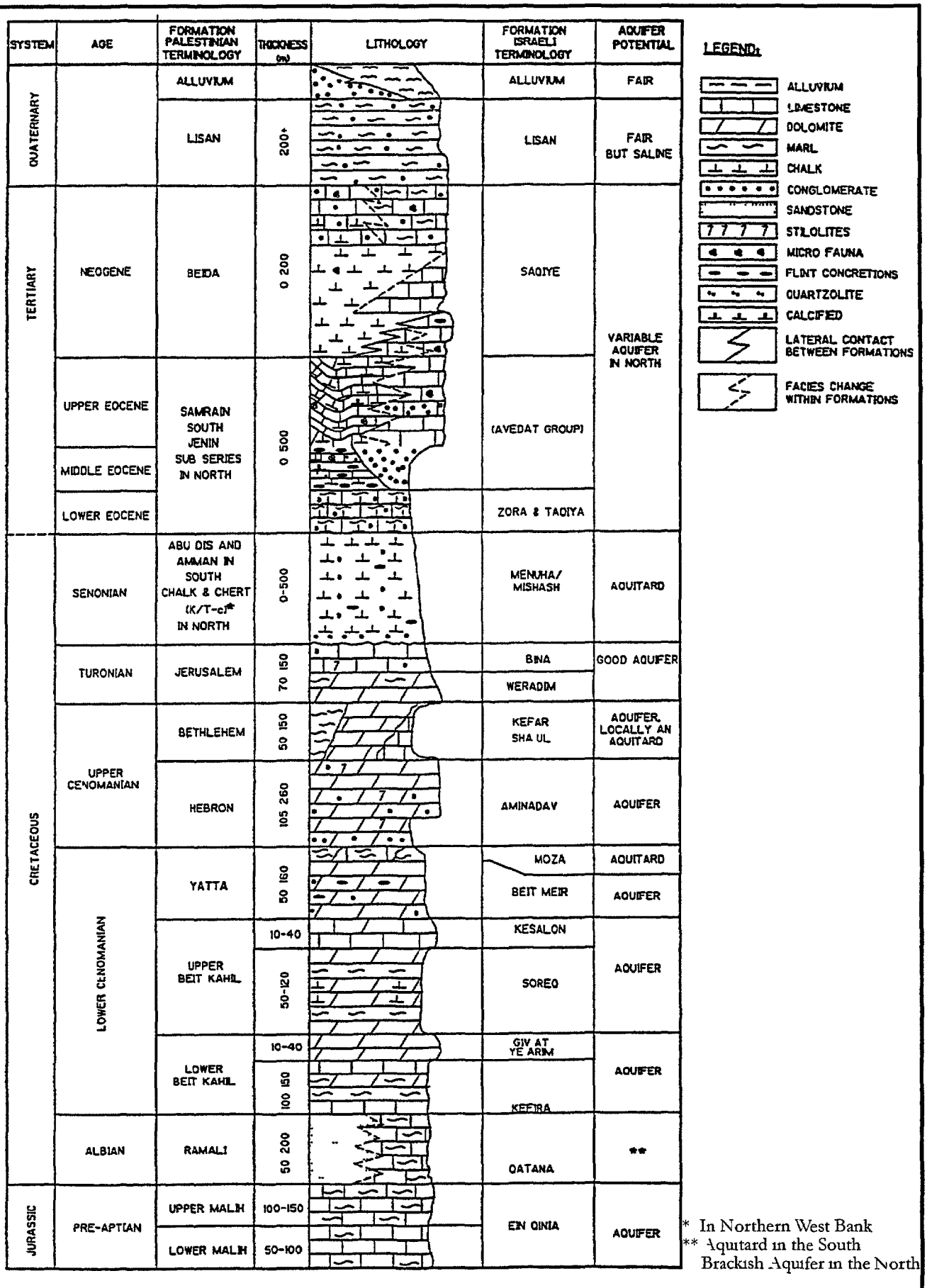


Figure 4: Generalized Geologic Cross Section

Source
CDM/Morganti

Privapps\Presentations\DK\Bob\Israel 07 98\Figs_02 cdr

65



* In Northern West Bank
** Aquitard in the South
Brackish Aquifer in the North

Figure 5: General Stratigraphy

Source
CDM/Morganti

Privapps\Presentations\DK\Bob\Israel 07 98\Figs_01 cdr

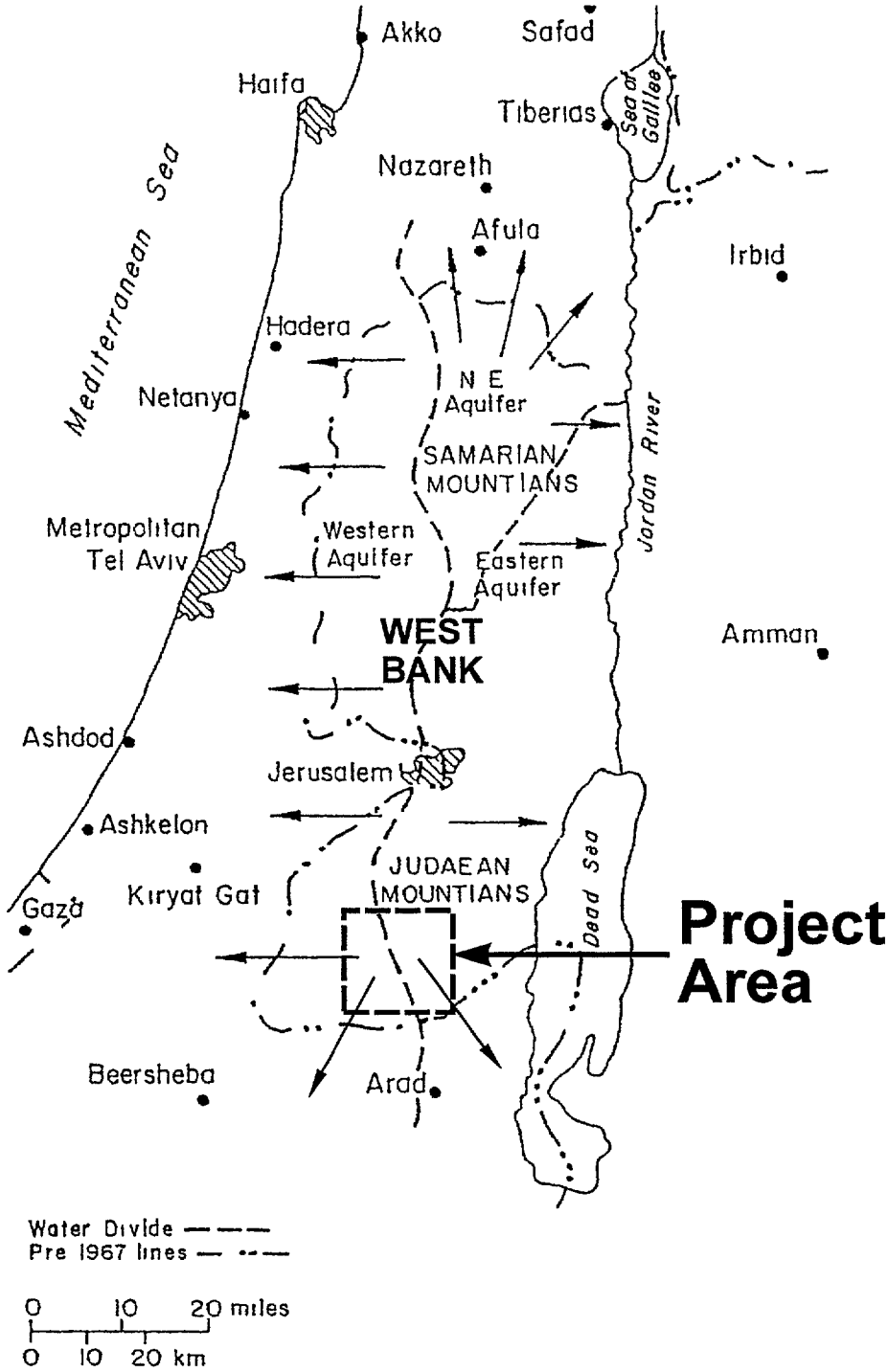


Figure 6: General Schematic of the Mountain Aquifer Systems

Source Modified from Assaf, et al, 1993

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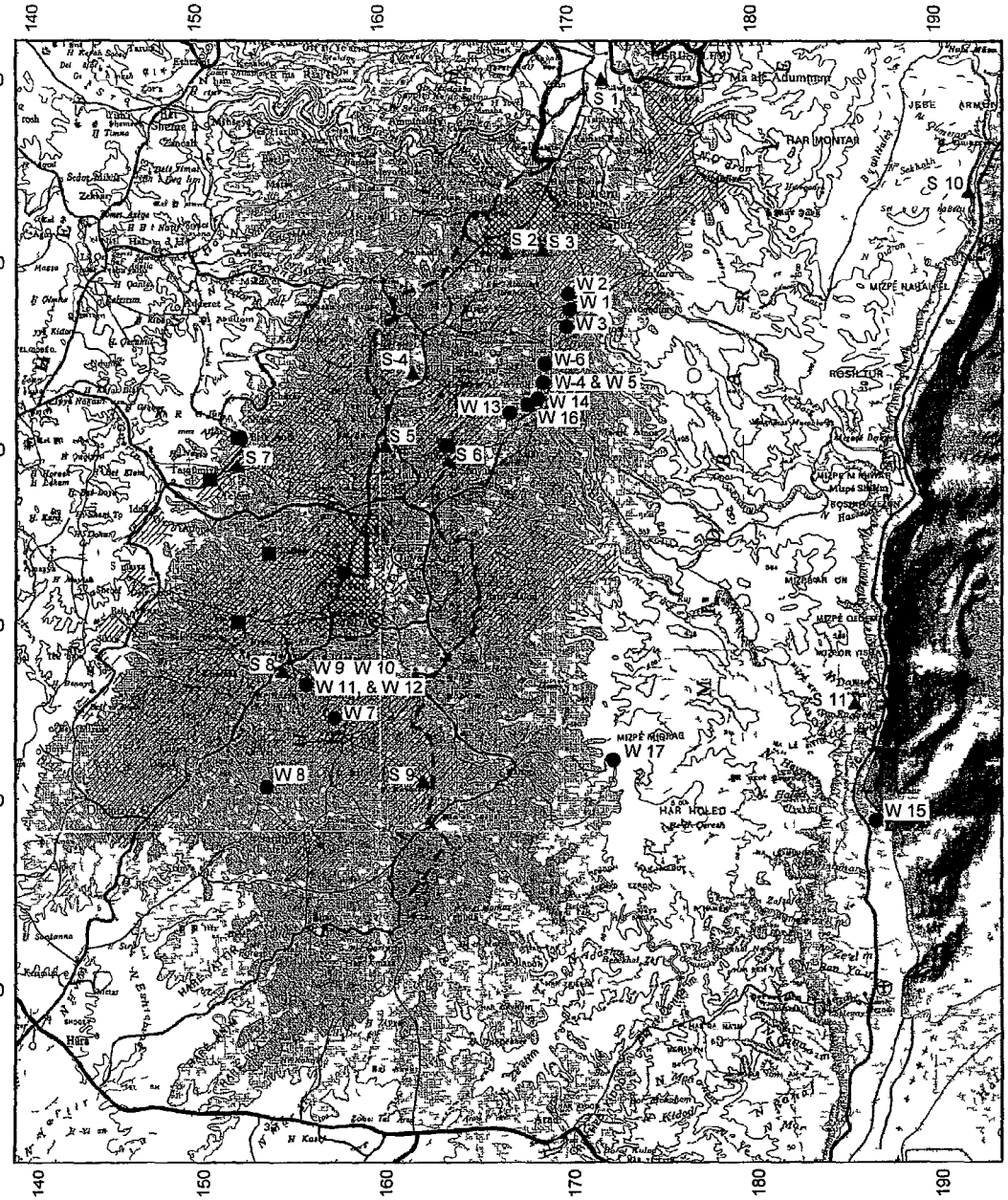

