Deutscher Tropentag - Bonn, 9-11 October 2001
Conference on International Agricultural Research for Development

Water Efficiency and Choices on Technology for Irrigation Systems: A Case Study on Farm Behavior in the Chinese Province Shaanxi

*E.-A. Nuppenau and Lan Fang **

**Department of Agricultural Policy and Market Research, Justus-Liebig-University, Senckenbergstrasse 3, 35390 Giessen, Germany*

Abstract

China is facing severe water shortages, especially in northern China. The empirical part of this study is conducted in Shaanxi province, Northwest China. More than 100 interviews were conducted in a specialized farming system and area, that has a great potential to produce apples under irrigation. Irrigation systems require choices on technologies, for instance, from conventional surface irrigation to modern drip irrigation. With respect to technology choices on economizing water use, water efficiency have been given priority. Especially, drip irrigation is considered water efficient, but investment needs are high. Some of the more modern techniques are already adopted, but farmers need more information on investment opportunities and scope for further modernization of irrigation schemes. The Chinese government supplies public water to farmers, control the water price, and also invests in large irrigation schemes that are potentially more water efficient; meanwhile farmers can use private wells to assure water deliveries. However, the problem is how to investigate farmers' and government's investments simultaneously, since they are complementary. A model shall help to clarify the need for both, private and public investment, in order to make water use more efficient. The economic benefits from applications of modern technologies are invested by farmer themselves and the government optimizes net return from investments. By increasing water efficiency the outreach of irrigation schemes can be increased and economic and ecological benefits will be accrued. In the model we combine water delivery and use options to show how increased water efficiency contributes to increased apple production.

1 Introduction

Water scarcity is a great challenge for agriculture in the 21st. century. Research on water efficiency has been given priority in many countries (Seckler et al., 1998). In particular, in countries that foresee water shortages, like in China (China water network, 2001), increased efficiency in water use is seen as a way to foster food production, to protect the environment, and to solve social conflicts in water rights, simultaneously. Increased efficiency in water use requires private and public investments. Private investments in technical equipment enables more precise application of water by farmers, such as drip irrigation instead of furrow irrigation. However, it is costly and farmers may not invest due to low economic returns on investments and high water prices. Too high water prices maybe an obstacle to investment, because farmers will abandon irrigation and go for dry land farming. In contrast, if the water prices are too low, no incentives for water saving exist. The water prices depends on public decisions on water deliveries, capacities of watersheds, costs of procurement, etc., and investment costs of public components in irrigation systems, such as canals, pumps, etc.; all together, they determine the public water price. Alternatively, farmers can dig wells, use purchased water procurement equipment, and perhaps have high costs for running and maintaining private equipment. Even parallel activities between public and private are prevalent.

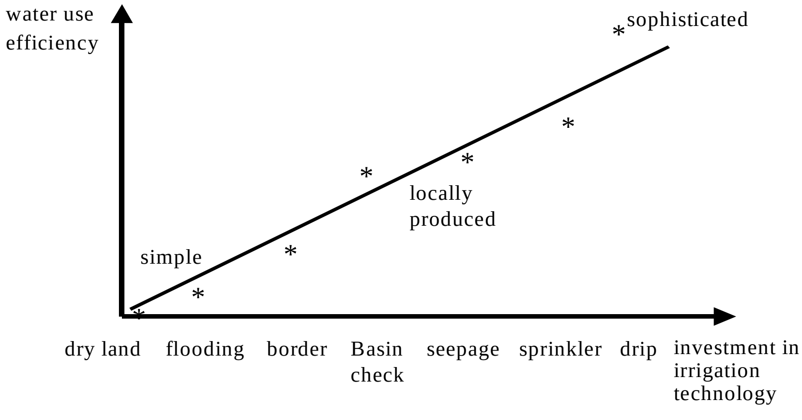
Not only private investments increase efficiency, public investments in canals could also increase water efficiency. For instance, less water losses in transport of water to the point of use (better conveyance), will increase the amount of water available and the outreach of irrigation facilities. Based on public provision and investment, better water distribution systems can be achieved by public investments. Overall, effective water use improves. Decreased water costs at points of sale to private users and only the interaction of complementary activities of the private and public sector may promise to delivery the urgently need rationalization of water, whereas water is wasted now. In a case study on the Chinese province Shaanxi we investigate farm behavior with respect to investments in different technologies and we will find out the potential to save water. Optionally, farmers can continue to irrigate with furrow irrigation, invest in different types of sprinkler and drip irrigation or invent on farm technologies that best fit their economic conditions. The government controls water prices, but farmers can use private wells to assure water deliveries. However, allocation of water might be still restrictive.

