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Assessing the Direct Economic Effects of Reallocating Irrigation Water to Alternative Uses

Concepts and an Application

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Abstract

Irrigation water reallocations are playing an increasingly important role in both developed and developing countries. With growing urban and environmental water demands, rising costs for the development of new water supplies, and irrigated agriculture usually including the least economically valuable use of water, transfers of irrigation water to alternative uses are increasing. However, such reallocations are often controversial, and it is often questioned whether the benefits resulting from these transactions are large enough to outweigh the associated costs.

This paper reviews the experience with irrigation water transfers, including the involvement of the World Bank. It discusses the problems of assessing the direct economic effects of reallocations, with a focus on the foregone direct benefits in irrigated agriculture. Because foregone direct benefits cannot easily be directly observed, they need to be estimated. However, assessments have shown widely differing estimates—even when the same methodology was used. The paper reviews the methodologies and model specifications used for estimating foregone direct benefits; illustrates the impact of different model specifications on the magnitude of estimates of foregone direct benefits based on an application in an example case; and draws conclusions with regard to future efforts in assessing reallocation effects, including calculating adequate compensation for farmers. Because estimating the direct benefits of irrigation expansion is methodologically equivalent to estimating foregone direct benefits from reduced irrigation water supplies, the findings have implications for a broader range of water allocation decisions.

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Assessing the Direct Economic Effects of Reallocating Irrigation Water to Alternative Uses: Concepts and an Application*

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1. Introduction

1. **Importance of Reallocations**. The reallocation of irrigation water to alternative uses is a major, and increasing concern in many countries. Irrigated agriculture is often by far the largest water user and usually includes the least economically valuable use of water. Growing urban water demands and a rise in the values placed on the environment and instream flows are intensifying the competition for limited water supplies. Climate change is worsening the situation in many regions. With new water supplies increasingly difficult and costly to develop, water reallocations from irrigated agriculture will play an increasingly important role for meeting these changing water demands and for improving the economic efficiency of water resource allocation.

2. In recent years, transfers of irrigation water to non-agricultural and often non-rural sectors have been growing both in the developed and developing countries. While systematic studies from developing countries are missing, there are indications that irrigation water allocations are increasingly taking place in the surroundings of rapidly expanding cities and/or industrial development (Molle and Berkoff, 2009). This is especially the case for cities in arid environments that run out of water in their immediate vicinity (such as Amman) and need to contemplate alternative water supplies often involving costly and distant transfers. Even in more water-abundant regions, cities in upper catchments (such as São Paulo) or in small coastal catchments (such Manila) may face serious water supply problems. In times of drought, the demand for water for urban supplies usually takes precedent over competing demands such as from agriculture, and irrigation water is temporarily transferred.

3. For developed countries, especially those with active water markets, more information is available that shows the trend toward increasing reallocations. For Australia, for example, the activity of water markets is yearly reported by the National Water Commission (2010). For Chile a review was recently carried out by Cristi and Poblete (2010). For the United States, Brewer et al. (2007) presented comprehensive data on the extent, nature and timing of water transfers across 12 western states from 1987-2005. They looked at both agriculture-to-agriculture and agriculture-to-urban transactions, and found evidence of reallocation pressures in both price trends and the nature of transactions. Prices were higher for agriculture-to-urban than for within-agriculture transfers[1], and prices for urban use were growing relative to agricultural use. Markets were responding in that the number of agriculture-to-urban transactions was rising, whereas the number of agriculture-to-agriculture transfers was not. Further, there

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[1] In part, this may reflect the differences in priority and reliability of rights purchased by cities, differences in transactions costs of moving water to distant jurisdictions and perhaps from higher differences in marginal values between the two uses.

was a shift from using short-term leases to using multi-year leases of water and permanent sales of water rights.

4. **Controversies with Reallocations**. In both developed and developing countries, reallocations of irrigation water are often controversial. In some cases, especially where water rights have been poorly defined and/or enforced, reallocations are carried out by administrative decisions and without properly consulting and/or compensating the agricultural water users. The resulting *political and social tensions* tend to be in proportion to the political clout of the constituencies that may lose in the transfer—in particular the farmers and possibly also the surrounding communities (Molle and Berkoff, 2009). But even in regions where water rights are well defined and enforced, such as the western United States, reallocations (especially those involving larger amounts of irrigation water) have been controversial. It has been often questioned whether the reallocations are *economically feasible*, i.e. whether the benefits resulting from these transactions are large enough to outweigh the associated costs (see, for example, U.S. National Research Council, 1992).

5. An underlying problem is that the benefits and costs associated with reallocations are usually not readily observable. In a market economy with perfect competition, direct impacts could be measured by the price for water, since the price would indicate the marginal (net) benefit gained or foregone in the respective uses. In the absence of a perfectly competitive market, when the prices are either distorted or not observable, the respective price needs to be estimated using different approaches. Estimates of the economic effects of irrigation water transfers to alternative uses have been presented in the literature since the 1960s—including estimates of direct benefits (DB) and, equivalently, foregone direct benefits (FDB) in irrigated agriculture, and also of potentially associated secondary and indirect benefits and foregone benefits. However, the assessments have shown relatively wide-ranging estimates of the effects, in particular with regard to how much worse off agricultural producers would be from irrigation water transfers (i.e., with regard to the magnitude of FDB). In part, the differences in estimates have been caused by the use of different methodologies (or estimation techniques); even when the same methodology has been used, differences in estimates may have been the result of different model specifications. Independent of the methodology and model specification used, previous estimates have almost exclusively focused on water delivery rather than consumption as measure of water quantity.

6. **Objectives of the Paper**. The paper intends to shed some light on the problem of assessing the direct economic effects of irrigation water reallocations to alternative uses—with a focus on FDB in irrigated agriculture. This includes: first, reviewing the methodologies and model specifications used in the literature for estimating FDB; second, illustrating of the impact of different model specification on

the magnitude of FDB estimates based on an application with a crop budget model and a representative farm model; and, third, drawing conclusions with regard to future efforts in assessing the effects of reallocating irrigation water to alternative uses, including calculating adequate compensation for farmers whose water supplies are reduced.

7. With regard to showing how different model specifications may lead to significantly different estimates of FDB and perhaps to differing policy conclusions, two aspects are of interest here: first, how to properly *identify and price non-contractual inputs* (those assumed to be owned by the firm), such as (i) management and entrepreneurial skills, and (ii) land and other (non-water) natural resources; and, second, how to *specify the measure of water use*. The most often-used measure is *delivery*, but *consumptive use* is perhaps of more significance.

