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WATER STRESS AND WATER WARS*

Abstract

This essay argues three propositions: 1) By 2025 a significant share of the world=s population will be living in countries which are water-stressed, at least by conventional criteria. 2) Nevertheless, macro evidence does not portend that the world will be unable to feed its growing population at that time. 3) Interstate armed conflicts over water, which were not very important in the last quarter of the twentieth century, seem unlikely to become more intense in the coming decades, especially since most countries have not utilized the enormous possibilities for saving scarce water.

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WATER STRESS AND WATER WARS

According to the United Nations Environment Program (UNEP, 2001), AThe world water cycle seems unlikely to be able to cope with the demands that will be made of it in the coming decades. Severe water-stress already hampers development in many parts of the world, and the situation is deteriorating.≅ Lester Brown (2005: 40) adds another alarm: AAs the world demand for water has climbed, water tables have fallen in scores of countries, including China, India, and the United States, which together produce nearly half of the world=s grain.≅

Violent disputes over freshwater appeared at the very beginning of recorded history. Some of these were resolved peacefully, like the conflict over well water between the clan of Abraham and King Abimelech (Genesis 21:25). Some were resolved through warfare, as when two Sumerian city-states, Lagash and Umma, clashed over the draining of a freshwater canal in the southern portion of today=s Iraq 4500 years ago.

The current conventional wisdom can be easily summarized: Because of a fast-growing population and the goal of reducing malnutrition in the world, we will need to grow ever more food in the future. Although food production can be increased by expanding the land under cultivation, the additional arable land is becoming more scarce. Of course, the yield of a given area of land can be enhanced through fertilizers and pesticides, and better types of plants, but from a global point of view, this way of increasing production is reaching the point of diminishing returns. Finally, food production can also be increased through more irrigation, which played a major role in the higher productivity achieved through the green revolution, but here too, we are running into limits due to the rapidly rising expense of new dams and irrigation systems. To feed their population in the coming decades, countries will need more irrigation water and, therefore, wars over freshwater will become more frequent.

Although such ideas about warfare are rejected by many scholars of warfare, it is nevertheless useful to review the available evidence to determine in what ways the conventional wisdom is wrong and why a more optimistic perspective is right. To develop some precise ideas about this alleged crisis, three issues need examination: (1) Is there an impending shortage of freshwater? (2) Is there an impending food crisis because of water shortages? (3) Will future wars be triggered by water shortages? I argue below that water-stress according to conventional criteria may become quite serious by 2025, but it will not necessarily lead to either a food crisis war.[1]

A. Is There an Unsustainable Stress on Freshwater?

In the last half of the twentieth century, global freshwater withdrawals increased 188 percent, while population increased 141 percent.[2] Nevertheless, the alarmist views cited above are not universal. For instance, Bjørn Lomborg, the self-styled Askeptical environmentalist≅ (2001:197), analyzes the available data and concludes: AWe [will] have sufficient water, but we need to manage it better.≅ What are the relevant data and what do they show?

1. How Can We Measure a Water Crisis?

Most international comparisons of water-stress (including this one) feature an impressive

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[1] Small-scale violence over water appears to occur more often within a country, rather than between nations. In this essay I do not address this issue of armed or civil disputes over water rights within national borders, a huge topic for which far less information is available than for international wars over water.

[2] The population datum come from Maddison (2003: 232); the datum on water withdrawals are calculated from data of Shiklomanov (2000:23), an international authority on water.

array of statistics, but several important facts must be borne in mind: The data on the availability of freshwater in many countries are not very good, and the comparability of such data from country to countries is limited.[3] Projections of future water are fraught with even more perils, and long-term predictions have varied enormously.[4] It is, of course, easy to generate a Acrisis of freshwater availability≅ by a prediction of high water usage, but this raises credibility issues. A final uncertainty about future water shortages arises from the impact of climate change on the availability and usage of freshwater in particular countries. I must leave for others, such as Alcamo and Henrichs (2002), to discuss these highly technical issues. One important study (Barnett, Adam, and Lettenmaier, 2005) also shows that the most important impacts of climate warming will not necessarily be the amount of precipitation in particular areas, but rather a change in the seasonal pattern of snow and glacier runoff to winter and early spring, away from late spring and summer when demand for water is highest, a phenomenon placing great strain on water storage capacity.

We must be careful how we define >water crisis= or >water shortage.= On the supply

[3] The World Resource Institute (WRI, 2000: 105) has noted: AStatistics are poor on water use, water availability, and irrigated area on a global scale.≅ Shiklomanov (2000:12), finds that in different monographs data on water resources can vary for individual continents by up to 30 to 40 percent. More informal measures of a water crisis, such as receding water levels of particular lakes, the drying up of certain rivers and streams, or falling water tables in particular areas, can tell much about local water shortages, even though they tell us little about water availability for a country as a whole.

[4] For instance, Rogers (1993: 126) shows that estimates made in the 1960s and 1970s for freshwater use in the U.S. by 2000 varied by a factor of five, with almost all estimates too high. Even though the U.S. GDP increased over the last quarter of the twentieth century, total water withdrawals declined, but I have found no predictions of such a development. On a global level Shiklomanov and Rodda (1991: 370) show that projections for world water withdrawals for 2000 ranged by a factor of almost three, and for 2025, by a factor of 2.4.

side, short-run difficulties must be distinguished from long-run problems. Families or nations may not have sufficient water in the short run because of lack of suitable infrastructure to deliver it, but this does not necessarily indicate a long-term problem if such infrastructure can be constructed at a reasonable price. For instance, although the Yellow (Hwang Ho) River in northern China is drying up, waters from the flood-prone Yangtze river in southern China can be transferred, a project now under construction.[5] Or a given amount of water can be used more efficiently, for instance, drip irrigation, where suitable, can be substituted for more water-using traditional methods. In forecasting a water crisis or serious water shortage, account must be taken of such long term countermeasures, but they seldom are. Moreover, if a shortage exists because the price of water is so low that the demand far exceeds the supply, the problem can be remedied by raising the price. If poor families in the population cannot afford sufficient water because the price is too high, they can be subsidized, so again, another >shortage= is eliminated.

For this essay several concepts used in the measurement of a stress on freshwater (a supply-side approach) need brief mention. *Renewable water* means merely that the water taken from lakes or the ground (including aquifers) does not result in a lowering of the water level of these sources. *Freshwater* includes all non-saline water; few sources provide information on the purity of this water, so in this study we must consider all surface and ground water as fresh. A *water withdrawal* occurs when humans take water from rivers, lakes, or the ground or collect it from rain. If fresh water is not recycled or reused by consumers, actual use is less because some

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[5] Barnett et al. (2005) suggest that the melting of the glaciers in the Himalaya-Hindu Kush region has resulted in a regression of the maximum spring stream-flow period by about 30 days and that, in a few decades when the relevant glaciers disappear, the water available for agriculture may suddenly decrease dramatically.

usable water is lost through evaporation, runoff, or seepage along the way. In addition to water withdrawals, freshwater can be obtained through desalinization or by importation from other countries, either by shipping it on tankers or by towing icebergs. Finally, *water-stress* arises when less freshwater for a jurisdiction is available than that indicated by conventional norms (found in the current literature), I must emphasize that water-stress is different from a *water scarcity,* which occurs when the demand for water at the current price is greater than the supply.

No single indicator gives a complete picture of a water-stress. Most measures are countrywide and do not indicate the particular areas of a country are experiencing difficulties in obtaining freshwater. Few measures (the Awater-vulnerability index≅ discussed below is a notable exception) take account of seasonal variation in rainfall, which for nations with monsoon weather patterns are quite extreme. I use three supply-side measures for the physical availability of freshwater.[6] Other more complex indicators are also available, but they are difficult to

[6] Data on water availability come from Gleick (2004: 257-62) and refer to 2000 or the closest year that could be obtained. Population data are for 2000 and come from the United Nations (2003), supplemented by data from the U.S. Census Bureau (2004). No data are available for the Western Sahara, but it is listed on the basis of qualitative evidence. Projections of the renewable water availability index are made with the assumption that freshwater availability remains the same as in 2000.

