

## PLANNING TO MEET FUTURE WATER NEEDS

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### ABSTRACT

Conservative projections foresee world population growing from approximately six billion to over eight billion people by 2050. During that same period, per capita food grain production, irrigated area, and the income of the poorest 20% are expected to decline. As a result, much of the world's population faces a future of poverty and hunger. These people, forced to the economic margins, often engage in harmful agricultural practices-fanning steep slopes, slash-burn agriculture, overgrazing-which increase soil erosion and flooding. In the context of growing population and poverty, this paper discusses several water-related issues: irrigation, depletion of groundwater, drainage, and flood control. Also discussed are the roles of government and the private sector in water resource management. Finally, it discusses the question of resource conservation or development, concluding that before conservation becomes a viable choice (especially for the poor), development is necessary. To help plan sound water projects in the future, this paper advocates the development of a global water resource inventory. It describes a start toward such an inventory-the IWMI "World Water and Climate Atlas"-and how it can be used.

### INTRODUCTION

Thomas Malthus published his *Essay on the Principle of Population* in 1798. In it he argued that without the checks of disease, war, and famine, humankind was doomed to eventually outgrow its ability to feed itself. Simply put, the geometric nature of unrestrained population growth would literally eat up any conceivable increase in agricultural production. His pessimistic vision destroyed the optimism of his age. After Malthus it seemed that the advances of modern science and technology no longer heralded a future of increasing and unbounded prosperity for everyone (Heilbroner, 1986).

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Today, in spite of enormous increases in agricultural productivity, the Malthusian vision continues to haunt the world. Current world population is approximately six billion. By 2050, conservative estimates predict that it will exceed eight billion; a simple extrapolation of the present rate of growth predicts that it will exceed ten billion. What makes this alarming is that, while agricultural production will undoubtedly increase, it is unlikely to keep pace. For example, 80% of the world's nutritional needs are met by the major food grains: wheat, rice, and maize. At current rates of growth, the production of these grains per capita can be expected to drop to 71 % of current levels; irrigated area per capita can also be expected to drop to 80% of current levels (Brown, et al., 1997; Brown, et al., 1998). Note that these numbers do not include the long-term effects of many current agricultural practices which deplete groundwater, pollute the environment, erode steep slopes, and create flood damage. If continued, such practices will push these numbers even lower.

Further complicating this scenario is the fact that 98% of population growth is in the developing world (National Geographic Society, 1998b). Unfortunately, some developing countries do not have the institutional and legal frameworks needed for planning and implementing sound long term agricultural and environmental policies. Others lack the political will to ensure that their populations are fed (Reid, 1998). Even where food supplies are plentiful, extreme poverty leaves many people without the means to feed themselves (Sen, 1981). Today, such problems have left about 20% of the world's population chronically undernourished and nearly the same amount without a reliable source of safe drinking water (Reid, 1998).

Escaping a Malthusian future is possible. To do so, it will be necessary to work on a global scale to expand the food supply, to reduce reliance on non-renewable resources, to decrease pollution, to control climate change, to increase economic prosperity, to promote stable and responsible governments, and, ultimately, to stabilize the population. This paper addresses only a small part of the solution: meeting future water needs.

In 1997 the International Water Management Institute (IWMI) and the Utah Climate Center at Utah State University (USU) set out to develop and publish an atlas of water and climatic data. With support from the governments of Japan and the United States an atlas for Asia was developed. This atlas provided an initial inventory of Asian water resources: reference evapotranspiration ( $ET_0$ ), 75% precipitation probabilities ( $P_{75}$ ), an index of the relative adequacy of rainfall for crop production ( $MAI = P_{75} / ET_0$ ), an estimate of the surplus or deficit of rainfall in meeting crop requirements ( $NET = ET_0 - P_{75}$ ), and the basic climatic information needed to use this information in simple crop models. IWMI has

continued to expand and refine the atlas and data products with various partner organizations (IWMI, 1999a).

To deal with the water resource issues facing the world between now and the year 2050, it is recommended that the IWMI atlas be supplemented with other land and water resource inventories, including: surface water availability, possible reservoir sites, and potential areas for irrigation. In addition, the development of the tools needed to make the best use of this information is suggested. By helping assess probable costs and benefits, such inventories and tools would enable developing countries to plan and develop irrigation, drainage, hydropower, and flood control projects that are both economically and ecologically sound.