EXPLANATION

- EAST WEST DRAINAGE DIVIDE
- HEBRON'S CURRENT SEWAGE DISCHARGE POINT
- S 10 LOCATED SPRING
- W 16 LOCATED WELL
- UNLOCATED SPRING
- 110 1000 METER NEW ISRAEL GRID

-N-

SCALE 1 250 000

0 5 10 MILES

0 5 10 KILOMETERS

Source Israel 1:250 000 Northern Sheet
Israel 1:250 000 Southern Sheet
Survey of Israel, April 1961

WELL AND SPRING LOCATION MAP
Hebron Area West Bank

Figure 7

Date 09/23/98

BEST AVAILABLE COPY

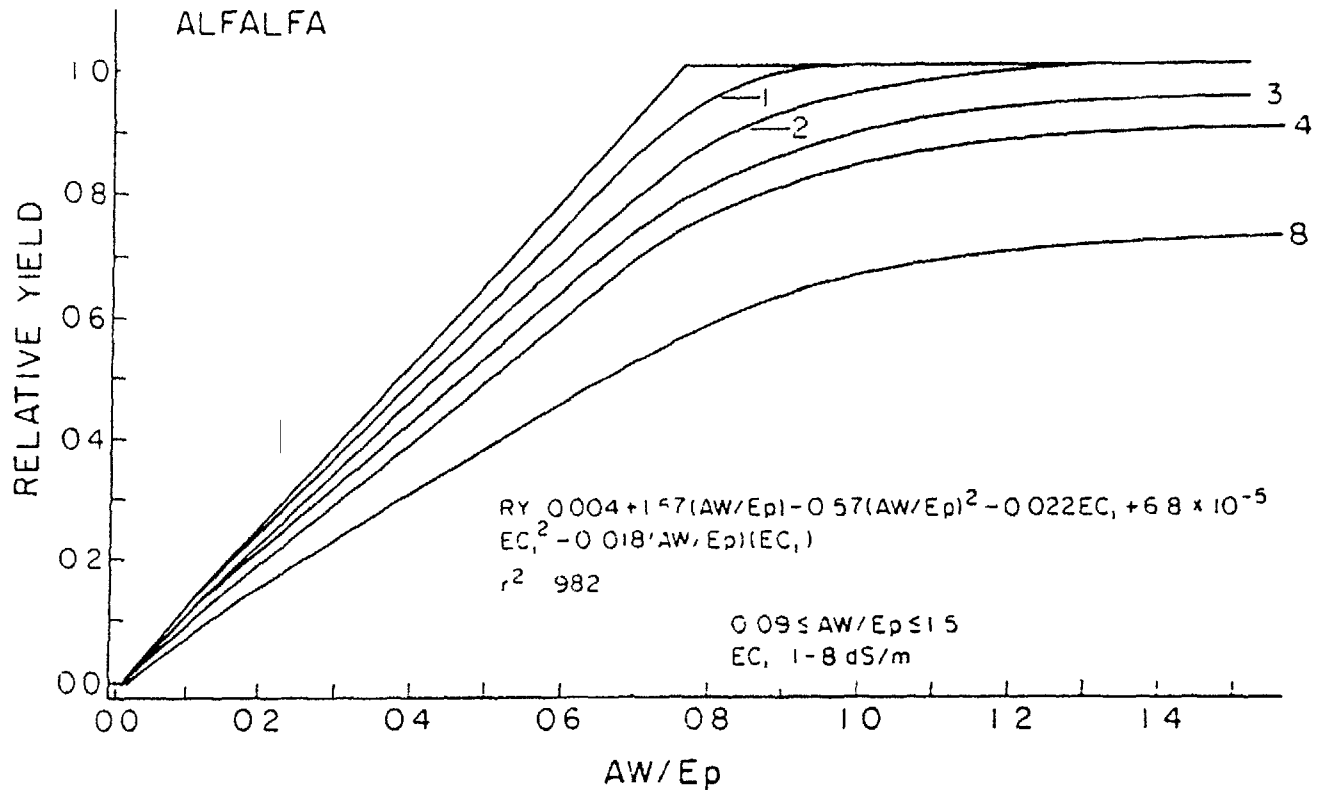

Figure 8: Computed Relative Yields of Alfalfa for Various Quantities of Applied Water

