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**UNITED NATIONS**

**ECONOMIC AND SOCIAL**

Distr.
LIMITED
E/ESCWA/SDPD/2005/WG.1/10
14 April 2005
ORIGINAL: ENGLISH

**ECONOMIC AND SOCIAL COMMISSION FOR WESTERN ASIA**

Workshop on "Training of Trainers on the Application of
IWRM Guidelines in the Arab Region"
Kuwait, 14-18 May 2005

# MODULE NINE

# WATER DEMANDS: MODELLING AND MANAGEMENT

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05-0235

| **MODULE 9**<br>**WATER DEMANDS: MODELLING AND MANAGEMENT** | |
|---|---|
| RATIONALE | The choices of an appropriate approach to water demand modelling play a vital role in making planning and management decisions. The discussion in this module comprises the methodological framework for three broad approaches, namely: historical extrapolation, statistical techniques and mathematical programming. This module also presents a review on how these approaches can be applied to the various water use activities, aiming at guiding the choice between modelling approaches.<br>Water demand management is a complex multi-disciplinary component of IWRM, involving technical, economic, institutional and policy measures. To illustrate the proposed framework of the analysis a case study will be discussed. |
| OBJECTIVES | 1. Define water demand modelling approaches<br>2. Choice of water demand modelling approach<br>3. To expose participants to the multi-disciplinary character of IWRM with a strong focus on water demand management.<br>4. To create awareness, understandings and experience with the concept and tools of demand management, the design and implementation of demand management.<br>5. To practice water demand modelling and management through a Case study. |
| MAIN REFERENCES AND BACKGROUND MATERIAL | - Khater, A. (1994) *An Overview of the Essence of Modelling Water Demands.* Proceedings of Water in the Gulf Region toward Integrated management, (eds. Water Science and Technology Association), 5-9 November, pp. 503-510.<br>- Mimi, Z., and Smith, M. (2000) *Statistical Domestic Water Demand Model for the West Bank*. Water International, International Water Resources Association (IWRA), 25(3): 464-468.<br>- Mimi, Z. (2001) *Water Demands: Modelling Approaches*. European Water Management, European Water Association (EWA), 4(2): 39-43. |
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**SESSION TOPIC SYNTHESIS**

| QUESTIONS FOR DISCUSSION | 1. Estimation of water use<br>2. Water demand modelling approaches<br>3. Choice of water demand modelling approach<br>4. Examples and case studies for implementing demand modelling and management |
|---|---|

**Introduction**
The procedures that are used for forecasting water demands may vary from relatively simple historical extrapolation to analytical models at various levels of sophistication. The chosen procedures will depend upon the quality and quantity of data and the purpose of the forecast.

**Modelling Approaches**
The choices of an appropriate approach to water demand modelling play a vital role in making planning and management decisions. The discussion here comprises the methodological framework for three broad approaches, namely: historical extrapolation, statistical techniques and mathematical programming.

**Choice of Modelling Approach**

<u>Domestic Water Demands</u>
A criticism of the historical forecasting procedures is that they try to solve a complex problem with a simple solution procedure that ignores many factors that could affect the future demand. Statistical techniques are very helpful in identifying factors to account for variations in domestic water use. The most commonly used statistical technique has been regression analysis.

<u>Agricultural Water Demands</u>
Statistical methods have not been widely used for modelling water demand relationships in agriculture while mathematical programming is a planning tool that is well suited for the analysis of water demand in the agricultural activities. Mathematical programming techniques are able to answer questions concerning economic demand for water, and to find the best solution in a set of feasible solutions. Linear programming is the most widely used technique for modelling agricultural activity.

<u>Industrial Water Demands</u>
Water is not a major input factor for industrial development, and the cost of water supply represents only a very small part of the total production cost or of the value of output. When the analysis is concerned with individual industrial plants, mathematical programming seems better suited. This is partly because the data problems of the statistical approach result in a rather crude average representation of the activity in question. When the problem at hand is of analysis beyond that of the individual activity, the model of choice is usually the statistical one.

**Water Demand in ESCWA Countries**
Total water demand during the past two decades has increased dramatically in ESCWA countries as a result of high population growth, urban migration, improvement in the quality of life, efforts to establish food self-sufficiency, and industrial development. Agriculture is the primary water consumer, representing 86 per cent of total water demand for the region in 1997. Total water demand was estimated at 181.1 BCM in 2000 and 261.8 BCM by the year 2025. Domestic and industrial water demand was expected to reach a total of 30.4 BCM and 55.5 BCM in 2000 and 2025, respectively.

In most of the ESCWA member States, there is a need for simultaneous implementation of supply and demand measures. In the past, water supplies were developed to meet demand; however, this practice has led to the mismanagement of water resources. Supply and demand management literally means the application of a range of physical and economic tools to increase water supply availability and produce greater efficiency in water utilization. Demand management measures are usually implemented to curtail and control demand in order to ensure that a limited supply will be able to satisfy demand. Demand management includes the implementation of water-saving technology, public awareness efforts, rebates for retrofitting, the modification of existing building codes, leak detection, pricing mechanisms and regulatory schemes. Supply management is intended to complement demand management through cost-effective programmes for water desalination, artificial recharge, the reuse of renovated water, recycling, the use of water of marginal quality, and water harvesting.

The main objectives are to reduce waste, increase supplies and better protect water quality. The implementation of demand management measures, supported by enforcement measures, has been shown to contribute significantly to the alleviation of water shortages and the efficient use of water, especially in the agricultural sector.

Demand management works best in an IWRM framework, which looks across sectors and makes proper links between policy instruments and impacts.