## WATER RESOURCE MANAGEMENT

### Managing a Scarce Resource

Considered on a global scale, the fresh water resources of the planet are more than adequate to meet all foreseeable future needs for agricultural, industrial, and domestic uses. However, considered on regional and local scales, the ability to meet water demands in some areas is limited. Geographic and seasonal variations in weather patterns create surface water shortages that have forced the development of ways to survive in desert regions and to cope with periodic droughts.

In excessively arid areas and seasons, groundwater has often helped meet shortfalls in water demand. Unfortunately, this is frequently a non-renewable resource and many areas of the world have become excessively dependent upon it for irrigation. In China, nearly all river basins depend on the over-pumping of aquifers. In India, seventeen districts have seen aquifers permanently depleted. Chronic over-pumping and aquifer depletion for irrigation also continues in central Mexico, California, the Great Plains of the United States, the Arabian Peninsula, and North Africa. Of the approximately 250 million hectares of irrigated land in the world, some 50 to 60 million are now irrigated from non-rechargeable groundwater; these will probably be forced out of production by 2050 unless adequate surface water supplies can be developed (Brown, et al., 1998). Sound resource conservation policies would reserve this non-renewable resource for making up serious deficits in surface water supplies during drought years.

Damming and diverting surface water to meet shortfalls is generally preferable to over-pumping aquifers. Unlike much groundwater, surface water is a renewable resource. With careful planning and management, water use can be balanced with

the amount of surface water available on a one-year, ten-year, or longer basis. Still, there are serious problems to be resolved.

Of these, the most intractable are the political conflicts over water in the arid regions of the world. In more than two hundred river basins, water is shared by two or more countries. Some twenty-two countries depend upon the flow of water from another country. Frequently, the season of maximum water demand is also the season of minimum water availability. Conflicts over who gets water and how much are almost inevitable. There is a need to come up with, and implement, practical solutions for providing enough agricultural, industrial, and domestic water for everyone. Unless this can be done, political tensions over water will only build over the next half century for, by the year 2050, some four billion people will live in regions that suffer severe water shortages (Simon, 1998).

Most recommended solutions are stopgap measures at best. Implementing policies to encourage water conservation and to reduce water pollution will, in the short term, ease demand by encouraging more efficient use of existing water supplies. While currently too expensive for agricultural and industrial uses, desalinization of seawater would increase the supply of available water. However, by themselves, these measures will not meet the demands of a growing population. Projected agricultural needs alone dictate that new water supplies must be developed.

Irrigation for agriculture in arid regions (about one-third of the inhabited area of the world) or during a dry season (often three or more months even in otherwise wet areas) is the principal consumptive use of water. In the United States, this amounts to an average annual application of irrigation water of 570mm. About half of this amount is from surface water. This is only 11% of the average annual flow of the Mississippi River and only 14% of the average annual surface runoff of the rainiest one-eighth of the continental U.S. Other areas of the world have a similar situation. Clearly, a major part of present and future water needs could be met by taking better advantage of existing surface water resources.

By creating a systematic inventory of global water resources, the countries of the world can more easily identify solutions for local water shortages. Developing regional water storage and transportation systems requires knowing where and when the excess runoff occurs; knowing how much occurs; and, determining where it is both technically and economically feasible to site such systems. This kind of information exists-although in a fragmented and non-systematic form-for much of the United States and other developed areas of the world; it needs to be created for those underdeveloped areas where most of the water shortages in the next half century will, most likely, occur.

### Managing an Over-Abundant Resource

Somewhere between one-third and one-half of most continents suffer from excessive precipitation. This frequently results in significant reductions in land use or in damages due to flooding. In Colombia, about nine percent of the land area floods annually, rendering much of it unsuitable for agriculture. In China, record-breaking floods in the spring of 1998 affected more than 300 million people and killed tens of thousands (Binyan and Link, 1998).