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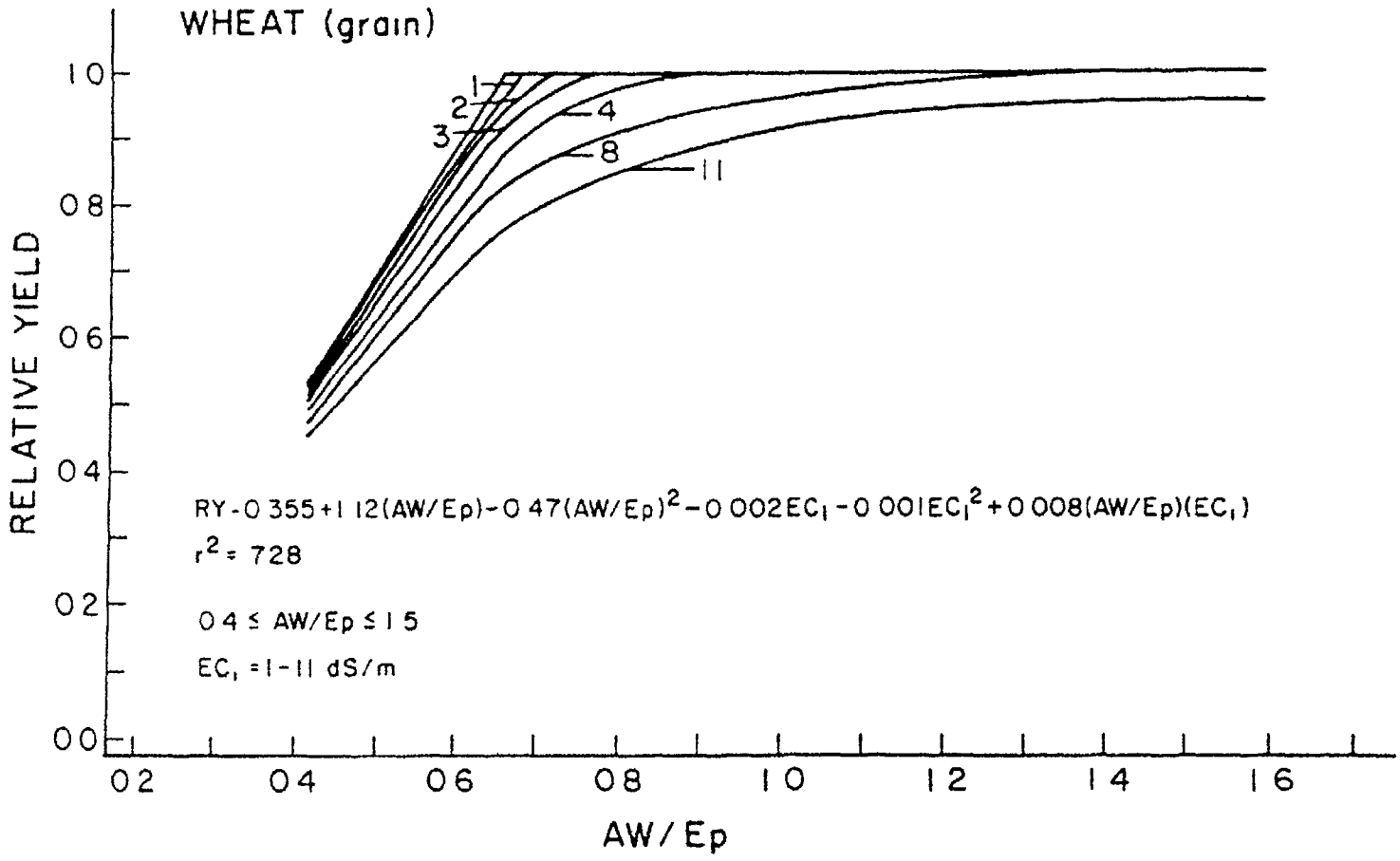
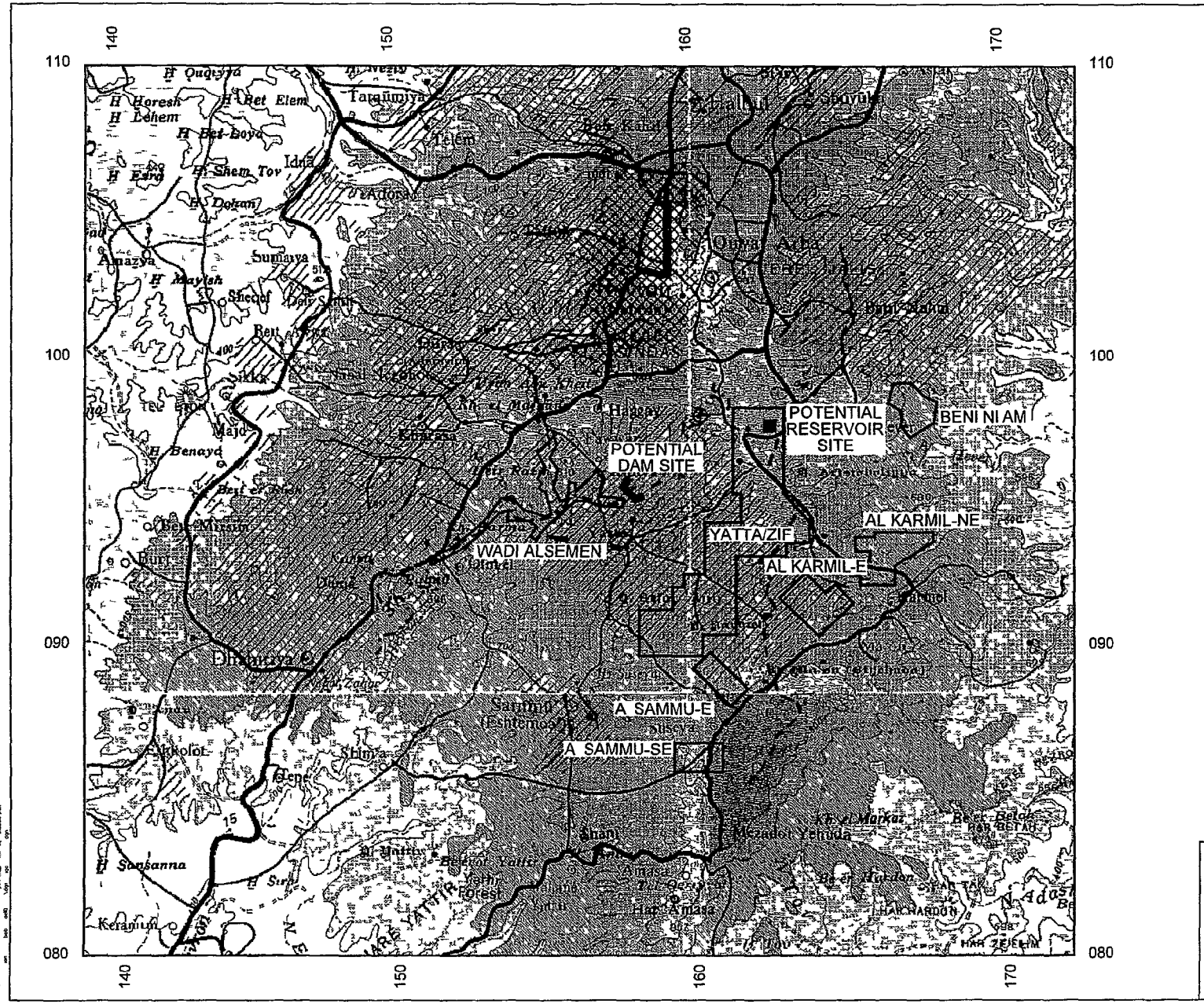


Figure 9: Computed Relative Values of Wheat (Grain) for Various Quantities of Applied Water

Privapps\Presentations\DK\Bob\Israel 07 98\Figs_02 cdr



EXPLANATION

- EAST WEST DRAINAGE DIVIDE
- PROPOSED WWTF LOCATION
- POTENTIAL FIELDS FOR IRRIGATION
- POTENTIAL RESERVIOR SITE
- POTENTIAL DAM SITE

-N-

SCALE 1 250 000

0 2.5 5 MILES

0 2.5 5 KILOMETERS

Source: Israel 1:250 000 Northern Sheet
Israel 1:250 000 Southern Sheet
Survey of Israel, April 1991

