Water Futures: A Review of Global Water Resources Projections[1]

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Introduction and Background

Water planners are among the few natural resource managers to think more than a few years into the future. At the local level, the long lifetime of dams and reservoirs requires planners to take a relatively long view. At a global level, numerous groups and individuals have made projections and estimates of future global freshwater use over the past few decades, some extending out as much as 60 or 70 years. The recently renewed interest in global water issues has stimulated several new efforts in this area. These new efforts are also taking advantages of advances in computer capabilities, the availability of better water data, and new concepts of scenario development. This paper offers an analysis and review of the major scenario projections and discusses the differences in their basic assumptions, methodologies, and approaches. These differences limit the validity of direct quantitative comparisons, but a general comparison highlights basic concepts in understanding global water use projections.

The future is largely unknowable. But planning requires that we at least think about possible futures, explore plausible paths, and identify risks and benefits associated with different outcomes. This has led to a growing interest in using scenarios, forecasting approaches, and "future" studies (see, for example, Schwartz 1991). This sort of planning has more than academic implications. In the water sector, expectations about future water demands and supplies drive enormous financial expenditures for water-supply projects. These projects, in turn, can often entail significant adverse human and ecological impacts. At the same time, failing to make necessary investments can lead to the failure to meet fundamental human water needs. The challenge facing water planners is to balance the risks and benefits of these kinds of mistakes.

While most water projections are usually done on a small regional scale by water agencies, municipalities, or companies, a number of more comprehensive, global scale assessments have also been done in an effort to get a broader picture of critical water

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[1] This publication is part of the World Water Vision of the 21st Century,(www.watervision.org), a global consultation project that aims to develop knowledge, raise awareness of water issues, produce a consensus on a vision for the year 2025 and contribute to a Framework for Action linked to the Global Water Partnership(www.gwpforum.org). This work was carried out for the Vision Scenario Development Panel under a Stockholm Environment Institute contract funded by Sida.

concerns. Most of these studies typically consist of separate regional and sectoral projections summed to provide a global view. Each regional or sectoral estimate carries its own sets of assumptions and methods.

Projections of global water use have become increasingly sophisticated in approach, and detailed in their temporal and spatial scale. Most of the earliest projections used variants on the same methodology – future water use was based on population projections, simple industrial, commercial, and residential water intensity (e.g., water per unit population or income) assumptions, and some basic estimates of future crop production as a function of irrigated area and crop yield. Early scenarios were typically single, “business-as-usual” scenarios with no variants. Most scenarios ignored water requirements for instream ecological needs, for navigation, for hydropower production, for recreation, and so on. These are difficult to calculate with any accuracy, and it is hard to estimate how much these activities will affect overall supply or demand numbers. Nevertheless, these water uses and activities will eventually need to be quantified and incorporated into future estimates.

Recently, projections have begun to include reassessments of actual water needs and water-use efficiencies, dietary requirements, cropping patterns and types, and ecosystem functions. Multiple scenarios have been published describing a wider range of results under a wider range of assumptions. Global scale water-use projections have also become increasingly sophisticated due to the growing capability of easily accessible computers to handle significant numbers of calculations and the growing availability of water-use data. Assessments that used to be done for continental areas or on a national basis are now being done for watersheds on smaller and smaller temporal and spatial scales.

The greatest constraint on future improvements in water forecasts now comes not from computer capability but from limitations on the quality, availability, and regional resolution of water data. Serious gaps in regional-scale data still exist and are unlikely to be filled soon. Certain types of water-use data are not collected or reliable. Some countries or regions still refuse to share water-related data with neighbors, or even their own scientists. Information on changing water-use patterns over time is often not available, making analysis of trends difficult. As a result, analysts should not assume that increasing model or scenario sophistication will lead to more accurate forecasts. In the end, these scenarios must still be treated as “stories,” as possible futures to be explored, with the understanding that choices we make today will determine which path we end up following, and which future we move toward.

Definitions

There is a tremendous confusion in the global water literature about the terms for “use,” “need,” “withdrawal,” “requirement,” “demand,” “consumption,” “water supply,” “available water,” and so on. Great care should be used when interpreting or comparing different studies. For the purposes of this review I have tried to standardize terms as follows: “Water withdrawal” refers to water removed from a source and used for human needs. Some of this water may be returned to the original source with changes in the quantity and quality of the water. The term “consumptive use” refers to water withdrawn from a source and mad unusable for reuse in the same basin, such as through irrecoverable losses, including evaporation, seepage to a saline sink, or contamination. Consumptive use is sometimes referred to as “irretrievable losses” (see, for example, De Mare and L’vovitch). The term “water use” is often used inconsistently, referring at times to consumptive use and at times to withdrawals.

A Review of 20th Century Water Scenarios and Projections

During the 20th century, water-resources planning has focused on using or making projections of variables such as populations, per-capita water demand, agricultural production, levels of economic productivity, and so on. These projections are used to predict future water demands and to then evaluate the kinds of systems necessary to meet those demands. As a result, traditional water planning tends to project future water demands as variants or extensions of current trends, independent of any analysis of specific human needs. Often these projections are done independently of estimates of actual regional water availability. The planning process then consists of developing suggestions of alternative ways of bridging the apparent gaps between this idealized projection of demand and anticipated supply.