In areas afflicted by too much rain, as well as in low-lying areas where surface runoff tends to collect for long periods, artificial drainage systems are often beneficial. Adequate drainage, whether artificial or natural, provides the soil aeration needed for crop root development and health. It also helps control the spread of disease. For instance, swampy areas have long been associated with malaria and yellow fever; drainage of these areas helps reduce the population of mosquitoes, the vector for transmitting these diseases.

Constructing dams for flood control can also be beneficial. Controlling the release of water down a watershed can reduce or eliminate flooding. As well as preventing deaths, this helps stop much of the damage to land, agriculture, and infrastructure that floods periodically cause. In addition, there are the obvious side benefits of generating hydropower, storing water for use during a dry season, and preventing the spread of water-borne diseases like cholera.

Still, dams are not a solution in all areas. Sometimes local ecosystems require periodic flooding to regenerate; in others, floods would not have occurred without a history of human damage to the environment. Many of the problems associated with excess precipitation, especially flooding and soil erosion, are caused by improper agricultural practices; in some developing countries this amounts to approximately 50% of the rain-fed agriculture. Farming steep slopes, slash-burn agriculture, and deforestation all destroy the capacity of the land to absorb precipitation and ease the flow of water down mountains and hills. Over-grazing destroys the plants whose root systems hold soil in place. Eliminating these problems would seem to be more ecologically sound-and, in the long run, less expensive-than building and maintaining dams. However, that may not be possible without a rapid rate of water resources development.

A global inventory of water resources would make it possible to assess the benefits and costs of drainage and flood control projects. Knowing how much precipitation generally occurs would help estimate hydropower potential. Flood prone areas could be identified. In turn, this would allow planning for the most ecologically sound and cost-effective ways to prevent or reduce flood damage.

Again, it is in the developing world where this information is most needed and would be most useful.

### Conservation or Development?

Although sometimes framed this way, addressing the world's present and future water needs is not a simple question of whether resources should be conserved or whether they should be developed. Conservation and development are not so easily separated. Conserving groundwater requires developing the surface water resources to replace it. Preventing various environmentally harmful practices, like farming on steep slopes and slash-burn agriculture, requires providing the poverty-stricken people who generally engage in these practices with some other, less destructive, means of feeding themselves. Land, water, and other resources need to be developed to the point that conservation becomes a viable economic choice for everyone.

Consider, for example, the case of Greece. In the late 1940s, the country was an environmental disaster. Most of the forests had been destroyed, the trees cut down to provide fuel. The mountains were eroded, torn apart by hillside farming, extensive overgrazing, and the resulting increase in flooding. Then, starting in 1947, large dams were constructed, new flood channels were excavated, rural electrification was provided, and private irrigation development was promoted. By 1968, the Greek gross domestic product (GDP) had quadrupled. Over those same twenty years, vast areas had been reforested and overgrazing was virtually eliminated. Farming on irrigated alluvial lands (and providing farmers with various goods and services) proved far more profitable than cutting firewood, overgrazing, or growing crops in mountainous areas.

In underdeveloped areas where population pressures-growth, poverty, migration-have led to or will lead to environmental destruction, there is a need to promote a rapid pace of resource development. Only if development can get ahead of population pressures and increase everyone's level of prosperity, will the survival of people at the economic margins no longer depend on making uneconomic and environmentally harmful choices. If this can be done, perhaps many economic and environmental travesties can be prevented; for instance, in Central America, poor people may not be compelled by their desperate situation to burn mahogany forests on steep slopes, to create an open patch of ground, to plant corn, to feed a starving family.

### Institutional Considerations

The world is rapidly developing a global economy in which everyone is interdependent. How one nation chooses to use or manage its land, water, and

energy resources can affect other nations; negative effects from poor choices are international, if not global, problems. As a result, there is an increasing need for international guidelines, agreements, and institutions to ensure cooperation on a global scale.

Historically, most governments have been poor managers of natural resources. Although many have created institutions to develop their resources, they have often been hampered by their focus on a single problem: controlling floods, or improving agriculture, or preserving the environment. Almost inevitably, various single-purpose agencies end up having opposing goals and competing with each other for scarce funds. Multi-purpose organizations, chartered to balance the costs and benefits of all purposes, have seldom been established.

