Irrigating Efficiently to Feed the World in 2050

Thomas D. Spears
President, Valmont Irrigation Division of Valmont Industries

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Introduction

The problem of water scarcity facing the world today and in the next few decades is quite serious. As I have explored in "Water Scarcity and Modern Irrigation" (Longo, Spears – 2003) utilizing highly efficient irrigation technology is a plausible solution to this problem, especially as modern irrigation uses less water and produces more food than traditional irrigated agriculture. In order to substantiate this proposal that efficiently irrigated agriculture offers the solution to the pending water scarcity crisis, I aim in this paper to lay out the quantitative data and qualitative assumptions from which my analysis derives. The calculation of future food demand and the dry land and irrigated land necessary to satisfy that demand is necessarily filled with debatable assumptions and estimates. The exact projection of food requirements and irrigated land requirements are less important than the confirmation that water availability for irrigated agriculture will present a major challenge, although a technically solvable problem, for the future. This paper attempts to project future irrigated agriculture demand and its associated costs, and concludes with a number of public policy recommendations for future action.

Food Demand

Food demand is driven by two primary factors: population growth and economic growth. While it is easy to see the relationship between population and food consumption, the influence of economic growth is less obvious. Essentially, wealthier people consume a greater quantity of calories on average than poorer people. This can be seen today in the difference in average kilocalories consumed by residents of the United States (roughly 3772 KCal/day) as compared to the world average consumption (roughly 2805 Kcal/day).[1] In addition, the calories consumed by wealthier individuals usually include significantly more meat than the diets of the poor. This is important to understand because calories consumed as meat are often produced using feed grains and take significantly more calories to generate than the direct consumption of the grains themselves. As a rule of thumb, one calorie of chicken requires two calories of feed grain to produce, one calorie of pork requires three calories of grain, and one calorie of beef requires five calories.

With these factors in mind, we can begin to make estimates of how much food demand will grow by 2050, as compared to our reference year (2000).

World Population

There are many estimates of future world population, which employ various assumptions about birth rates, death rates, economic growth rates, disease and medical advances. Most forecast world population around 9-10 billion by 2050. For the purpose of this analysis, the author selected a model developed by the International Institute for Applied Systems Analysis (IIASA) developed in 1996.[2] Population in 2000 is roughly 6.1 billion people. The model predicts population as low as 7.0 billion and as high as 13.0 billion in

2050 based on the assumptions utilized in the modeling process. The scenario with moderate assumptions for both mortality and birth rate produces a result of 9.9 billion population by 2050, which is used in the subsequent calculation. By comparison, the U.S. government census bureau projects approximately 9.1 billion in population in the same time frame.[3]

Gross World Product (GWP)

Projections of GWP are more difficult to come by and more volatile than population projections. The energy industry, which must make long term economic estimates for the purpose of long term capacity planning, is the best source of GWP that the author has found. According to the Energy Information Administration's International Energy Outlook for 2002, 1999 Gross World Product was $30.6 trillion dollars (in 1997 dollars) and will grow to $59.7 trillion (in 1997 dollars) by 2020.[4] This is a 3.2% annual average growth rate. The author assumed, conservatively, that this rate of growth would decline in 2020-2050 to roughly 2.4%, resulting in a GWP in 2050 of $122.5 trillion dollars (in 1997 dollars). By my analysis, then, GWP per capita will grow from $4,984 in 1999 to $12,408 in 2050.

Calorie Consumption

In 2000, at $4,984 per capita GWP, the average world citizen consumed 2,805 Kcalories/day. The average United Sates citizen with a per capita GDP of $33,109 consumes 3,772 Kcalories/day. Interpolating between these numbers using the $12,408 per capita GWP expected in 2050 would imply per capita consumption of roughly 3,070 Kcalories/day per capita. To this number, the author has added an additional 6% resulting from the substitution of meats for grain. This implies an average per capita farm output of 3,262 KCal/day required to support human consumption. We are now in a position to estimate the farm output required to feed the world population as a percentage of 2000 farm output. The calculation is as follows:

$$\text{Output Growth} = 100\% * \frac{(9.9 \text{ Billion} * 3{,}262)}{(6.1 \text{ Billion} * 2{,}805)} = 187\%$$

Land Availability

Irrigated and non-irrigated land totaled 1,497 million hectares in 2000, according to UNFAO.[5] Despite this large quantity of cultivated land, there remain significant reserve lands in the world, which could be converted to agricultural use. FAO estimates that cultivation could be successfully carried out on 2,600 million hectares.[6] While increases in cultivated land are likely to be seen in the next 50 years, the author believes widespread growth of non-irrigated land is unlikely for several reasons.