On a regional scale, the official California Water Plan is an excellent example of this kind of approach. Every several years the California Department of Water Resources issues an updated Plan. The most recent version, released in late 1998, is similar in form and approach to every one of the seven earlier versions going back to the original one published in 1957 (CDWR 1998). Using fairly constant water intensity (water use per person) projections coupled with projected increases in population, CDWR concludes that California water problems and policies in 2020 will be little changed from today. The state will grow the same kinds of crops on about the same amount of land. The larger urban population will continue existing patterns of water use, with minor changes in some residential water-use technology and efficiency. Water used by aquatic ecosystems will remain the same or even decrease. And the projections of total demands exceed available supplies by several billion cubic meters, a shortfall projected in every CDWR report since 1957.

On a larger scale, almost every early global water projection used the same approach and reached the same conclusion, leading many observers (including the author of this paper) to worry about major shortfalls and shortages in the future. In some areas of the world, such shortages and shortfalls are already manifest, and new problem areas are likely to emerge in coming years. At the same time, it is important to note that every one of the early global water projections estimated far greater demands for water than have actually materialized, many of them by a substantial margin. This suggests that the traditional methods used by water scenario developers are missing some critically important real world dynamics. Below I describe some of the most comprehensive global water assessments of the mid-20th century.

Nikitopoulos 1962, 1967

In the 1960s, a Greek hydrologist estimated total global water withdrawals by major sector for the year 2000 (Nikitopoulos 1967). In his work he assumed average annual domestic, industrial, and agricultural water needs on a per-capita basis, and then adopted population estimates to get projected future withdrawals. He did an additional estimate of ultimate water needs based on average annual per-capita use for domestic, industrial, and agricultural purposes assuming a standard of living equal to the existing standard in the US. In this study, **domestic** consumption was estimated to be 500 liters per person per day (lpcd), with another 500 lpcd required for **industrial** water use. For **agricultural** water use, the study assumed that 700 square meters of irrigated land would be needed to grow food for each person, with an average of 1,000 mm/year of irrigation water required in addition to rainfall; this amounts to an additional 700 m^3/year. Total annual ultimate water use per person in 2000 was thus estimated to be about 1,065 m^3 per person or a total of 6,730 cubic km^3 (Nikitopoulos 1962). Rather than project population farther into the future, he then tried to calculate a global carrying capacity based on water availability.

L'vovich 1974

In 1974, M. I. L'vovitch published an assessment of global water-resources supply and use that a quarter century later remains one of the most comprehensive and detailed ever done (L’vovich 1974, 1979). Detailed assumptions were made for a variety of human uses to the year 2000, including domestic and industrial water use, irrigated and non-irrigated agricultural water demands, and hydropower, navigation, and fishery water requirements. L'vovich developed two different scenarios for 2000: a "business-as-usual" scenario and a "rational use" scenario. The work of L'vovich has formed the basis of much of the global water modeling done since then.

In the business-as-usual scenario, L'vovich assumed that average domestic per-capita withdrawals would increase to 400 liters per person per day (lpcd) with the widespread adoption of central sewerage. He assumed each of the projected 6.3 billion humans in the year 2000 will use this amount, leading to a total domestic water withdrawal of 920 cubic kilometers. Consumptive use of water in this sector was assumed to be under 20 percent of withdrawal, but the remaining water is assumed to be sewage, requiring substantial volumes of runoff for "dilution."

For power production, L'vovich assumed that water-use per kilowatt-hour of electricity produced would decrease, as efficiency increased. For closed-cycle cooling plants, he assumed about three liters of water are evaporated per kWhr of electricity generated, with far higher levels "withdrawn" for use and returned to the source. In open-cycle or once-through plants, total consumptive use is lower but total withdrawals are higher. Assuming that future consumptive use in this sector followed existing patterns, L'vovich estimated that water consumption for the energy sector would increase by a factor of 20 to 200 km^3/year, while withdrawals increase to 3,100 km^3/year. He then notes, however, that this figure is unacceptably large because of the temperature discharge constraints, and reassesses power needs by assuming increases in water-use efficiency. In this case he assumes that water consumption per unit energy decreases to half of its 1960s value. Water withdrawals and consumption would thus increase by a factor of seven between the early 1970s and 2000, while world energy use would increase 17-fold. In this case, total water withdrawals for power-plant cooling would be about 1,550 km^3/year and consumptive use about 100 km^3/yr (L'vovich, p 305-306).

Gross industrial water "use" in the year 2000 under current trends was assumed to increase by a factor of 15 between the early 1970s and 2000 to 6,000 km^3, while actual industrial withdrawals were projected at 3,000 km^3/year, implying a reuse factor of 2. L'vovich is one of the few analysts to consider this issue of reuse. Consumptive industrial water use in the year 2000 was projected to be 10 percent of gross use, or 600 km^3/year. He assumes extremely large additional volumes of water are needed to dilute industrial pollutants. Because of the huge volumes of water required in this "business as usual" scenario, L'vovich developed a "rational use" scenario for industrial and public water use, in which no sewage water is generated (all water is recycled and reused) and all industrial and power water supply needs are met with closed systems. This greatly reduces total “water supply” estimates, as shown below, and is one of the few early examples of an alternative scenario.

In the “business as usual” scenario, projected agricultural water use (irrigated agriculture) in the year 2000 was determined by assuming a per-capita annual food consumption of 800 kg of grain (twice the 1970s amount) feeding 6.3 billion people, for a total annual production requirement of food crops (grain equivalent) of approximately 5 billion tons. Irrigated agriculture is assumed to furnish 40 percent of this grain, or 2 billion tons. Using crop yields of 4 tons per hectare, the total irrigated area needed would be 500 million hectares, of which 425 M ha would be irrigated with clean water, and 75 M ha irrigated with sewage water. L’vovich assumes that 8,000 cubic meters of water per hectare will be required for irrigation. Thus total withdrawals of water for irrigation would be 4,500 km^3/year, of which 4,000 would be consumed (L’vovich, p.314). Because part of this water is wastewater enriched in organic fertilizer, L’vovich adds a correction for the possible increases in crop yields on lands using this water and recalculates total water needs downward to 4,250 km^3 withdrawn and 3,850 km^3 consumed. These data are for food crops only. If "technical" crops, such as for natural fibers, are included, L'vovich estimated total withdrawals of irrigation water in the year 2000 would be 4,400 km^3 per year and total consumptive use would be 4,000 km^3 per year (L’vovich, p. 314-315).