LOCATION OF POTENTIAL IRRIGATION SITES

Hebron Area West Bank

Figure 10

Date 09/23/98

BEST AVAILABLE COPY

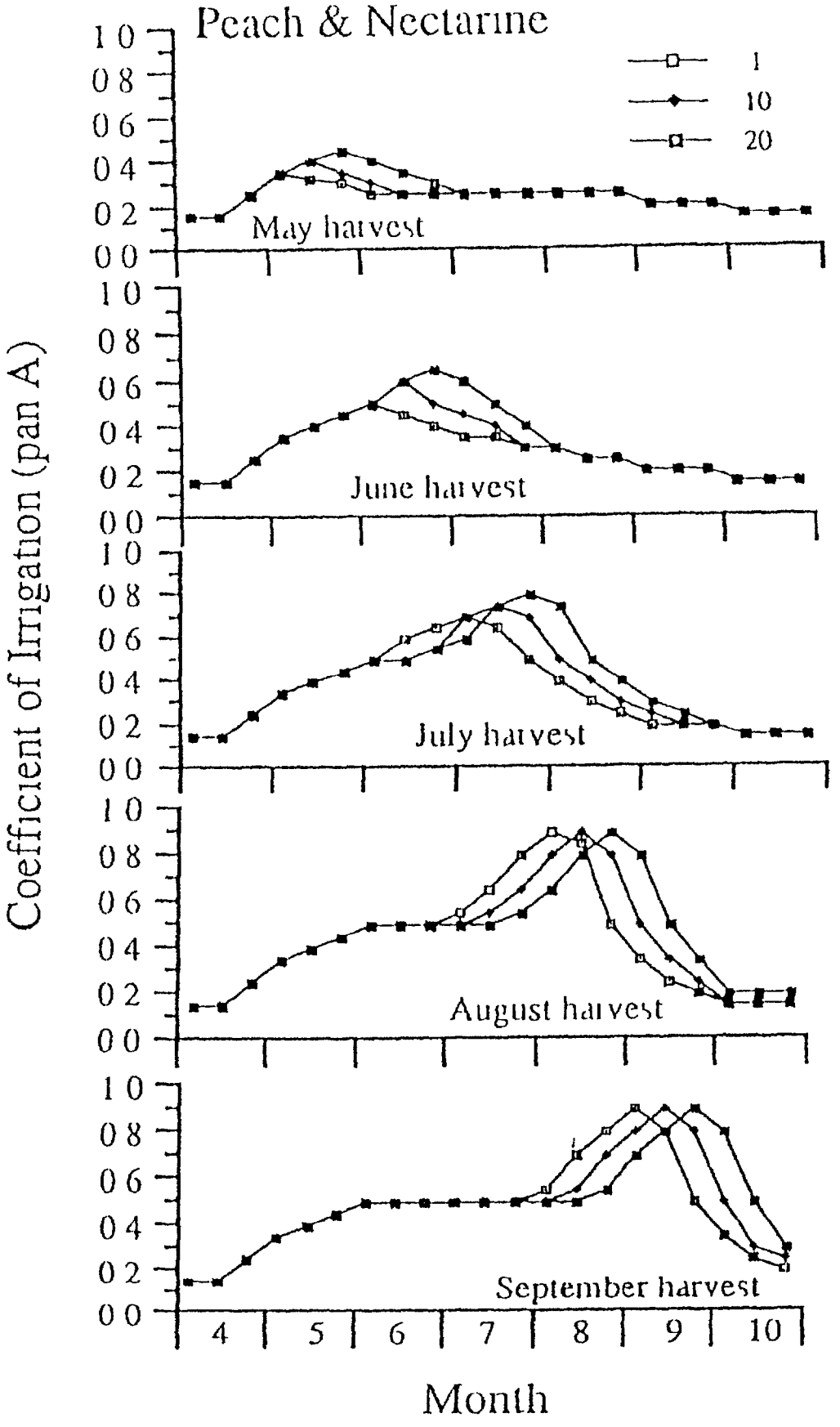


Figure 11: Class A Pan irrigation Coefficient for Peach and Nectarine in Relation to Harvest Date

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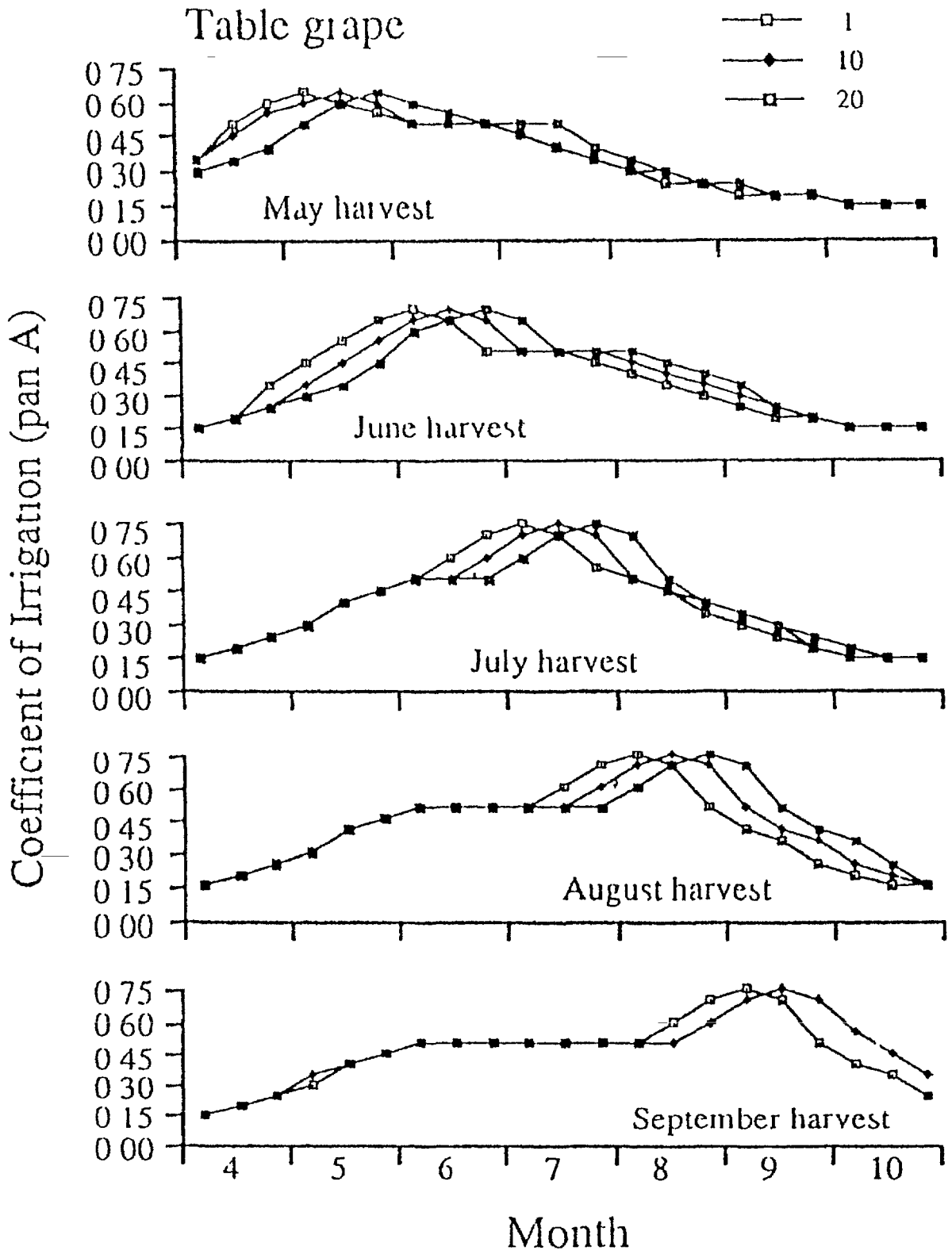

Figure 12: Class A Pan irrigation Coefficient for Grapes in Relation to Harvest Date