- Over the thousands of years of human civilization, most of the best and most productive non-irrigated land has already been put into service.

- The environmental costs of further land development, particularly non-irrigated land development are huge. We do not believe that future governments will be more accepting of rainforest destruction or the elimination of critical natural habitat in Africa in the future than they have been in recent history.
- Urbanization of the world population will continue to take some of the world's most productive land and convert it to uses with higher economic utility. A good example of this phenomena is China, which according to a 1999 IIASA study has over 20 million hectares of potential farmland in reserve. Under current practices roughly 1.0 million hectares of this land are put into production annually, but an offsetting 1.2 million hectares are lost each year to urbanization and other causes.[7]
- Total cultivated land was stable from 1990 (1,503 million ha) to 2000 (1,497 million ha). Non-irrigated land actually declined by almost 35 million hectares in the same time period.[8]

Unlike high quality dry farmland, the supply of land which could be cultivated using irrigation is relatively plentiful.

Availability of Non-Irrigated Land

The assumption for this study is that acceptable dry farming area will remain roughly constant over the next 50 years at roughly 1,225 million hectares.

Availability of Irrigated Land

The author allowed irrigated land to be an independent variable in the calculations.

Crop Yields

Starting in the late 1960's, agriculture experienced significant growth in average yields, which is sometimes referred to as the "green revolution". The "green revolution" was a concerted effort by Western agricultural experts to bring the benefits of modern farming to the developing world. Among the tools used to accomplish this objective were new seed varieties, improved cultivation techniques, the increased use of chemicals and fertilizers, and the increased use of irrigation.

The "green revolution" produced rapid increases in yield through the late 1960's and all of the 1970's, after which time yields have continued to grow, but at a declining rate each decade. If fact, throughout the 1980's and 1990's, growth in irrigated land was an increasingly important driver of crop yield growth, which overall was slowing. In the post- "green revolution" world, what kind of yield growth can be expected and in particular, how much growth in yields can we expect with dry land farming? In order to better understand this question it is instructive to examine the typical yield growth during the last decade in the United States.

Examining yield growth for corn and soybeans in the United States from 1991 to 2002 (using USDA yield data) can give us some insight into the future yield growth in the balance of the world across all crops. For the years in question, conducting a linear regression on the yields for both crops shows that corn yield has grown 1.5% per year and soybean yield has grown 0.9% per year.[9]

In our analysis we used 0.8% per year average yield increase across all crops excluding the yield improvement caused by increased irrigation as our projection for the next 50 years. This quantity was selected for several reasons.

- Yield growth rates have progressively fallen in the U.S. since the 1960's. It is likely that we will see further reduction in yield growth in future years.
- The author wanted to exclude from the estimate the impact of additional irrigated land and its effect on yield growth, as this is the exact quantity to be calculated in the analysis. Irrigated land can produce much greater yield than dry land. An often quoted statistic is that the 20% of global irrigated land produces 40% of all crop output. In order for this to be true, irrigated land would have to be 2.7 times more productive than dry land. While our experience indicates that this number is too large, it gives an indication of how critical a role irrigation plays in improved yield. Valmont's experience indicates irrigated land yields closer to 2.2 times that of non-irrigated land.[10]
- Based on a study in the growth of irrigated land in the U.S., the author estimates that roughly 1/3 of yield growth is a result of increased irrigated land.

Our analysis ignores the potential for another "green revolution" generated by genetically modified organisms (GMO's) that could dramatically improve yield. To date the author is unaware of any dramatic improvements in yield shown by GMO's currently on the market or soon to be released.

Calculation of irrigated land required for food production.