Projections of water withdrawals for 79 nations up to 2025 come from Shiklomanov (1998) and are based on population estimates from the United Nations (1998). From these data, I calculated the per capita change in water withdrawals between 2000 and 2025 and then, using population projections from United Nations (2003) recalculated the water withdrawals for these countries for 2025. For 2050 I assumed that the change in the rate of per capita withdrawal would be the same in the 2025-2050 period as in the 2000-2025 period. Shiklomanov also presents total water withdrawals for 26 world regions. For the countries with missing data, I calculated the water withdrawals from each region excluding the specified countries, determined the per capita increase in withdrawals of the regional residuals, and used this as the estimate for all of the countries in the region for which Shiklomanov did not make specific estimates.

interpret and supply few additional insights.[7]

a. The *freshwater-availability indicator* focuses on the per capita availability of renewable freshwater including water from rivers in international river basins (Falkenmark, 1989).[8] Taking all uses of water into account, she designates nations with 1700 cubic meters per person per year of available water as having infrequent water shortages, 1000 cubic meters of water per person per year as being Arelatively water-stressed≅; and 500 cubic meters or less per person per year or under as indicating a Achronic water scarcity.≅ I use 1000 cubic meters per person per year (2740 liters per person per day) as one of my measures of water-stress.

This indicator has the advantage that it is easy to calculate and understand. Combined with a population projection, it can also serve to approximate the per capita amount of freshwater available in the future, other than that obtained through desalinization or importation. At the same time it has several notable disadvantages. It approaches the problem only from the supply side, measuring only renewable surface and groundwater flows, and does not take the demand side into account. Farming accounts for about 70 percent of the usage of the world=s water and relatively arid agricultural nations may requite more water for irrigation than nations with plentiful rainfall or those importing a large share of their food. This indicator also says nothing about how the freshwater is used and whether the potential availability of water is realized in an

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[7] These alternative measures include the water poverty index formulated by the National Environment Research Council, Centre for Ecology and Hydrology (2002) and by Sullivan (2002); and the International Water Management Institute=s indicator of relative water scarcity (Seckler, et al., 1998). For our purposes it seems best to focus on the individual components of freshwater availability, of which the three indices discussed above provide a useful picture.

[8] I have inverted Falkenmark=s index since she focuses on the competition for water, i.e., the number of people per cubic meter of available water.

efficient manner, which depends in part on the nation=s infrastructure. For instance, according to Gleick (2004: 261), in 2001 Israel had a renewable freshwater availability of about 198 cubic meters per person per year, and yet it has been able to function as a modern nation by employing sophisticated water usage techniques.

b. The *relative-water-stress indicator* focuses on freshwater withdrawals. More specifically, it is the ratio of annual water withdrawals to the annual freshwater availability. High stress is considered to be a ratio of more than 40 percent; medium-high stress, from 30 to 40 percent; and medium stress, from 20 to 30 percent.[9] These limits, of course, are arbitrary and accordingly a country such as Belgium is considered a nation of high water-stress, even though its current ratio seems sustainable for the indefinite future. The relative-water-stress measure requires a projection of water withdrawals in the future, a calculation which, as indicated above, is not easy to make. The projections by Shiklomanov which I use in this discussion predict that on an aggregate basis water withdrawals will increase about 32 percent between 2000 and 2025.[10]

An interesting alternative measure to the relative-water-stress index is the ratio of the

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[9] A UN report (1997: 29) places moderate stress at 10 to 20 percent.

[10] Gleick (2000: 59) reports nine forecasts made between 1995 and 2000 of global water use (or withdrawals) in 2025; they ranged from 3635 to 5500 cubic kilometers. Several recent estimates deserve special mention: In a publication by the Stockholm Environment Institute, Raskin, et al. (1997) foresee water withdrawals in 2025 between 4500 and 5500 cubic kilometers. The UNEP (2003:150) forecast of water withdrawal for 2020 would, if extrapolated, mean that in 2025, water extraction will be 5740 cubic kilometers; they also claim that in 2020 two-thirds of the world=s people will be living in water-stressed countries, a statement based on a questionable definition of Awater-stressed.≅ From data presented by Rosegrant, Cai, and Cline (2002: 263), we can derive a prediction of 4450 cubic kilometers of water withdrawals in 2025. For better or worse, I use the Shiklomanov estimates which fall roughly in the middle of the most recent extrapolations under Abusiness-as-usual≅ scenarios.

groundwater removed to the estimated groundwater recharged. Such a measure summarizes the change in the water table of a nation. It is, however, difficult to estimate and is available for only a limited number of nations.[11]

c. The *water-reliability indicator* has been calculated by Raskin et al. (1997) and is a composite of three separate measures: a measure of the ratio of water storage to water usage (this ratio takes into account the use of monsoon water in other parts of the year), a coefficient of variation of precipitation, and the dependency on water from an international river basin.[12] Each of these three criteria are rated on a scale of one to four, running from no-stress to high-stress, and are added to form the combined index. For the analysis below, I select only those countries with an overall evaluation of Ahigh-stress.≅

2. Water-Stressed Countries in 2025

Table 1 about here.

Table 1 presents estimates of countries projected to be water-stressed in 2025 according to any one of the three previously discussed indicators: freshwater-availability, relative-water-stress, or water-reliability. Several features of this listing deserve brief comment: (a) As we would expect, the largest single block of water-stressed nations are in North Africa and the Near East. More specifically, 37.5 percent of the 56 listed nations (and 82.3 percent of the nations deemed water-stressed by all three criteria) are in this region. (b) A stricter definition of

[11] Such data are available from Gleick (2004: 84-86) and the World Resource Institute=s AEarthtrends,≅ at <http://earthtrends.wri.org/searchable_db/index.cfm?theme=2>.

[12] This water-reliability index is part of a larger composite measure which includes the same relative-water- stress indicator discussed above and also a coping-capacity index, which is measured by the per capita GDP.

Table 1: Countries Projected to be Water-Stressed in 2025

Sub-Saharan Africa
Burkina Faso, Burundi, Cape Verde, Comoros, Djibouti, Eritrea, Ethiopia, Kenya, Malawi, Rwanda, Somalia, South Africa, Swaziland, Sudan

North Africa and Near East
Afghanistan, Algeria, Bahrain, Egypt, Iran, Iraq, Israel, Jordan, Kuwait, Lebanon, Libya, Mauritania, Morocco, Oman, Qatar, Saudi Arabia, Syria, Tunisia, U.A.E., Western Sahara, Yemen

Rest of Asia except former USSR
Maldives, India, Korea (South), Pakistan, Singapore

Europe, former USSR
Armenia, Azerbaijan, Belgium, Cyprus, Lithuania, Kazakhstan, Malta, Moldova, Portugal, Spain, Turkmenistan, Ukraine, Uzbekistan

North and South America, Oceania
Barbados, St. Kitts and Nevis, Peru

Notes:

The countries listed are deemed water-stressed by one or more of three criteria discussed in the text: water-availability (less than 1000 cubic meters per person per year), relative-water-stress (water withdrawals to water availability greater than 40 percent), or water-reliability (equal to four). Countries meeting these criteria for all three indicators are underlined. Data were not available for all three indices for the following countries: Barbados, Malta, St. Kitts and Nevis, and Western Sahara

The sources of data for the water-availability and relative-water-stress indices are discussed in footnote 5. The water-vulnerability calculations come from Raskin, et al. (1997).

water-stress by any of the criteria would reduce the number of listed countries. For instance, by defining stress, as measured by the water-availability index, to be 500 (rather than 1000) cubic meters per person per year, we would eliminate six nations from the list (Burkina Faso, Comoros, Eritrea, Ethiopia, Malawi, and Cyprus). (c) Water-stress is exacerbated by high population growth. Of the 56 nations for which water-stress is predicted, 25 (44.6 percent) have a projected annual population growth of 1.5 percent or more.[13]

Table 2 about here.

Table 2 aggregates the data presented above to provide a global perspective for 2025 and also presents several new indicators measuring personal access to freshwater. Using the criteria for water-stress from Table 1, the data show that roughly one tenth of the world=s population now live in water-stressed countries, but that this figure will jump to about one-third by 2025, estimates that accord with those of others, such as Seckler, et al. (1998). A major factor underlying this increase is the inclusion of India among the water-stressed nations in 2025, but not 2000. If it were excluded, the increase between 2000 and 2025 for all countries would be roughly seven percentage points.[14] China is not included among the water-stressed nations, but if North China were a separate nation, it would probably be water-stressed by the criteria discussed above and would have to be added to the totals.