L'vovitch calculated total water consumed for rainfed agriculture by making assumptions about water requirements to grow grains, determining the area of land planted to food crops, and making assumptions about future increases in grain yield per hectare. Yields were assumed to triple and reach 1.8 tons per hectare while total grain production was assumed to experience a four- to five-fold increase to 3 billion tons. For future projections, he extrapolates a general trend of reducing water consumption per unit agricultural output (i.e., higher efficiency) but a general increase in total water used for plant growth. Assuming that 1.7 billion hectares of land are planted to food crops, total consumption of water on unirrigated farmland will be about 2,500 km^3/year instead of the present 1,260 km^3/yr. This additional expenditure of water will come in part from arid lands and in part from land with sufficient water; according to L'vovich, an overall decrease in runoff of 700 km^3 will be required to meet this need.

Other human activities, including hydropower, navigation, and fisheries, will also require water withdrawals and use. Future evaporative losses will increase with an increase in reservoir area. L'vovich projected that a total of 500 km^3 of evaporative losses from reservoir surfaces will occur by 2000, with additional withdrawals and consumption for fisheries, livestock, and navigation. Tables 1 and 2 summarize L'vovich's conventional and "rational use" projections.

Table 1
L'vovich Year 2000 Conventional Assumptions Projection (km^3/year)
(L'vovich 1974)

	Withdrawals	Consumption
Residential/Drinking water	920	180
Livestock	150	100
Power Industry	3,100	270
Industrial	3,000	600
Irrigated agriculture[a]	4,400	4,000
Non-irrigated agriculture[b]	700	700
Hydropower & navigation	500	500
Fishery & sports fishing	175	85
TOTAL[e]	12,770	6,350

Note: L'vovich included many different possible scenarios. This one, from Tables 29, 30, and 32 in his book, reflect his business-as-usual variant.

a includes food and fiber crops, and 450 km3 of wastewater.

b An additional 1,240 km^3 of rainfall is used for non-irrigated agriculture. The 700 km^3 listed here is the reduction in runoff from expansion of rainfed agriculture and hence is counted as additional human water use over current conditions.

Table 2
L'vovich Year 2000 "Rational Use" Projection (km^3/year)
(L'vovich 1974)

	Withdrawals	Consumption	Discharge of sewage
Water supply (all types)	1,500	1,050[a]	0
Irrigated agriculture	3,950	4,000[b]	400[c]
Non-irrigated agriculture[d]	700	700	0
Hydropower & navigation	500	500	0
Fishery & sports fishing	175	85	90
TOTAL[e]	6,825	6,335	490

Note: L’vovich included many different possible scenarios. This one, from Table 32 in his book, includes a more efficient variant.

a excluding 450 km^3 of sewage used for irrigation

b including 450 $km^3$of sewage used for irrigation

c some pollution from agricultural runoff

d An additional 1,200 km^3 of rainfall is used for non-irrigated agriculture. The 700 km^3 listed here is the reduction in runoff from expansion of rainfed agriculture.

e these numbers do not always correspond to L'vovich's text. This table is repeated verbatim from the original source (p. 329), but readers should go to the text for details and clarification.

Kalinin and Shiklomanov (1974) and De Mare (1976)

Kalinin and Shiklomanov’s work (in Russian) is described by De Mare (1976). They base their estimates on trends from numerous statistics and special reports concerning present (1974) and future water use. In addition to domestic, industrial, and agricultural water use, they calculate reservoir losses from increased evaporation. Kalinin and Shiklomanov state “for reliable forecasts it is necessary to have information about the tendencies and possible changes of specific water consumption,” which the authors note are difficult to consider or predict. Per-capita values for consumptive uses and withdrawals are adopted for various regions and end-use sectors and multiplied by population projections. For industrial water use, they assume a North American standard of 1,200 m^3/p/year. Total 2000 water withdrawals were estimated to be 5,970 km^3. Most of their estimates were adopted by de Mare.

In 1976, de Mare (1976) produced an assessment of global water use in the year 2000 using as a base several existing assessments of world water resources. The original purpose of the paper was to serve as input for the 1977 UN Water Conference in Mar del Platta, Argentina and work was carried out under contract with the UN and in close contact with the Secretariat of the International Federation of Institutes for Advanced Study (IFIAS).

De Mare assumed it is unlikely that regions with high “specific” (per-capita) consumption will reduce their domestic use – a standard assumption of traditional water planners. In his assessment, most of the developing regions were assumed to reach 200-300 liters per person per day (lpcd) for domestic needs, with a higher per-capita water use in the industrialized regions. De Mare assumed industrial water use in the year 2000 would also vary depending on region, with a range from 100 to 2,000 m^3 per person per year. The high value was given for industrialized North America, which assumes a significant increase from actual per-capita industrialized water use in the region. De

Mare assumed global industrial water withdrawals would be 1,775 km^3 per year by the year 2000.

Agricultural figures from Kalinin and Shiklomanov were adopted directly by de Mare except for Africa. De Mare's African agricultural assumptions are not adequately explained. Data on water losses from reservoirs were also adopted directly from Kalinin and Shiklomanov. Table 3 summarizes De Mare's year 2000 per-capita water withdrawal assumptions by region. Table 4 summarizes total water withdrawal by region, also for the year 2000.