This empirical work is supplemented by a suggestion for modeling the impacts of private and public investments in water saving technologies on the system. In the paper we will show how information on investments in water saving can be integrated in a spatial model of an irrigation system. It is the "objective" of the irrigation scheme to maximize profits from irrigated land, in our case orchards, taking into consideration that the farmers have to pay differently for water, if different water procurement strategies are pursued. On the one hand farmers have costs for private water procurement and on the other hand they can buy water at the point of sale from the government or private supply. The government invests in public facilities for water deliveries and minimizes investment costs, given private benefits from water use as revealed by local water prices.

2 Linking investments to water efficiency and irrigation scheme operations

The basic idea for the need to research on links between water efficiency and investment in irrigation technology can be comprehended following Diagram 1. Firstly, Diagram 1 hypothetically outlines the relationship between technical water efficiency and private investment in irrigation technology. Clearly in reality technologies are discrete.

Diagram 1: Water efficiency and private investment

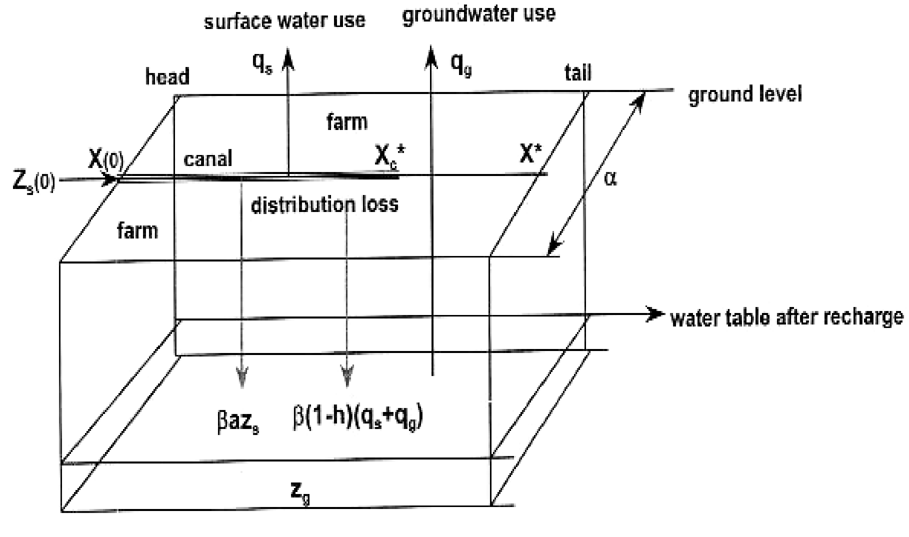


For instance, lowest investments are for flood, furrow or border irrigation. High investments are needed for sprinkler or drip irrigation. In principle technology offers a wide spectrum and practically or normally a highly differentiated range of option for choice on technology is available. Note, that theoretically even more choices on investments are open on the upper level of expenses. As been shown, very drip of water maybe supported by a computer. The interesting question is what is the appropriate level of technology and how do water savings contribute to long term profits or viability of irrigation schemes? We have to mention, in this context, that we not only look at financial investments in straight water application; similar reflects are relevant with respect to labor and perhaps heavy physical investment, for instance, in terracing or land clearing.

For the economic part, we presume that we can translate the resource needs for different type of water saving technologies in monetary terms. Then, we end in a continuous line of accelerated savings due to investments, presumably in our paper given as a linear relationship. Defining water efficiency as the water acquired by the product in relation to the water applied by the farmer, higher water efficiency translates directly in water saving for a given production of food, in our case apples, vice versa. Physical water use efficiency is the key to economic efficiency of watersheds (Cai et. al., 2001).

Pursuing the idea of saving water from the farmer to watersheds or irrigation schemes we, secondly, come to the desired impacts of public investments on the level of water savings in whole schemes. Diagram 2 shows how the irrigated surface of a scheme is linked to procurement and use of water. Water losses in the canals by transport are partly re-integrated and some water losses can recaptured by wells, though losses occur.