[13] Some commentators also mention that water-stress is related to population density, the argument being that higher land density forces more water-intensive methods of agriculture. Thirty (53.8 percent) of the nations in Table 1 have 1.6 hectares of arable land per person or less.

[14] Unfortunately, an indicator of water reliability is not available for 2050. Calculated with only two measures, the water-availability and relative-water stress indicators, the share of the global population in water-stressed nations increases only 3 percentage points between 2025 and 2050.

Table 2: Percentage of the World=s Population in Countries With Current or Projected Water-Stress

	2000	2025
<u>A. Supply side</u>		
All countries with water-stress according to any of the three criteria	11.8	35.5
India alone (included as water-stressed in 2025, but not in 2000)	16.8	17.4
North China alone (China as a whole is not included as water-stressed)	3.3	2.9
<u>B. Demand side</u>		
Countries with a low percentage of population having access to safe drinking water		
Less than 50 percent of population with access to safe drinking water	5.1	-
50 to 75 percent of population with access to safe drinking water	7.6	-
Countries with a low percentage of population having enough water for basic human requirements		
Less than 50 percent of population meeting basic water needs	8.7	-
50 to 75 percent of population meeting basic water needs	8.6	-

Notes:

Sources for Part A: see footnote 5 and Table 1. I have roughly estimated that the population in the water-stressed areas of north China numbered 200 million in 2000 (according to Revenga et al., 1988, in the early 1980s the Yellow River basin alone had a population of 153 million) and have projected the same population growth rate for this area as for the rest of the country (as estimated by the United Nations, 2003).

Sources for Part B: Data on access to freshwater come from Gleick (2002, Table 3) and WHO (2005); data on population meeting basic water requirements for human activities from Gleick (1996). Since access to freshwater or to meet basic water needs depends on infrastructure investment, reliable projections cannot be made.

Part A of the table suggests that, according to conventional criteria, a significant share of the world=s population will be living in water-stressed countries in 2025. As argued below, however, this does not necessarily lead to a food shortage, given the enormous amount of fresh water which is wasted.

Part B of the table presents data on issues not yet discussed, namely, the share of the world=s population in countries without access to safe drinking water and in countries without

sufficient water for cooking, health, and other human purposes. In recent years Aaccess≅ is defined as 20 liters per person per day from a source within one kilometer of the user=s dwelling; Asafe≅ is defined in terms of the technology used for obtaining the water, rather than by a direct measurement of its purity. Access to safe drinking water has, of course, critical implications for health. For instance, in 2000 people dying from water-borne disease (such as hookworm, infectious diarrhea, trachoma, or schistosomiasis) numbered at least 2.1 million; and such illnesses accounted for at least 75.6 million DALYs (disability life years, i.e., healthy life years lost (Gleick, 2004: 273). The available data show little correlation with the other indices of a water shortage on the supply side, and only three unfortunate countries, Oman, Qatar, and Yemen, reveal a water stress on both the supply and demand indicators.[15] A related indicator is the percentage of the population obtaining at least five liters per person per day, which Gleick (1996) roughly calculates is the minimum needed only for drinking, sanitation, washing, and other personal needs. (This is roughly double the amount necessary for survival, as calculated by others; it also does not include other uses for water such as agriculture.)

[15] An alternative index, which unfortunately is available for only a limited number of countries, is Gleick=s (2002: 102-3) calculation of total reported domestic water use per person per day.

These demand indicators are really measures, not of a supply shortage, but of poverty and the lack of suitable infrastructure to get the available water to the households of the nation. Such measures are also a glaring sign of the failure of international assistance to help fulfil a vital development and health need. Currently, the trumpeted Millennium Development Goal of halving the proportion of people without sustainable access to safe drinking water by 2015 seems unlikely to be met.

B. Is There an Impending World Food Shortage because of Water Stress?

Various economists and organizations dealing with agriculture and water have made some sophisticated projections of the world=s food supply in 2025. Rather than focus on the details of these forecasts, I will discuss the broad assumptions that underlie these predictions.

Food requirements: According to median projections of the United Nations (2003), in 2025 and 2050 the world=s population should be respectively 29 percent and 47 percent higher than in 2000. If the composition of agricultural production remains the same, the value of food production must increase by at least these amounts for the global population to have the same per capita food consumption as in 2000. As per capita incomes rise, however, the composition of food production changes, primarily in a water-using direction. As a generous guess, let us assume that this would increase the value of food production by one third, so that in 2025, food production would have to increase 38.5 percent, not merely 29 percent.

Moreover, if we wish to reduce malnutrition in the world, then global food production must also grow faster than the population. Various international organizations have estimated that between 14 and 21 percent of the world=s population was undernourished in 2000.[16] For the sake of safety let us assume the higher estimate and,

[16] The low measure is the FAO=s (2003: 31-3) plus an estimate of 1.5 percent of the population of the industrialized nations as undernourished. From data supplied by Kates

arbitrarily, that these undernourished would need to consumer 25 percent more food to achieve a proper diet. This means that world food production would have to increase 5.5 percent. Thus, to eliminate malnourishment by 2025 and to meet the rising food demand from a greater population and higher incomes, food production between 2000 and 2025 must increase 40.8 percent.

While such an increase in food production seems considerable, perspective can be gained by noting three facts: First, between 1975 and 2000, total food production increased at an average rate of 2.3 percent a year (FAOStat, 2005). Second, over this period there was no sign of a deceleration of this average annual growth in food production.[17] Third, as discussed below in greater detail, during the same period land productivity (food per hectare of arable land) also increased rapidly and showed no sign of decelerating. For these reasons it should not be surprising that between 1970 and 2000, the world price indices for food (and also for agriculture as a whole) fell considerably (World Bank, 2005: Table 6.4). Nevertheless, such a mechanical extrapolation must be accepted cautiously because certain previously unimportant constraints may have an influence on future food production.

Arable land: Between 1975 and 2000, arable land in use increased only 5.5 percent, and during the same period a marked deceleration of the increase in arable land use is also apparent (FAOStat, 2005). Although the land classified by the FAO as Aagricultural,≅ but used for pasture, rangeland, and other non-crop purposes, is roughly 3.5 times greater than

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undernourished was roughly 19 percent. The high measure of 21 percent is by the World Bank (2005: 67) and is the percentage of the world=s population living on $1 a day or less. If we included as undernourished the percentage of the world=s population living on $2 a day or less, this estimate would be 53 percent.

[17] This and the following generalization are based on the results of fitting a quadratic exponential growth curve to the FAO data on total world food production and total arable land.

the arable land under use, much of it has quite low-quality soil. Most specialists seem to believe that the potential for intensive food production on such land is relatively low. It is not entirely clear how much of this low potential is due to previous use that degraded the soil or led to wind and water erosion; and how much was due to naturally poor soil fertility and climatic conditions. Though rich agricultural lands are still being opened in some countries, such as Brazil, it is possible that the world=s total crop lands will not be significantly greater in 2025 than in 2000 when we take into account the deceleration of the increase in arable land arising from the withdrawal of certain lands now used for crop production. The latter phenomenon is due to problems associated with poor land or water management, such as erosion, water logging, salinization, or other oft-discussed farming problems.

Irrigated land: The percentage of arable land in use that is irrigated increased from 11 percent in 1961 to 14 percent in 1975 and to 20 percent in 2000 (FAOStat, 2005). Between 1975 and 2000 the number of hectares under irrigation increased 46 percent, but over the period the annual increase was decelerating and, on a per capita basis, actually declined a few percentage points. Although a mechanical extrapolation suggests that the area under irrigation will increase to 32 percent by 2025, such a projection seems highly unrealistic (Postel, 1993) for several reasons:

First, the cost of building irrigation dams is rising, in part because the best sites have already been used. Although the number of large dams (defined in terms of height and reservoir storage), which have served as one source of irrigation water, increased ninefold between the end of World War II and the end of the twentieth century, dam construction hit a peak in the 1970s and, in the 1990s, fell drastically (World Commission on Dams, 2000: 9). At this point there were few large rivers left that had not already been controlled in this way. It was also becoming evident that these dams often come with high environmental, social, and economic costs. As a result of the Nasser Dam, for instance, considerable land in the lower Nile has lost fertility and river fishing in the Nile delta has also greatly suffered.