In 2000, according to the United Nations FAO, there were roughly 1,225 million hectares of dry land cultivated and 272 million hectares of irrigated land.[11]

Total crop output is the product of non-irrigated area multiplied by non-irrigated yield plus the product of irrigated area multiplied by irrigated yield. With annual yield growth of 0.8% for non-irrigated land, and the estimate that irrigated yield is 2.2 times non-irrigated yield in 2000, we can solve these equations for irrigated area in 2050 as follows:

Total output = (Dry Area * Dry Yield) + (Irrigated Area * Irrigated Yield)

Year	Dry Land Area (M HA)	Yield (Mil KCal/HA)	Dry Land Output (Tril KCal)	Irr. Land Area (M HA)	Yield (Mil KCal/HA)	Irrigated Land Output (Tril KCal)	Total Output (Tril KCal)	Avg. Yield (Mil KCal/HA)
2000	1,225	3.45	4,223	272	7.58	2,063	6,286	4.20
2010	1,225	3.74	4,580	323	7.88	2,544	7,125	4.60
2025	1,225	4.22	5,173	410	8.36	3,424	8,597	5.26
2050	1,225	5.17	6,337	582	9.31	5,420	11,757	6.51
CAGR '00-'50	0.0%	0.8%	0.8%	1.5%	0.4%	2.0%	1.3%	0.9%

Is there enough water to satisfy irrigated land needs?

Availability of Water

In 2000 humans withdrew roughly 3,900 billion cubic meters of water and consumed 2,329 billion cubic meters.[12] In a perfect world the excess withdrawals of water can become the source for consumption for other users. We see this happening today particularly where municipal and industrial waste water is partially treated and then used as irrigation water for agriculture. Although there is a limited amount of this type of water reuse today, we expect to see significantly more of it in the future. With this in mind, we can look at historic withdrawals of water as the ultimate supply available to humans, while water consumption represents the current demand if all non-consumptive withdrawals are re-used. If we fully re-used all excess withdrawals today, there would be a 1,571 billion cubic meter excess supply of water.

New Sources

Development of new sources of supply has slowed considerably. If we linearly regress historic growth in withdrawals, over the last 50 years (1950 – 2000), we find that roughly 51 billion cubic meters of supply were added annually.[13] From 1990-2000, only 30 billion cubic meters were added annually. The author estimated that the rate of growth of the last decade would continue to decline by 50 billion cubic meters per decade over the next 50 years. This assumption accounts for the increasingly higher costs of source development and the increasing unwillingness of humanity to disturb natural systems in the search for new water sources. Utilizing this assumption results in an estimated supply of water in 2050 of 4,650 billion cubic meters.

Demand Growth

- Municipal – If we assume that municipal demand is a function of population and wealth, which can best be represented by the product of population and per capita gross world product, we can estimate that global municipal demand will grow from 71 billion cubic meters[14] of water per year to 284 billion cubic meters by 2050. (Demand in 2050 = Demand in 2000 * (population * per capita GWP in 2000) / (population * per capita GWP in 2050).
- Industrial – Here the author makes the assumption that water per unit of economic output will remain flat in the future. This is almost certainly incorrect, as history in the United States has shown that industry responds to the cost of water and reduces the amount consumed as costs increase. On the whole, we can expect that the industrial share of water usage will grow somewhat slower than predicted due to cost pressures. Under the assumed circumstances industrial consumption goes from 93 billion cubic meters[15] in 2000 to 372 billion cubic meters in 2050. (Demand in 2050 = Demand in 2000 * (GWP in 2050) / (GWP in 2000)
- Agriculture – With the increased pressure on irrigated land to produce a greater portion of world agriculture, and with no change in irrigation practices, agricultural water consumption would grow from 2,165 billion cubic meters today[16] to 4,634 billion cubic meters by 2050. (Demand in 2050 = Demand in 2000 * (Irrigated land area in 2050) / (Irrigated land area in 2000).

Supply and Demand

If water supply grows to 4,650 billion cubic meters by 2050 (an average of 15 billion cubic meters/year), and the sum of municipal, industrial and agricultural demand is 5,290 billion cubic meters, we clearly have a significant (640 billion cubic meters annually) water gap by 2050. It is important to remember that this water gap includes a very liberal assumption in the growth of water reuse, with reuse satisfying 1,571 billion cubic meters of demand annually in 2050.

What solutions are available?

It is the author's belief that conservation, particularly in agriculture, represents the best available solution to the coming water shortage. However, there have been numerous other alternatives for supply or demand management also presented by academics, government and industry. It is worth mentioning a few of these other alternatives before further discussion of the agriculture conservation alternative.