8. With this approach, the paper aims to help inform the policy and operational dialogue on projects involving irrigation water reallocations to alternative uses and, in particular, help clarify some problems in previous economic analyses. This will contribute to the larger goal of improved water resource allocation and management in line with the World Bank Group's Water Resources Sector Strategy (World Bank, 2004). It will also contribute to improved project economic analysis as called for by the recent report of the Bank's Independent Evaluation Group on Cost-Benefit Analysis in World Bank Projects (IEG, 2010). Beyond Bank staff, the intended audience of the paper also comprises academics and policy-makers involved in work on water (re-)allocations, including in agricultural water management, integrated urban water management, and environmental management.

9. **Organization of the Paper**. The paper is organized as follows: A review of the experience with irrigation water allocations in developed and developing countries, including a typology of some reallocation characteristics, is presented Section 2. Section 3 outlines the conceptual framework for the economic feasibility of water transfers and, in particular, for measuring FDB. Previous research, including an overview of the applied methodologies and associated issues, is discussed in Section 4. The method of this paper is presented in Section 5, and the main results in Section 6. Finally, Section 7 summarizes the key insights of the paper, and discusses their implications.

2. Experience with Irrigation Water Reallocations

2.1 Review of International Experience

10. Interesting reviews of the experience with irrigation water reallocations are provided by two recent sources: Molle and Berkoff (2006; summarized in Molle and Berkoff, 2009), and a special issue of the journal *Paddy and Water Environment* with ten articles, including an overview article by Levine et al. (2007). The former presents a large number of case studies from 19 countries, and the latter 9 case studies from 7 countries. The countries range from the western United States and Europe to China and Taiwan, China and a range of countries in South-East Asia, South Asia, Middle East and North Africa, and Latin America. The irrigation water is often transferred to rapidly growing cities, but also to industry (for example, a Coca-Cola plant in Kerala, India) and the environment (Australia and the United States).

11. Both reviews also try to not only document but also categorize the large and growing reallocation experience, including according to different types and mechanisms of transfers, and compensation issues. Some of the distinctions are not always clear-cut.

12. **Types of Transfers**. One distinction can be made between *temporary* and *permanent* transfers. Temporary transfers typically occur during emergencies such as a drought. Once the emergency is over, allocations revert to the original pattern. Permanent transfers may be *outright* or *gradual* transfers. Gradual transfers occur, for example, when a source of water tapped by several users is progressively diverted to a city; initially, the effects may be diffuse and largely unidentifiable.

13. Another distinction is between transfers of a *large* or *limited* percentage of the irrigation water source of origin. Outright permanent transfers, for example, may have large impacts when the transfer amounts to a large part or all of an existing source (e.g. the conversion of irrigation reservoirs to municipal use in China), or may be more easily accommodated if only a limited percentage of the available supply is diverted.

14. **Transfer Mechanisms**. A further categorization can be made based on the mechanism of the transfer, i.e. a transfer of *formal and informal rights* to the use of water or by *administrative decision*. In many developed countries, such as the western United States, reallocations take place through the transfer of *formal* rights.[2] This may occur in a *free market* with the price reflecting market conditions either in real time, or over a longer period (such as a season), or permanently. Because free markets usually fail to

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[2] Depending on the legal arrangements, water rights may be transferred separately from land rights, or they may be attached to the land.

account for externalities[3], market sales of formal rights normally take place in a *regulated market* where the terms of the sales are set and monitored and enforced by a public agency (such as the Water Bank implemented by the State of California during times of drought). Alternatively, the transfers are made by *legal means*. This occurs when legislation sets out the terms on which transfers are to be made, for example, by establishing clear priorities at times of drought, or by requiring transfers for environmental objectives (such as in Australia). Transfers in *informal rights* may occur spontaneously in markets without regard to third party or externality effects (and sometimes even when transfers are not allowed by law). Mostly they are small-scale and involve farmer-to-farmer transfers.

15. Not least because there are relatively few successful and fair water markets[4], transfers by administrative decisions are the most important mechanisms for reallocating irrigation water, both historically in developed counties and to this day in developing countries. These transfers can be made by *formal decision*, such as by a national, provincial/state or basin entity depending on the legal functions assigned to each under the constitution or in law. When formal administrative decisions to transfer water are taken unilaterally, they merge into the final type—informal transfers *by "stealth"*. In this category, Molle and Berkoff (2006) distinguish between decisions (i) by means of *management of existing resources* (an example is the operation of the Angat reservoir that supplies water to irrigators and to Manila, the capital of the Philippines); (ii) by means of *investment in diversions from rivers or reservoirs* (for example, the major project of the city of Hyderabad to increase its water supplies by drawing water from the Krishna river which is disputed by three states); (iii) by means of *investments in wells* (such as the out-pumping of agricultural users in Yemen); and (iv) by means of *encroachment on irrigated areas* as cities expand (such as in the cases of Cairo, Lima, and Manila).

16. **Compensation Issues**. A final distinction is between transfers *with* and *without compensation*. In the case of markets, compensation is paid. The price for the irrigation water may depend on a number of factors, such as the extent of competition among buyers and sellers, the duration of the transfer (including temporary or permanent), the reliability and security of a water right, or the amount set by the agency to induce the desired level of participation in the case of a water bank. In the case of a reallocation not being voluntary but by administrative decision, compensation may or may not be paid. If it is by formal decision, compensation is more likely paid if farmers giving up water supplies are readily identifiable, and can bring political pressure to bear on the decision makers. Sometimes efforts are made to reduce "losses" in conveyance, distribution and/or application of irrigation water by financing improvements in

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[3] An externality of an economic transaction is the impact on a party that is not directly involved in the transaction (also called side effect or third-party effect).

[4] As Molle and Berkoff (2006) note, positive experience with water markets seems to be confined to countries with a strong legal, institutional and regulatory background and relatively wealthy stakeholders, such as the United States, Australia, and Chile.

the physical and managerial infrastructure. There may also be reliance on indirect methods to provide compensation, including tax relief and crop subsidies. Transfers by stealth usually do not involve compensation, although later complaints can trigger ex-post measures. No details are provided by Molle and Berkoff (2006 and 2009) and the articles in the special issue of *Paddy and Water Environment* for the case studies that involved compensation with regard to the amount of compensation and how it was determined.

17. Overall, no matter what type of transaction is involved, when irrigation water reallocations involve larger amounts of water, there are usually controversies involving political, social and economic issues. This paper focuses on the economic aspects. The main question in this regard concerns the economic feasibility of the water transfer—and the opportunity of improving the efficiency in water allocation and thus in economic welfare. A related question is the adequacy of compensation of the farmers with reduced water supplies, and the proper accounting of externalities and third party effects.

2.2 Involvement of the World Bank

18. **Analytical Involvement**. Some earlier work of the World Bank has dealt with the issue of water reallocations. In a World Bank-ODI joint study, water conservation and reallocation were discussed as important means of water demand management, and best practice cases in improving economic efficiency and environmental quality presented (Bhatia et al., 1995). With regard to the water reallocation between sectors, including from agriculture to other sectors, the study focused on water markets, trading of water rights, water banking, and water auctions with examples from Australia, Chile, India, and the United States.