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# MODULE 9

## WATER DEMAND: MODELLING AND MANAGEMENT

## A. WATER DEMAND MODELLING

### *A.1 Introduction*

Water management, especially in ESCWA countries, calls for planning with consideration being given to the use of non-conventional sources of supply. As a result, there will be a substantial increase in water costs, and the problem of water supply can no longer be seen simply as development of new sources. Accordingly, levels of demand should be affected, and anticipation of water problems and identification of control factors will depend on the forecasts of future water demand.

The procedures that are used for forecasting and modelling water demands have been reviewed and discussed comprehensively by Khater (1994) and may vary from relatively simple historical extrapolation to analytical models at various levels of sophistication. The chosen procedures will depend upon the quality and quantity of data and the purpose of the forecast. This module addresses the growing interest in the examination of water demands and the need to pay careful attention to modelling and forecasting water demand in the future. This module also discusses the framework of the alternative approaches to water demand modelling and presents a review on how these approaches can be applied to the various water use activities using a case study aiming at guiding the choice between modelling approaches.

### *A..2. Estimation of water use*

Water use data from water supply agency (i.e., water utility company) records can be used for examining historical trends in water use and disaggregating total use into seasons, sectors, and specific end uses within each sector. Water production records are a good source of data on total water demands in the area served by a public system. Water utilities usually have one or more production meters that are generally read at least daily. The usefulness of the production data for water demand analysis may include, but not be limited to: (1) the analysis of unaccounted water use (comparing production with water sales data), (2) the measurement of the aggregate effect of emergency conservation campaigns on water use.

### *A.3. Modelling approaches*

Demand models provide simplification, or abstraction, of complex physical reality and the processes involved in it, and serve as tools in the solution of demand forecasting problems. The choices of an appropriate approach to water demand modelling play a vital role in making planning and management decisions. The discussion here comprises the methodological framework for three broad approaches, namely: historical extrapolation, statistical techniques and mathematical programming (Khater, 1994).

Historical Extrapolation

The first step in the analysis of water demands in an area served by a public water-supply system is to determine average annual rates of water use. The simplest rate is the gross per capita water use that is determined by dividing the total annual amount of water delivered to the distribution system by the estimated population served. Although there are many types of forecasting approaches, they can be reduced to several prototypical methods that differ with respect to the level of disaggregation and the structural complexity of water-use equations. The simplest technique, known as time extrapolation, extrapolates the average change in past water use records into the future. The forecasting equation can be written as (Dziegielewski et al, 1996):

$Q_t = f(Q_{h1} \ldots Q_{hm}, t)$

Where: $Q_t$ : water use in forecast year t
$Q_{h1} \ldots Q_{hm}$ : historical time series of water use

A distinctive class of forecasting approaches introduces a simple water use relationship in which total water use is represented as the product of the number of users and an average rate of water use.

Statistical Techniques

In the statistical modelling of water demand relations, a water activity is conceptualized as a black box with input and output variables, and their associated costs or prices are defined. In the black box representation, inputs and outputs are known as explanatory variables and dependent variables, respectively. Among the explanatory variables one should distinguish the so called exogenous variables that have an effect on the dependent variables but are not explained by the model. These include variables such as administered prices, and environmental standards (Kindler and Russell, 1984).

A statistical model of a water demand relation can generally be expressed as

$$D = f(X_1, X_2, \ldots X_n) + E$$

Where D denotes demand, $f(\quad)$ the function of explanatory variables $X_1, X_2, \ldots, X_n$ and E is a random error variable describing the effect on D of all factors other than those explicitly considered in the form of explanatory variables. In practical applications, the analytical form of function $f$ is commonly assumed to be either additive, multiplicative, or a combination of the two. These possibilities translate into linear, full logarithmic, or semi logarithmic forms:

$$D = a_0 + a_1 X_1 + \ldots + a_n X_n + E$$
or
$$\ln D = b_o + b_1 \ln X_1 + \ldots + b_n \ln X_n + E$$
or
$$D = c_o + c_1 \ln X_1 + \ldots c_n \ln X_n + E$$

Where D is the total unit amount of water demand; $a_o \ldots, a_n$ , $b_o, \ldots, b_n$ and $c_o, \ldots, c_n$ are the structural parameters of the alternative models, $X_1, \ldots, X_n$ are explanatory variables, and E is the random error term. These forms are convenient because they allow for easy estimation of model parameters by use of multiple regression analysis (Taylor et al, 1987).

The identification of appropriate explanatory variables is closely connected with determination of a suitable model structure for each dependent variable. The ordinary least squares method is the most commonly used technique for estimation of model parameters under the assumptions mentioned about the random error term. In the modelling process, after estimating the model parameters, the next step that should proceed using the model is verification and validation of the model (Norusis, 1991).

Mathematical Programming

Mathematical programming techniques are concerned with establishing the best or optimal solutions to decision-making problems. Thus, they involve the use of optimisation methods such as linear, integer, dynamic, and multi-objective programming. A mathematical programming model of water use activity is a combination of unit processes written in the form of a set of inequality and equality constraints of the system, where the decision variables are the levels of operation of the process. The objective function for the model represents the criterion for choosing the optimum combination of unit processes, the measure that must be minimised or maximised. In water demand analysis, it is most common that the objective function represents cost. In such cases the problem is stated as follows (Khater, 1994; Hall and Dracup1970; Gupta and Hira 1997).

Find X that minimises $f$ (X)
D = $f$ (X) + E
Subject to the constraints
$g_i$ (X) < 0, i = 1,2, ….., m
and
$l_i$ (X) = 0, i = 1,2, ……, p

Where X is an n- dimensional vector called the design vector, which denotes the levels of unit processes, $f$ (X) is the objective function to be minimised and $g_i$ (X) and $l_i$ (X) are respectively, the inequality ($g_i$ (X) < 0) and equality constraints ($l_i$ (X) = 0). The number of variable *n* and the number of constraint *m* and / or *p* are not to be related in any way.