- Water pricing at the "true" cost of water – Would help encourage conservation of water, particularly in industry. If imposed on municipal and agricultural users, it would inordinately impact the poor by driving up the costs of food and personal water usage.
- Desalination – Very energy intensive and very expensive. Of limited utility except for rich countries/regions, unless there is a major technical break-through.
- Water Transfers -- Expensive and very difficult to implement on a large scale due to environmental opposition.
- Salt Water Plants -- Allows irrigation with sea water. Might have some potential in dry coastal regions. Will require acceptance of dietary change.
- Water Re-Use – A very viable and practical method to increase the effective water supply. For this study we assumed that 100% of all non-consumed water is re-used.

Conservation of agricultural irrigation water.

Modern agricultural irrigation systems are significantly more water efficient than traditional irrigation methods. The vast majority of irrigated agriculture utilizes gravity irrigation which is roughly 40% - 50% efficient.[17] Modern pressurized systems such as subsurface drip and LEPA (Low Energy Precision Application) mechanical move can achieve much greater water application efficiencies. Subsurface drip irrigation systems are typically characterized as 90-95% application efficient.[18] Mechanical move systems can also achieve application efficiencies of 90% or higher.[19] These modern irrigation systems produce higher yields than gravity irrigation due to their better uniformity of water application and their timely availability. The amount of "crop per drop" improvement with modern irrigation is generally somewhere between 100% and 200% greater compared to traditional gravity flow. While some of the water saved in individual fields would have eventually made it back into the water basin (see the discussion of the basin argument in “Water Scarcity and Modern Irrigation”), and could potentially have been used again, it is Valmont’s experience that a significant portion of the water conserved in individual fields represents net water consumption reductions for the purpose of satisfying human needs.

Based on Valmont’s experiences the author believes that a 100% increase in crop yield per unit of water applied to the field is a conservative assumption when employing modern pressurized agricultural irrigation equipment (a 40% increase in output and a 30% reduction in water consumption).

With this estimate of the impact of modern pressurized agricultural irrigation equipment, we can calculate the potential water savings in 2050 by employing these technologies. The relevant equations used are given below:

Irrigated output = (efficient irrigated area * gravity yield *1.4) + (gravity irrigated area * gravity yield)

Water consumption = (efficient irrigated Area * 0.7 * gravity water consumption rate) + (gravity irrigated area * gravity water consumption rate)

Year	Scenario	Irrigated Food Output (in Tril KCal)	Efficient Irr. Area (Mil HA)	Gravity Irr. Area (Mil HA)	Total Irr. Area (Mil HA)	Estimated Water Consumption (Billion M^3)
2000	Current	2,063	26	246	272	2,165
2050	Business As Usual	5,420	56	526	582	4,634
2050	Low Investment	5,420	100	464	564	4,371
2050	Moderate Investment	5,420	200	324	524	3,778
2050	Med-High Investment	5,420	300	188	484	3,186
2050	High Investment	5,420	400	44	444	2,593

The moderate investment scenario saves more than enough water in total to close the calculated supply/demand gap. The actual required area of irrigation development with modern irrigation equipment will obviously depend on a complex interaction of major demographic factors, new technology development, and the validity of a number of assumptions. Political will power and the desire to preserve the natural environment are also factors that will significantly impact how the future emerges with respect to fresh water usage.

What might it cost?

Generally, pressurized irrigation systems require investment in the range of $800/ha for center pivot/linear (mechanical move) systems, and about $1,700/ha for subsurface drip.[20] If we assume that the bulk of new investment will be in mechanical systems (around 90% of production land in the U.S. that utilizes efficient pressurized irrigation today use sprinkler or mechanical move irrigation systems) a weighted average figure of $1,200 ha is not unreasonable to use. Average life of the systems must also be taken into account. Mechanical systems last on average 25 years.[21] Average life of subsurface drip irrigation systems are less certain as the technique is less mature. For the purpose of this analysis, an average life of 15 years was used. We utilized a weighted average life of 23 years for this analysis for the combination of mechanical and subsurface drip systems. Rough investment costs can be found in the table below.

Initial investment = $1,200 per hectare * Pressurized area

Replacement investment = 2000 Initial investment *50 years/23 years average life + ½ * 2050 initial investment * 50/23

Note that the figure of ½ is used in the above equation assuming that approximately half of the newly developed pressurized systems will be installed early enough to need replacing during the 2000 to 2050 time period.