Table 3
De Mare Year 2000 Per-capita
Water Withdrawal (cubic meters per person per year)
Projections by Region and Sector
(De Mare 1976)

Region	Domestic m^3/p/yr	Industrial m^3/p/yr	Agricultural m^3/p/yr	Reservoir losses m^3/p/yr
Europe	150	400	185	10
USSR	130	500	1,310	70
Asia	75	150	5,585	25
Africa	50	100	400	85
North America	260	2,000	1,050	110
South America	20	200	190	35
Oceania	110	700	750	150

Table 4
De Mare Year 2000 Total Water Withdrawal Projections
(De Mare 1976)

Region	Total Water Withdrawal Km^3/yr
Europe	405
USSR	640
Asia	3,140
Africa	520
North America	1,025
South America	290
Oceania	60
Total	**6,080**

Includes water losses from reservoirs

Falkenmark and Lindh 1974

Malin Falkenmark and Gunnar Lindh published several different estimates of water withdrawals and consumption in the mid-1970s. These are summarized in Table 5 and Table 6. In their 1974 paper,[2] rather than make a projection based on typical use in industrialized nations, their estimates relied on the varying rural and urban needs of the time. Using United Nations urban-rural population projections,[3] they assumed domestic water needs would be 400 liters per person per day (lpcd) for urban areas and 200 lpcd for rural areas. For other water uses, they relied on the same approach as L'vovitch, with minor variations. For example, for industrial uses, Falkenmark and Lindh base their estimate on the use of water at that time by Swedish industry – 500 m^3 per person per year. Applying this figure to the entire world's population, the world's available freshwater resources would all be needed for wastewater transport, i.e., for dilution and disposal. Therefore, their alternative was to assume that 90 percent of industrial wastewater could be recycled so that only 10 percent of the wastewater plus irretrievable losses from production (estimated at an additional 20 percent) would have to be replaced by fresh water. Consumptive use of water by industry thus amounts to 30 percent of the total, or 140 m^3 per person per year.

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[2] See also Falkenmark, M. and Lindh, G. (1974) "Impact of water resources on population" Swedish contribution to the UN World Population Conference, Bucharest.

[3] United Nations (1974) Concise report on the World Population Situation in 1970-75 and its Long Range Implications" Dept. of Economic and Social Affairs. ST/ESA/SER.A/56, New York.

For estimating agricultural needs, Falkenmark and Lindh assumed that 12 people could be supported by the agricultural production of one hectare of cropped land, requiring 700 to 900 mm/year of irrigation water. This corresponds to a per-capita consumptive use of 585 to 750 m^3 per year for agriculture.

Table 5
Falkenmark and Lindh Year 2000 Water Withdrawal and Consumption Projections (km^3/yr)
(Falkenmark and Lindh 1974)

Region	Year 2000[a]	Year 2000[b]	
		A	B
Europe	520	741	536
Asia	3,500	4,826	3,465
USSR	310	430	312
Africa	780	1,044	742
North America	290	437	317
South America	600	859	616
Australia/Oceania	30	46	33
Total	6,030	8,380	6,030

A: without wastewater reuse

B: with wastewater reuse

a Cited in de Mare (1976)

b Cited in Falkenmark and Lindh (1974)

Excludes explicit water losses from reservoirs

Table 6
Falkenmark and Lindh Year 2015 Water Withdrawal Projections
(Falkenmark and Lindh 1974)

Sector	2015 Withdrawal (no industrial reuse) km^3/yr	2015 Withdrawal (90% industrial reuse) km^3/yr
Domestic	890	890
Industrial	4,100	1,145
Agricultural	5,850	5,850
Total	10,840	7,885

Year 2015 population is assumed to be 8,155 million.

Source: Falkenmark and Lindh 1974

Excludes explicit water losses from reservoirs.

World Resources Institute (1990) and Belyaev (1990)

Year 2000 projections for water withdrawal, consumptive use, and waste in return flow are summarized in one of the annual World Resources reports by the World Resources Institute (WRI 1990, pp.167-173; Table 8). Of the 3,500 km^3 withdrawn for human use each year in 1990, around 2,100 km^3 are used consumptively. The remaining 1,400 km^3 are returned to rivers and lakes. In the WRI projection, global withdrawals are expected to rise two to three percent annually until the year 2000. Primary data and water-use projections for 2000 were developed by region and sector by a team of Soviet hydrologists (directed by A.V. Belyaev) and from a United Nations conference paper by Asit Biswas. Table 7 summarizes the WRI estimates. Little detail is given in the WRI source on the background assumptions made.

Table 7
World Resources Institute Year 2000 Water Withdrawal and Consumption Projections
(WRI 1990)

Region	Withdrawals (km^3/year)	Consumptive Use (km^3/year)
Europe	404	158
Asia	2,160	1,433
USSR	533	286
Africa	289	201
North America	946	434
South America	293	165
Oceania	35	22.5
Total	4,660	2,700

From Table 10.3, WRI 1990

Belyaev's estimate from the USSR Academy of Sciences, Institute of Geography, Moscow (described in WRI 1990), also offers an analysis of water withdrawals and consumption for 2000. Single projections are made for the irrigation, domestic, and municipal sectors. A range is provided for the industrial sector. The values summarized in Table 8 are the sums of the sector estimates.