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APPENDIX A

PHOTOGRAPHS

Photo 1 City of Hebron sewage outfall

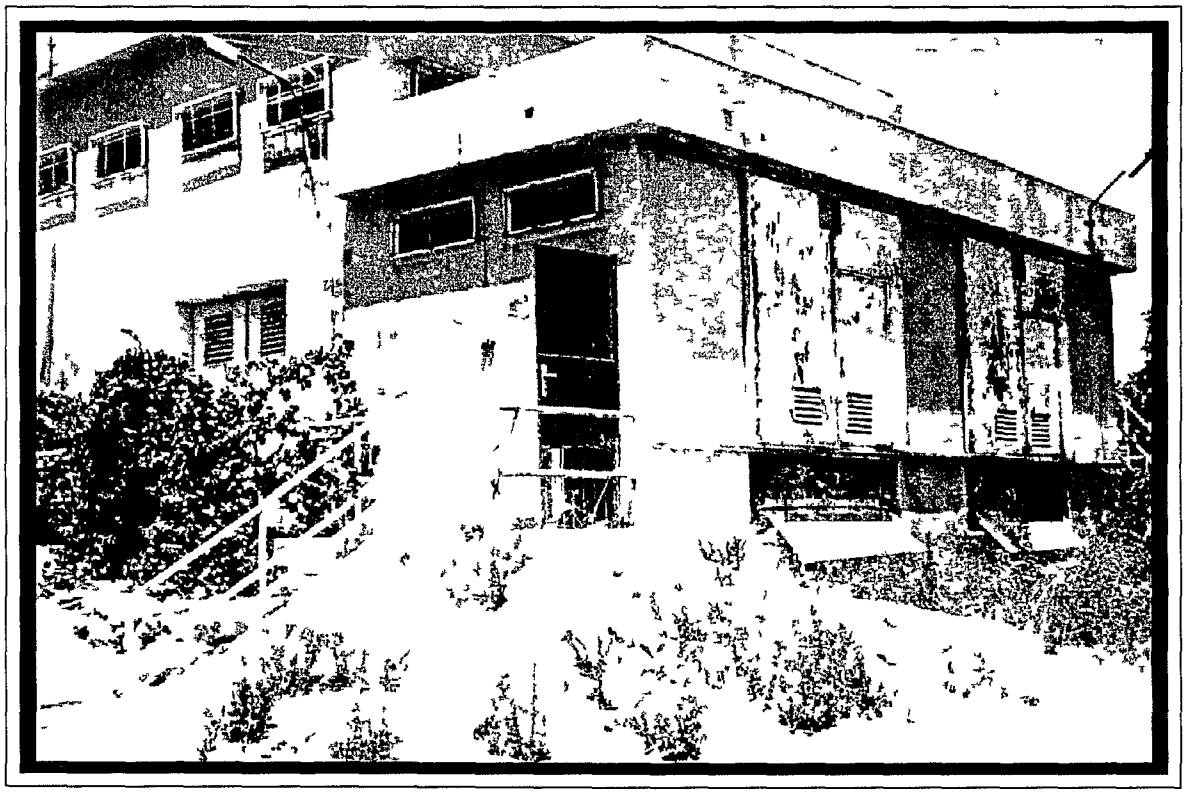

Photo 2 City of Hebron abandoned sewage pump house

Appendix A

Photo 3 City of Hebron abandoned sewage treatment ponds

Appendix A

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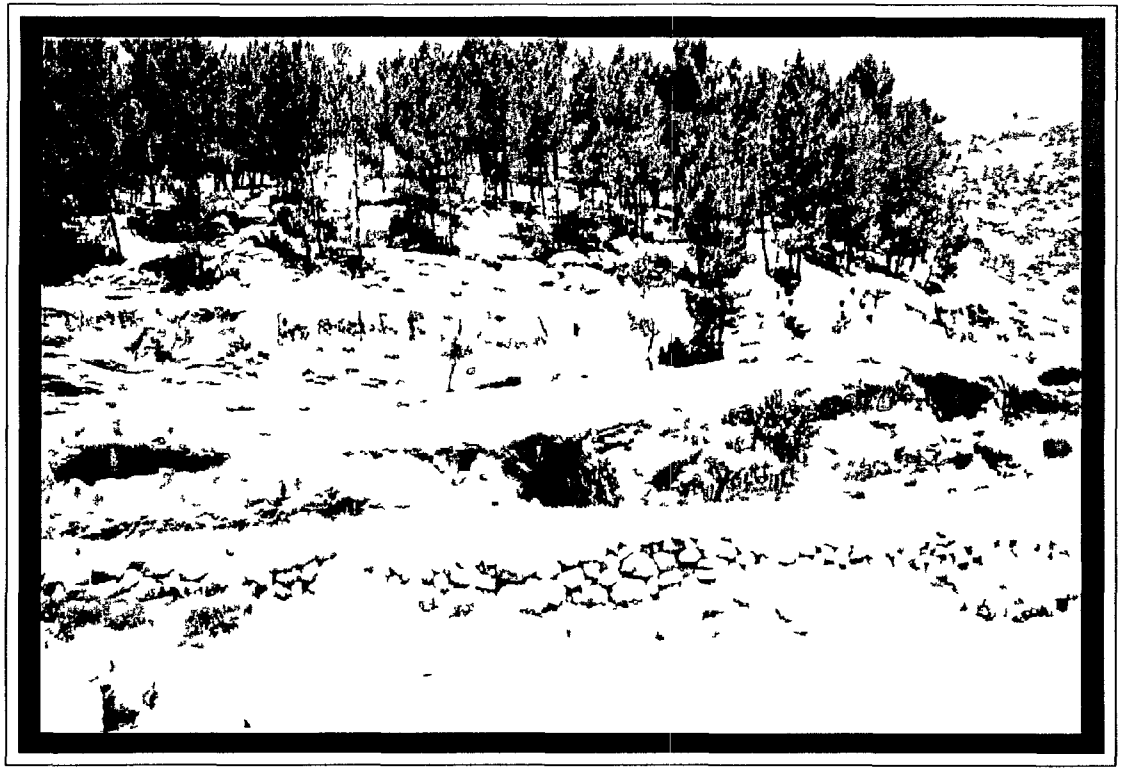