A linear programming model is applicable for the solution of problems in which the objective function and the constraints appear as linear functions of the decision variables. Integer programming is used when the variables are restricted to non-negative integer values. Dynamic programming technique is well suited for the optimisation of multi-stage decision problems when decisions have to be made sequentially at different points in time and space, and at different stages in the decision making process (Ossenbruggen, 1984).

The choice of objective function expressed in terms of decision variables is governed by the nature of the problem, being the criterion with respect to which the solution to the problem is optimised. In some situations, there may be more than one criterion to be satisfied simultaneously. An optimisation problem involving multiple objective functions is known as a multi-objective programming problem.

## *A. 4. Choice of modelling approach*

The choice between modelling approaches depends on such factors as data availability, data reliability, skills, and access to computational facilities. But this choice is also linked to the intended application of the model to be constructed. One way of summarising the links between application and model type is to look at combinations of two principal characteristics of a specific application: the level of analysis, and the problem to be addressed. However, the variety of situations under which demand analysis is required is so large that there is simply no way to provide a general recommendation of the best way to proceed (Khater, 1994; Kindler and Russell, 1984). The following discussion on the application of demand models for the various water use activities provides guidelines for the choice of modelling approach.

### Domestic water demands

A criticism of the historical forecasting procedures is that they try to solve a complex problem with a simple solution procedure that ignores many factors that could affect the future demand. Statistical techniques are very helpful in identifying factors to account for variations in domestic water use. The most commonly used statistical technique has been regression analysis.

Domestic water demands have been the subject of considerable statistical modelling. In these model studies, per capita water use has been correlated with income, household size, price, number of occupants…etc. (e.g., Bhattacharya (1982) and Clarke and others (1997).

In general, the following empirical relationship is most often used in practice to determine the domestic water demand in human settlements (see example in Box1):

$$Q = K_l (k_d q P + Q_i)$$

Where:

$K_l$ is the coefficient denoting the water loss in the water supply network;

$k_d$ the coefficient denoting the changes in the mean daily water consumption during 1 year;
$P$ the number of inhabitants;
$Q_i$ the required reserve amount of water for extinguishing potential fires.
$q$ the specific daily water consumption per individual.

The future number of inhabitants can be calculated using the following formula:

$$P_{t+n} = P_t(1+r)^n$$

where:

$P_t$ the present number of inhabitants;
$r$ population growth rate.
$n$ the number of years for which the number of inhabitants needs to be calculated.

Agricultural Water Demands

Statistical methods have not been widely used for modelling water demand relationships in agriculture while mathematical programming is a planning tool that is well suited for the analysis of water demand in the agricultural activities. Mathematical programming techniques are able to answer questions concerning economic demand for water, and to find the best solution in a set of feasible solutions. Linear programming is the most widely used technique for modelling agricultural activity.

Although Linear Programming is the most widely used technique for modelling agricultural water demands by individual and regional activities, a number of other mathematical programming and simulation methods have also been applied. The study of Palmer-Jones (1977) is representative in this respect.

Models used in agricultural water demand analysis vary in complexity and methodology. To estimate crop water requirement in the conventional approach, the area to be developed for irrigation is specified and multiplied by a coefficient reflecting the volume of water required per unit area, thus giving an estimate of the water requirements. The Food and Agriculture Organisation of the United Nations (FAO) has developed a computer program for irrigation planning and management (CROPWAT) in 1984. The Modified Penman-Monteith method can be used with CROPWAT software to calculate reference and crop evapotanspiration as well as irrigation requirements for any irrigated area (FAO, 1984; FAO 1992; ARIJ 1998).

In general, the following empirical equation is used for computing the required amount of water for irrigation:

$$Q_{ir} = q_{ir}\frac{S}{K_s + K_a}$$

Where:

$S$ is the area suitable for irrigation, i.e. area that is irrigated or will be irrigated expressed in ha;
$K_a$ the coefficient of water loss in the irrigation network;
$K_s$ the applied irrigation system coefficient f effectiveness; and
$q_{ir}$ the specific water demand expressed in $m^3$/(month/ha).

The specific water demand depends on the climatic conditions, plant evapotranspiration, water reserves of the soil, ground water level, and the empirical methods used for computing evapotranspiration values. The general equation for determining the quantity of water is as follows:

$$q_{ir} = (ET_c - P_e)\times 10 - (R_i - R_f) - H$$

Where:

$$ET_c = ET_0 \times K_c$$

and where:

- $ET_c$ is the evapotranspiration of the plants that are grown in mm/month;
- $ET_o$ is the reference evapotranspiration in mm/month;
- $K_c$ the plant factor
- $P_e$ the effective precipitation in mm/month which depend on the total precipitation , run off conditions and the infiltration, and is determined experimentally;
- $R_i$ the water reserves in the ground which can be used in the beginning of the computation procedure, expressed in $m^3$/ha;
- $R_f$ the water reserves in the ground at the end of the computation period, expressed in $m^3$/ha; and
- $H$ the possible ground water input in the water supply in $m^3$/ha.

The effective precipitation can also be calculated using empirical relationships or tables recommended by FAO.

Water Demand for livestock husbandry

The water requirements for livestock raising depend on the type of livestock that is involved, the feeding technology and the maintenance of the livestock farms. The following equation can be used for determining the required quantities of water in this field:

$$Q_s = k_d (q_k N_k + q_s N_s)$$

Where:

- $k_d$ is the fluctuation coefficient if the mean daily water consumption during the year;
- $q_k$ the average daily water consumption per head of meat cattle *l*/day;
- $q_s$ the average daily consumption of water per sheep and goats *l*/day;
- $N_k$ the total number of meat cattle that is raised; and
- $N_s$ the total number of sheep and goats.