Table 8
Belyaev Year 2000 Water
Withdrawals and Consumption Projections
(Belyaev 1990)

Region	Water Withdrawals km^3/year	Water Consumption km^3/year
Europe	381 – 481	143 - 148
Asia	2,020 –2,040	1,315 – 1,320
Africa	220 – 225	133 - 138
North America	840 - 850	332 - 342
South America	230 - 240	110 - 120
Oceania and Australia	28.5 - 29	17
USSR	475 - 485	235 - 240
Total	4,195 – 4,350	2,284.5 – 2,320

Shiklomanov (1993 and 1998)

In 1987 Shiklomanov and Markova (from the State Hydrological Institute in St. Petersburg – then Leningrad) published a set of estimates of current and projected water-resources use by region and sector (see Shiklomanov 1993 for an English-language version of this work). Water use was broken down for the agricultural, industrial, and municipal sectors, and for water lost from reservoir evaporation. Both water withdrawal and consumptive uses were estimated for the years 1990 and 2000. Shiklomanov used population and economic factors as driving variables, with detailed assessments completed for many regions around the world, which were then aggregated to continental scale. For some regions, improvements in water-use efficiency are implicit in the simple assumption that water use continues at current rates (a declining per-capita water use) rather than a trend of continuing per-capita increases.

Increases in water requirements over 1980 levels are projected for all areas, with the largest increases in South America and Africa. Decreases in overall consumptive use are possible, he suggests, due to improvements in industrial re-use of water. Agricultural water withdrawals are projected to decrease as a fraction of total water withdrawals as industrial water withdrawals increase at a faster rate. Evaporative losses from reservoirs exceed industrial and municipal consumptive uses, but remain far below agricultural consumptive uses. Table 9 shows his projected water withdrawals and consumption by region.

Shiklomanov and the Russian group have continued to refine their assessments, releasing a new comprehensive analysis in 1998 as part of the Comprehensive Assessment of the Freshwater Resources of the World prepared for the Commission on Sustainable Development of the United Nations. This new work (see Table 10) considerably reduces past projections, such that their year 2025 estimates for water withdrawals and consumptive use are actually below their earlier estimates for the year 2000 (Shiklomanov 1998).

Table 9
Two Different State Hydrological Institute Year 2000 Water Withdrawal and Consumption Projections
(Shiklomanov and Markova 1987)

Region	**2000 Water Withdrawals km^3/year**	2000 Water Consumption **km^3/year**
Europe	444	109
Asia	3,140	2,020
Africa	314	211
North America	796	302
South America	216	116
Oceania and Australia	47	22
USSR	229	113
Total	5,186	2,893

Includes about 210 cubic kilometers in water losses from reservoirs

Table 10
Shiklomanov Year 2000, 2010, 2025 Water Withdrawal and Consumption Projections
(Shiklomanov 1998)

Continent	Historical Estimates of Use								Forecasted Use		
	1900	1940	1950	1960	1970	1980	1990	1995	2000	2010	2025
Europe	37.5	71	93.8	185	294	445	491	511	534	578	619
	17.6	29.8	38.4	53.9	81.8	158	183	187	191	202	217
North America	70	221	286	410	555	677	652	685	705	744	786
	29.2	83.8	104	138	181	221	221	238	243	255	269
Africa	41.0	49.0	56.0	86.0	116	168	199	215	230	270	331
	34.0	39.0	44.0	66.0	88.0	129	151	160	169	190	216
Asia	414	689	860	1222	1499	1784	2067	2157	2245	2483	3104
	322	528	654	932	1116	1324	1529	1565	1603	1721	1971
South America	15.2	27.7	59.4	68.5	85.2	111	152	166	180	213	257
	11.3	20.6	41.7	44.4	57.8	71.0	91.4	97.7	104	112	122
Australia & Oceania	1.6	6.8	10.3	17.4	23.3	29.4	28.5	30.5	32.6	35.6	39.6
	0.6	3.4	5.1	9.0	11.9	14.6	16.4	17.6	18.9	21	23.1
Total (rounded)	579	1065	1366	1989	2573	3214	3590	3765	3927	4324	5137
	415	704	887	1243	1536	1918	2192	2265	2329	2501	2818

Remarks: Nominator - water withdrawal, denominator - water consumption.

Includes about 270 cubic kilometers in water losses from reservoirs for 2025.

Gleick 1997

Using a disaggregated "end-use" approach instead of traditional supply/demand projections, Gleick developed a sustainable water "backcast" for the year 2025. Model assumptions included future water use by region and sector under a set of explicit sustainability criteria and limits. In this "Vision" scenario, total domestic water use in 2025 is estimated using two assumptions: (1) the world's entire population has access to a "basic water requirement" (see Gleick 1996) of at least 50 liters per person per day to meet basic needs; and (2) regions using more than that amount in 1990 implement water-efficiency improvements that reduce per-capita domestic water use toward the level presently used in the more efficient nations of Western Europe -- around 300 l/p/d. The net result is that total domestic water needs in 2025 are not substantially different than current estimates – approximately 340 cubic kilometers per year. The overall distribution of that water use is far more equitable than today's distribution.

For the agricultural sector, Gleick's projections are also based on specific human needs: assumptions about dietary needs in each region and the water requirements to produce calories of specific food types. Model assumptions include reductions in per-capita meat consumption in Europe and North America combined with increases in calorie consumption in the developing world. In the agricultural scenario, all regions are assumed to reach a minimum of 2,500 calories per person per day by the year 2025 and those regions currently consuming more than 3,000 calories per person per day experience dietary changes that reduce per-capita daily consumption toward the 2,500 calorie level. Meeting these needs will require not just production goals, but policies for open food markets and transfers.