Photo 4 Aquifer recharge zone north-west of Hebron

Photo 5 Tree nursery irrigated with spring water north-north west of Hebron

Appendix A

Photo 6 Rainfed crops north-west of Hebron

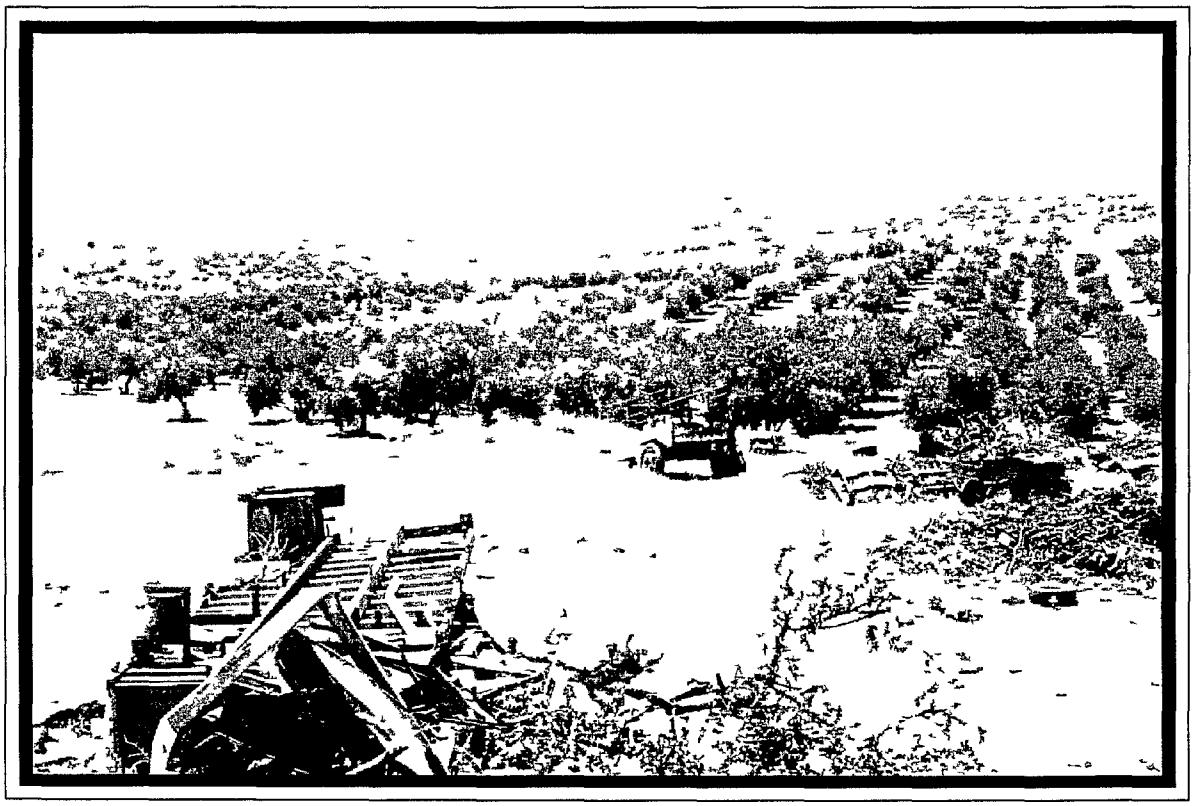

Photo 7 Rainfed crops south-east of Hebron, near Yatta

Appendix A

Photo 8 Irrigation of corn with sewage near Tal Shahar

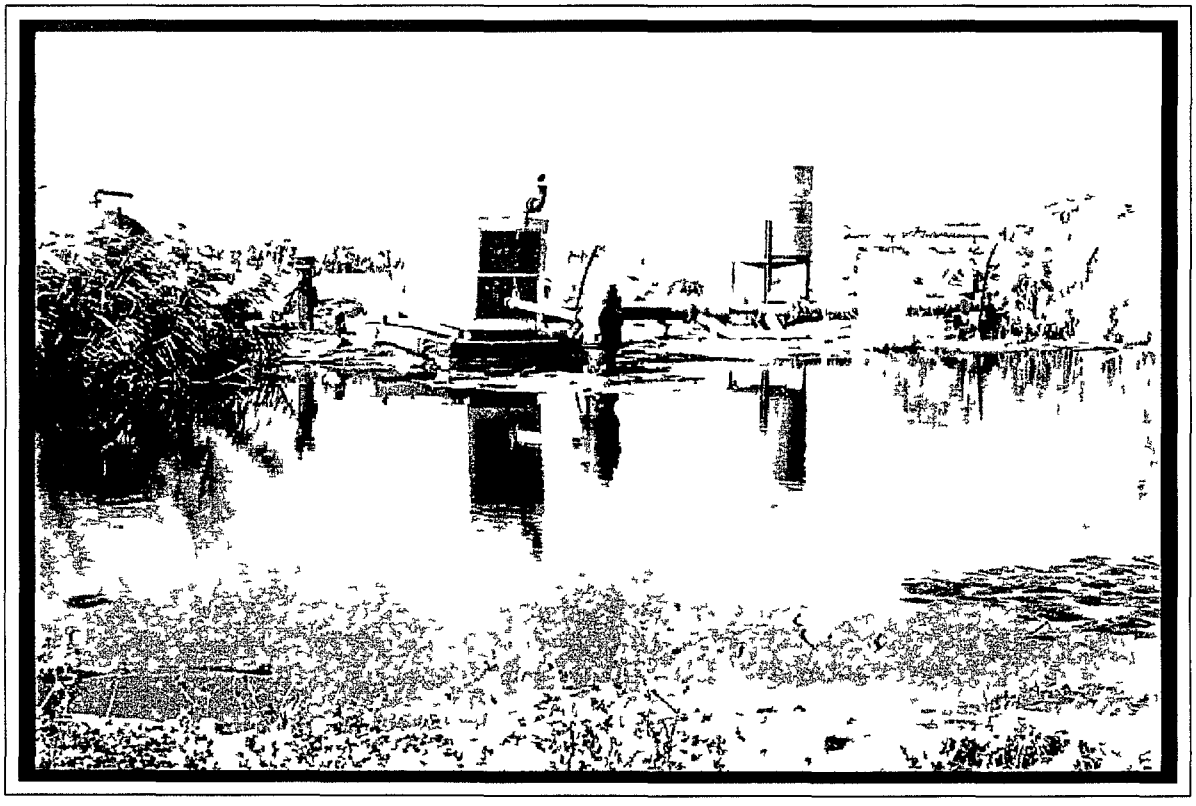

Photo 9 Sewage storage pond near Tal Shahar

Appendix A

Photo 10 Corn irrigated with sewage near Tal Shahar

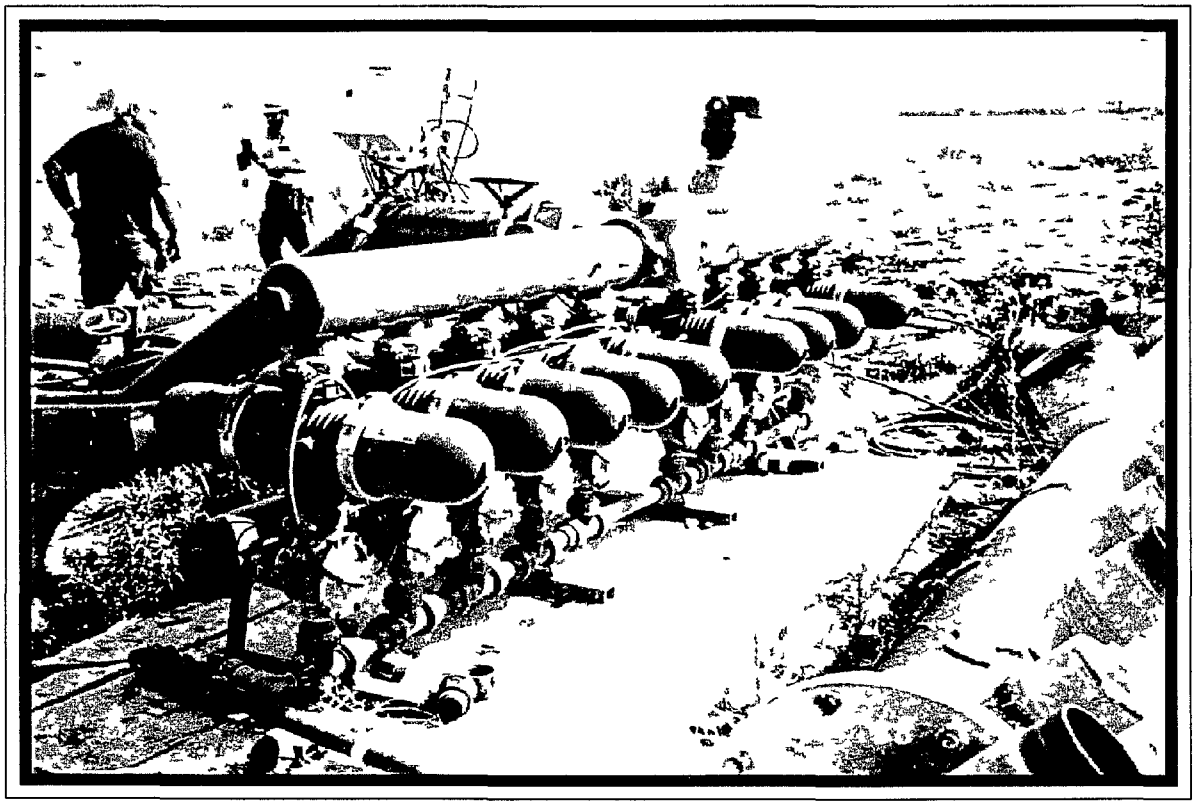

Photo 11 Filter system for irrigation water (sewage) near Tal Shahar

Appendix A

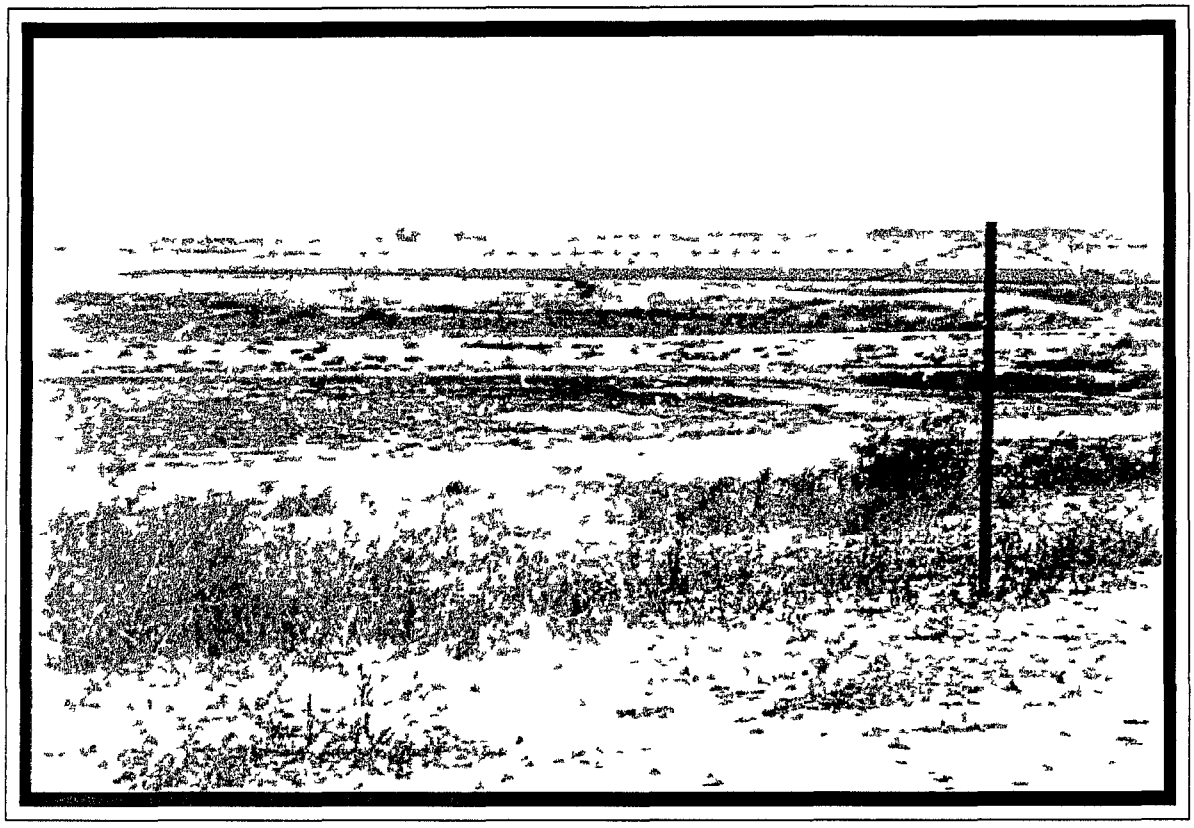

Photo 12 Raw sewage pond near Be er Sheva

Photo 13 Sewage effluent holding reservoir (prior to irrigation) near Be er Sheva