Turning directly to irrigation systems, there has been a growing realization of their capital and maintenance costs, which are seldom covered to a significant degree by fees for irrigation water. Moreover, higher energy costs often add considerably to the expense of irrigation.

A final factor discouraging to future irrigation projects is the increasing salinization of land that is already irrigated, which reduces land productivity. According to Gleick (2000: 269), roughly 20 percent of irrigated land is adversely affected by moderate or greater salinization, and another 4 percent of the non-irrigated land is similarly affected.[18]

The deceleration of the increase in irrigated land is, however, not catastrophic because the aggregate impact of irrigation on agricultural production is often highly overestimated.[19] Of course, the relative productivity depends on local conditions, but for the world as a whole, the FAO [1993: Chapter 1] estimates that when the total irrigated land was 16 percent of total arable land, it produced between 30 and 40 percent of the world=s food (FAO 1993: Chapter 1).[20] This suggests that, on aggregated basis, irrigated land was 2.25 to

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[18] The FAO, places the total percentage of salinated land at fifty percent (Raped, 1986: 6).

[19] In this discussion I neglect water usage in agriculture for purposes other than irrigation because it seems relatively unimportant. For instance, the FAO (1993: Chapter 1) estimates that livestock drank 21.9 cubic kilometers of water a year, but in terms of the world=s total water withdrawals, this is a minuscule amount (slightly more than one-half of 1 percent). One-fifth of the total value of fish production also comes from freshwater aquiculture; although estimates of the water needed are not readily available, this should also account for only a small portion of freshwater withdrawals.

[20] Two other estimates deserve note. The UNEP (2003: 151) states that agriculture accounted for more than 70 percent of freshwater usage and that irrigated land (which , as noted above, was about 20 percent of the arable land) provided about 40 percent of the world=s food. This means that the productivity of irrigated land was 2.7 times that of

3.50 times more productive than non-irrigated land. If this average held between 1975 and 2000, the increase in irrigated land accounted for an increase in food production of somewhere between 6 and 10 percent. Taking into account the increase of arable land used in agriculture, such a calculation suggests that productivity-enhancing measures other than irrigation led to an increase in food production in the last quarter of the twentieth century between 60 and 64 percent.

If such productivity trends continue for the next quarter century, then more than enough food will be produced than is necessary to feed the growing population at current standards and, moreover, to eliminate malnourishment (if crop production is the basic cause), even without an increase in irrigated area.[21] Of course, some have questioned the underlying assumption about the increase in agricultural productivity; they have suggested that crop yields are peaking and cannot go much higher; and some have even rumbled about decelerating (or even declining) crop yields due to salinization and erosion. I find no evidence of decelerating or declining land productivity in the 1975-2000 period (or, for that matter, in the 1961-2002 period) when using an index of total food production per hectare (calculated from FAOStat, 2005). For particular types of food, such as cereals, signs of a small deceleration of growth of productivity are evident in the 1975-2000 period. The

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unirrigated land. Shiklomanov (2000:16) claims that when 15 percent of all cultivated lands was being irrigated, they produced almost half of the total crop production in value terms. This means that the land productivity differential was roughly 4.6 times.

[21] My assessment of future irrigation needs differs dramatically from that of the International Irrigation Management Institute [1992], which claimed that by 2020-2025, an estimated 80 percent of the additional food supplies required to feed the world will depend on irrigation. Any assessments about the need for future irrigation depends, of course, on assumptions about increasing land productivity due to better seeds, farming techniques, fertilizers, and other measures; and it is unclear what underlay their estimates. The Institute also seems to focus primarily on wheat and rice, which are water-intensive crops, while I focus on overall food production.

explanation for this might be that the demand for cereals shifted downward as world per capita incomes rise, so that less attention was paid to cereal productivity. Decades of research on agriculture productivity for tropical areas have also begun to achieve a payoff, which should continue for some decades. For instance, of the 38 countries with an agricultural productivity per hectare increasing at 1.5 percent or more per year between 1975 and 2000, 30 were in countries partly or wholly in the tropics.[22]

In brief, the projected necessary increase in world food production does not seem to require the vast extension of irrigation with its concomitant demand for more water that occurred in the last quarter of the twentieth century. Rather, the rise in land productivity attributable to other factors such as better farming practices, better crops, and more efficient use of the currently available freshwater, may be more than sufficient.

This conclusion, however, focuses on food supply and demand for the entire world, In 2025 individual countries may, of course, produce less food than is necessary to feed their populations. This problem can be resolved by importing food, but such an economically efficient solution means that the goal of national food self-sufficiency must be scrapped, a price that some policy makers may find politically painful to pay, particularly for grains.

C. Will Future Wars Be Triggered by Water Shortages?

I have argued that although the share of the world=s population in water-stressed countries will increase, it does not seem likely that the world will face a food shortage due to scarcity of water in the next quarter century. This assumes that countries manage their water

[22] These estimates were calculated from data from FAOstat. It also might be noted that in 2000 these 38 countries comprised 59 percent of the world=s population. Excluding China, which is located only to a small extent in the tropics, this share of the world=s population falls to 38 percent.34 countries experienced a fall in agricultural production per hectare in the same period, but they comprised only 3 percent of the world=s population. 168 countries are used in these calculations.

resources and water uses in a responsible fashion. Such an assumption, however, may be questioned so that we must directly confront directly the issue of wars over water.

The role of water as a cause of international disputes is controversial. Some believe that access to freshwater has been an important cause of past wars. Nevertheless, in a study of 412 international crises for the period 1918-1994, Aaron T. Wolf (1997) finds only seven directly related to access to freshwater. Moreover, in three of these, no shots were fired. Nevertheless, such an argument, as many have noted, focuses only on the past, when population pressures and demand for water were not as great as they will be in 2025. Given its frequent citation, many agree with the statement of a former World Bank vice president, Ismail Serageldin, who noted in the mid-1990s AIf the wars of this century were fought over oil, the wars of the next century will be fought over water.≅[23] In a personal communication to me, however, he complained that few of the hundreds citing this quotation include the remainder of his sentence: Aunless we change our approach to managing this precious and vital resource.≅

To assess directly the possibility of water wars, we must consider past experience more carefully and then look at the future in terms of possible flashpoints for armed conflict in the various international river basins over water resources. We must also examine the means for avoiding such clashes, either by more efficient use of water or by dispute resolution.

1. Possible Lessons from Past Wars over Water

[23] According to Dr. Serageldin, this statement was first made in a public speech in Stockholm in August 1995. Part of his statement is summarized by Crossette (1995). This has been a common view in Egypt and was previously expressed by Anwar Sadat and Boutros Boutros-Ghali when he was a Deputy Prime Minister. The latter two declarations, however, seemed less to be political predictions than veiled threats to Ethiopia not to dam the Blue Nile for some large-scale irrigation projects.

A major difficulty in analyzing water wars arises from loose terminology, because words such as >conflict,= >dispute,= >tensions,= >hostile actions,= and >war= are often conflated. Moreover, water is sometimes only one of many factors leading to armed conflict between nations, so that it is often difficult to assess the importance of water per se as the cause of war. In the following discussion I distinguish between *all-out wars* with formal declarations from *major military conflicts* involving invasions and the use of heavy, military equipment and *minor military conflicts* involving military skirmishes and limited fighting. It must also be noted that, according to Wolf et al. (2003: 30): AThe record of acute conflict over international water resources is overwhelmed by the record of cooperation . . . Furthermore, once cooperative water regimes are established through treaties, they turn out to be impressively resilient over time, even when between otherwise hostile riparians, and even as conflict is waged over other issues.≅

Using the listings of water incidents from the sources cited in Table 3, I have found no instances of an all-out war over water issues in the second half of the twentieth century. However, some analysts, such as Klare (2001: 139), argue that the Arab-Israeli war of 1967 Awas largely triggered by fighting over control of the tributaries of the Jordan River.≅

Table 3 about here.

