# SIMPLIFICATION OF PLANNING TO MEET FUTURE DEMANDS FOR FOOD AND WATER

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## ABSTRACT

There is now insufficient food for half of the world's population and in many areas the population is increasing faster than the food supply. Part of the current food supply is produced by depleting groundwater, overgrazing, degrading agricultural lands, and slash and burn agriculture. In order to conserve resources for future generations, these practices need to be eliminated. Countries with a good food supply also have good population stability. If food production from irrigated alluvial lands can be increased fast enough, then irrigated agriculture can stabilize population growth and greatly reduce the depletion of resources. Slash and burn agriculture results in deforestation, flooding of alluvial lands, and erosion. High priority needs to be given to eliminating this practice. This paper present methods and equations for simplifying water resource development planning and management. The World Water and Climate Atlas is briefly described. Development of a surface water Atlas is proposed. Some of the benefits that have resulted from the construction of large dams and the irrigation of alluvial lands are described.

## INTRODUCTION

There is increasing concern relative to the world's future supplies of food and water. Within a 30-year period (1970 to 2000) the world population increased 62 percent while grain cropland per person declined 36 percent. Storm damage increased 40 fold. (See World•Watch, March/April, 2000.)

Rangelands are overgrazed and degraded. Some large areas of grain lands have gone out of production due to erosion. Grain comprises 80 percent of the world's food chain. Food production from slash and burn agriculture needs to be decreased and gradually eliminated. Increased production from irrigated agriculture can reduce resource degradation.

Unfortunately, perhaps 20 to 25 percent of presently irrigated lands are irrigated by overpumping ground water. As water tables decline, much of these irrigated

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areas will go out of production. An estimated 29 percent of irrigated lands are subject to salinization, (Suarez 2002). Some of these lands may be reclaimed but others will be taken out of production permanently.

In many developing countries, increasing use is made of slash and burn agriculture. This practice is very destructive of many natural resources. Erosion and flood damage are increased. Valuable timber is destroyed. The smoke from the fires interrupts transportation and commerce and increases health problems.

Prescott-Allen (2001) indicates that, based on 1996-97 data, 50 percent of the world's population have insufficient food and only 10 percent are indicated to have a good food supply. Food sufficiency is rated based on the World Health Organization targets. There should be less than 20 percent prevalence in the stunting of children and no more than 10 percent for the prevalence of low birth rates when food is adequate.

Prescott-Allen (2001) proposes the objective of a stable population. Of 180 countries rated for stability of population, 60 are rated as good and 42 as bad. Most countries with a good or fair food sufficiency are also rated as having good or fair population stability. Afghanistan has the lowest rating of food sufficiency (27 percent) and has poor population stability.

Almost one fifth of the world's population lives on less than $1.00 a day, (World Bank, 2001). Almost half of the world's population lives on less than $2.00 a day and millions, mainly children, go to bed hungry at night (Wolfensohn 2000). In China, India, and 54 other countries there is not enough material goods and income to secure basic needs and decent livelihoods, (Prescott-Allen, 2001).

There is a need to conserve resources for use by future generations. Slash and burn agriculture, overgrazing, overpumping of groundwater, and the degrading of agricultural lands should be reduced and if possible eliminated. It is proposed that the rate of irrigation development be accelerated to facilitate the reduction of production from sources that are non renewable or damaging to the environment. This will require an increase in water storage facilities and in transbasin diversions. In a period of rapid technological advances it would be irresponsible to fail to meet these needs. Good policies for resource use and conservation will also reduce violent conflicts (Renner, 2002).

The ecosystem wellbeing index is not rated as good for any country but is rated as bad or poor for 40 countries. Land and water use are not good in any country. Land use is bad or poor in 58 percent of the countries and water use is bad in 47 percent (Prescott-Allen, 2001).

The low-income countries with more than 40 percent of the world's population are attempting to industrialize. If they were to now have $CO_2$ emissions per capita equal to that of the United States it would more than double the worlds $CO_2$ emissions. Considering projections of population increases and increases in $Co_2$ emissions from the other countries, the potential harmful effects are cause for serious concern. There is urgent need for a careful evaluation of these effects. Also the high-income nations should assume an obligation to use their wealth and technology to help low income countries develop without depleting or polluting resources and without doing harm to the world's ecosystem wellbeing.

The objective of this paper is to call attention to an approaching food and ecosystem crisis and to present suggestions of methods that are designed to simplify and facilitate planning for the future sustainable development of land and water resources.