Diagram 2: Structure of a model to economies on water efficiency



A distribution of water from the head to the tail of an irrigation through public canals imposes losses of water. Farmers use surface water from the canal to produce food q_S and farmers can use groundwater to produce q_S. Together production from both sources determines profits. The most crucial thing is that the outreach of water (i.e. length of canal) determines the profitability of irrigation by farmers. Those who are not served by the public system, because losses occur in the canal or because farmers close to the head deduct too much water, incur higher procurement costs or profit looses because private operation of wells and pumps is costly and also has the danger that the water table goes down. Because of common property problems, many irrigation systems are purely based on private water extraction from ground water and show strong deterioration of the groundwater tables.

These features straight apply to the study area. In dry years, public water provision facilities are quickly running out of water and many farmers have to pay high prices for "private" water. Water is transported over long distances; apparently, not in canals as "public" water but by trucks. As alternative farmers have drilled boreholes and the water tables is down imposing high water costs on them. To solve such problems, primarily by investments in technology, Umetsu and Charkravorty (1998) have suggested to characterize the system of water inefficiency by a coefficient "h" for water efficiency (inefficiency, respectively) of farmers and "a" as water efficiency in the canal. Efficiency measures can be influenced by investments: "h" is a function of investment "I" (Diagram 1) and "a" is a function of "m", i.e public "m"oney spend in irrigation systems.

3 Field study

To investigate the actual situation and test the scope for improving water efficiency in China, we have chosen an apple production area in Northwest China. The main idea is to get structured data on the irrigation system, farm profitability, and investment behavior of farmers to model adequately the impacts of water pricing and interaction of private and public investment; whereas we assume or show that investments are too low.

Survey site

A study survey was conducted from August 2000 to January 2001 in Liquan County, Shaanxi Province, China. This county lies north of the Guanzhong Basin and south of Weibei highland, it extends from 108°17′40″ to 108°41′46″ east longitude, and from 34°20′51″to 34°50′02″ north latitude. It covers 1010 km^2 and arable land is 56667 ha. By 1999 the population is 446,800, among them the rural population accounts for 406,200, i. e 90.9% of the total population. Population densities is 442 people per km^2.
The main operation is apple production. Apple production was introduced 10 years ago because, by selling higher priced apples than producing grains, farmers can only assure their livelihoods. With very small fields conversion of revenues from apples into purchase of grains was considered the only way to maintain food security for the most vulnerable people, living even in the most dry areas. The alternative would be poverty. However, in average years farmers can make a net gain from apple production, by selling apples and buying food grains. Because of this background, increased water efficiency in apple production may stabilize farm income and contribute to food security.
Precipitation of Liquan County is normally only 558mm per annum; historically it was a typical rainfed agricultural area, and suffers from drought; very frequently, almost once every two years, droughts occur and water is short. In the survey area farmers live near public canals, and get water for applying surface irrigation. Some farmers have convenient water access and get relatively cheaper water and they overuse this water applying surface irrigation. The other farmers living far away from the public canal or in mountainous areas apply seepage irrigation. Basin check irrigation or modern sprinkler and drip irrigation are also prevalent, even dry land farming is an option for poorest farmers. Farmers use the expected water supply for high value crops on a limited area and either leave the remaining land fallow or plant drought resistant crops; low-value crops are only planted occasionally in the hope for unexpected rainfall. In our case, farmers perceived food security as dependent on high apple yields. Since fields are small, this means that water and irrigation contributes strongly to survival.

Different technologies in the survey areas

One hundred and forty-nine interviews were conducted in the areas. Among them, 76 farmers applied flooding irrigation, 16 farmers applied border irrigation, 11 farmers applied seepage irrigation (, 21 farmers applied basin check irrigation, 7 farmers applied sprinkler irrigation, 11 farmers applied drip irrigation, and 8 farmers applied dry land farming. Flood irrigation is a traditional technique in China. It is characterized by low labor input, simple technology, but, water is largely wasted and water logging occurs. Increased salinity and alkalization are by products. The utility coefficient of water or technical efficiency of water (if counted as used to applied water) is only 30-40%;