Table 3 lists military engagements between countries that probably arose from disputes over the water control in the last quarter of the twentieth century. Where border or other issues were also involved, it is often difficult to determine whether water was the critical cause for armed conflict. Several aspects of the list deserve note: First, in this period relatively few armed conflicts arose over the allocation of water, which accords with the general decline in inter-state warfare (Gleditsch, 2002). Second, in five of the seven military engagements that did occur, either one or both nations were water-stressed in 2000,

Table 3: Interstate Military Engagements over Water, 1975-2000

River basin	Countries involved	Date	Event
A. Wars listed by the International Peace Research Institute, Oslo (PRIO)			
Cenepa	Peru-Ecuador	1995	Engagement near river; primarily a war over territory, rather than a water dispute per se. PRIO lists this war with as one of Aminor intensity≅ with probably less than 100 casualties.
Orange	South Africa- Lesotho	1998	South African troops occupied the Katse and Mohale dam areas when taking one side of an internal Lesotho conflict. PRIO lists this entire conflict as one of Aminor intensity≅ with slightly less than 120 deaths.
B. Other Military Engagements but Not Classified as Interstate Wars by PRIO			
Tigris-Euphrates	Iraq-Syria	1975	Dispute about filling of upstream dams; transfer of troops; closing of air space.
Tigris-Euphrates	Iran-Iraq	1986	Iranian-Kurdish guerillas attacked Dukan dam; water issues are unclear but appears part of Iran-Iraq war, 1980-88.
Karnaphauli	Bangladesh-India	1991	Shootout between paramilitary police about an irrigation channel.
Kura-Araks	Armenia-Azerbaijan	1992	Armenia gained control of Sarsangskaya dam in Nargorno-Karabakh; appears a part of the Armenia-Azerbaijan war (1991-94), rather than a separate war over water.
Senegal	Mali-Mauritania	1999	Mali herdsmen refused to let Mauritanian horsemen use a water hole; small battle ensued.

Notes: This list excludes cases where the dispute did not escalate to use of military force but remained at the level of massing of troops and serious threats. The data on water disputes come from lists by Gleick (2004) and Wolf et al. at: <www.transboundarywaters.orst.edu/projects/events/> The PRIO lists are found at: <www.prio.no/page/CSCW/_research_detail/Programme_detail_CSCW/9649/45925.html>.

according to at least one of the three criteria discussed above (the two exceptions were the military engagements in the Orange and the Karnaphauli River basins). Third, armed conflicts over water were much more frequent in the previous quarter-century from 1950 through 1974. Nevertheless, if we exclude those that concerned the Jordan River basin and clashes between Israel and its neighbors in this period, the number of armed conflicts was roughly the same in the two twenty-five-year periods.

The relative infrequency of water wars suggests that from a cost/benefit perspective, the gains from armed conflicts over water are often dubious, especially when the long-term expenses of occupation and costs of handling subsequent tensions are taken into account. Even when a powerful downstream nation simply destroys an upstream dam and then withdraws, this could have not only a severe short-term physical impact downstream but a costly long-term financial one, resulting from the loss of the upstream neighbor=s cooperation in other areas and the necessity to maintain a large army. Such a cost/benefit calculation does not require a high degree of rationality.

2. Future Wars over Water?

Some commentators argue that for wars over water, the past does not serve to predict the future. For instance, Postel (1999, Chpt. 7) and Klare (2001, Chpts. 6 and 7) point out that water problems worsened considerably in the last two decades of the twentieth century in many international river basins and that in the future the stakes will be higher than ever, especially where the water will be insufficient to serve the rising perceived needs of the various riparian states.

Consensus is lacking, however, on the critical conditions for an armed conflict over water resources. Klare (2001: 139) notes that water shortages need not lead to conflict where states enjoy good relations with one another and have a history of resolving differences through peaceful negotiations. I might add that even enemies can cooperate over the allocation of water.[24] Homer-Dixon (1999) argues on the basis of real-politik that wars over river water between upstream and downstream neighbors are likely only under a narrow set of circumstances: A[T]he downstream country must be highly dependent on the water for its national well-being; the upstream country must be threatening to restrict substantially the river=s flow; there must be a history of antagonism between the two countries; and, most important, the downstream country must believe that it is militarily stronger than the upstream country. . . the situation is particularly dangerous if the downstream country also believes it has the military power to rectify the situation.≅ In most, but not all of the cases reported in Table 3, the downstream nation started the conflict; in the Peru-Ecuador conflict, however, it is unclear whether Peru could have extensively utilized the water and whether this was not primarily a boundary dispute.

How can we predict future wars over water? One way to approach the problem is to use the results of statistically studies of past wars over water to foresee the future. A group of specialists in war have produced several regressions studies in recent years (e.g., Toset et al.,

2000; Furlong and Gleditsch, 2003; and Gleditsch, et al., 2004) showing that over the past hundred or more years, armed conflicts over water that resulted in at least one death are significantly and positively related to such variables as whether the regime is unconsolidated or autocratic, the size of the river basin, whether a major power is involved; and negatively related to such variables as years at peace, the level of economic development of the

[24] Water disputes can be peacefully resolved, even between unfriendly countries. For instance, Israel and Jordan were hostile for many years, but the two countries held secret negotiations to cooperate over water during the period. Their water treaty of 1994 covered not only the allocation of the waters from the Jordan and Yarmouk Rivers but also the Araba/Arava groundwater aquifer and the contamination of these joint water resources. Although India and Pakistan fought two wars, the Indus River Commission survived these conflicts and its members cooperated over water issues (Wolf, et al., 2003).

countries involved, and whether they have an alliance. For purposes of prediction, objections can be raised because the barrier for defining armed conflict is too low - certainly 25 deaths or less does not constitute a major war and, moreover, the definition of water stress is unsatisfactory. Wolf, et al. (2003), who are specialists in water issues, reach conflicting conclusions on the basis of single variable correlations showing that no matter how it is measured, water stress is not a significant indicator of water disputes and, moreover, neither government type nor climate show any pattern of impact on water disputes. But since these do not hold other variables constant, their use in predicting the future can be questioned.

Given such divergent results in predicting water wars from a regression approach, it seems more useful at this time to employ a more transparent approach for looking at these issues. The starting point is a list of 261 international river basins, which have been listed by Wolf and his associates (1999), updating and correcting a 1978 register of 214. Then second step is to use two different criteria for isolating those river basins which are most at risk of armed conflict. Finally, I apply an index to distinguish those river basins which, according to additional criteria, are most at risk.

Table 4 about here.

The first criterion for isolating the river basins most at risk of armed conflict is the *institutional-physical approach,* which focuses strictly on the role of water-stress as a potential cause of war. Starting with the list of countries predicted to be water-stressed in 2025 (listed in Table 1) I then apply three criteria that would increase the probability of conflict:[25] (a) some countries in the international river basin will experience water-stress by

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[25] Use of the water-vulnerability criterion in Table 1 also meets the argument by Yoffe, et al. (2004) that armed water conflicts are more likely in regions with extreme climatic conditions characterized by high hydrological variability. While water withdrawals from the river basin are, in fact, more telling than the geographical size of the country, appropriate data are not available.