More dramatic, however, are the projected reductions in water needed to grow these diets. These reductions are the result of changes in the water-intensive components of diets, particularly meats. A North American diet that currently requires over 5,000 liters per person per day to grow today can be reduced to less than 3,500 lpcd, still higher than any other diet but a considerable water savings nevertheless. Similar reductions are developed for each region. Additional assumptions are included about changes in irrigation efficiency, cropping intensities, and irrigated area.

Even with these assumptions, the Gleick Vision scenario projects that overall irrigation requirements would go up substantially between now and 2025. This seems an inevitable result of the anticipated increase in population. Nevertheless, the increases that occur could be far less than the increases anticipated by conventional development scenarios. In 2025, this approach produces a projection of agricultural water consumption of 2,930 km^3/year.

Gleick also argues that future industrial and commercial water demands could look significantly different than today's because of shifts in energy technologies, increases in water-use efficiency, and a change in industrial makeup. At the same time, an increased use of recycled water could further reduce total industrial withdrawals. As developing countries industrialize, they have the potential to "leapfrog" directly to more efficient technologies. The opportunity to bypass certain styles of development would permit many nations to move directly to industries and energy systems that are less consumptive of water. Both of these trends can also be seen in the scenario work done by Raskin et al. (1997).

For his study, Gleick assumed major reductions in industrial water demand in the industrialized nations (driven by increases in the efficiency of water use and shifts in the structure of industry) and an increase in minimum industrial water use in developing countries. Urban water use in developing countries was assumed to increase to at least

100 cubic meters per person per year -- a level described by Shuval (1994) as appropriate minimum levels for a moderately efficient industrialized nation. By 2025 in Gleick's Vision scenario, total industrial water withdrawals remain virtually the same as 1990 levels at around 1,000 km^3/year but the per-capita industrial water-use distribution is far more equitable than today. Per-capita industrial water use in almost all developed regions has dropped — most dramatically in Europe and North America and increased in Asia, Africa, and Latin America both on a per-capita and absolute level. Despite the improvements described in this projection, industrial water-use efficiency in most developed countries has still not reached the level of Japan's or California's in the early 1990s, as measured by both per-capita industrial water use and by industrial economic productivity per unit of water used. These measures suggest that even greater improvements could be achieved without imperiling healthy industrial production.

Total global water withdrawals for 2025, presented in Table 11, are projected in this scenario to be approximately 4,500 km^3 in 2025.

Table 11
Gleick Year 2025 "Vision" Water Withdrawal Projections
(Gleick 1997)

Water Sector	Withdrawals km^3/yr
Agriculture	2,930
Industrial	1,000
Domestic	340
Total	4,270

Gleick estimates an additional 225 km3/yr will be lost from reservoir evaporation.

Raskin et al. 1997, 1998

Raskin and a group of researchers at the Stockholm Environment Institute/Tellus Institute in Boston developed a set of scenarios of future water use in an effort to explore future conditions – "what if" scenarios (Raskin et al. 1995, 1997, 1998). Using a computer model tool developed for projecting resource demands under different socio-economic conditions, they evaluated possible water withdrawals separately for the agricultural, industrial, and domestic sectors and for a variety of regions around the world. The principal drivers of these scenarios are demographic and macroeconomic projections, coupled with estimates of water "intensity," defined as water use per person or per unit of economic production. For some regions and sectors, scenarios were developed where water intensities are projected to decline, reflecting improving water-use efficiency. These intensities are then combined with future population and GDP estimates. The initial estimates were done for 2025. In the follow-up report Raskin et al. 1998), projections are done for both 2025 and 2050 under a “Reference” (business as usual) scenario and a “Policy Reform” scenario designed to meet specific sustainability targets.

For the domestic sector, water intensity in North America is assumed to decrease toward the average in OECD (Organization for Economic Co-operation and Development) countries, while domestic intensities in developing countries increase toward the OECD average. Overall, this leads to substantial increases in total domestic withdrawals. Similar assumptions are made for the industrial sector, where water intensities in developed countries such as the United States are beginning to decline as water-intensive industries are replaced by low water-using industries and as industrial water-use efficiency improves. These trends are assumed to continue, but are swamped by major increases in total industrial water use in the developed countries, which is projected to rise dramatically because of growth in economic development and populations.

Agricultural water-use projections are done differently in the Raskin et al. work than in most conventional scenarios, which simply make assumptions about land and water requirements per person or use broad assumptions about water needs per ton of agricultural product. These scenarios include more detail on irrigation water intensities, crop yields, cropping intensities, and trends toward improved irrigation efficiency (Leach 1995, Raskin et al. 1998). Combining their various regional assumptions with population projections, Raskin et al. (1997) show global irrigated land area growing at 0.3 percent annually between 1990 and 2025, an increase in irrigation efficiency of eight percent over this period, and rising cropping intensities. Overall, the 1997 scenarios report that total freshwater withdrawals under a “mid-range” scenario will rise to 5,000 km^3 by 2025 from their estimated base of 3,700 km^3 in 1990. Their 2025 “low-range” and “high-range” scenarios for 2025 are 4,500 km^3 and 5,500 km^3 respectively. No water losses from reservoirs are included.