Industrial Water Demands

Water is not a major input factor for industrial development, and the cost of water supply represents only a very small part (usually below 1%) of the total production cost or of the value of output. Because the purposes to which the water is used in industrial processes vary widely, and there are different uses of water within an industrial plant, the development of specific and accurate relationships explaining water use patterns is difficult. When the analysis is concerned with individual industrial plants, mathematical programming seems better suited. This is partly because the data problems of the statistical approach result in a rather crude average representation of the activity in question. When the problem at hand is of analysis beyond that of the individual activity, the model of choice is usually the statistical one (Khater, 1994).

The development of a sufficiently "realistic" industrial mathematical programming model requires specialised expertise and a great deal of cost and technological data. These necessary data are, of course, only a subset of the data required for constructing and operating the modelled facility anyway, but this does not mean that such data are easily collected. In addition, the development and operation of a model typically require considerable outlays in terms of both human and computer time (Stone and Whittington, 1984). In general, the total water demand of various industries can be computed using the following empirical relationship:

$$Q_i = \sum_{i-1}^{n} q_i P_i$$

where:

- $q_i$ — is the specific water consumption per unit product "*i*" of the branch of industry expressed in $m^3$/unit product;
- $P_i$ — the total daily production "*i*" of a branch of industry in a given area; and
- $i$ — the type of industrial production in a considered area.

Water Demand for tourism

The water demand in tourism and sports depend on the type of facilities on offer, on the climatic conditions, on the time of year and on the number of individuals using the facilities. The general equation for calculating the water demand in this field is:

$$Q_t = k_d q_t N_t$$

Where:

- $k_d$ — is the fluctuation coefficient if the mean daily water consumption during the year;
- $q_t$ — the average daily consumption of water per individual *l*/day; and
- $N_t$ — the average number of tourists who use the facilities.

## *A..5 Examples and Case Studies*

CDM (1997) used historical extrapolation to project domestic and industrial demands for the West Bank (see the training example in Box 1) while a statistical approach was used to develop the domestic demand model for the Rammallah District (See Box 2) to monitor the different factors affecting the domestic water demand. Mathematical programming can be was used in modelling agricultural activities of the West Bank (See Box 3) and can be used to maximize profit and optimise water consumptions (see Box 4).

*BOX 1:EXAMPLE OF HISTORICAL EXTRAPOLATION TO PROJECT DOMESTIC WATER DEMAND IN MY CITY*

**What is the projected water demand for "MY CITY" for the year 2025?**

The first step for projecting water demand is to estimate the present domestic water demand. Estimates of the present water consumption rates for **"MY CITY"** is based on a questionnaire survey sent out to the responsible utilities. Based on the questionnaire response, the following is a summary for year 2002: the population is 234390 capita; network supply is 15980 $x10^3$ $m^3/y$ and billing records is 12944 $x10^3$ $m^3/y$.

From the above data, the per capita consumption for year 2002 is 186 l/c/d; the overall loss is 19%; the apparent consumption (without losses) is 151 l/c/d. For the purpose of projecting future domestic demands, three variables will be considered:

(1) Unaccounted for water and water losses in distribution systems
It is assumed that the target for the year 2025 is to reduce the percentage to 10% for **"MY CITY"** due to the new water infrastructure and distribution system that will be constructed by the coming years.

(2) Per Capita water consumption

On average, developing areas usually have a rate of increase of 2.0% per year for water demand.

(3) Population

Most population forecasting methods require the knowledge of past and present population concerned. These methods use the initial population (from Central Bureau of Statistics of the country) as a base for projecting into the future. Broadly speaking methods of population forecasting are graphical methods, ratio methods, and mathematical methods. Mathematical methods such as the geometric growth model are commonly used. The geometric model can be expressed as:

$P_{t+n} = P_t (1+r)^n$ geometric growth model

Where:
$P_{t+n}$ : population at time (t+n)
$P_t$ : population at present time
r : rate of growth per unit time
n : length of time for which the projection is made.

For **"MY CITY"**, it is assumed that the population growth rate is 2.5%. Based on the above assumptions and data the following can be concluded

- Population in 2030 = 467959 capita (r =2.5 %; n = 28; $P_t$= 234390)
- Projected per capita consumption for the year 2030 = 263 l/c/d (r = 2%, n=28; $P_t$= 151 l/c/d)
- Projected domestic demand for the year 2030 = 467959 capita x 263 l/c/d = 123073 $m^3$
- Adding the expected losses in the distribution networks = 123073 $m^3$ x 1.1 = 135381 $m^3$

### *BOX 2: CASE STUDY ON DOMESTIC WATER DEMANDS MODEL*

The water balance in the West Bank shows a severe deficit. Scenarios and strategies are formulated in order to overcome the deficit problem. These include horizons for better management of the existing water resources and the enhancement of new ones. This case focuses on demand modelling as one of the key issues for effective water management. The developed statistical domestic water demand model assesses the factors, which influence domestic water use, and determine the parameters that may help in demand management. Rammallah City is used as a case study to illustrate the proposed framework of the analysis. The developed model indicates that water authorities can use price as a tool to ration or encourage reduced water consumption in households only in rich water areas. The primary data source was a questionnaire survey sent out during summer of 1998, to 473 a random sample of consumers. The aim of the questionnaire is to gather information on personal characteristics, water use and consumption, economic activities and general housing conditions. The household variables assumed to have a reliable impact on domestic water consumption for Rammallah District household include: number of occupants, price of water, number of children, income level, irrigated area, lot size, number of cars, number of taps, and the number of rooms. Model was generated by multiple regression analysis. The variable symbols and somewhat abbreviated definitions for factors hypothesised as influencing domestic water consumption were:

$q$ = average quantity consumed (l/c/d)
$X_1$ = number of cars per household
$X_2$ = number of children
$X_3$ = monthly income (U.S $)
$X_4$ = lot size in square meters
$X_5$ = number of occupants per dwelling
$X_6$ = the price of water that varies with individual household consumption (U.S $)
$X_7$ = number of rooms
$X_8$ = irrigated area ($m^2$)
$X_9$ = number of taps inside the house or in the courtyard

The linear equation of best fit generated by multiple regression models is:

$$q = 228.463 + 1.091 X_1 - 6.939 X_2 + 0.002 X_3 + 0.021 X_4 - 8.374 X_5 - 52.961 X_6 - 1.592 X_7 + 0.004 X_8 + 3.683 X_9$$

The price factor as often quoted in the literature is a very important management tool. Quantitative results can be produced from the above model by estimating the price elasticity of demand, which measures the willingness of consumers to give up water use as a result of rising prices, or conversely, the tendency to use more as price falls. In one sense, price elasticity reflects the availability of opportunities for water conservation, or for substituting other goods or services for water. The price elasticity for households in Rammallah derived from the model was -0.6, meaning that if other factors held constant, a 10 percent increase in price would lead to about 6 percent change (decrease) in the amount of water purchased. The water utility authorities can use price as a tool to ration or encourage reduced water consumption in households only if there is price elasticity and in rich water areas. Obviously, this is an acceptable practice and water resources will be conserved if it is applied taking the following points into account:

- The poorest of the society will be provided with basic minimum requirements of water at the minimum price.
- Factors such as “capacity to pay”, “benefits derived”, “proportionate cost of service” and “health impacts” have to be considered.

*Source: Mimi and Smith 2000*

*BOX 3: CASE STUDY ON MODELING AGRICULTURAL ACTIVITIES*

The following mathematical model can serve as an integrated model for optimization of use of land and water resources in agriculture. The objective function of the model is to maximize profits. There are three major constraints, the first constraint relates to the availability of land for agriculture use. The second constraint defines the total amount of water allocated for a district. The third one relates to the crop production, different marketing potentials and food security requirements. Combining these three constraints, the following equation has been developed to maximize profits for district j, from crops i, and using irrigation system s. Several additional constraints may be introduced to enrich the model and to account for realistic restrictions in the system such as type of soil and proper season. The equations can be easily solved using the available mathematical software for linear programming.

Maximize profits of district j

$\sum i \sum s[P_{ij} * X_{ijs}] - \sum i \sum s[C_{ijs} * L_{ijs} * X_{ijs}] - \sum i \sum s [W_{ijs} * L_{ijs} * X_{ijs}] * P_{*wj}$

Land Constraint

$\sum i \sum s [L_{ijs} * X_{ijs}] \leq \sum s L_{*js}$ $\forall j$

Water Constraint

$\sum i [W_{ijs} * L_{ijs} * X_{ijs}] \leq W_{*js}$ $\forall j, s$

Commodity Balance

$\sum s X_{ijs} \geq [C_{*ij} + E_{ij} - M_{ij}]$ $\forall i$ in a given district j

**Definitions**

$\forall$ For all

$P_{ij}$ Price for crop i in district j ($/ton)

$X_{ijs}$ Output of commodity crop i in district j using irrigation system s (ton)

$C_{ijs}$ Total cost to produce crop i in district j using irrigation systems s ($/1000 $m^2$)

$L_{ijs}$ Amount of land required to grow one ton of crop i in district j using irrigation system s (1000 $m^2$/ ton)

$W_{ijs}$ Water required to produce crop i in district j ($m^3$/1000 $m^2$)

$P_{*wj}$ Price of water for agricultural use in district j ($ /$m^3$)

$L_{*js}$ Total amount of agricultural land in district j available (1000 $m^2$)

$W_{*js}$ Total amount of water allocated for agricultural use in district j and irrigation system s ($m^3$)

$C_{*ij}$ Total consumption of crop i in district j (ton)

$E_{ij}$ Total exports of crop i from district j (ton)

*Source: Mimi 2001*

*BOX 4: PRODUCT MIX PROBLEM*

A certain farming organization operates three farms of comparable productivity. The output of each farm is limited both by the usable acreage and by the amount of water available for irrigation. Following are the data for the upcoming season:

| Farm | usable acreage | water available in acre feet |
|---|---|---|
| 1 | 400 | 1500 |
| 2 | 600 | 2000 |
| 3 | 300 | 900 |

The organization is considering three crops for planting, which differ primarily in their expected profit per acre and in their consumption of water. Furthermore, the total acreage that can be devoted to each of the crops is limited by the amount of appropriate harvesting equipment available.

| Crop | minimum acreage | water consumption | expected profit In acre feet per acre |
|---|---|---|---|
| A | 700 | 5 | $200 |
| B | 800 | 4 | $300 |
| C | 300 | 3 | $100 |

In order to maintain a uniform workload among farmers, it is the policy of the organization that the percentage of the usable acreage planted must be the same at each farm. However, any combination of the crops may be grown at any farms. The organization wishes to know how much of each crop should be planted at the respective farms in order to maximize expected profit. Formulate this as a linear programming problem.

**Solution**

The key decision is to determine the number of acres of each farm to be allotted to each crop. Let $x_{ij}$ (i= farm 1,2,3; j =crop A,B,C) represent the number of acres of *i*th farm to be allocated to the *j*th crop.