Table 4: International River Basins with a Potential for Armed Conflict over Water:

River basin	Water-stressed countries in the basin	Non-water-stressed countries in the basin	Indicator A	Indicator B	Indicator C	PACW score 0 to 9
A. Institutional-physical approach						
Africa						
Awash	Djibouti, Ethiopia, Somalia	-	3.0	0.0	0.0	3.0
Incomati	South Africa, Swaziland	Mozambique	1.5	0.0	0.0	1.5
Juba-Shibeli	Ethiopia, Kenya, Somalia	-	2.0	0.0	0.5	2.5
Lake Turkana	Ethiopia, Kenya, Sudan	Uganda	3.0	0.0	0.5	3.5
Maputo	South Africa, Swaziland	Mozambique	2.0	0.0	0.0	2.0
Nile	Burundi, Egypt, Eritrea, Ethiopia Kenya, Rwanda, Sudan	Congo (Zaire), Tanzania, Uganda	0.5	0.5	1.0	2.0
Asia						
Aral Sea basin	Kazakhstan, Turkmenistan, Uzbekistan	Kyrgyzstan, Tajikistan, China	2.5	0.2	0.0	2.7
Indus	India, Pakistan	Afghanistan, China	1.5	0.1	2.0	3.6
Jordan	Egypt, Israel, Jordan, Lebanon, Syria	-	0.0	0.3	0.5	0.8
Tigris-Euphrates	Iran, Iraq, Jordan, Saudi Arabia, Syria	Turkey	2.5	2.0	1.5	6.0
Europe						
Danube	Moldova, Romania	15 nations including Hungary, Serbia, Austria, and Germany	0.5	1.6	0.0	2.1
Dniester	Moldova, Ukraine	Poland	1.0	0.0	0.0	1.0
Dour/Duero	Portugal, Spain	-	0.5	0.0	0.0	0.5
Guadiana	Portugal, Spain	-	0.5	0.0	0.0	0.5
Tegus/Tejo	Portugal, Spain	-	0.5	0.0	0.0	0.5
B. Institutional-political approach: Wolf-Yoffe-Giordano (2003: 52)						
Africa						
Incomati	-	South Africa, Mozambique, Swaziland	2.0	0.0	0.0	2.0
Kunene	-	Angola, Namibia	1.5	1.0	0.0	2.5
Lake Chad	Algeria, Sudan, Libya	C.A.R., Cameroon, Chad, Niger, Nigeria	1.0	0.0	0.5	1.5
Limpopo	-	Botswana, Mozambique, South Africa, Zimbabwe	2.0	0.0	0.0	2.0
Okavango	-	Angola, Botswana, Namibia, Zimbabwe	2.5	0.0	0.0	2.5
Orange	-	Botswana, Lesotho, Namibia, South Africa	2.0	0.9	0.0	2.9
Senegal	-	Guinea, Mali, Mauritania, Senegal	1.0	0.3	0.5	1.8
Zambezi	-	Angola, Botswana, Congo (Zaire), Malawi, Mozambique, Namibia, Tanzania, Zambia, Zimbabwe	2.0	0.5	0.0	2.5
Asia						
Ganges-Brahmaputra	India, Bangladesh	Bhutan, China, Myanmar, Nepal	0.5	0.2	1.0	1.7
Han	Korea (South)	Korea (North)	3.0	0.0	2.0	5.0
Kura-Araks	Armenia, Azerbaijan, Iran	Georgia, Russia, Turkey	1.5	0.3	0.0	1.8
Mekong	-	Cambodia, China, Laos, Myanmar, Thailand, Vietnam	1.5	0.0	0.0	1.5
Ob	-	China, Kazakhstan, Russia	2.5	0.0	0.0	2.5
Salween	-	China, Myanmar, Thailand	3.0	0.0	1.5	4.5
Tumen	-	China, Korea (North), Russia	3.0	0.0	0.0	3.0
Americas						
La Plata	-	Argentina, Bolivia, Brazil, Paraguay, Uruguay	1.5	0.1	0.0	1.5
Lempa	-	El Salvador, Guatemala, Honduras	2.0	0.0	1.5	3.5

Note: Data on the area of river basins in each country come from Wolf, et al. (1999). The most downstream nations in each basin are underlined. See the appendix for the definitions of the components of the PACW (propensity-for-armed conflict over water) index and how it is computed.

2025; (b) a significant area of these water-stressed nations is in the basin; and (c) the water-basin area in these water-stressed nations covers a significant portion of the entire water basin.[26] For this purpose I start with the entire list of countries predicted to be water-stressed in 2025 in Table 1. The fifteen water basins, listed in the upper half of Table 4, fit these three criteria.

The second criterion for isolating river basins most at risk of armed conflict is the *institutional-political approach,* which has been advanced in one way or another by a large number of political scientists. They reject the notion that water-stress will have much to do with future armed conflicts over water and, instead, point to particular characteristics of the nations that might become involved in a military conflict. For instance, Russett (2006) points to such factors as the degree of democracy in the countries involved, their trade interdependency, their military capability, their alliances, and their participation in international organizations. Other political scientists argue for other determinants of war but, unfortunately, few focus on water issues. The most relevant empirical study in this genre which focuses on river basins is by Wolf, Yoffe, and Giordana (2003). They argue that wars over water are more likely to be found in river basins with riparian nations unused to cooperating with each other (a situation intensified by a history of ethnic conflicts) and that lack the institutional capacity to coordinate their basin development projects, such as dams or irrigation systems. They calculate the probability of war and, although they do not provide sufficient detail for others to replicate their results, I include in the lower half of Table 4 their list of seventeen water basins where armed conflicts are most likely to occur.

[26] More specifically: a) The countries must be listed in Table 1; (b) At least 10 percent of the land mass of each country must be located in the water basis. (c) At least 10 percent of the land area of the basin is located within the borders of these water-scarce countries.

It is noteworthy that none of the river basins listed in the institutional-physical list overlap with those in the institutional-political list. Of the thirty-two basins, thirteen do not include any water-stressed nations and, of the remaining, eleven have never featured any conflict. To select those basins where armed conflict is most likely, a more systematic approach is needed and, for this purpose, I employ an index, described in more detail in the Appendix, of the Apropensity for major armed conflict over water≅ (PACW). It contains three elements: the lack of past cooperation over water issues in the past; past conflicts (not necessarily leading to fatalities) over water; and geographical factors that increase, or decrease the propensity of war. Since so few disputes over water issues have occurred in the past few decades (the period most relevant for making projections), the weights of these three factors can only be subjective, but since the relevant data are provided, readers may reweight these factors as they please. The PACW index is a ten-point scale running from 0 (no propensity) to 9 (high propensity) and is the sum of three components. The nations listed under the institutional-physical approach have an average PACW score of 2.1; those under the institutional-political approach, 2.6 .

If we use a PACW score of 4.5 (the midpoint of the scale) or higher to indicate that armed water conflict is most likely in the future, this suggests that such combat is unlikely in any of the listed river basins up to 2025 except the Tigris-Euphrates, Han, and Salween basins. If the trigger point is lowered to 3.5, then by 2025 the list is expanded to include the Indus, the Lempa, and the Lake Turkana basins. Of these six nations, indicator B shows that armed conflict over water arose in the last quarter of the 20^{th} century in only two of them (the Indus and the Tigris-Euphrates). Since the Lempa and Salween basins also do not include any water-stressed nations, they can be dropped from further discussion.

Three of the remaining four river basins designated as having the highest probability of armed conflict, namely the Tigris-Euphrates, the Indus, and the Han river basins include countries where political tensions over a variety of issues, not just water, have been endemic in the last few decades. Whether disputes over water will serve as a flashpoint or merely a contributing factor for armed conflict is difficult to say. The remaining river basin, the Lake Turkana basin, did not experience armed conflict over water, although by 2025 one of the nations, Kenya, will be water stressed. One other water basin, namely the Nile, has often been cited as a possible locus for future armed conflict over water, but the two countries most at odds - Egypt and Ethiopia - are geographically separated by a third country (Sudan), a situation that complicates prediction.

Although this exercise does not allow exact predictions the intensity of future water disputes in these basins or whether armed conflict will erupt, it does suggest that the most probable loci for water wars up to 2025 are relatively few. These results also suggest that that armed conflict over water will probably not be more frequent than they are today.

Many commentators reject this kind of macro approach used above, and, instead, focus more on micro issues that possibly might lead to armed conflict. Little agreement can be found among them, however. For instance, Postel (1999, Chpt. 7) sees five hot spots for serious water disputes: the Aral Sea region and the Ganges, the Jordan, the Nile, and the Tigris-Euphrates basins. Klare (2001) focuses on four river basins: the Nile and the Tigris-Euphrates, where water allocation is the prime issue; and the Jordan and Indus, where water and a variety of political issues are intertwined. For the Nile he emphasizes that Ethiopia, which had roughly the same population as Egypt in 2000, will have a third more than Egypt in 2050 and will be forced to use waters from the Blue Nile to feed its growing population, thus taking water away from Egypt. Homer-Dixon (1999) mentions only the Nile as a future trouble spot, claiming that the conditions for armed conflict will not exist for the Indus, Paraná, Euphrates, and Mekong rivers. DuPont (2001: 126-30), on the other hand, claims that water cooperation between riparian nations in the Mekong basin is fragile although he speaks of Aconsiderable tensions≅ in the future, rather than armed conflict.