Another frequent problem is that few governments have the institutional capacity and expertise required for resource development and use. In those that do, this capacity has sometimes eroded over the years. For instance, in 1902 the United States created the Bureau of Reclamation (USBR) to develop land and water resources on a river-basin-wide scale in the sixteen western states. By 1951 more than 100 dams and 33 power plants had been constructed. Internationally, the USBR provided its expertise in river-basin studies and planning in Asia, Africa, and Latin America. Unfortunately, the planning, design, and construction activities have largely ceased; emphasis is now on management and conservation.

Consequently, governments -- whether national or international -- should promote private-sector development of natural resources, including water. Private efforts would help ensure that projects are economically sound, as well as likely to last beyond the next change of government. To do so, governments need to create the legal and institutional framework that will encourage responsible private development projects. They need to pass and enforce laws which: provide private access to land and water resources on a competitive basis; prevent the destructive exploitation of those resources; and, promote multiple-purpose development efforts. In addition, they should develop, support, and use international institutions that will serve as the long-term repositories of the expertise and information needed for making sound resource development and conservation decisions.

In 1999, the Worldwatch Institute noted that the world's three richest people had assets that exceed the combined gross domestic product of the world's forty-eight poorest nations (Brown, et al., 1999). To end their needlessly inevitable cycles of poverty and hunger, these countries need to develop their land and water resources in an economically and environmentally sensible fashion. Perhaps, if these forty-eight poorest nations were to create the favorable circumstances outlined above,

they could attract sorely needed investments from the three richest people (and others).

## WATER RESOURCE ATLASES

### The IWMI "World Water and Climate Atlas"

International organizations like the International Water Management Institute (IWMI)-working with universities such as Utah State University (USU), the University of East Anglia (UEA), and the Australian National University (ANU)-are already working toward developing global resource inventories and the expertise to use them. With the development of the IWMI "World Water and Climate Atlas" (IWMI, 1999a), a start can be made to address-on a global and international basis-some of the technical, economic, and environmental issues involved in increasing irrigated area per capita, balancing available surface water with demand, improving agricultural potential in areas with poor drainage, and preventing flood damage.

For instance, this atlas provides the basic information needed for simple crop modeling. Minimum and maximum temperature data can be used to identify regions which meet the temperature requirements for specific crop cultivars. This information, combined with reference evapotranspiration and crop coefficients, enables the estimation of seasonal water requirements for the crops. Planners can then determine whether existing water resources are adequate and, if not, potential areas for their development.

As this atlas is refined -- with added and improved data, better analysis software, and more experience using the data -- it could become an important planning tool. By using a standard and readily accessible base of information, solutions that have proven beneficial in some areas can be evaluated for application in other similar situations. After all, given the current rate of population growth and barring some Malthusian disaster, there is a pressing need to better manage world water resources over the next half century. The information in this atlas provides a firm foundation upon which preparations for that future can be made.

### A Climate Classification Atlas

Since plant adaptation and the potential for rainfed agricultural production depend principally upon temperatures and water availability, a world atlas of climate classification for agriculture would be very useful as well (note that much of the base information is included in the IWMI atlas, but needs to be extracted and coupled with crop-specific information). To be useful, this atlas need not be



complicated. In fact, two climate classifications—one based on temperatures and the other based on water availability—would serve most planning needs (Hargreaves, 1977).

Table 1 shows the first of these climate classifications. This classification is based on monthly average temperatures and the length of the growing season. An atlas classifying the world on this basis, ideally combined with a comprehensive database of crop temperature requirements, would allow local planners to identify specific cultivars suitable for projects in their area.

Table 1. Temperature-Based Climate Classification

Climate Type	Temperature Criteria
Polar	All months below 10°C
Boreal	1 to 3 months above 10°C
Subtemperate	4 to 5 months above 10°C
Temperate	6 to 9 months above 10°C
Subtropical	10 to 12 months above 10°C
Tropical	All months at 17°C or above

The second climate classification, shown in Table 2, reflects water availability. This classification divides climates into seven classes based on a moisture adequacy index (MAI) which measures the water constraints on agricultural productivity for that climate.