19. Several water allocation mechanisms, which in principle also apply to reallocations, were discussed in a Policy Research Working Paper by Dinar et al. (1997). Among the mechanisms included were marginal cost pricing[5], public (or administrative) water allocation[6], user-based allocations[7], water markets, and mixed systems of allocation. The experience with water markets was again illustrated with examples from Australia, Chile, India, and the United States.

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[5] A marginal cost pricing mechanism targets a price for water to equal the marginal cost of supplying the last unit of that water. An allocation that equates water's unit price (the marginal value of water) with the marginal cost is considered an economically efficient allocation of water resources.

[6] Public allocation is prevalent in most large-scale irrigation systems, where the state decides what water resources can be used by the system as a whole, and allocates and distributes water within different parts of the system.

[7] User-based allocations are practiced in many farmer-managed irrigation systems, including by timed rotation, depth of water, area of land, or shares of the flow.

20. **Operational Involvement**. As part of the ESW, a quick review of water-related Project Appraisal Documents (PADs) approved since 2000 has been made using the water project database of the World Bank's Independent Evaluation Group (IEG). Searches were carried out with terms such as "water reallocation" and "water transfer". A few project documents mentioned that water reallocation would be considered as a measure of demand management. This was the case, for example, in the India Maharashtra Rural Water Supply and Sanitation Project approved in 2004, with the aim of reducing the need for additional infrastructure for water supply and sanitation. The Brazil Ceara Integrated Water Resources Management Project approved in 2000 included a study of intersectoral water allocation in selected watersheds. The project that most explicitly addressed and supported irrigation water reallocations to higher value uses, including environmental and industrial uses, was the China Xinjiang Turpan Water Conservation Project approved in 2010. With the introduction of basin-wide monitoring and management of consumptive use, it intended to ensure that reallocations would take place in terms of consumptive use, and that compensation programs for farmers giving up water supplies were formulated and implemented.

21. However, beyond the relatively few projects that explicitly mention water reallocations and transfers, there are many others that may implicitly affect allocations to irrigated agriculture, including projects supporting inter-basin or even inter country transfers and involving dams. Also projects promoting efficiency improvements in irrigation systems by lining canals and providing incentives for switching to improved irrigation technologies with the aim of moving the "saved" water to other purposes would fall into this category. Furthermore, many urban water supply projects may tap into water resources that directly or indirectly have benefited other (including agricultural) uses downstream. Often project preparation does not consider at all, or does not try to qualitatively or quantitatively assess, the economic costs and benefits associated with such reallocations.

22. Quantitative assessments are more often carried out when projects provide additional water for irrigated agriculture. As part of the economic analysis, the direct economic benefits (DB) resulting from the additional water to irrigated agriculture are estimated. However, the project documents often do not discuss in any detail the assumptions and model specifications on which the estimates have been based. Many of the issues pointed out later in this paper for assessing FDB related to the transfer of irrigation water *away* from agriculture also apply the case for assessing DB associated with the transfer of water *to* agriculture.

3. Conceptual Framework

3.1 Economic Feasibility of Water Transfers

23. In order for economic welfare to improve from a reallocation of water among use sectors, the reallocation from sector *i* to sector *j* would need to yield incremental gains to sector *j* in excess of the forgone benefits in sector *i*.[8] Building on Young (1986; 2005) who, in turn, had built on earlier writing of Howe and Easter (1971), the economic feasibility of the water transfer can then be tested by developing measurements for two conditions as described below.

24. **Conditions for Economic Feasibility.** The *first condition* is that the direct economic benefits[9] and secondary economic benefits[10] in the receiving sector, net of transaction and physical conveyance costs, need to be greater than the foregone direct and secondary economic benefits in the sector where the water is presently used.[11]

$$DB_i + SB_i > FDB_i + FSB_i + TPC + CC \tag{1a}$$

where:

DB_i = direct benefit (value) to receiving sector *j*;
SB_i = secondary benefit to receiving sector(s) *j*, if any;
FDB_i = foregone direct benefit (value foregone) in source sector *i*;
FSB_i = foregone secondary benefit in source sector *i*, if any;
TPC = transaction and planning costs (for information, contracting and enforcement of transfer agreement plus project design costs); and
CC = (physical) conveyance costs, including possible storage costs.

25. A *second condition* is the costs of the transfer must less than those which would be incurred for the best (least-cost) alternative source of water supply for the receiving sector.

$$FDB_j + FSB_j + TPC + CC < AC \tag{2a}$$

where:

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[8] This would also hold for transfers from lower- to higher-valued agricultural uses.

[9] Direct economic benefits are those accruing to the actual users of water.

[10] Secondary economic benefits accrue due to market links to suppliers of inputs and processors of outputs.

[11] An important point about the notation used in equations 1a and 1b is that, for simplification, each of the expressions represents the *present discounted value* of the concept. Thus, each expression assumes a known discount rate, known production, water transfer and consumption technologies, known product and input prices and a time horizon appropriate to the problem situation.

AC = alternative cost.

26. It is conjectured that within an economic efficiency framework, if secondary benefits in the receiving area (SB) are greater than or equal to foregone secondary benefits in the supplying area (FSB) and the relevant markets clear rapidly, these two terms an be dropped from the feasibility test and attention focused on FDB. Such an assumption, while seemingly plausible, would rest on an empirical analysis of both SB and FDB that has, to our knowledge, not been yet attempted. Also, even if one were to ignore FSB on economic efficiency grounds, its measurement might be of interest on distributive grounds. For example, one might be concerned with compensating owners of immobile assets[12] in the originating area, as are Howe and Goemans (2003).

27. **Extended Conditions**. Further extending the simple model of feasibility conditions above to reflect not only the actual users of water but also third parties outside of the transaction that may be affected (within and perhaps beyond the given river or groundwater basin), the *first condition* then requires that direct and secondary benefits in the receiving sector plus benefits from indirectly affected sectors from diversionary and instream uses as well as nonuser benefits, if any, net of transaction and physical transport costs, exceed foregone direct and secondary benefits plus indirect losses to third parties, if any.

$$DB_j + SB_j + IB_k + NB_k > FDB_i + FSB_i + FIB_k + FNB_k + TPC + CC \tag{1b}$$

where:

IB_k = indirect benefits in sector(s) *k*, if any;
NB_k = nonuser benefits in sector(s) *k*, if any;
FIB_k = foregone indirect benefits in sector(s) *k*, if any; and
FNB_k = foregone nonuser benefits in sector(s) *k*, if any.