Year	Scenario	Area Pressurized (Million HA)	Total Initial Investment ($ Billion)	Replacement Investment ($ Billion)	Investment above Business As Usual ($ Billion)	Annual Investment Above Business As Usual ($ Billion)
2000	Current	26	$22.6	N/A	N/A	N/A
2050	Business As Usual	56	$48.3	$102.0	0	0
2050	Low Investment	100	$86.9	$144.0	$80.5	$1.6
2050	Moderate Investment	200	$173.7	$238.0	$262.0	$5.2
2050	Med – High Investment	300	$260.6	$333.0	$443.0	$8.9
2050	High Investment	400	$347.4	$427.0	$625.0	$12.5

The "business as usual" case represents a reasonable estimate of the investment that will occur in pressurized systems if development trends from 2000 are extended to the year 2050, particularly the mix between efficient irrigation and gravity irrigation. It is interesting to note that without major public policy intervention in the next 50 years, private industry is likely to invest around $150 billion in modern irrigation equipment. This is because modern irrigation equipment is a productivity tool for farmers that earn a positive economic return. This makes accomplishing the goal of achieving an additional $260 billion (the total investment required to go from the "business as usual" case to the "moderate investment" case) in investment much easier as it is not necessary for public sources to provide full funding for these on-farm systems. Agriculture in much of the world, however, will require incentives to make these relatively large investments, as most of the world's farmers do not have sufficient capital to afford modern efficient irrigation investments.

It is the author's opinion that government and public entities need only partially fund investments in pressurized agricultural irrigation to achieve the results needed to adequately conserve water.

Public Policy

In light of this analysis, what should public policy be with respect to agricultural irrigation? While the author does not have a complete vision for all aspects and implications for the future of irrigated agriculture, a few thoughts can be offered.

1. Nations should be discouraged from holding food security as the ultimate goal of their agricultural sector. As irrigation water availability is likely to be the limiting factor in food production by 2050, we will need to irrigate where the available, sustainable water supplies reside. In the competitive advantages of the world's nations, food production for some relatively dry regions is simply impractical. No nation should ever have to worry about being cut off from world trade in food, and so the global community should make a commitment to continue selling food to every country, even pariahs.

2. Nations have a responsibility to ensure that water resources are developed and used in sustainable ways that are also consistent with basic human, industrial, agricultural and environmental needs. The needs of the poorest of earth's citizens for water access, sanitation and affordable food need to be given special consideration. Otherwise, competing interests are likely to outbid the poor in pursuit of scarce water.
3. Sources of additional water supply will need to be developed aggressively, but the needs of the natural environment cannot be ignored.
4. Water reuse should be vigorously pursued with the goal of making all non-consumed water withdrawals available for consumption.
5. Water pricing should be used to encourage conservation among industrial water users and some municipal users.
6. Nations must take responsibility for the social impacts of improved agricultural productivity (urbanization of the population, education and development of alternative employment opportunities). Agriculture is similar to other industries in that increased human productivity is necessary for economic gain for the farmer. This means that as productivity grows, we will see continual reduction in the human labor required to carry out agriculture, consolidation of farms, and greater resulting economic performance. It also means that rural populations will shrink as much farm labor becomes unnecessary. We see these impacts as predictable, economically inevitable and necessary to achieve more efficient and economically sustainable agricultural production. The author knows of no examples were traditional subsistence farming and strong capital accumulation and productivity growth coexist.
7. New agricultural development should be planned and implemented with modern pressurized irrigation systems in mind.
8. Governments should provide incentives for investment in modern pressurized irrigation equipment. Today effective incentives range from investment subsidization to low cost loans to loan guarantees.
9. Yield enhancing technologies must continue to be pursued vigorously as faster yield growth will reduce pressure on fresh water sources for irrigation.

Fresh water limitations represent a major challenge for food production in the twenty-first century. With competition from other sectors, agriculture stands to be the net loser in any battle for access to water. Such a situation will have its greatest impact on the lowest rungs of the economic ladder, where the need for water and food is intense, but the means to compete for this resource are limited. We possess the tools today to greatly reduce the water intensity of irrigated agriculture -- efficient irrigation and water reuse. Proper planning and public policy can avert what could be an agricultural water crisis in the years to come.

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