Border and basin check irrigation are also a kind of flood irrigation but with small scale. It means a big plot of field is divided into several small plots, in order to retain water. Normally it requires more labor and some additional expenses; the utility coefficient is around 45-60%. Seepage irrigation was developed locally by Chinese farmers. It functions like drip irrigation, but it doesn't require so many expenses as costly purchased equipment for modern drip irrigation; thought, equipment is on the market. The utility coefficient of water is around 70-80 percent. The main disadvantages are too big holes where water can leak and no control to be plugged by tiny sands or soil are present.
Applied sprinkler irrigation is a kind of modern technology. It is characterized by a production increase of 20-40%, higher efficiency in water use at approximately 80%, and less salinity. Another advantage is saving of cultivated land by 15-20% due to water transport on the field without furrows, ditches or paths in the fields, also ridging, etc. Drip irrigation is currently the most advanced and effective irrigation technology. It is characterized by high production capacity, increasing and higher efficiency in the use of water at approximately 95% and fertilizer can be added to the water. The effect of fertilizer can raise production by than 100%. Salinity is reduced by low drainage.

4 Preliminary finding

Primary data analysis

Table 1 shows some results from a preliminary data analysis. In principle tendencies are as been hypothesized in the introductory chapter. The major complication is that the year 2000 was a year of very low apple prices and hence gross margin (column 4)

Table 1 Mean analysis based on different technologies, Findings from 2000

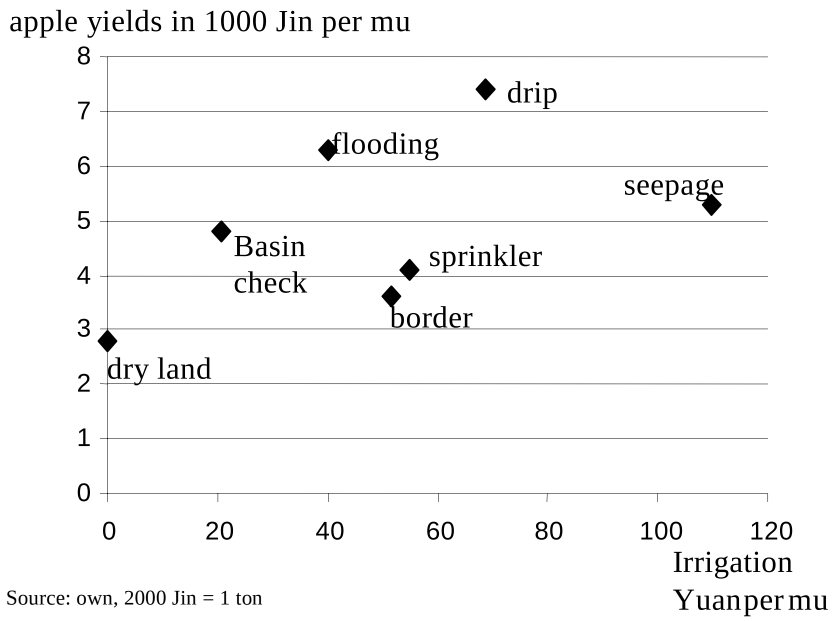
Technologies	Apple yields	Apple price	Irrigation	Gross margin**	Gross margin***
	Jin per Mu*	yuan/kg	(yuan)	yuan per mu	yuan per mu
Dry land farming	2867,39	0,28	0,00	-270,23	691,43
Flooding irrigation	4059,73	0,34	54,94	-416,86	1010,58
Border irrigatiom	3688,44	0,48	51,68	63,88	1249,63
Basin check irrigation	4842,40	0,40	20,57	-41,55	2381,08
Seepage irrigation	5254,00	0,70	109,90	936,13	5889,46
Sprinkler irrigation	6278,57	1,38	40,00	3357,76	14637,72
Drip irrigation	7424,75	1,56	68,82	4339,67	19786,06

Technologies	Water price per cubic meter	Water applied	Distance	Labor cost	Ratio
	(yuan)	m3/mu	(m)	per mu	
Dry land farming	20,00	0,00	16625,00	547,43	
Flooding irrigation	0,24	217,23	757,24	832,82	9,34
Border irrigation	0,29	188,63	792,5	789,99	9,78
Basin check irrigation	0,29	71,67	0,00	626,34	33,78
Seepage irrigation	8,00	19,30	6821,00	316,70	136,11
Sprinkler irrigation	1,41	35,71	533,00	396,91	87,90
Drip irrigation	2,12	32,73	1591,82	287,09	113,43