28. The *second condition* would then require the following:

$$FDB_i + FSB_i + FIB_k + FNB_k + TPC + CC < AC \tag{2b}$$

29. Although these conditions seem straightforward, an important but still controversial question of policy significance is conceptualizing and measuring the magnitude of FDB resulting from the reallocation of water rights from irrigated agriculture. In addition to its role in studying water allocation policy, this information may be significant for assuring adequate compensation for those giving up their water supplies. Information on FDB is typically lacking because prices in properly functioning water

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[12] An example of an immobile asset may be a well.

markets, which in principle would adequately reflect the underlying FDB, are usually not observed and need to be estimated via modeling procedures.[13]

3.2 Measuring Foregone Direct Benefits

30. The theoretical basis for assessing by how much agricultural producers would be worse off from a reduction in irrigation water supply (i.e., FDB) is conceptually the same as the one developed for assessing how much producers would be better off from an increment in water supply (i.e. DB).[14] Thus the approach for measuring FDB from reallocating irrigation water to alternative uses is the neoclassical theory of production and the theory of the firm (Young, 2005).

31. A concept of "water-related net rents" as a measure of welfare gains and losses (in terms of willingness to pay for producers' or intermediate goods) was presented in Young, (2005, Section 3.5). For the long run case, this measure was shown to be calculated by estimating expected total revenue and subtracting from it anticipated costs of purchased inputs plus opportunity costs of inputs owned by the firm.

32. **Production Function**. To illustrate the conceptual framework, the single product case is shown. The production function can be written symbolically as:

$$Y = f\,(X_{M}, X_{H}, X_{K}, X_{L}, X_{C}, X_{W}, E) \qquad (3)$$

where:

Y = quantity of an output; and
X = the quantity of an input.

33. The time frame is one crop cycle (which typically is equivalent to one year, although some climates permit more than one crop cycle per year). The subscripts *M*, *H*, and *K* refer to inputs that are typically purchased (called *contractual inputs* in the technical economics literature). The subscripts have the following meanings: *M*: materials, energy and equipment; *H*: labor; and *K*: (borrowed) capital. The capital and operating costs of the farm's water distribution system (ditches, pipes, sprinklers, and the like, and the energy to operate them) are here treated as part of the materials, energy, and equipment costs. Although they often may also be purchased, the remaining inputs are assumed here to be *owned* or *non-*

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[13] It should be noted that there is also some controversy about FSB and how to properly account for the forward and backward linkages that may be foregone due to the transfer of water out of the agriculture sector. This is a topic that is beyond the scope of this paper.

[14] As pointed out by Freeman (2003) for the measurement of any welfare change, this is because of the fundamental symmetry between benefits and costs as changes in the utilities of individuals.

contractual. The owned inputs are specialized inputs, those whose prices, in reality, are determined after the fact by the outcomes of managerial decisions, but in water valuation practice must be estimated *ex ante* by opportunity costs. The subscript *L* refers to (unimproved or rainfed) land, *C* refers to equity capital of the firm, and *W* refers to water. E stands for opportunity costs of owned skills, management, technical knowledge, and entrepreneurial creativity.

34. It is important to recognize that while the above process closely resembles that found for farm crop decision-making in the conventional farm management literature, it differs in significant ways. Conventional farm crop budgets typically calculate the residual returns to total owned (non-contractual) inputs. The aim here is to go further and determine returns only to the irrigation water input. It is clear that accurate specification of the inputs belonging in the production function and accurate estimation of quantities and prices of those inputs are crucial to deriving accurate estimates of the residual contribution.

35. **Rent Function**. Moving from the production function to the long-run rent function, and assuming that durable input costs are expressed in annual equivalent terms, the basic (at-site) annual water-related rent formula for a single commodity can be written as:

$$R^{W1} = [Y \text{ x } P_Y] - [(P_M \text{ x } X_M) + (P_H \text{ x } X_H) + (P_K \text{ x } X_K) + (P_L \text{ x } X_L) + C + E] \quad (4a)$$

where:

R = rents; and
P = price.

36. The superscript *W* stands for water and the superscript *1* identifies an at-site value. It has become conventional to standardize the net rent formulas in terms of land, i.e. expressed in per unit land (acres, hectares).

37. The formula represents the *at-site* measure of a long-run welfare change (i.e. the firm’s long-run willingness to pay for water for a crop on a unit land area, or conversely—in the case of interest here—the foregone benefit or value of removing or transferring water from a unit of land area). Usually, water quantity and cost are measured *at* site--at the firm’s receiving point, which may be either the connection to a canal delivery system or, for a groundwater supply, the wellhead. By convention, this is the value used in irrigation investment evaluations, to be compared with annualized costs of supplying water to the same point of use.

38. Because they are commensurate with values computed for instream uses, such as environmental enhancement or energy production, *at-source* values are most appropriate for use in comparing

intersectoral allocations. For the at-source (raw water) value, the delivery costs of moving water from the source to the site must be deducted. The delivery costs may be an annual fixed charge per unit land (denoted D) or, less often, a variable charge per unit water volume. Expressing delivery charges as an annual fixed charge per acre or hectare, the at-source water-related rent per unit land is:

$$R^{W2} = [Y \text{ x } P_Y] - [(P_M \text{ x } X_M) + (P_H \text{ x } X_H) + (P_K \text{ x } X_K) + (P_L \text{ x } X_L) + C + E + D] \tag{4b}$$

The superscript *2* identifies an at-site value. Equation 4b is less than 4a by the amount D, so:

$$R^{W2} = R^{W1} - D \tag{4c}$$

39. Finally, dividing R^{W2} through by W will give the rents and delivery costs conventionally in water volume ($/acre foot or money/cubic meter) terms.

3.3 Specifying the Measure of Water Use

40. In a basin context, when analyzing competing water demands involving the agricultural sector, it is useful to distinguish among three measures of water use: Water withdrawals, deliveries, and consumptive use. *Withdrawal* measures the amount of water diverted from the surface or ground water source. *Delivery* refers to the amount of water delivered to the place of use, i.e., the farm; it is defined as the difference between water withdrawn and the amount of water lost in transit from the point of withdrawal to the point of delivery. *Consumptive u*se is the amount of water that is actually depleted—lost to the atmosphere from evaporation and transpiration from plant and soil surfaces, embodied in plant products, or otherwise removed from the immediate water environment. The difference between withdrawals and consumptive use is called return flow.

41. **Delivery versus Consumptive Use**. In field irrigation situations, delivery exceeds consumptive use for several reasons, mainly because of on-farm transit losses and field losses due to the imprecision of the water application practices. Farmers also may not know the precise amount of irrigation water needed and apply more water than strictly necessary; or they may have to apply water in excess of consumptive use to carry salts below the crop root zone. With consumptive use typically amounting to 40% to 60% of deliveries, return flows represent a relatively large portion of deliveries, and in many river basins constitute an important part of downstream water supply.