Alcamo et al. 1997

The Center for Environmental Systems Research of the University of Kassel, Germany developed a global water model, WaterGAP (Water – Global Assessment and Prognosis) and evaluated water use and availability for nearly the entire terrestrial surface of the world. Version 1.0 of this model, described in Alcamo et al. (1997) works on a watershed basis and takes into account socio-economic factors that affect domestic, industrial, and agricultural water use, as well as physical and climatic factors that affect surface runoff and groundwater recharge. Calculations are done on a grid cell scale of 0.5 degrees longitude and latitude and aggregated to the watershed and country scale. Three different scenarios are developed –low, medium, and high water-use cases. Domestic water use in a country is estimated by multiplying population by an assumed per-capita water use. Industrial water use is estimated by multiplying industrial GDP by water intensity (water use per unit GDP). Per-capita use and water-intensity assumptions for the medium and low scenarios assume different levels of improvements in water-use efficiency as a function of income. Agricultural water use in WaterGAP is split into water requirements for livestock and water requirements for irrigation. Livestock water use is assumed to vary only with livestock population; water use per head is assumed to remain at the 1995 levels. Irrigation water estimates are developed by multiplying water use per hectare times estimates of irrigated area. Water use per hectare is assumed to be a function of climate, cropping intensity, and water-use efficiency. These factors are varied for the low, medium, and high scenarios. Table 12 shows the 1995, 2025, 2075 global water use estimates for the Medium scenario, along with a breakdown of water use by sector. Additional regional data are presented in the original source.

Table 12
Alcamo et. al. Global Projections for Water Use by Sector,
1995, 2025, and 2075 Medium Scenario (cubic kilometers per year)

	Total	Agricultural	Domestic	Industrial
1995 Estimate	3,046	2,022	296	728
2025 Medium	4,580	1,724	621	2,235
2075 Medium	9,496	1,826	1,290	6,380

Excludes water losses from reservoirs

Seckler et al. 1998

The International Water Management Institute (IWMI) released a study in mid-1998 assessing world water demand and supply to the year 2025 under different scenarios. IWMI created a simulation model based on a conceptual and methodological structure that mixes various strategies from earlier assessments. It includes a submodel of the irrigation sector that they describe as more thorough than any previously used

(Seckler et al. 1998). Two alternative scenarios are developed, with different assumptions only about the productivity of agricultural water use: the first scenario is a "business as usual" scenario; the second assumes a high degree of effectiveness in the use of irrigation water.

Projections are made for three sectors: agricultural irrigation, domestic, and industrial water use (see Table 13). Irrigation is a function of irrigated area, withdrawals of water per hectare of irrigated area, reference evapotranspiration rates for different countries and seasons, and irrigation effectiveness. Two separate irrigation scenarios are developed. In both, per-capita irrigated area is assumed to be the same in 2025 as it was in 1990. Thus differences in water use between the two scenarios depend exclusively on assumptions about the change in basin irrigation efficiencies, according to the authors. In the BaU scenario, irrigation effectiveness in 2025 is assumed to be the same as in 1990, so future irrigation withdrawals are determined purely by multiplying 1990 irrigation withdrawals by population increases. The second scenario assumes that most countries achieve an irrigation effectiveness of 70 percent, with some differences for particular countries.

Seckler et al. note the domestic water assumptions of Gleick's (1996) "basic water requirements" paper and double domestic water use in countries reported to be using less than 10 cubic meters per person annually. They note their concerns with the quality of the data on per-capita domestic withdrawals in some countries, a concern also noted in Gleick (1996). For countries using more than 10 cubic meters per person annually, Seckler et al. project 2025 demand on the basis of a relationship between per capita GDP and per-capita withdrawals provided by Mark Rosegrant of the International Food Polic Research Institute, modified for some regional differences. Domestic and industrial use are capped in countries with a high GDP at the 1990 level. Overall 2025 withdrawals increase 45 percent over 1990 values, a smaller increase than population growth because per-capita increases in low water-using countries are offset by decreases in per-capita use in high water-using countries. It is important to note that the base 1990 water-use estimate of Seckler et al. is far below that of other analysts, leading to a significant reduction in their estimate of future water use compared to other projections. They estimate 1990 water use at 2,900 km3; Raskin et al. estimated 1990 water use at 3,700 km3; Shiklomanov (1998) estimated it at 3,590 km3.

Table 13

Seckler et. al. Global Projections for Water Use by Sector,

1990 and 2025 BaU and High Irrigation Efficiency Scenarios (cubic kilometers)

	Total	Agricultural	Domestic and Industrial
1990 Estimate	2,907	2,084	823
2025 Business as Usual	4,569	3,376	1,193
2025 High Irrigation Efficiency	3,625	2,432	1,193

Excludes water losses from reservoirs

Analysis and Conclusions

Many conventional development water scenarios have been prepared over the past quarter century. Looking at the various studies that have been done over the past few decades, two noteworthy trends can be observed. First, the earlier projections greatly overestimated the magnitude of future demands because of the basic approach of extrapolating existing trends. Second, the methods and tools used for forecasting and scenario analysis have been getting more and more sophisticated, permitting a wider range of exploratory scenarios and a better understanding of the driving factors behind changes in demands for water.

The projections reviewed above are presented graphically in Table 14 and Figure 1. This figure also shows actual water withdrawals over time up to 1995. As these data show, the earlier projections greatly overestimated future water demands by assuming that use would continue to grow at, or above, historical growth rates. Actual global withdrawals for the mid-1990s were actually only about half of what they were expected to be 30 years ago. The reasons for this are varied, ranging from the failure to keep up with water needs in many parts of the world to major improvements in the efficiency with which water is used in all sectors. But the foggy nature of our crystal balls highlights the importance of developing better methods for making projections of future needs.

Such methods are beginning to appear, as advances in computer modeling and speed develop and as better water use data are collected and made available. Nevertheless, the major lesson to be learned from past experience with water projections is that they must always be considered as possible futures, not as predictions, and that water planners should use them as tools for evaluating the risks and benefits of alternative water policies, rather than as straitjackets that limit our ability to respond to uncertainties and future surprises. As the proverb states: seeing the future is good, but preparing for it is better.