Appendix A

Photo 14 Cotton irrigated with untreated sewage effluent using drip irrigation system near Be'er Sheva

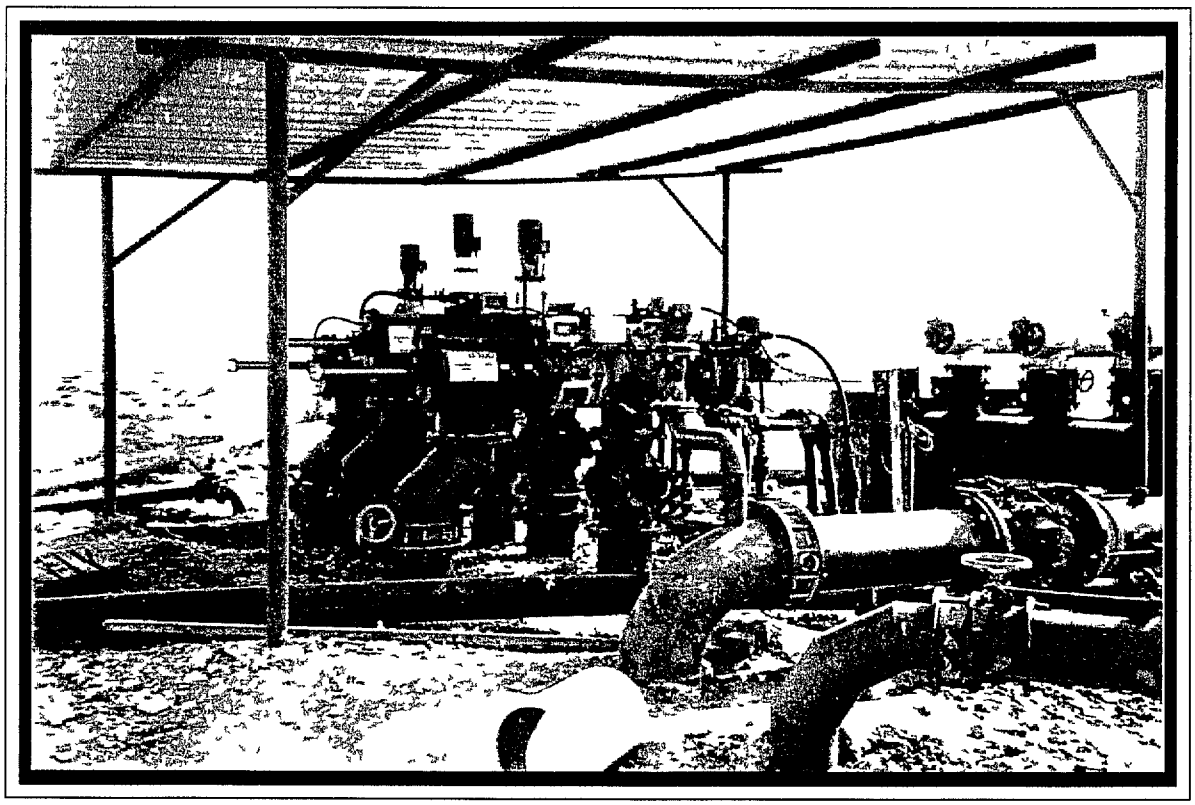

Photo 15 Pump and filters for sewage effluent used for irrigation near Be er Sheva

Appendix A

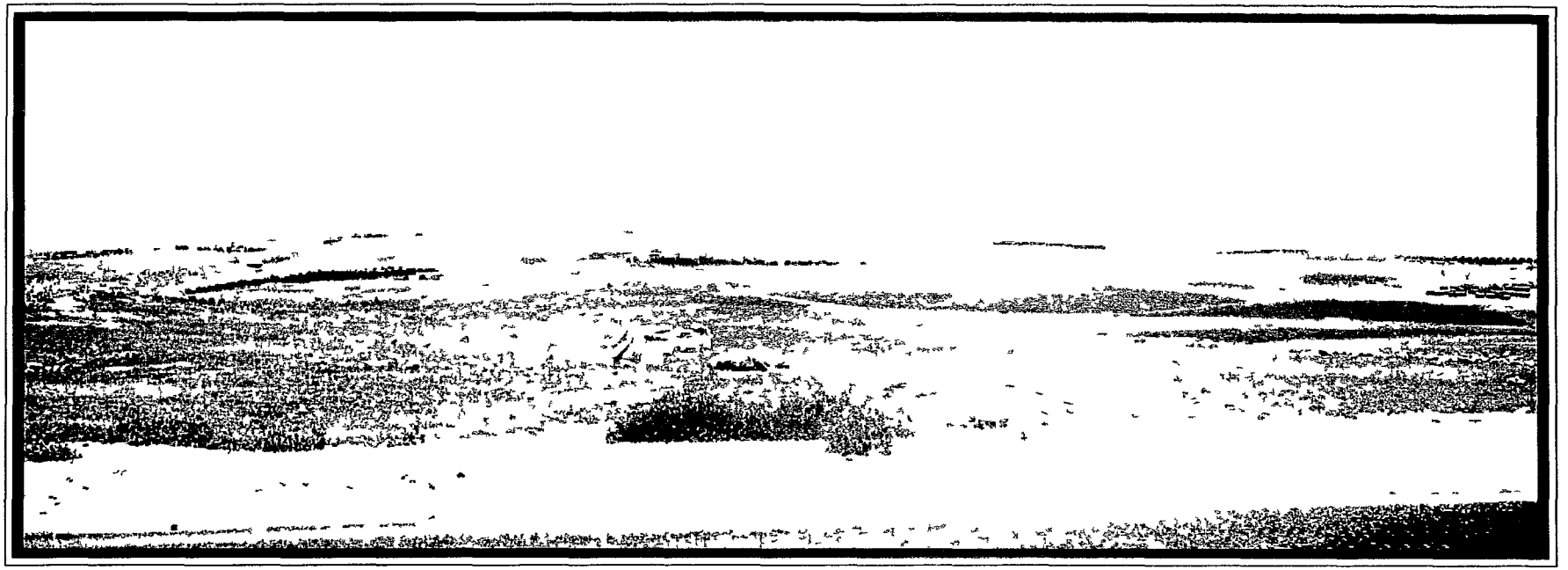

Photo 16 Road south of Karmel showing primary area proposaed for irrigation

Photo 17 Road south from Karmel showing primary area proposed for irrigation

Appendix A

Pnvapps\Presentations\DK\Bob\Israel 07 98\Photo_02 cdr

APPENDIX B

ASSUMPTIONS USED IN COST ESTIMATES

APPENDIX B

ASSUMPTIONS USED IN COST ESTIMATES

The cost analyses were based on prices prevailing in the West Bank in 1998 Engineering costs, including design, construction supervision, surveying, and soil testing, were taken at 10% of the total cost

1) Pipelines The cost estimate for pipelines includes labor and materials as follows

- Excavation of ditch 1 0 to 1 5 m deep (75% rock)
- Purchase of pipes, transportation, unloading, and stringing of pipes along the line
- Purchase and installation of accessories and special parts for pipes
- Leveling of ditch bottoms and bedding with selected local material Laying and cutting of pipes
- Preliminary cover of pipes with selected compacted soil layer
- Final cover with compacted local soil
- Concrete works in boxes and blocks, including cement and steel reinforcing bars
- Cutting trenches through asphalt roads, wherever required, and repairing roads after completion of work
- Passing of pipelines under existing sewers and/or water pipes

a Gravity conveyance line, 1500 mm diameter

- Supply of precast concrete pipes
- Excavation and installation of precast concrete pipes
- Engineering design and supervision (10%)
- Contingencies

b Force Main

- Supply of 500, 600, 750, and 900 mm ductile iron pipes
- Excavation and installation of pipes
- Engineering design and supervision
- Contingencies

2) Pumping Stations The estimate for construction of the pumping stations includes labor, materials, and equipment as follows

- Earthwork-stripping and leveling of terrain in every kind of soil, including rock, preparation of access roads
- Concrete, masonry, and brickwork
- Supply and installation of all pumping equipment, mechanical and electrical
- Pipe work, including suction and pressure pipes, drains, etc
- Various metal work including fencing, gates, rails ladders, gangways, and covers

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Effluent Storage Reservoir The cost estimates for the storage reservoir includes

- Purchase of land needed for the reservoir
- Earthwork-including excavation in all kinds of rock
- Access roads
- Compaction of the reservoir embankments
- Control valves on the inlet and outlets
- Fencing around the reservoir
- Steel gates to the site
- Guard room

4) Land Price $5,000/dunum in 2005
$8,000/dunum in 2010
$10,000/dunum in 2015
$15,000/dunum in 2020