42. Water economists have long recognized the importance of considering the different measures of water use in their analysis.[15] Nevertheless, most research on water use in irrigated agriculture—including research on estimating FDB from reallocations of irrigation water—has concentrated on delivery and paid little attention to consumptive use. This is because delivery is usually the farmers' decision variable, and information on the consumptive use of irrigated crops (and, for that matter, return flows) has not readily been obtained. Slowly this situation is now changing—with more advanced hydrologic-agronomic modeling approaches, and cheaper and more reliable methods for using remote sensing to estimate consumptive use.

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[15] For example, Bain, Caves, and Margolis (1966) drew attention to the problem "of placing any emphasis on gross, rather than net, demands for water, since the over-all adequacy of water supplies depends on the net consumption occurring in any given use" (p. 16).

4. Previous Analyses

43. Estimates of direct benefits (DB) from irrigation water and, equivalently, FDB from irrigation water reallocations have been presented in the literature since the1960s. Both behavior-based *inductive techniques* and *deductive techniques* relying on applied non-market methods for valuing producers' uses of water have been applied.

44. **Application of Inductive Techniques**. A few studies have used behavior-based *inductive techniques* such as direct observations in water markets and surrogate land markets. An example is Jaeger and Mikesell, 2002, who perceptively made their estimates in terms of consumptive use.

45. **Application of Deductive Techniques**. While the inductive techniques require data that are costly to obtain and/or rarely observable, and may be outdated, the deductive techniques can be adapted to *ex ante* analysis from more readily available data. Thus most studies have employed deductive techniques ranging from the simple residual imputation approach to more complex input-output models and CGE frameworks.[16]

46. Some early approaches to assessing FDB relied on value-added measures (payments to primary resources) from regional Leontief *input-output type models* (e.g. Wollman, 1963; Hartman and Seastone, 1970). More recent formulations of input-output models to assess the impact of irrigation water transfers include Howe et al. (2000) and Howe and Goemans (2003).

47. *CGE models* have been applied since the 1990s for assessing FDB in irrigated agriculture. See, for example, Berck and Robinson, 1991; Seung et al., 1998; Goodman, 2000; and Seung et al., 2000. A few years ago, the World Bank's Development Research Group applied CGE models to study water sector issues. The modeling work also included macro-level CGE models linked to micro-level farm models to estimate the effect of various water policies, including allowing for irrigation water transfers, for the case of Morocco and South Africa (Roe et al., 2005; Hassan et al., 2008).

48. In the agricultural sector, the *residual imputation approach* and its extensions, in particular mathematical programming, have been the most frequently used methods for assessing FDB. As outlined in the previous section, the general conceptual framework assumes: If the physical production function and the optimal quantities of all the other inputs are known and input and product prices reflect competitive market conditions, then these inputs' distributive shares can be deducted from the total value

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[16] By incorporating intersectoral linkages, input-output and CGE models have been applied to estimate not only FDB in irrigated agriculture, but also FSB.

of the product and the remaining economic rent can be imputed to the unpriced input, i.e. water (the residual claimant).

49. A basic version of the residual imputation approach, the budgeting method, was, for example, used by Chang and Griffin to estimate agricultural costs of irrigation water transfers to urban uses (1992). Linear programming based representative farm models were applied by Hamilton et al. (1989) to analyze the potential of allowing some irrigation to move to hydropower use in critical low flow periods. Taylor and Young (1995) estimated FDB by developing a discrete sequential stochastic program to model the sequential nature of crop production decisions and the uncertainty of water supplies and rainfall. Sunding et al. (2002) used three alternative models to evaluate the impacts of water reduction in irrigated agriculture in California's Central Valley for improving water quality in the San Francisco Delta estuary. Based on discrete sequential stochastic programming combined with a hydrological model, Houk et al. (2007) estimated foregone benefits from water transfers from agriculture to instream flows in the Platte River for critical habitat purposes in Nebraska.

50. **Issues with Deductive and Inductive Techniques**. Although conceptually straightforward, in practice several problematic issues arise with the residual imputation approach which so far have not been much examined in the literature (Young, 2005). They include accurately specifying the physical production function, specifying technologies, and assigning correct prices for the non-water purchased inputs as well as the outputs. Furthermore, non-water *owned inputs* pose a particular challenge. Both production theory and empirical evidence suggest unresolved problems in properly identifying and pricing inputs owned by the firm. Theory suggests that owned inputs such as household labor, equity capital, management and entrepreneurial skills, and land and possibly other (non-water) natural resources should be accounted for. Empirical observations of land market transactions and more elaborate hedonic pricing using farm sales data and econometric techniques show that typical residual imputation studies yield higher valuations than do market transaction-based studies. If, for example, in a long-run context of analyzing FDB the contributions of some of these non-water owned inputs are neglected in calculating the residual claimant for water, then the value assigned to water is erroneously large because it includes returns not just to water, but to the ignored owned inputs. Results from such analyses would yield exaggerated estimates of FDB from decreased water supplies.

51. Similarly, the studies that used the value-added measure from regional input-output models to estimate FDB also produced overstated FDB—because changes in value-added consist not only in the

contribution of water to the value of output, but the contribution of all primary resources which implicitly are assumed to all have a zero opportunity costs (Young and Gray, 1985; Young, 2005).[17]

52. A review of previous estimates of irrigation water values uncovers a few anomalies, among them a systematic inconsistency between econometrically-based (inductive) *ex post* valuations analyzing observed actual land and water market *behavior* and valuations based on deductive models of *hypothetical* farmer decisions. Behavior-based valuations consistently show lower (in dollars per unit volume) valuations than those grounded on the more common deductive models relying on models of hypothetical producer actions.

53. The partial explanation is because these approaches tend to measure different things. The land value and the more complex hedonic property value methods estimate at-source values that are, other things equal, lower than at-site measures. For the most part, behavior-based methods are appropriate for estimating *at-source*, *ex post* values for *long-run, private* contexts. (However, they can be adjusted to yield at-site values.) Because they measure past behavior at a specific place and for a specific period, these methods are more useful for validating conceptual models and cross-checking deductive studies than for evaluating proposed investments or allocation decisions. The methods based on observed market behavior also have the advantage, weighty to most economists, of being based on actual rather than hypothetical farmer decision-making.

54. The residual imputation methods are, however, widely adaptable for *ex post* or *ex ante*, long-run or short-run, public or private planning. Nonetheless, deductive techniques as conventionally applied to evaluating proposed irrigation water resource investment and allocation policies appear to yield overestimates of willingness to pay for water. Deductive techniques are liable to misspecification, primarily omission of variables (particularly opportunity costs of owned inputs) and overly optimistic price and productivity assumptions. Especially for high-valued crops, inadequate accounting for rents to owned managerial inputs and equity capital may lead to an overstatement of the net returns to water. When an inappropriate conceptual framework is adopted, as when value-added or related measures from regional economic models are adduced as measures of willingness to pay, deductive techniques are subject to serious overestimation. More generally, where owned inputs other than water are also specialized, so that their “prices” are determined as rents once the results of previous decisions can be observed, the results of residual analysis are subject to an unavoidable indeterminacy.