MAI (sometimes used as  $A_{75}$ ) is easily derived from the 75% probability rainfall amount ( $P_{75}$ ) and reference crop evapotranspiration (ET<sub>o</sub>):

$$MAI = P_{75} / ET_o \tag{1}$$

In turn,  $P_{75}$  is most conveniently derived from mean precipitation ( $P_m$ ) and the standard deviation in the amount of rainfall (SD):

$$P_{75} = P_m - 0.74 SD \tag{2}$$

The 75% probable streamflow  $Q_{75}$  can be calculated from Eq. 2 by substituting  $Q$  for  $P$ . Note, however, that Eq. 2 is less accurate for use when  $P_m$  is less than 30%

of ETo; when this is the case, calculating  $P_{75}$  with a ranking distribution or other similar technique may be preferable.

Table 2. MAI-Based Climate Classification

Climate Classification	MAI Criteria	Water Constraints on Productivity
Very Arid	All months with MAI $\leq 0.33$	Not suited for rainfed agriculture
Arid	1 or 2 months with MAI $\geq 0.34$	Limited suitability for rainfed agriculture
Semi-Arid	3 or 4 months with MAI $\geq 0.34$	Suitable for crops requiring a 3 to 4 month growing season
Wet-Dry	5 or more consecutive months with MAI $\geq 0.34$	Suitable for crops requiring a 5 or more month growing season
Somewhat Wet	1 or 2 months with MAI $> 1.33$	Natural or artificial drainage required
Moderately Wet	3 to 5 months with MAI $> 1.33$	Good drainage required
Very Wet	6 or more months with MAI $> 1.33$	Very good drainage required

The criteria for the climate classes and the water constraints were based on research which used various crop trials to develop an empirical equation for relative yield (Y) as a function of water availability (X):

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

Note that  $Y = 1.0$  for maximum yield under prevailing conditions of fertility and management and that  $X = 1.0$  for the water required to produce that maximum yield. In the trials, the majority of data for X was in the range of 0.30 to 1.20. The research showed that with  $X = 0.30$ , Y was about one-third of potential; for  $X = 1.20$ , Y was about 93% of maximum; and, for  $X = 1.33$ , Y was about 78% of maximum. Essentially, Y falls off rapidly with increasing values of X (Hargreaves, 1975). Consequently, regions and time periods with MAI  $> 1.33$  need drainage to maintain production levels.

IWMI (1999b) used Eq. 3 and a modified classification to map agricultural potential for South Asia. The modified classification uses MAI of 0.38 replacing 0.34, and consists of the first four classes.

MAI is also relevant in terms of the application of fertilizer. Experience with dry farmed wheat in Iran indicated that fertilization was usually profitable when all months during the period of actual growth had MAI values above 0.33. In another case, a mass fertilization project in El Salvador financed by USAID failed because MAI values on many of the farms were too low during the pollination period. For fertilizer to be worth applying to increase yields, there must first be a minimum of moisture.

### A Surface Runoff Atlas

To identify areas for irrigation, drainage, flood control, or hydropower projects, planners need to know how much surface runoff to expect and when to expect it. Consequently, a resource atlas of surface runoff would also be extremely useful. Since runoff is determined principally by rainfall and evapotranspiration, it is possible to estimate surface water flow from these two parameters (both are included in the IWMI atlas). This is particularly valuable since measuring actual runoff levels can be difficult. Obtaining reliable data requires good equipment, well-trained personnel, adequate measuring site selection, and diligent field inspection. In addition, flood flows are hard to measure: frequently the rating curve must be extended significantly above measured data points; over-bank flow is difficult to estimate. Consequently, in areas lacking the resources and expertise to make actual measurements, it is often easier and cheaper to estimate runoff.

For a rough estimate of runoff, suitable for planning purposes, where extensive streamflow data are not available, the MAI climate classification can be used. For instance, Table 3 shows the average annual depth of runoff for the seven climate classifications derived from a study of 110 climate stations in the United States (Hargreaves and Samani, 1986; and, Geraghty, et al., 1973).