## METHODS AND EQUATIONS

A moisture adequacy index (MAI) was developed for use by the Inter American Geodetic Survey (IAGS) in natural resource inventories. Reference crop evapotranspiration ($ET_o$ as defined later) is used as the index of water requirements. The 75 percent probable rainfall amounts ($P_{75}$) are compared with $ET_o$. The equation for moisture adequacy is:

$$MAI = P_{75}/ET_o \qquad (1)$$

$P_{75}$ can be computed from the mean rainfall (Pm) and its standard deviation (SD). The relationship is:

$$P_{75} = Pm - 0.74\ SD \qquad (2)$$

Values of MAI have been used for studies of rainfall adequacy for many countries. The usual time step has been monthly, although some studies have also used 10-day and shorter time steps.

Hargreaves (1975) related relative water adequacy (X) to relative yield (Y) where Y = 1 for the maximum yield under prevailing conditions and X = 1 for the water required for maximum yield. The equation is:

$$Y = 0.8\ X + 1.3\ X^2 - 1.1\ X^3 \qquad (3)$$

Reference crop evapotranspiration ($ET_o$) as used in this paper is as defined in FAO Irrigation and Drainage Paper 56 (Allen et al. 1998). Hargreaves (1977) found that $ET_o$ could be calculated from mean temperature ($T_m$) and solar radiation ($R_s$). The equation in degrees Celsius is:

$$ET_o = 0.0135\ R_s\ (T_m + 17.8) \qquad (4)$$

Equation 4 was used in various country-wide studies and by Utah State University in two worldwide studies. Due to the paucity of reliable measured data for $R_s$, data from the Atlas by Lof et al. (1966) were used. Wu (1997) evaluated (4) and recommended that this equation be used for irrigation scheduling.

$R_s$ can be computed from the temperature range (TR) and extraterrestrial radiation ($R_a$) where TR is mean maximum minus mean minimum temperature. By combining the equation for $R_s$ with (4) the 1985 Hargreaves $ET_o$ equation was derived. The equation is:

$$ET_o = 0.0023\ R_a\ (T_m + 17.8)\ TR^{0.50} \qquad (5)$$

where $T_m$ is in degrees Celsius and $ET_o$ and $R_s$ are in the same units of equivalent water evaporation.

Equation 5 has been evaluated by comparisons with the FAO Penman-Monteith $ET_o$ method with data from various well watered sites. For a time step of five or more days the comparisons are very acceptable. Equation 5 has been recommended for use by ASCE and FAO (Allen et al. 1996 and Allen et al. 1998). Unfortunately, various attempts to evaluate (5) have been made using data from various non-irrigated sites. Some of these have included data from several dry months. Comparisons using data from both irrigated and non-irrigated sites in the same climate indicates that computed values for the dry months are biased by aridity. The FAO-Penman-Monteith values may be biased as much as 30 percent. Those from (5) are biased also but only about half as much. Therefore, data from non-irrigated arid and semi-arid sites should not be used for calculating $ET_o$ by means of the FAO Penman-Monteith method, unless adjustments of the data can be made to correct for site aridity.

Hargreaves (1988) reviewed the literature on extreme rainfall distributions. Various researchers have reported a worldwide similarity of distributions. Extreme rainfall events vary in depth (D) with the fourth root of the duration (t) and the return period (T). In equation form:

$$D = K\ (t \times T)^{0.25} \qquad (6)$$

As a result of numerous comparisons with the Gamma probability distribution, it was found that the 20 year return period rainfall amount ($P_{05}$) can be calculated from the mean (M) and the standard deviation (SD). The equation is:

$$P_{05} = M + 2.05\ SD \qquad (7)$$

Equation 7 can be used for events other than rainfall.

## WORLD WATER AND CLIMATE ATLAS

The Atlas was developed jointly by the International Water Management Institute (IWMI) and the Utah Climate Center at Utah State University with funding from the Government of Japan and with cooperation from other agencies and institutions. Global coverage is provided at 2.5-minute grid spacings. The data used are for the period 1961-1990. Annual, monthly, and 10-day summaries are given. The temperature parameters are: average, mean daily maximum, and mean daily minimum. The precipitation parameters are: total (P), 75 percent probability ($P_{75}$), number of days with precipitation (DWR), and the standard deviation (SD). The agricultural parameters are: $ET_o$ (from 5), MAI, and NET (NET = $ET_o - P_{75}$).