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[17] Another reason is the lack of provision in input-output models for input substitution or other responses available to farmers when faced with reduced irrigation water supplies. Results from other studies, including from some of the mathematical programming models that allow for a range of adjustment options, suggest that at least initially losses in direct benefits (or FDB) are relatively small (Scheierling et al., 2004).

55. In sum, the estimated FDB depends on the decision or policy context in which the estimate is developed. Analysts must distinguish between private and public accounting stances, short-run and long-run decisions, at-source and at-site values, per period and capitalized values. Proper accounting for the contributions of specialized owned inputs is vital in applying residual imputation methods.

56. **Consideration of Water Use Measures**. Independent of the particular method employed, the previous studies based on deductive techniques have concentrated on the effects of reductions in water deliveries, and have uniformly ignored the effects of reductions in consumptive use. None of the FDB assessments has so far been specified in terms of consumptive use as a measure of water input.

5. Method of Study

57. In this paper the basic approach to estimating FDB is the residual imputation method. An agroeconomic model is employed that combines a crop simulation model, which estimates the effect of alternative irrigation water delivery scheduling options on consumptive use and crop yield, with a mathematical programming model designed to reflect farmers' optimal land, water use, and irrigation technology decisions given certain constraints such as available land and water supplies. Details on the crop simulation model are in Scheierling et al. (1997), and on the agroeconomic model in Scheierling et al. (2004; 2006).

58. **Study Area**. An irrigation organization in northern Colorado, the Cache La Poudre Irrigation Company, was chosen as the study area. It is one of about a dozen farmer-owned irrigation organizations located in Weld County, one of the richest agricultural counties in the United States. Its service area is located near the South Platte River which, together with its tributaries, serves Colorado's most important agricultural region and major urban-industrial centers. Dating back to the late 19th century, the irrigation district owns some of the most senior water right decrees for surface flows, which under Colorado's prior appropriation system guarantee highly secure and reliable water supplies. The water right can be transferred as long as other water rights holders are not injuriously affected (Getches, 2008). The courts usually consider the historical use of the right and require that the water consumption of the new use is not greater than the historical consumptive use. This limitation is designed to protect other water right holders dependent on the return flow regime, by aiming to ensure stream conditions present at the time of their respective appropriations.

59. Return flows are very important in the South Platte basin. Deep percolation from ditches and irrigated land reaches the river's unconfined shallow alluvial aquifer, where it becomes available for pumping or to replenish surface flows downstream. On the basis of comparisons of basin inflows to total surface and groundwater withdrawals, the water in Colorado's portion of the South Platte basin is estimated to be used and reused by a factor of about 2.5 before it reaches Nebraska. More than 80% of the withdrawals in the South Platte basin continue to be used for irrigated agriculture, but there is increasing pressure to make some of that irrigation water available for growing urban and environmental demands.

60. **Agroeconomic Model**. The main features of the crop simulation model include the modeling of water and solute movement through the soil, and of simultaneous water uptake by plants. It is formulated to capture the effects of irrigation timing as discrete-input events, and estimates water-crop production

functions that show the impact of alternative irrigation schedules on water deliveries, consumptive use, and crop yield. Each irrigation event is assumed to consist of the same amount of net water infiltration into the soil, becoming available for plant water uptake or deep percolation. The amount of water which actually must be applied to achieve this net infiltration depends on the irrigation technology chosen.

61. The economic model is a deterministic single-period linear program formulated for the long-run planning context. Using the water-crop production functions from the agronomic model as an input, it calculates the choice of crop mix, irrigated acreage, number of irrigations, and irrigation technologies that maximizes net return in the irrigation district, as well as the implied water delivery and consumptive use amounts. Activities included in the economic model are the main crops of the study area, which can be irrigated with different irrigation technologies and treated with varying numbers and timing of irrigations. Farmers are assumed to be well informed about the water-crop production functions, and to apply limited water only in these combinations which result in the highest crop yields for the available water.

62. On the basis of the residual imputation approach, unit net returns per acre are calculated for each activity by subtracting from total revenue per acre the variable costs (labor, materials, fuels, but exclusive of water supply costs), and the annual overhead costs (including management) and annualized capital costs (inclusive of a land charge estimated at the value of the land in its next-best use, which is assumed to be the production of nonirrigated winter wheat). An illustration of a unit net return calculation is in the Annex (see columns ‘with owned inputs’). The unit net returns are used in the objective function of the economic model. Constraints in the model are defined for land and typical annual water deliveries. An accounting constraint is included to measure consumptive use. Other constraints are formulated to reflect the cropping pattern in the study area. The net return to water for farmers in the irrigation organization is calculated as net return emerging from the objective function minus the annual cost of water supply.

63. **Data and Model Specification**. The agroeconomic model uses the service area of the irrigation organization as a representative farm. The main crops are corn grain, alfalfa, edible dry beans, corn silage, and sugarbeets. Mean annual precipitation is about 35.6 cm, with about 44% occurring during the irrigation period. Water distribution is almost exclusively carried out with surface irrigation technologies, including open ditches with siphons, and gated and flexible pipes with and without surge. In an average year, farmers use surface and groundwater amounting to about 148.4 million m^3 of water for a service area of approximately 16,188 hectare (40,000 acres), and apply several irrigations per crop and season. The typical net infiltration per irrigation event in the study area is about 7.6 cm.

64. Yield estimates from the crop simulation model were used to calculate total revenue per acre. Volatility and inflation were removed from crop prices by taking a five-year average of prices for the period 1989-93 deflated with the GNP Implicit Price Deflator. Variable costs were based on advice from Colorado State University extension agents. To reflect the cropping pattern in the service area, sugar beets were limited to 7 percent and dry beans to 17 percent of the total irrigated area. Corn silage may be grown on up to 12 percent, and alfalfa on up to 27 percent of the area. The area for corn grain was not constrained. Each crop can be irrigated with any of the five irrigation technologies and receive up to nine irrigations (beans up to eight). These assumptions generated 245 activities for which unit net returns were calculated and included in the economic model.

6. Model Results

65. The presentation of model results focuses on estimates of FDB and, in particular, on showing how different model specifications lead to significantly different estimates of FDB. Two aspects are studied here with regard to their effect on the magnitude of FDB estimates:

- the proper identification and pricing of non-contractual inputs, i.e. inputs owned by the firm other than water, and their inclusion or non-inclusion as cost; these *owned inputs* comprise here (i) management and entrepreneurial skills, and (ii) land; and
- the specification of the *measure of water use*, either in delivery (the most-often used measure) or in consumptive use (in many cases the more significant measure).