3, Alternatives to War: More Efficient Use of Existing Water Resources

Even though there is a high risk of violent conflict, wars do not necessarily need to occur. More specifically, water-stress does not necessarily lead to a water shortage since a country can tap new sources of freshwater, or it can use its existing water supplies more efficiently. Usually both alternatives seem less expensive than the costs, both economic and human, of armed conflict and these alternatives deserve attention.

Table 5 about here.

Table 5 presents some rough estimates of the cost of obtaining water from fifteen different sources. Most of these methods require a steep increase in the price of water from rivers, lakes, or underground aquifers if the project is to cover costs, but if the increase is imposed slowly, political damage might be minimized.[27]

New sources do not necessarily need to be tapped, because enormous amounts of water are wasted. Gleick (2002: 307) provides data for various cities and countries showing that water unaccounted for by any usage ranges from 10 to 60 percent. For many countries the difference between water withdrawn and water usage is often about a third or more. In view of such wastage, water-saving investments are often much less expensive than tapping new sources of water. Many water-saving methods, however, require a country to change its

[27] In the United States, the relative price of water and sewer service (in relation to all other goods contained in the consumer price index) increased 46 percent between 1975 and 2000, and more than doubled over a half century, without any noticeable adverse consumer reaction. These data come from the Bureau of Labor Statistics website (2005) and the Council of Economic Advisors (various years)..

Table 5: Estimated Capital and Maintenance Costs of Water Supply Alternatives

	$ cost per cubic meter	Index
Cloud seeding	0.01	48
Recycling waste water (only secondary treatment)	0.09-0.17	56
Ground water recharge	0.15-0.18	69
Reservoir storage (storage costs only)	0.16-0.32	100
Diversion projects (interbasin)	0.16-0.32	100
Reverse osmosis (for brackish water)	0.16-0.51	140
Towing icebergs	0.02-0.85	183
Recycling waste water (AWT)	0.26-0.63	186
Electrodialysis	0.36-0.69	220
Desalinization of brackish water	0.25-1.00	263
Freezing methods on brackish or salinated water	0.47-0.82	271
Distillation	0.84-1.40	471
Transport tankers	1.25-7.50	1838
Desalinization of sea water	1.30-8.00	1954

Note: The data come from Gleick (1973a: 414-15) and have been converted to 1985 dollars. The index is the average of the range provided in the table, which I normalized at the storage costs of a reservoir. AWT means secondary treatment plus nitrogen and phosphate reduction, filtration, and carbon adsorption. The electro dialysis assumes total dissolved solids between 2000 and 5000 parts per million. Gleick=s Table H.26 gives a higher estimate of recycling wastewater than those reported in this table (which came from his Table H.27).

The costs do not include complementary infrastructure, for instance, the need for skilled technicians for desalinization, the need for port and storage facilities for water transported by tankers, the need for equipment to melt ice and collect water for the transport of icebergs (still an unproven method) or the equipment and facilities for water reuse. Although the cloud seeding appears inexpensive, Gleick notes that its certainty of success can only be rated as Alow to moderate≅ which suggests that the low-cost evaluation may not be justified.

laws and institutions to develop, manage, and maintain its water infrastructure more effectively, to promote efficient use of water resources, to adopt better water pollution controls, and to carry out utility reforms including the introduction of pricing structures that encourage water saving measures.

On the supply side, many alternative strategies to use water more efficiently are readily available. Since agriculture now accounts for roughly 70 percent of water withdrawals in the world, controlling waste in this sector is a useful starting point. Currently, less than half the water diverted from reservoirs for irrigation actually benefits crops (Postel, 1993), so that lining of irrigation channels and ditches to minimize seepage would be an important step.[28] A complementary investment would be for improved field drainage, which would not only use the available water more effectively but, sometimes, would also allow the runoff to be recycled. Irrigation practices that reduce transpiration, for instance, the use of spray or drip methods, would also reduce water waste in many situations. Reforming the current systems of water rights, especially those giving priority water allocations to the original claimants, despite how they use it, would permit water to be distributed to where it can be more efficiently used, especially to agricultural products that demand relatively less water.[29] In certain cases and for certain crops, the use of recycled and/or lightly treated sewer water for irrigation purposes is safe and saves freshwater. Land reclamation and the prevention of land degradation will increase absorption of water and groundwater recharge, so that more water can be extracted from groundwater and subsurface aquifers. Limitations on the use of certain

[28] Merrett (2002) presents data on twelve alternative irrigation distribution systems in Bangladesh and shows that a simple surface pipe system using high-density polyethylene has the lowest capital and maintenance cost than any of the other systems.

[29] For instance, beef requires 15,000 to 70,000 kilograms of water per kilogram of food produced, while potatoes require only 500 to 1,500 (Gleick, 2000: p. 78).

water-polluting insecticides and fertilizers and more rigorous pollution controls would make more water available for human use downstream without extensive treatment. Water in agriculture can also be saved by reducing crop lost in harvesting, in insect damage and disease, and in distributing and marketing. Gleick (2000: 77) reports post-harvest rice losses varying from 10 to 37 percent, and losses from grain and legume harvesting run as high as 50 percent in some places.

Supply-side measures in the industrial, municipal, and household sectors have also received considerable attention in recent years. These include recycling of water used for cooling purposes in industry, paying closer attention to leaks in water mains and pipes, and switching to less-water intensive processes and products. Although expensive, investment in desalinization plants to extract usable water from the sea is becoming an increasingly more attractive option for obtaining freshwater, especially for countries in the Near East, which, to a certain extent, can utilize solar energy for this purpose.

On the demand side a variety of alternatives are available. In agriculture, farmers can afford to waste water if it is inexpensive. In the United States, for instance, an average farmer buys irrigation water at only 17 percent of its real capital and operation costs and, consequently, they often use this water for low value products such as hay, alfalfa, and other pasture crops (Repetto, 1986: 18). In six Asian countries (Indonesia, South Korea, Nepal, the Philippines, Thailand, and Bangladesh), farmers pay between 4 and 18 percent of a moderate estimate of operation, maintenance, and capital costs of irrigation water and this situation is not atypical of many other countries in the world (ibid.: 5). The worst example might be Saudi Arabia, which has used highly subsidized water from its desalinization plants and from its rapidly falling water table to grow water-guzzling wheat in the hope of achieving the elusive and expensive goal of food self-sufficiency. Indeed, for while it even exported some of this wheat.

In the industrial, municipal, and consumer sectors, many demand-management techniques are available, and some of them are crucial, such as universal water metering and charging of full water costs. Where water-saving consumer appliances are available, the traditional models could be banned. For instance, in American homes the flushing of toilets is the largest single consumer use of water (Wolf and Gleick, 2002:4), but toilets that require less water could replace the standard models. Certain water-using practices could also be limited. For instance, in California, water used for residential outdoor purposes, such as swimming pools and lawn watering, accounts for one fifth of all urban water use; this is more than double the amount of freshwater consumed by industry (Gleick, Haasz, and Wolff: 105) It might be added that watering lawns does not require fresh water resources, and gray water, storm runoff, or reclaimed wastewater could well serve the same purpose.

Although many other ways of saving water can be listed, a crucial question arises: Will such methods ever lead to a significant reduction in total water use? An interesting case study is the United States. The U.S. is one of the most profligate consumers of water in the world (Gleick, 2004: 245-251), yet even here the statistics are encouraging: 3 percent less water was withdrawn in 2000 than in 1975, though the population in the same period grew 30 percent (ibid.: 314-6), which means that per capita withdrawals decreased 25 percent.[30] Since 1990 the use of water has tapered off dramatically in China so that it appears to be slightly lower than the population increase (Gleick, 2002, p. 317).

[30] Calculations of consumer income elasticities of demand for water, which range from 0.14 to 0.46 (Renzetti, 2002), are irrelevant for such estimates because for the world as a whole, direct consumer demand for water constitutes about 10 percent of total water usage. Industrial output elasticities for water, ranging from 0.13 to 0.32, are similarly irrelevant, in part because such usage constitutes about 20 percent of world water usage, in part because much water (for instance, for cooling) is recycled. (Data from WHO 2000: 6).