The objective is to maximize the total profit:

maximize $Z = (400\ x_{1A} + 400\ x_{2A} + 400\ x_{3A}) + (300\ x_{1B} + 300\ x_{2B} + 300\ x_{3B}) + (100\ x_{1C} + 100\ x_{2C} + 100\ x_{3C})$

Constraints are formulated as follows:

For availability of water in acre feet:

$5\ x_{1A} + 4\ x_{1B} + 3\ x_{1C} \le 1500$

$5\ x_{2A} + 4\ x_{2B} + 3\ x_{2C} \le 2000$

$5\ x_{3A} + 4\ x_{3B} + 3\ x_{3C} \le 900$

For availability of usable acreage in each farm:

$x_{1A} + x_{1B} + x_{1C} \le 400$

$x_{2A} + x_{2B} + x_{2C} \le 6o0$

$x_{3A} + x_{3B} + x_{3C} \le 300$

For availability of acreage for each crop:

$x_{1A} + x \quad + x \quad \ge 700$

$x_{1B} + x_{2B} + x_{3B} \ge 800$

$x_{1C} + x_{2C} + x_{3C} \ge 300$

To ensure that the percentage of usable acreage is same in each farm,

The equations can be easily solved using the available mathematical software for solving linear programming problems.

## A..6. Concluding remarks

The process of projecting water demands should be directed towards analytical modelling approaches such as statistical techniques and mathematical programming if reliable and valid data are available. The superiority of analytical models over extrapolation methods lies not only in their greater accuracy but also in their capability of including economic factors and assessing the consequences of various policy options. One advantage of the mathematical programming approach over the statistical one is that the costs and prices may be allowed to vary beyond their values recorded in the past and the resulting predictions of the demand may be accepted with reasonable confidence.

Because of the diversity of local conditions under which demand analysis is required, general rules of standard solutions can only be of limited value in working out details of modelling procedures. However, based on the nature use of activities, mathematical programming as a planning tool seems well suited for the analysis of a wide range of demand forecasting problems in the agricultural and industrial activities. On the other hand, the statistical approach appears to be most promising for modelling domestic water demands.

## A. 7. Water demand in ESCWA countries

Total water demand during the past two decades has increased dramatically in ESCWA countries as a result of high population growth, urban migration, improvement in the quality of life, efforts to establish food self-sufficiency, and industrial development. Agriculture is the primary water consumer, representing 86 per cent of total water demand for the region in 1997. Total water demand for domestic, industrial and agricultural purposes in the ESCWA region amounted to 140 BCM in 1990 and was estimated at 181 BCM for 2000, as shown in Table 1. Total water demand was expected to reach 181.1 BCM in 2000 and 261.8 BCM by the year 2025. Domestic and industrial water demand was expected to reach a total of 30.4 BCM and 55.5 BCM in 2000 and 2025, respectively (ESCWA 2003).

Industrial activities in most of the ESCWA member countries have also contributed to the increase in total water requirements, though not as dramatically as agricultural activities. In 1990, industrial water demand in Egypt, Iraq, Jordan, Lebanon, the Syrian Arab Republic, and the West Bank and Gaza Strip totalled 6.3 BCM, and only 0.3 BCM in the GCC countries and Yemen. Industrial demand for the whole region as a whole amounted to 6.7 BCM in 1993 and 8.6 BCM in 1997. Industrial water demand accounted for between 0.4 and 11.3 per cent of total demand, the smaller percentages being reported for the GCC countries. Countries with a relatively well-established industrial infrastructure include Egypt, Iraq and the Syrian Arab Republic. Industry is still fairly limited in the southern part of the region. Industrial demand is projected to reach 9.4 and 18.6 BCM in the years 2000 and 2025, respectively, with the highest demand in Egypt, Iraq and the Syrian Arab Republic.

Agricultural water requirements account for most of the water used in the ESCWA region. Demand reached 123.2 BCM in 1990, increasing to 136.5 BCM in 1997. Agricultural water demand in the ESCWA region is estimated at 150.7 and 206.3 BCM in the years 2000 and 2025, respectively.

*TABLE 1. PAST AND PROJECTED WATER DEMAND FOR THE ESCWA REGION, 1990, 2000 AND 2025, (MILLIONS OF CUBIC METRES)*

| | **1990** | | | **2000** | | | **2025** | | | **Total demand** | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | **Domestic** | **Agricultural** | **Industrial** | **Domestic** | **Agricultural** | **Industrial** | **Domestic** | **Agricultural** | **Industrial** | **1990** | **2000** | **2025** |
| Bahrain | 112 | 120 | 17 | 132 | 124 | 26 | 169 | 271 | 169 | 249 | 282 | 609 |
| Egypt | 2 700 | 49 700 | 4 600 | 2 950 | 59 900 | 5 350 | 6 300 | 69 100 | 10 900 | 57 000 | 68 200 | 86 300 |
| Iraq | 3 800 | 45 200 | 1 450 | 4 300 | 52 000 | 9 700 | 8 000 | 90 000 | 10 000 | 50 450 | 66 000 | 108 000 |
| Jordan | 190 | 650 | 43 | 388 | 791 | 63 | 700 | 900 | 160 | 883 | 1 242 | 1 760 |
| Kuwait | 295 | 80 | 8 | 375 | 110 | 105 | 1 100 | 140 | 160 | 383 | 590 | 1 400 |
| Lebanon | 271 | 875 | 65 | 312 | 950 | 150 | 1 100 | 2 300 | 450 | 1 211 | 1 412 | 3 850 |
| Oman | 117 | 1 150 | 5 | 262 | 1 500 | 85 | 630 | 1 500 | 350 | 1 272 | 1 847 | 2 480 |
| Qatar | 107 | 109 | 9 | 147 | 185 | 15 | 230 | 205 | 50 | 225 | 347 | 485 |
| Saudi Arabia | 1 508 | 14 600 | 192 | 2 350 | 15 000 | 415 | 6 450 | 16 300 | 1 450 | 16 300 | 17 765 | 24 200 |
| Syrian Arab Republic | 650 | 6 930 | 146 | 1 280 | 15 370 | 480 | 2 825 | 19 430 | 1 300 | 7 726 | 17 130 | 23 555 |
| United Arab Emirates | 513 | 950 | 27 | 750 | 1 400 | 30 | 1 100 | 2 050 | 50 | 1 490 | 2 180 | 3 200 |
| West Bank and Gaza Strip | 78 | 140 | 7 | 260 | 217 | 18 | 800 | 420 | 70 | 225 | 495 | 1 290 |
| Yemen | 168 | 2 700 | 31 | 360 | 3 150 | 61 | 840 | 3650 | 134 | 2 899 | 3 571 | 4 624 |
| Total | 10 509 | 123 204 | 6 600 | 13 866 | 150 697 | 16 498 | 30 244 | 206 266 | 25 243 | 140 313 | 181 061 | 261 753 |