66. This allows for the development of FDB measures under *four model specifications*:

- FDB is shown first with a specification that calculates residual rents as returns to owned inputs (revenues minus contractual costs).[18] This result is compared with what is regarded to be a more theoretically correct specification that also deducts estimated opportunity costs of non-water owned inputs (i.e., charges for management and land).[19]
- Each of these estimates is then calculated on a per-unit water basis: FDB per unit water delivered, and FDB per unit water consumed.

67. Model results are presented in two steps: first, for a crop budget model (corn silage in this example); and second, for the representative farm model based on the application of the agroeconomic model to the service area of the irrigation organization as outlined in Section 5.

6.1 Results for a Crop Budget Model

68. To illustrate how the analysis is built up for a representative crop, the calculations for one acre of corn silage irrigated with four irrigations per season with flexible pipe technology are shown in the Annex. The results for the four model specifications are summarized in table 6.1. The columns show the calculations for net returns (i.e. FDB estimates) for the two specifications regarding owned inputs: where their opportunity costs are ignored, and where estimated charges for owned inputs are deducted. The

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[18] Using the illustration in the Annex with corn silage grown on 1 acre, this implies total revenue minus variable cost (without the inclusion of the management charge) minus annual overhead and annualized capital costs (without the inclusion of the land charge), as shown in the columns ‘without owned inputs’.

[19] See in the Annex the columns ‘with owned inputs’.

charge for management is assumed to be 5% of total revenues. For the opportunity cost of land, an estimate of the net returns per acre to non-irrigated winter wheat production on similar soils in the area is used. For corn silage, water delivered—using flexible pipe (with an assumed application efficiency of 40%) and four irrigation events (each with a net infiltration of 7.6 cm)—amounts to 7,709 m^3 per hectare, while water consumed is estimated to be about 4,656 m^3 per hectare.

Table 6.1 Estimates of Unit Net Returns for Corn Silage (1 hectare)

	Without Owned Inputs	With Owned Inputs
Description	Value/Cost per Hectare	Value/Cost per Hectare
Net Return	**557.99**	**429.28**
Annual Cost of Water Supply	129.20	129.20
Net Return to Water	**428.79**	**300.08**
Water Delivery	7,709 m3	7,709 m3
Net Return per m3 of Water Delivery	**0.056**	**0.039**
Consumptive Use	4,656 m3	4,656 m3
Net Return per m3 of Consumptive Use	**0.092**	**0.064**

69. A comparison of estimated FDB in net return per acre foot of water delivered and water consumed for each owned-input specification shows:

- FDB estimates per unit delivered are considerably (about 43 percent) larger where owned input charges are assumed to be zero.
- For each owned input price specification, the FDB estimate is significantly (about 64 percent) higher for the consumptive use specification than for the delivery version.

6.2 Results for the Representative Farm Model

70. The results for the representative farm model are based on the calculations from the agroeconomic model, which represents the cropping patterns with the five main crops in the service area of the irrigation organization. The optimization results show that the whole service area of 16,188 ha is irrigated using the available 148.4 million m^3 of surface and groundwater supplies. Consumptive use for

the service area is estimated to amount to 78.3 million m^3. When the opportunity costs of non-water owned inputs are included, the value of the objective function representing the total annual net return for the service area amounts to $6.4 million; when owned inputs are neglected, the total annual net return is estimated to be a third higher. Table 6.2 presents the results for the four model specifications.

Table 6.2 Estimates of Net Returns for Representative Farm Model (16,188 hectare)

	Without Owned Inputs	**With Owned Inputs**
Description	**Value/Cost for Representative Farm**	**Value/Cost for Representative Farm**
Net Return	**8,367,467**	**6,373,573**
Annual Cost of Water Supply	2,067,067	2,067,067
Net Return to Water	**6,300,400**	**4,306,506**
Water Delivery	148 million m3	148 million m3
Net Return per m3 of Water Delivery	**0.042**	**0.029**
Consumptive Use	78 million m3	78 million m3
Net Return per m3 of Consumptive Use	**0.080**	**0.055**

71. For the irrigation organization as a whole, a comparison of FDB estimates in net return per acre foot of water delivered and water consumed for each owned-input specification shows:

- When owned inputs are neglected, FDB estimates per unit delivered are again considerably (about 45 percent) larger than when they are included.
- And, of course, FDB for the consumptive use specification are larger (in this case, about 90 percent) than that for delivery—in inverse proportion to their estimated quantity per acre.

72. A comparison of the FDB estimates of table 6.2 with those of table 6.1 shows that the values for corn silage for all model specifications are higher than the values for the irrigation organization as a whole, suggesting that corn silage is a higher value crop than some of the others in the crop mix (in this case, for example, alfalfa).

73. The illustration of the calculations of unit net returns in the Annex, and their link to the estimates for the representative farm model, indicates the close relationship between FDB estimates and the level of

crop prices. The higher the crop prices, the higher would be FDB estimates, independent of the four model specification.[20]

74. The net return estimate for the model specification ‘with owned inputs’ as measure of FDB in table 6.2 represents the direct economic effects of a permanent irrigation water transfer away from the service area of the study area, and indicates the level of the appropriate annual compensation to the farmers. The equivalent fully capitalized price of the transfer would be FDB/i, where i is interest rate (Young, 2005).

75. Overall, the main purpose of the model results presented here is to illustrate an application of the conceptual framework for estimating FDB from irrigation water reallocations (or, equivalently, DB from additional water allocations to irrigated agriculture). It is seen that a wide range of FDB estimates is derived depending on the chosen model specification.

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[20] The close relationship between crop price levels and FDB estimates becomes even more important to consider in a world with increasing volatility in crop prices, and points to the need for sensitivity analyses or even more formal methods such as Monte Carlo analyses..

7. Summary and Conclusions

76. Within the general context of assessing the economic feasibility of transferring irrigation water to alternative uses, this analysis has addressed the problem of conceptualizing and, for a case example, implementing the measurement of foregone direct benefits (FDB) of such a transfer. One motivation for the paper was the observation from the published literature that different techniques yielded distinctly different estimates of FDB. In particular, deductive techniques seem to generally yield higher estimates of the value of irrigation water than do inductive estimates based on actual observed market behavior. Furthermore, even with the same technique a wide range of estimates was reported. A second motivation was a concern that while most estimates measure water use in terms of delivery (the amount received by the water user), a more appropriate measure would be consumption (the lesser amount evaporated from crops and soils).

77. One source of the difference in estimates of FDB is hypothesized to be a misspecification of the production function in deductive (residual imputation) models, in which the opportunity costs of owned inputs are not accounted for. Model results are reported, based on irrigated crop conditions in the South Platte Valley in northern Colorado. With a crop budget approach for a single crop (corn silage), and for an agroeconomic model of a representative farm, analyses of net return to water are shown for, first, alternative specifications for the value of owned inputs, and second, alternative assumptions concerning the measure of water use (delivery or consumption).