Table 3. MAI-Based Runoff Estimations

Climate Classification	Average Annual Runoff Depth (mm)
Very Arid	15
Arid	35
Semi-Arid	120
Wet-Dry	200
Somewhat Wet	290
Moderately Wet	440
Very Wet	935

By classifying the local climate, reasonable typical runoff values can be obtained. More accurate local estimates can be made by regressing the 75% probability stream flow ( $Q_{75}$ ) with the average monthly MAI occurring 15 days earlier (Hargreaves and Merkle, 1998). In a study of eight watersheds this yielded the following empirical equation (with an  $r^2$  of 0.92):

$$Q_{75} = 3.45 + 12.0 \text{ MAI} \quad (4)$$

If reliable streamflow data can be obtained for a nearby area, together with the climatic data for calculating MAI, a similar empirical equation can be developed which can be used to extend streamflow estimates to surrounding areas as well as to estimate local responses to severe storms.

A resource atlas which provides worldwide values of MAI coupled with reliable streamflow data is needed. This information, with the tools to analyze it, would enable planners to estimate typical local runoff as well as plan for extreme weather.

#### Other Resource Atlases

Several other land and water resources atlases are needed. These include: extreme rainfall, soils, and topography. Much of the data needed for such atlases exist in dispersed form, or collected without the tools to use them. For instance, a topographic atlas with a simple means of calculating slopes for a local area and, thus, identifying potential erosion problems would enable planners to select better sites for development projects and identify the potential costs associated with development there. An atlas of extreme rainfall possibilities would allow developers to calculate minimum parameters for various construction projects: the

minimum capacity for a canal, the minimum strength of bridge pilings, etc. A soils atlas, using standardized soils classifications, would be useful for both irrigation and construction.

Ideally, publicly funded international organizations (FAO, for example) would take on two tasks. First, they need to compile, maintain, and regularly update the data needed for these atlases; most importantly, these data need to be gathered on a consistent and world-wide basis. Furthermore, they need to make these data available in open, standard formats that will allow anyone to make use of the data (i.e., no proprietary data formats designed to force users to use a specific software package); in the world of the internet this would probably best be done with online databases, with published table structures and definitions, which could be accessed by anyone over the network with standard SQL database queries. Second, these organizations need to act as a clearing-house for the techniques used for analyzing the data. There should be approved, standard methods of analyzing the data for estimating extreme rainfall events, forecasting typical surface runoff, calculating evapotranspiration, etc. This way planning for various parts of the world, both costs and benefits, can be more easily compared. However, the software to apply these methods can and should be developed in the private sector, where market forces will encourage competition, resulting in cheaper software, the continued adoption of new technology, and rapid responses to changing user needs.

## SUMMARY AND CONCLUSIONS

The need for increasing water resource development is urgent. Without an accelerated rate of development, poverty, hunger, insecurity, and the degradation of the natural environment will increase. By 2050, if present trends continue, the world will be a place where severe droughts create intractable political conflicts in dry areas and severe floods destroy farms, infrastructure, and lives in wet areas. Groundwater supplies will have been pumped disastrously low and remain unreplaced. Potential irrigable lands will continue untilled and unproductive. Steep slopes will have been denuded, farmed, and abandoned to erosion. Forests will have been burned to open clearings, to plant crops for a year or two, and then vacated in favor of newly burned tracts of forest. In fact, through lack of use and support, the world may have lost the institutional capacity to develop our water resources. The ability to feed the world's population will have been severely damaged.

Unlike Thomas Malthus, the world need not peer blindly into a bleak future. In the two centuries since he published the *Essay on the Principle of Population*, the number of people in the world grew six-fold, from one billion to six billion

(National Geographic Society, 1998a). Nevertheless, over that period, the human race did not experience a worldwide Malthusian crisis of spiraling population, dwindling resources, and, as a result, declining levels of prosperity. Instead, there were immense increases in agricultural yields, industrial production, and, more importantly, populations in the developed nations of the world were stabilized. The lesson to be learned from the past two hundred years is that, although basically correct, Malthus did not see some of the subtleties in the connection between population and prosperity. Most notably, he did not realize that rapid and widespread economic development could tame population growth. If prosperity can be extended to the developing nations of the world quickly enough, their populations will stabilize and the poorest people will no longer be forced to the economic margins. With this process completed, there is every reason to believe that the world will face a future with enough resources to provide everyone with healthy, productive, and meaningful lives. Certainly, there are many complex obstacles blocking the way to world-wide prosperity. None is insurmountable. A concerted effort to inventory global resources—land as well as water—and to manage them in a careful, responsible fashion would be a beneficial first step.

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