*Source: Compiled by the ESCWA secretariat from country papers, regional and international sources (1992, 1994, 1995, 1996, 1997 and 1999), and questionnaires.*

## B.EFFICIENCY IN WATER USE – MANAGING DEMAND

The integrated approach calls for the implementation of both supply and demand management measures to balance supply and demand. Module 8 (Balancing Supply and Demand) discusses the various options for meeting supply and demand. One essential option is demand management. In the second part of this module demand management option will be analysed through case studies.

In most of the ESCWA member States there is a need for simultaneous implementation of supply and demand measures. In the past, water supplies were developed to meet demand; however, this practice has led to the mismanagement of water resources. Supply and demand management literally means the application of a range of physical and economic tools to increase water supply availability and produce greater efficiency in water utilization. Demand management measures are usually implemented to curtail and control demand in order to ensure that a limited supply will be able to satisfy demand. Demand management includes the implementation of water-saving technology, public awareness efforts, rebates for retrofitting, the modification of existing building codes, leak detection, pricing mechanisms and regulatory schemes. Supply management is intended to complement demand management through cost-effective programmes for water desalination, artificial recharge, the reuse of renovated water, recycling, the use of water of marginal quality, and water harvesting. The main objectives are to reduce waste, increase supplies and better protect water quality. The implementation of demand management measures, supported by enforcement measures, has been shown to contribute significantly to the alleviation of water shortages and the efficient use of water, especially in the agricultural sector.

Demand management reflects a major shift in the approach to water resources management, away from traditional supply development (construction of physical infrastructure to capture more water for direct use) to an improvement in efficiency of use, conservation, recycling and reuse of water. Demand management looks at changing demand and the way people use water in order to achieve more efficient and cost effective water use. It can help to reduce wasteful use of the resource, which represents an opportunity lost as well as the use of water without an economic purpose. Demand management can sometimes obviate the need for physical or infrastructure investments, providing real efficiency gains to society. Demand management works best in an IWRM framework, which looks across sectors and makes proper links between policy instruments and impacts.

Demand management applies at river basin level, at the level of large users of water (utilities, industry), and at the level of agricultural users and households and communities. While different techniques may be used at each level the approach is similar. Demand management aims directly to change human practice and behaviour and is hence linked closely with social change instruments, regulatory and economic instruments and communication and knowledge. The use of demand management should be supported in the overall policy framework and built into planning for IWRM. Serious effort is required for demand management since most water users believe they have a right to use (and waste) water freely, without appreciating the impacts of wasteful water use on society and the environment. Education should change attitudes in the long term and communication campaigns are needed to change short-term behaviour on water saving in drought emergencies.

The key to improved efficiency lies in setting up mechanisms for changing peoples' attitudes and behaviour towards water use. Such mechanisms include:

- *Education, awareness campaigns and communication*, including programmes to work with users at school, community and institutional level;
- *Economic incentives* including tariffs and charges for water use (domestic, industrial, agricultural) and for provision of environmental services (module 10);
- *Subsidies or rebates* for more efficient water use can be useful.

*Regulations and byelaws* can be used to set standards for water consumption. These may explicitly aim to prevent "waste, misuse or undue consumption" in public water supply. Byelaws and regulations can also cover standards and use of water appliances, e.g. water fittings and appliances, which are required to achieve minimum standards of water efficiency. Such tools can change behaviour and stimulate the introduction of lower water consumption technologies. (Module 3)

*Technologies for reducing consumption* vary by application and context - e.g. drip irrigation to replace flood irrigation; and retrofitting and pressure reduction. In agriculture, crop patterns are modified to reduce water use (France, Tunisia). Shifting management of irrigation water at field level to farmer groups (governments retaining bulk supply responsibility) creates the possibility of more efficient use and can make volumetric charging possible. (Module 13)

## *B.1 Recycling and reuse*

Recycling and reuse is a useful planning and management tool at *the river basin level*. Urban effluent can be treated and returned to aquifers or rivers for dilution by natural flows and re-abstraction downstream (although there is a need to ensure the quality of returning effluent will not impose ecological or health risks). Treated effluent from industrial or municipal treatment plants may be piped directly for use in agriculture and horticulture (although the level of treatment should be adequate to minimize health risks, and recycled sewage only used for crops with low uptake of water/pathogens). Irrigation return water from drainage canals can be reused if mixed with fresh water. Water returned to rivers or used for groundwater recharge should be controlled in both quality and quantity by discharge permits or other regulatory tool, which take into account the needs of the aquatic environment and water available for dilution.

Recycling and reuse is feasible for *individual water users* in industry, institutions and large buildings, and even at household level, to make the most of available water through recycling treatment processes. For instance, in water-short urban areas, water from rooftops or paved surfaces can be used for toilet flushing, some-times with additional grey wastewater.