Information on how to use the Atlas can be obtained from IIMI@cgnet.com and the Atlas is available on the Internet at http://www.iwmi.org, http://www.cgiar.org/iimi, or http://climate.usu.edu. Hargreaves and Merkley (1998) describe the Atlas and some of its uses.

A digital elevation model (DEM) is available for use with the Atlas. For most of the world the interval is 30 arc seconds. Also, most of the world has been mapped at a scale of 1:50,000 with a 20 m contour interval. Sometimes use of the topographic maps is restricted because of the military value of these maps. However, the maps are usually available to responsible individuals provided the benefits from their use are properly documented. The DEM is available from the U.S. Geological Survey as described by Lacroix et al. (2000).

## CLASSIFICATION OF CLIMATE

Hargreaves and Merkley (1998) prepared a summary of optimum and operative temperatures for five crop groups. Most crops are in two groups. One has a minimum operative temperature of 5°C and the other of 10°C. Hargreaves (1977) proposed two classifications of climate. One is based on temperature and the other on the Moisture Availability Index (MAI). The MAI classification is presented as Table 1.

Some judgment is required in using Table 1 since adequate moisture at low temperatures does not promote plant growth, except when stored in the soil and used later.

The annual depth of runoff for each of the seven MAI classifications was calculated from long-term averages of surface runoff for the United States. The values shown in Table 1 are averages. There was significant variation in runoff for each classification. This may result from differences in temperature, land use, soil depth texture and permeability, vegetation, and rainfall distribution and intensity.

Hargreaves et al. (2001) made some comparisons using runoff records from tropical countries. Where comparisons were made, the runoff from tropical watersheds was more than the averages obtained for the runoff data from the United States.

Table 1. MAI-Based Climate Classification and Average Annual Runoff

| **Climate Classification** | **MAI Criteria** | **Water Constraints on Productivity** | **Average Runoff in mm** |
|---|---|---|---|
| Very Arid | All months with MAI □ 0.33 | Not suited for rainfed agriculture | 15 |
| Arid | 1 or 2 months with MAI □ 0.34 | Limited suitability for rainfed agriculture | 35 |
| Semi-Arid | 3 or 4 months with MAI □ 0.34 | Suitable for crops requiring a 3 to 4 month growing season | 120 |
| Wet-Dry | 5 or more consecutive months with MAI □ 0.34 | Suitable for crops requiring a 5 or more month growing season | 200 |
| Somewhat Wet | 1 or 2 months with MAI > 1.33 | Natural or artificial drainage required | 290 |
| Moderately Wet | 3 to 5 months with MAI > 1.33 | Good drainage required | 440 |
| Very Wet | 6 or more months with MAI > 1.33 | Very good drainage required | 935 |

## A STREAM FLOW ATLAS

A world Atlas of runoff from watersheds would be very useful for purposes of development planning. A summary should be made of existing records. This should include 10-day, monthly, and annual means and standard deviations. Various methods for estimating runoff from climate could be tested and evaluated. Estimates could be made for unmeasured watersheds. IWMI has indicated interest in finding ways to estimate runoff from climate data.

## DAMS AND DAMSITES

Almost half (three billion) of the world population live on less than $2.0 a day and millions, especially children, go to sleep hungry every night (Wolfensohn, 2000). Half of the world population has insufficient food (Prescott-Allen, 2001). What would the world be like without food production made possible by existing dams? Some become emotional about the beauty of wild and scenic rivers. Sometimes the benefits of dams to the environment are overlooked.

In Greece, the Truman Doctrine (American Aid for Greece and Turkey) provided assistance for the construction of large dams and appurtenances for flood control. These activities lead to rural electrification and a rate of development that increased the economy four-fold in 20 years. Herding of goats, cutting of firewood, and farming on steep slopes became uneconomical. This made possible the reforestation of hundreds of thousands of hectares of eroding mountains.

In Brazil, during the 1960's and 70's the air in the large cities became very polluted. This is also a problem in many of the world's large cities. Then in Brazil large dams were constructed and large areas were planted to sugar cane. Sugar cane was used to produce alcohol and alcohol was substituted for gasoline. The change from fossil fuels to energy from alcohol and hydropower cleared the pollution in the cities. This improved the environment in Brazil and reduced the emissions of greenhouse gasses thereby providing worldwide benefits.

In California, as dams and flood control facilities were constructed and valley lands were irrigated, there was a resulting rapid decline in the non-irrigated farming of steep hillsides and mountainsides. Dams facilitated soil conservation and erosion control.