APPENDIX C

ACTION PLAN FOR AGRICULTURAL REUSE OPTIONS

APPENDIX C

ACTION PLAN FOR AGRICULTURAL REUSE OPTIONS

This plan of action was developed to assist USAID in implementing the agricultural reuse option and incorporating this option into the conceptual design for the proposed wastewater treatment plant for the Hebron area

Many unknowns are associated with implementing the agricultural reuse option The following actions are recommended to resolve some of these unknowns so that design and implementation can continue The first three action items are considered the most urgent to allow continued planning for the wastewater reuse option The order of the remaining actions does not indicate their importance

1 Salt Loading in the Sewer High salinity values have been identified in the wastewater discharge, several industries have been identified that are producing this salinity A detailed water quality evaluation is required We recommend that a local research institution such as Hebron University be involved in this evaluation The PWA could also be involved in the study The water quality investigation for agricultural reuse should be directed primarily toward the following parameters

Electrical Conductivity	Total Dissolved Solids (TDS)
Calcium	Sodium
Magnesium	Manganese
Iron	Chlorides
Boron	

The analysis could be expanded to include other parameters (such as parameters necessary for the design of the wastewater treatment system), but the above are the most important for irrigation Prior to developing a final sampling plan, the proposed sampling parameters should be coordinated with other planning groups

2 Industrial Waste Discharges In conjunction with Item 1, a detailed evaluation of the options for eliminating the high-salt waste streams should be conducted This study should determine the volume of waste generated, and identify alternative disposal methods and associated costs The economic impact on individual industries of requiring alternative disposal methods also should be reviewed

3 A detailed economic analysis is required to determine whether the irrigation reuse option could be economically sustainable after USAID makes the initial capital investment This analysis would include an evaluation of the crops that could be grown, and the commercial market (including exportability) for those crops Most crops suitable for growing in the Hebron area will require 5 to 7 years to mature

4 Detailed Maps Available maps are of insufficient scale to do detailed planning for agricultural reuse, including identifying the location of storage reservoirs, dams, and irrigation land Detailed maps should be prepared using an airphoto base map Airphotos probably exist that cover the desired area

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5 Selection of Land for Irrigation General land areas have been identified However, a detailed land survey is required to identify individual tracts of land The suitability of the land for individual crops must also be determined

6 A landownership study must be undertaken to identify the owners of the proposed lands, and ownership maps prepared It must also be determined if the owner will participate in an irrigation project

7 Wastewater reuse in the Hebron area may require action by the Joint Water Committee (JWC) The agricultural reuse option should be discussed with the JWC and other agencies to gain their input and approval early in the planning process

8 A more complete water balance (daily flows, irrigation requirements, storage requirements) will be required, possibly as part of the economic analysis

9 An environmental impact assessment of wastewater storage reservoirs is required and a geotechnical and environmental assessment of any potential dam site would be required

The above action items could be expanded, but we believe that these are the most critical for continued planning for this project We recommend that the first three action actions items be implemented before moving forward with the design of the project

APPENDIX D

LIST OF CONTACTS

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Modern Tannery Company Ltd
West Bank - Hebron
Ind Zone Tel 02-929497

U S Agency for International Development
West Bank and Gaza Mission
John C Starnes
Office Director
Water Resources Office
USAID
U S Embassy
71 Hayrkon St
Tel Aviv 63903
Tel 972-3-511-4862
Fax 972-3-511-4888

U S Agency for International Development
West Bank & Gaza Mission
Tom Delaney
Program & Project Development Office
USAID
U S Embassy
71 Hayarkon St
Tel Aviv 63903
Tel 972-3-511-4889
Fax 972-3-511-4888
Cellular 050-612-124
E-mail todelaney@usaid gov

United State Agency for International Development
Anan Masri-Engineer
M S C Water & Waste Engineering
E-mail amasri@usaid gov
Tel 02-6227297 Fax 02-6259484
Celluler 050-545-385
Home 09-2385010

LIST OF CONTACTS (continued)

Israel Association for Water Resources
P O B 6381 Jerusalem 91063,Israel,
Phone (972-2)5384403, Fax (972-2)5388704
Dr Gavriel Weinberger
Executive Member
Residence Merkaz Hanegev 39, Beer - sh eva, 84548,Israel,
Tel 972-7-6495798
Fax 972-7-6480359,
E-mail ghz100@netvision net il

Israel/Palestine Center For Research and Information (IPCRI)
Gershon Baskin, Ph D
Israel Director
P O Box 51358
Jerusalem 91513
Tel +972-2-647-6054/5/6
Fax +972-2-647-6057
Mobile Phone 50-258-382
Beeper Tel 058-212121 # 93705
E-mail peace@netvision net il
Home page http //www ipcri org

Israel/Palestinian Center For Research and Information (IPCRI)
Robin Twite, O B E
Environmental Progams Director
P O Box 51358
Jerusalem 91513
Tel +972-2-647-6054/5/6
Fax ++972-2-647-6057
Residence +972-2-641-0023
E-mail peace@netvision net il
Home page http //www ipcri org

Akrum Jalal Tamimi, Ph D
Vice Persident
Planning and Development
Hebron University
P O Box 40, Hebron
Tel 972-2-0995/6
Cellular Mobile 972-50-499-536
Fax 972-2-9929303
e-mail akrum@PalNet com

LIST OF CONTACTS (continued)

Palestinian Water Authority
Water Resources Program
Dr Ihab Isam Barghouthi
Economic Advisor
P O Box 891, Ramallah, West Bank
Tel (972)2 995-9155 Fax (972) 2 995-9154
e-mail pwaiib@planet edu

Palestinian Water Authority
Mr Fadel Kawash
Deputy Head of PWA
Ramallah

Dr Awni A Khatib
Associate Professor of Chemistry
Vice - President
Planning & Development
Hebron University
P O Box 168, Hebron- West Bank
Tel-fax (home) 972 2 9924847
Tel Work 9929293/fax 9929303

Palestinian Environmental Authority (Pen A)
Prof Dr Sufian Sultan
President of Pen A
Tel 972(2)9925328 Fax 9929279-9929269
P O Box 296 Hebron

Eng Imad Al -Zeer
Hebron Municipality Water Department
Tel 22 28121/2/3
Home 554236

Awni Abdul Rahman Attiah Elmanasrah
Director, Hebron Dirictorate of Agriculture
Tel Work - 992-7846/7
Home 572-5173

Mr Mustafa Abed Al Nabi Al Natsheh
Mayor of Hebron
Hebron

Mr Kamal Al Duweik
Member of Hebron Municipal Council
Hebron

Mr Mussa Abu Gharbiyah
General Director
Palestinian Environmental Authority
Al - Bireh
Tel 02-2981495

LIST OF CONTACTS (continued)

Mr Jibrin Shawar
Hebron Dirictorate of Agriculture
Hebron
Tel 02-222 7846/7

Mr Khaldoon Najim
Postgraduate Student
Hebron University

Mr Yousef Subuh
Postgraduate Student
Hebron University

Dr Yossi Gutman
Tahal Consultants, Ltd
Tel 03-692-4728
Fax 03-692-4608

Musbah A A Tahboub
Head of Heath Department
Hebron Municipality
Tel 02-9928121
Fax 02-9928293

Gideon Sagi Ph D
Head, Water Quality Deputy
Duby Segall Irrigation Consultant
Israel Water Works Association
8 Shaul Hanelechst
P O Box 40003
Tel-Aviv 64733 ISRAEL
Tel 03-6956138
Fax 03-6950530

LIST OF CONTACTS (continued)

Dr Israela Ravina
Dean of Agricultural Engineering Department
Technion – Israel Institute of Technology
Technion City, Haifa 32000
Israel
Tel 972-4-829-2620
Fax 972-4-822-1529

Prof Uri Zoller
Haifa University-Oranim
Kiryat Tivon 36006, Israel
Tel 04-242740
Fax 04-345069

Mr Mustafa Nuseibeh
West Bank Water Authority
Ramallah
Tel 02 2958748

Dr Abraham J Melloul
Hydrogeologist
Hydrological Survey
P O Box 6381
Jerusalem
Tel 972-2-388-702
Fax 972-2-388-704

Itzhak Inbar
Netafim
Kibbutz Hatzerim
Tel 972-7-647 3111
Fax 972-7-643 2817

Mr Abraham Sanati
Tal Shaher
Dnemek Soreke 78805
Cell Phone 052 569143

95

LIST OF CONTACTS (continued)

Volcani Research Center
The following individuals provided consultation to the team

Menachum Ben-Hur
Isaac Shainberg
Aviva Hadas
Amos Hadas
Ellen Graber
Arie Nadler
Abraham Meir
Nava Haruvy
Isaac Klein
Pinehas Fine