Recycling and reuse has wide applicability in general, but particular techniques or levels of recycling and reuse depend on local priorities and possibilities, and economic feasibility. It is most appropriate in areas where there are extreme water shortages, high water costs and high technical capabilities. High levels of technical management, monitoring and regulatory skills are needed for recycling and reuse to be both safe and effective. However, some less sophisticated techniques are being developed, such as guideline ratios for safe mixing of waste water and fresh water which can make this tool suitable for less developed areas. Also, low technology options of using gray water for irrigation are useful.

Use of recycling/reuse approaches can be stimulated through policy instruments (charges and tariffs which can increase the cost effectiveness of recycling and reuse,) and regulations and byelaws and incentive schemes to stimulate change. Regulations can be introduced to change industrial practice in water use. Awareness raising and the use of information and communication tools can stimulate recycling and reuse.

## *B.2. Improved efficiency of water supply*

Efficiency in the supply and delivery of water includes efficient use of the resource, as well as efficiencies in canal and pipe distribution networks. Efficiency of supply can take place on many levels. *Rainwater harvesting* is an approach whereby rain is collected and stored in the soil profile, or in tanks, ponds, or cisterns, providing water for irrigation or domestic purposes, rather than immediate evaporation. Rainwater harvesting is particularly useful where rainfall is highly seasonal and can reduce the volume lost to the community in run-off. It has applications in both rural and urban areas where rainfall can be collected from roofs and hard surfaces.

At the level of water utility, efficient supply management may involve improvements in: abstraction, treatment, bulk transfers, local distribution, consumer meters, revenue collection, appropriate economic analysis and accounting procedures. Important tools for improving water supply efficiency for utilities include: universal metering, distribution zone metering and leakage and pressure reduction. See Box 5 as a case study

Dual supply systems of different water quality for different uses can be a cost effective option (and may be useful for recycling and reuse). In irrigated agriculture where there are often heavy water losses before the water reaches users (up to 50%) there is considerable scope for improvement. Improvements in conveyance and distribution and field application can be used to change traditional open canal systems to pipe conveyance and sprinkler/drip irrigation.

A balance needs to be struck between the capital investment needed to expand supply capacity and investment in operations and maintenance, and the cost of rehabilitation to make the most efficient use of existing resources and facilities. Water savings will often postpone major capital investments in supply infrastructure.

*BOX 5: CASE STUDY ON REDUCTION OF LEAKAGE IN DRINKING WATER SUPPLY SYSTEMS: RAMMALLAH DISTRICT,*

Water is one of the most valuable natural resources in Palestine. Therefore, it is very crucial for the Palestinians to achieve maximum efficiency in the management of their water resources. Many Palestinian localities still lack the existence of water networks while many others suffer from the poor conditions and high losses in their networks. A project was implemented to determine water leakage and procedures for leakage reduction in the existing network in Rammallah District.
The method is based on three main steps:

- Tracing leaks of the supply network by means of tightness tests and measuring minimum night flow;
- Pinpointing the leaks;
- Repairing leaks.

Consequently, the amount of leakage for the study area was found to be 176601.6 m3/year. Pinpointing and maintenance actions were applied. Consequently, the amount of leakage will be largely reduced (from 5.6 L/sec to 0.16 L/sec) i.e. $117,556 is saved yearly. The network should be monitored continuously in order to detect leaks as soon as they occur.

*Source: Mimi et al 2003*

## C. EXERCISES

1. The trainees can discuss the case study in Box 6 and identify similar cases from their counties

2. The trainees can list demand management options that could be adopted in their countries.

*BOX 6: CASE STUDY ON MOROCCO: DEMAND MANAGEMENT IN URBAN WATER SUPPLY*

This case study highlights the problems facing the drinking water supply of the Rabat-Casablanca coastal area and the measures taken to reduce water demand. These measures are linked to technical issues, tariffs and the implementation of new ways of managing the drinking water and sanitation departments.

**Main IWRM Tools**
C3. EFFICIENCY IN WATER USE – Managing demand and supply
C3.1 Improved efficiency of use
C3.3 Improved efficiency of water supply
C7. ECONOMIC INSTRUMENTS - Using value and prices for efficiency and equity
C7.1 Pricing of water and water services

**Description**
Since the 1930s, the drinking water supply of the Rabat-Casablanca coastal area has depended on water transfers from groundwater. Assessments carried out during the 1980s, based on patterns of water use at that time, showed that by 2010, transfers would have to be extended to include the surface water of Oued Sebu, if water requirements were to be met. The investments required to realise this water transfer together with investments in production, distribution and sanitation in the Bou Regreg Basin would have been considerable, as well as incompatible with the State budget. This situation highlighted the importance of water demand management to balance water demand with the water available. Within this framework, a policy initiative was undertaken to contain the water demand of the area. This was based primarily on tariff measures, raising awareness of water saving opportunities among users, improved efficiency of supply (production and distribution) and involvement of the private sector in water distribution. Implementation of this policy led to a significant reduction in water demand in the area:
- A decrease in the production of drinking water of almost 20 million m3 in Casablanca and Mohammedia between 1998 and 2000;
- A decrease in the production of drinking water of almost 10 million m3 in Rabat and Bouznika between 1998 and 2000 and
- A predicted drop in water demand of about 30% by 2020.

**Lessons learned**
- Strong integration of water demand management in water policies was very effective in strengthening the country's water security;
- Involvement of the private sector in water resources management can be an effective solution to water resource management problems and
- An adequate tariff structure is the principal measure for encouraging a water economy.

**Importance of case for IWRM**
The results obtained highlight clearly the importance of water demand management:
- Water savings are likely to be produced;
- Reduction of water discharges will ensure the protection of the natural environment;
- Strong participation of water users for financing water resources management and
- Substantial reduction in investments for the realisation of works.

All these aspects reinforce the significance of an integrated management approach to water resources use practices or subsurface activities.

*Source: GWP ToolBox - Case study No. 103, 2003*

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