In brief, many countries can avert the consequences of a severe water shortage either by obtaining freshwater from new sources or, as is more likely in most nations, taking measures to conserve the water they already have.

4. Alternatives to War: Dispute Mediation

Mediation can help defuse potential armed conflicts over water and the global capacity for such mediation has been enhanced over the last few decades by the development of new technical and financial instruments, dispute resolution institutions, and internationally recognized water treaties.

On the technical and financial sides, a variety of new tools that aid water basin cooperation have been developed in the past few decades: these include many new analytic tools for determining more exactly the impact of various proposed projects and real-time monitoring tools so that nations can determine whether their partners are living up to their agreements. Furthermore, most development banks have restrictions on lending without the agreement of all riparians to public water projects in any specific country.[31]

In the last decades of the twentieth century, utilization of dispute resolution mechanisms for water conflicts have become more frequent. For instance, in 1993 the International Court of Justice resolved a dispute between Hungary and Slovakia about the Gabcikovo Project on the Danube; and in 2000 the court mediated a dispute between Namibia, Botswana, and Zambia over access to the waters of the Zambezi/Chobe River. Similarly, in 2004 the Permanent Court of Arbitration settled a dispute between France and the Netherlands over pollution of the Rhine River. Dispute resolution mechanisms for water disputes are also in place in the Organization of African States and the Organization of

[31] Unfortunately, few private banks follow such guidelines. For instance, Turkey financed its Southeastern Anatolia Project (GAP) through private institutions without securing the agreement of its riparian neighbors..

American States.

In addition, certain NGOs are playing more important roles in mediation. For instance, the Committee on International Waters of the International Water Resources Association, has organized high-level meetings for a frank exchange of ideas between governmental and professional representatives from riparian states in river basins with a high potential for armed conflict. Under other auspices various regional forums (Middle East, Asia, and Latin America) have met to discuss water issues. In addition certain international organizations, such as the Global Water Partnership, have brought experts together and made them available for consultation on technical issues.

Some international treaties also cover various aspects of water disputes, particularly the Convention on the Law of the Non-Navigational Uses of International Watercourses, which the UN General Assembly adopted in 1997 (after twenty-seven years of negotiation). Some commentators, such as Postel (1999: 149), criticize this agreement as too vague and general to be of much practical help in hammering out water-sharing agreements, especially since the Convention sets up various criteria to take into account in these negotiations without specifying their relative importance.[32]

River basins with many riparian states can find themselves in complicated disputes that are a challenge to resolve. In the two lists in Table 4, those of the Aral Sea Lake Chad, the Zambezi, the Danube, the Mekong, and the Nile all fall into this category. The first three are not governed by very adequate water treaties, although they do have standing commissions to help iron out disputes; the last three have water treaties that are more adequate yet still imperfect. Another complex case occurs when water negotiations are mixed

[32] She also notes (p. 150) that only three countries voted against this Convention - Burundi, China, and Turkey - and that the latter two are powerful upstream countries with little fear of retaliation from their downstream neighbors.

with a variety of political issues. For instance, McCaffrey (1993) notes that as a consequence of the occupation of the West Bank after the war in June 1967, Israel gained control of a large groundwater aquifer which now provides at least one-fourth of Israel=s water. This dependence has complicated negotiations about control of this disputed territory because of the high cost of alternative water sources. Moreover, the negotiations over return of the Golan Heights are complicated in a similar way by the necessity to agree upon the use of several streams that originate in Syria and feed into the Jordan River. Similarly, negotiations between India and Pakistan over the Indus River basin must also deal with Kashmir, through which the river flows. Nevertheless, these intricate cases can be, and often are, satisfactorily resolved although the negotiations often last for years.

D. Final Remarks

In this essay I have presented evidence for three propositions:

First, by 2025 a significant share of the world=s population will be living in countries which are water-stressed, at least by conventional criteria. Since most countries have not yet utilized the enormous possibilities for water saving, however, the Astress≅ may have no large-scale negative impacts on agricultural production or the prospects for armed conflict.

Second, macro-evidence suggests that the world will be able to feed its growing population, even though growth of food production through irrigation agriculture will not be as important in the first quarter of the twenty-first century as it was in the last quarter of the previous century. Nevertheless, considerable investments in irrigation will still be necessary.

Third, armed conflicts between nations have not been very frequent in the last quarter of the twentieth century and although water stress is increasing, other conditions do not appear to be changing sufficiently to warrant the expectation that Awater wars≅ will intensify in the next several decades. This expectation is bolstered by the development of effective ways of conserving a country=s available freshwater, which reduce the temptation to appropriate water from a neighboring state, by the increasing effectiveness of new technical methods of monitoring water treaties; and of the increasing availability of institutions and methods for resolving disputes over water.

All this suggests that in the coming decades the probability for major armed conflicts between nations over water is low. With increasing localized water stress in nations with weak central governments, in contrast, interstate water conflicts may increasingly lead to armed civil disputes. This possibility must, however, be left for others to discuss.

APPENDIX: CALCULATION OF THE PACW INDEX

The index for the Apropensity for major armed conflict over water≅ combines three elements: the lack of past cooperation over water issues; past conflicts (not necessarily leading to fatalities) over water; and geographical factors that increase, or decrease the propensity of war. Since so few disputes over water issues have occurred in the past few decades (the only period that seems relevant for making projections for 2025), the weights of these three factors can only be subjective. Since the relevant data are provided, readers may reweight these factors as they please. This very rough index, labeled as the Apropensity for major armed conflict over water (PACW),≅ is a ten-point scale running from 0 (no propensity) to 9 (high propensity) and is only used for discussion purposes to narrow the list of countries in Table 4 for special consideration. It is the sum of three components:

Indicator A (40 percent of the total PACW indicator) focuses on past cooperation over water issues, as revealed by water treaties between the nations in the basin.[33] A score of 0 indicates that they have treaties stipulating the allocation of water and monitoring of water withdrawal; further, they have a joint council to oversee the river basin and a dispute resolution mechanism with designated third party arbitrators if the issue cannot be resolved by the signatory nations. A score of 3 indicates that none of these conditions is present and a score in between 0 and 3 reflects that some of these conditions are in place.

[33] The data come from the International Freshwater Treaties Database compiled by Aaron T. Wolf et al. at

< http://www.transboundarywaters.orst.edu/projects/internationalDB.html>.

Indicator B (40 percent of the total PACW indicator) focuses on the actual interaction between the nations in the basin over water and is the sum of two different ratings. The first is Gleick=s listing (2004: 244-52) of serious (but not necessarily armed) conflicts focusing on the control of water. Between 1975 and 2000 he lists 31 such incidents between nations. I have given each international incident in a specified water basin a score of 2 if armed violence occurred, or a score of one if serious threats, troop movements, and the like were employed without resort to violence. The second draws from the International Water Event Database, which records several thousand incidents between 1975 and 2000. Each is rated on a scale of seriousness and I have selected those with a score of -7 (formal war), -6 (extensive war acts causing deaths and dislocation), -5 (small-scale military acts, including skirmishes), -4 (provocative actions including inciting riots, financing rebellions, harboring rebels, nationalizing property owned by the other country without compensation) and -3 (hostile actions including troop mobilization, boycotts, closing borders, recalling ambassadors, and the like).[34] For each river basin I added up the score and then scaled them so that the average was the same as the Gleick data.

Indicator C (20 percent of the total PACW indicator) runs from 0 to 2 and focuses on two geographical factors that influence the propensity for armed conflict. The first factor is based on the hypothesis that larger the number of nations sharing the basin, the less likely is armed conflict because such bilateral combat may generate hostile responses from the other nations in the basin not directly involved in the original dispute. The second factor is based on the hypothesis that armed conflict is less likely if one nation in the basin is very

[34] This is compiled by Wolf et al. at: <www.transboundarywaters.orst.edu/projects/events/>. I have omitted acts rated as -2 and -1 because they seemed too petty to include. Actions with positive numbers cover various types of cooperative actions.

much larger (in terms of population) than the others, since it is less expensive for this large nation to bully the others to obtain the water it needs, rather than engage in warfare. I have subjectively combined these two factors.

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