Note: * **, gross margin by current apple price; ***, Gross margin calculated by average apple price.
Source: Own calculation on survey and data from Bureau of Water (1999)

were negative for some farmers; primarily for those that had low apple yields due to drawbacks in water application. However, it is already clear that farmers that are capable to bring as much water to the trees as possible at low levels of water losses were still in the position to make profits. In column 5 of Table 1 we correct gross margins on the basis of average prices to show, what farmers normally earn. Additionally Table 1 shows that the average distance of dry land and flood irrigation farmers to the canal is the highest. These farmers had to pay high water prices on private markets which kept them in a trap of being capable only to apply low standard technologies in irrigation.
It is also obvious to see that the farmers who applied surface irrigation got negative returns, as they had the lowest apple prices, at least in this harvest season of abundant apple supply; on the contrary those farmers hat used modern technology got higher prices, though they normally pay higher price for water than the formers. We associate this findings with better quality of apples under modern irrigation technology: Another argument for the spread of technologies and recognition of investments. Modern technologies improve the quality and productivity of the apples and farm income increase.
We can depict some finding also in a Diagram. Diagram 3 shows, as a preliminary substitute for the to be accomplished relationship between water efficiency and investment, how costs of irrigation are related to apple yields. By that we, for simplification, assume that a straight relationship exists between yields and water efficiency as well as a straight relationship between irrigation costs and investment. This can be identified in Diagram 3 as a first hind. A straight relationship between irrigation costs, including water prices and equipment cost per annum, seem to exist. The envisaged model is of great help to identify means to reduce irrigation costs. However, it has to be mentioned that water prices and some elements of investment costs in irrigation, as they count in irrigation costs, are distorted by government interventions and we have to find out real costs.

Diagram 3: Irrigation costs and apple yields



Source: own, 2000 Jin = 1 ton

Primary conclusion from the field study

We following aspects and findings are retrievable from the field study:

1. Traditional surface irrigation still plays a key roll in Shaanxi Province.
2. Water prices and investment in on-farm technology become higher with distance between public water provision, as a canal, and location of water application.
3. Farmers located upstream use much more water than farmers located downstream.

4. Farmers using drip irrigation make the highest profits among all the technologies.
5. Seepage irrigation, on average, is relatively more water efficient and economic viable for Chinese farmers than the other two modern technologies.

5 Modeling

Based on the above outline of structural questions in water efficiency and the empirical findings, we will design a model that will help us to cope with the simultaneous need for investment in private technologies and public infrastructure for irrigation. The basic idea was outlined by Caswell and Zilberman (1985) and is alread depicted in Diagram 2. The model proposed here follows, then, the approach by Umetsu and Charavorty(1998). It describes conjunctive water use of surface and groundwater. A central planer or a owner of the water provision utility is assumed to invest optimally in a canal irrigation project and charges each farmer the shadow price of water in the project area, varying with location from the head to the internally calculated tail of the irrigation system. There is an aquifer underlying the project area and individual farmers have a choice of using groundwater in conjunctive with surface water distributed by the irrigation canal (see Diagram 2). There is seepage from the canal and from the farmer's fields which goes into the ground and recharge the aquifer. a mathematical solution determines the optimal project area (length), surface water use, groundwater use, conveyance expenditure, investment in on-farm technology, and the optimal initial stock of surface water. The main idea is to change water efficiency coefficients in the application of water to produce farm products from public and private water procurement.

We consider a water project for a single cropping season. Apple growing is assumed for the entire project area. Water (z_s) flows from the head point of the project area through the canal and farmers deduct x_s and x_g in order to irrigate fields spread by the width "α" over the surface. Flows are formulated as spatial differential equations. Farmers are located on both side of the canal and the project area is rectangular with the same α width at any location on both side of the canal, and the project areas are given as X (equivalent to water needs at location x) where x is the distance measured from the canal source (Diagram 2). Farmers receive water distributed by the authority from the canal to their individual farms. Homogenous land quality and no uncertainty are assumed. Then the authority is assumed to choose $q_s(x)$,$q_g(x)$, $k(x)$ and X, the end point of the project area, so as to maximize net benefit from the water project. By that we get a mathematical formulation that summarizes (integrates) over the whole irrigation scheme:

$$\text{Maximize } \mathbf{NB}(z_s(o)) = \int_o^x \{[\, pf[\,(q_s+q_g)h] - I - F - w\, q_g]\, \alpha - k\,\}\, dx$$

$q_s,\ q_g,\ k,\ x$ to be maximized!