Slash and burn agriculture is increasing in many countries. Data are scarce on the extent and the harmful effects of this practice. A careful evaluation is needed. Dams for flood control and the irrigation of alluvial lands could provide a valuable alternative to slash and burn agriculture.

There is evidence that not to reduce carbon dioxide emissions would truly damage the global economy. The nuclear option is of highly questionable viability. Of all other non-carbon alternative energy sources, low-head waterpower from small dams is the least expensive. The next least expensive is wind (Ayres, 2001). Wind is now becoming competitive with coal and oil. It is not only a clean energy source but is a rich source of new employment (Renner, 2001).

In Brazil, during the 1960's, USAID provided assistance by arranging for studies made by the US Bureau of Reclamation. Dam sites and resources were investigated. These studies resulted in significant development. Fourteen dams were constructed in the State of Bahia. For these USAID furnished the services of an engineer. Half of the labor was paid in food from the Food for Peace Program. The U.S. Army donated the construction equipment from surplus and the Brazilian Army operated the equipment as a training exercise. This type of development could be included in the planning for food sufficiency. It would seem desirable for use in countries critically short of food such as Afghanistan.

The DEM and available topographic maps can be used to identify potential damsites. Priority should be given to locating economically feasible off stream sites and to locating suitable transbasin diversions form wet areas to arid areas. Sites for dams should be selected so as to minimize flooding of alluvial lands and displacement of people. A world inventory of suitable dam sites is recommended.

## SOME ADAPTATIONS OF METHODS

The moisture availability index (MAI) has been used to determine the level of water adequacy required for the use of fertilizer to be economical. IWMI (1999) mapped MAI for South Asia and related monthly values to the relative yield equation (Eq. 3). MAI has been used in Iran and El Salvador to determine when and where it is economical to apply fertilizer.

Equations 6 and 7 can be used with the Atlas values for 10-day rainfall amounts. Twenty-year return period extreme depths of precipitation for a duration of 10-days can be converted to other durations and return periods by means of Eq. 6.

The Atlas and Table 1 have been used for determining areas of excessive rainfall that may be used in transbasin transfer to irrigate arid and semi-arid lands. The Atlas can be also used for determining irrigation requirements, needs for drainage, probable flood risks and for many other uses.

## SUMMARY AND CONCLUSIONS

The world's population is increasing. About half of the present population lack sufficient food. Rangelands are overgrazed. Cropland is being degraded. Most of the required increase in food production must come from irrigated lands. However, due to overpumping of groundwater and salinity irrigation is not sustainable on a significant portion of the presently irrigated lands.

Methods and equations are given in order to facilitate planning for future increases in irrigation and in food production. These include a rainfall adequacy index (MAI), a water-related relative yield equation, and equations for extreme rainfall depths of fall.

Use of a MAI-based classification of climate is proposed. This classification is recommended over other classifications because it relates to the potential for food production and to water availability from rainfall for crop production. It can be used to estimate values of annual runoff and to determine when and where it is profitable to fertilize non-irrigated crops.

A world streamflow Atlas is proposed. This Atlas would be a summary of available long-term runoff records and would include correlations and estimations based on the relationships between climate and runoff.

About half of the world's population lives on less than $2.0 per day and millions, especially children, go to bed hungry every night. The population of many developing areas is increasing faster than the food supply. Groundwater resources are being depleted. Various farming practices are destructive of resources. Most of the required increase in food production must come from increases in irrigated area. When consideration is given to the competing demands for water, there seems to be no viable alternative to storing and transporting more water.

A world inventory of possible new damsites is proposed. There has been far too much emotion relative to the construction of dams. Increasing effort should be made to mitigate possible adverse effects of dams. However, dams now have a very important role in food production, environmental protection, and in the production of clean energy. There have been large benefits to the environment from the positive effects from dam construction. If priority can be given to minimizing the flooding of alluvial lands and the displacement of people and to finding off-stream sites and more efficient means of allowing fish to pass through or around dams, there will be less opposition to their construction.

The present food shortage is to an important degree due to the increase in population. However, a good food supply stabilizes population. By increasing the area under irrigation and increasing the food supply the world's population can be stabilized.

In Brazil, renewable energy was developed to replace much of the use of fossil fuels. A worldwide emphasis on research and development of renewable energy is needed. The world's leading economics should provide leadership in this effort. This effort could have a large positive effect on the future environment.

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