Table 14
Summary of Various Global Water Forecasts

Author	Publication year	Forecast year	Withdrawal (km3/yr)
Nikitopoulos	1967	2000	6,730
L'vovich	1974	2000	6,825
Kalinin and Shiklomanov	1974	2000	5,970
Falkenmark and Lindh	1974	2000	6,030
Falkenmark and Lindh	1974	2000	8,380
Falkenmark and Lindh	1974	2015	10,840
Falkenmark and Lindh	1974	2015	7,885
De Mare	1976	2000	6,080
Belyaev	1990	2000	4,350
World Resources Institute	1990	2000	4,660
Shiklomanov and Markova	1987	2000	5,186
Shiklomanov	1998	2000	3,927
Shiklomanov	1998	2010	4,324
Shiklomanov	1998	2025	5,137
Raskin et al. Low	1997	2025	4,500
Raskin et al. Mid	1997	2025	5,000
Raskin et al. High	1997	2025	5,500
Gleick “vision”	1997	2025	4,270
Alcamo et al. Medium	1997	2025	4,580
Alcamo et al. Medium	1997	2075	9,496
Raskin et al. Reference	1998	2025	5,044
Raskin et al. Reference	1998	2050	6,081
Raskin et al. Policy Reform	1998	2025	4,054
Raskin et al. Policy Reform	1998	2050	3,899
Seckler et al. Business as Usual	1998	2025	4,569
Seckler et al. High Efficiency	1998	2025	3,625

Notes:

1990 Withdrawals (Estimated by Shiklomanov 1993), 4,130 km^3

1990 Withdrawals (Estimated by Shiklomanov 1998), 3,590 km^3

Where possible, evaporative losses from reservoirs have been excluded in order to make comparisons consistent.

Sources: See references for full citations and for specific assumptions underlying each projection.

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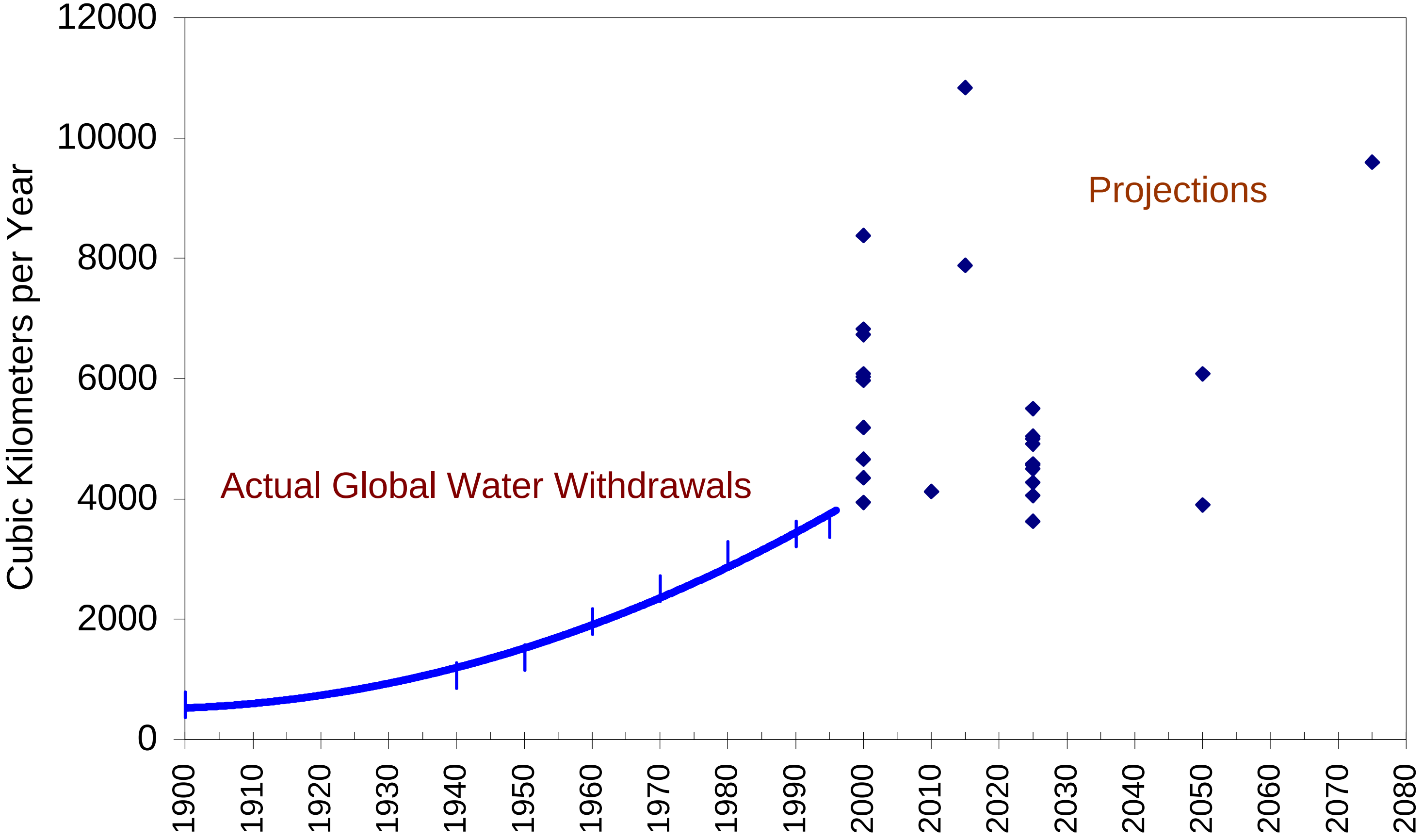

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