Subject to 4 stated constrains (1),(2),(3) and (4) which are differential equations as "...' "

$z_s'(x) = -\, q_s(x)\alpha - a(x)\, z_s(x)$ (1): differential equation of water

$z_g'(x) = -\, \beta a(x)\, z_s(x) + \beta(1-h)(\,(q_s+q_g\,)\alpha - q_g(x)\alpha$ (2): water from groundwater

$a = a_0 - a_1\, I(x)$ (3): (note, linear form Diagram 1

$h = h_0 - h_1\, k(x))$ (4): (linear as public knowledge)

where

p = a constant output price, assuming price-taking producers;

*X** = the optimal length of the project area;

I = the expenditure of on-farm investment;

k = is public expenditure for investment
F = is the fixed cost for irrigated farming. A pumping cost, *w*, is assumed to be const. over the project area and the unit cost of conveyance is considered to be unity.
Zs(0) = the initial stock of surface water at the source flowing into the canal.

Subscripts *s* and g denote surface and groundwater, respectively. The fraction of water lost in conveyance per unit length of the canal is represented by h*(x)* with h*(x)>=0*, and the *a(x)* is depended on *I(x)*, the farm expenditure per unit surface area. It varies with location of the canal, *x*. The farmers control I(x) and the public authority k(x).
Essentially, the model can be solved as Chakaravorty et al., (1999) have shown. The result includes water flows, shadow prices and investments, both private and public. Recursively, by the investment we can refer to the technological choice of farmers. The technological choice depends on the location in the irrigation scheme. By that we will be capable to demonstrate that it is rational to have different technologies in one irrigation scheme at different locations. Furthermore, Chakaravorty and Umetsu (1999) have already provided a structured overview over the needed data input, we are taking also into consideration in our model application. The model is currently under development. It uses GAMS and discrete modeling rather that continuous modeling.

5 Discussion

It was shown that net benefits from irrigation, as expressed by the objective function of a benevolent owner of an irrigation scheme or a central water planner, can be optimized by improving investments of on-farm technology and conveyance costs. We assumed a public irrigation facility of contributing canals to private water use. By having a preliminary data basis the empirical part and the theoretical part we will be put them together. That will offer scope to simulate different policies on water prices and public investments in Chinese irrigation schemes. The model starts for simplification with apples as a mono-culture. Further applications have to take multi-cropping into consideration.
If optimization of an entire basin is considered, it maybe optimal to allow for significant water losses from the canal and the fields by having different crop wise efficiency in water use. This will dependent on costs of water transport over longer distance. Apparently, choices on crop can be also modeled in the given context. That requires more information on the farming system, but, would definitely enrich the analysis.

References

Bureau of Water Resources of Liquan County, 1999, Annals of County of Liquan, Yearbook of Rural Economy of Shaanxi, Department of Agriculture of the Shaanxi, Province, Xian, 263-273.

Cai., X., Ringler, C., Rosegart, M., 2001, Does efficient water management matter? Physical and economic efficiency of water use in the river basin. ETD Discussion paper No.2, International Food Policy Research Institute (IFPRI), Washington,

Caswell .M. and Zilberman D., 1985. The Effects of Well Depth and Land Quality on the Choice of Irrigation Technology. American Journal of Agricultural Economics, Vol.68, pp. 798-811

Charkravorty, U. and Umetsu, U., 1999, Basin wide water management : a spatial model. Unpublished Manuscript. Department of Economics, Emory University, Atlanta, Georgia, USA and the Graduate School of Science and Technology, University of Kobe, Kobe, Japan

Chakaravorty, U., Hochman, E., Zilberman, D., 1999,A Spatial Model of Optimal Water Conveyance. Journal of Environmental Economic Management, Vol.29, pp.25-41

China water network, 2001, http://www.h2o-china.com

Umetsu, C., Charkravorty, U. 1998, Water conveyance, return flows and technology choice. Agricultural Economics, Vol. 19, pp. 181-191

Seckler, D., Amarasinghe, U., Molden, D., de Silva, R., Barker, R., World Water Demand and Supply 1990 to 2025: Scenarios and Issues. Research Report 19, International Water Management Institute, Colombo-Sri Lanka.