78. It is seen that a wide range of FDB estimates per acre foot is derived depending on the chosen model specification. Estimated FDB is, of course, significantly lower when the estimated opportunity costs of owned inputs (management and non-irrigated lands in this study) are included in the calculations. As indicated above, for the model specifications related to owned input costs, the specification in which an estimated opportunity cost is charged for owned inputs is preferred. And, for the water quantity measures, the consumptive use measure of FDB is, of course, higher than the corresponding measure using delivery as the measure of water use.[21]

79. The model results indicate that a transfer of the water from the irrigation organization that intends to avoid third-party effects should only comprise 4,656 m^3 (the consumptive use amount) and not 7,709 m^3 (the delivery amount)—a substantial difference—and farmers should be compensated according to the former. The modeling exercise becomes even more insightful if not all, but only part of the water of the

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[21] This perhaps indicates that the “high” prices observed on Colorado water markets may in part reflect actual FDB in consumptive use terms as much as reflecting the conventional assumption of unearned rents from strong urban and environmental demands.

irrigation organization is to be transferred and, especially, if subsidies for “more efficient” irrigation technologies are considered with the intent to transfer “saved” water to alternative uses (see Scheierling et al. 2004; 2006).

80. Based on the insights gained in this study, fruitful *future analytical work* could comprise the following:

- The study has concentrated on deductive techniques and, in particular, the residual imputation approach. An interesting extension to further explore the differences in FDB (and DB) estimates may be to further compare the application of deductive and inductive techniques.
- The focus of the paper has been on the conceptualization and measurement of FDB and, equivalently, DB. Another important exercise would be to have a closer look at the conceptualization and measurement of FSB and SB, including distinguishing between direct and secondary benefits.

81. Future *operationally-oriented activities* may involve the following:

- The literature suggests that irrigation water transfers are increasing, both in developed and developing countries, and in the latter especially around rapidly growing cities. More focus on the economic implications of likely reallocations associated with different water-related interventions may contribute to averting serious tensions in the affected areas.
- The application presented in this paper is in financial terms. For an application to developing countries, further considerations would have to be given to the question on how to convert into economic terms.
- The paper has shown that model misspecification can have significant impacts on the magnitude of FDB and DB estimates, which may contribute to differing policy conclusions. For example, by excluding non-water owned (non-contractual) inputs, FDB estimates are larger and thus also the perceived cost of irrigation water transfers. Conversely, when DB for planned irrigation area expansion is estimated (for example, in connection with an ex-ante economic analysis), and important owned inputs and sometimes even contractual inputs are omitted, the expected benefits to farmers will be overstated and may lead to the conclusion that a project is economically feasible when in fact it is not. This may also lead to overstated perceptions on farmers’ repayment capacity for part or all of the costs of irrigation water supply facilities. Further guidance on this may be helpful.

References

Bain, J.S., R.E. Caves, and J. Margolis. 1966. *Northern California's Water Industry: The Comparative Efficiency of Public Enterprise in Developing a Scarce Natural Resource*. Baltimore, MD: John Hopkins Press.

Bhatia, R., R. Cestti, and J. Winpenny. 1995. *Water Conservation and Reallocation: Best Practice Cases in Improving Economic Efficiency and Environmental Quality*. A World Bank-ODI Joint Study. Water & Sanitation Program. Washington, DC: World Bank.

Berck, P., S. Robinson, and G. Goldman. 1991. "The Use of Computable General Equilibrium Models to Assess Water Policies." In A. Dinar and D. Zilberman (eds.) *The Economics and Management of Water and Drainage in Agriculture*, Norwell, MA: Kluwer Academic Publishing, pp. 489-509.

Brewer, J., R. Glennon, A. Ker, and G.D. Libecap. 2007. *Water Markets in the West: Prices, Trading, and Contractual Forms*. NBER Working Paper Series. Cambridge, MA: National Bureau of Economic Research.

Chang, C., and R.C. Griffin. 1992. "Water Marketing as a Reallocative Institution in Texas." *Water Resources Research* 28(3):879-90.

Dinar, A., M.W. Rosegrant, and R. Meinzen-Dick. 1997. *Water Allocation Mechanisms: Principles and Examples*. Policy Research Working Paper No. 1779. Washington, DC: World Bank and International Food Policy Research Institute.

Cristi, O., and C. Poblete. 2010. *Qué nos dicen los conservadores de bienes raíces del mercado de aguas en Chile*. Working Paper Series, Escuela de Gobierno, Universidad del Desarrollo. Santiago, Chile.

Freeman, A.M., III. 2003. *The Measurement of Environmental and Resource Values: Theory and Methods*, 2nd ed. Washington, D.C.: Resources for the Future.

Getches, D.H. 2008. *Water Law in a Nutshell*, 4rd ed. West Publishing: St. Paul, MN.

Goodman, D.J. 2000. "More Reservoirs or Transfers? A Computable General Equilibrium Analysis of Projected Water Shortages in the Arkansas River Basin." *Journal of Agricultural and Resource Economics* 25(2): 698-713.

Hamilton, J.R., N.K. Whittlesey, and P. Halverson. 1989. "Interruptible Water Markets in the Pacific Northwest." *American Journal of Agricultural Economics* 71(1):63-75.

Hartman, L.M., and D. Seastone. 1970. *Water Transfers: Economic Efficiency and Alternative Institutions*. Resources for the Future. Baltimore, MD: John Hopkins Press.

Hassan, R., J. Thurlow, T. Roe, X. Diao, S. Chumi, and Y. Tsur. 2008. "Macro-Micro Feedback Links of Water Management in South Africa: CGE Analyses of Selected Policy Regimes." Policy Research Working Paper 4768. Development Research Group. Washington, DC: World Bank.

Houk, E.E., M. Frasier, and R.G. Taylor. 2007. "Evaluating Water Transfers from Agriculture for Reducing Critical Habitat Water Shortages in the Platte Basin." *Journal of Water Resources Planning and Management* 133(4):320-28.

Howe, C.W. ,and K.W. Easter. 1971. *Interbasin Transfers of Water: Economic Issues and Impacts.* Baltimore, MD: Johns Hopkins University Press.

Howe, C.W., J.K. Lazo, and K.R. Weber. "The Economic Impacts of Agriculture-to-Urban Water Transfers on the Area of Origin: A Case Study of the Arkansas River Valley in Colorado." *American Journal of Agricultural Economics* 72:1200-04.

Howe, C.W., and C. Goemans. 2003. "Water Transfers and Their Impacts: Lessons from Three Colorado Water Markets." *Journal of the American Water Resources Associati*on, October, 1055-65.

IEG (Independent Evaluation Group). 2010. *Cost-Benefit Analysis in World Bank Projects*. Independent Evaluation Group. Washington, DC: World Bank.

Jaeger, W.K., and R. Mikesell. 2002. "Increasing Streamflow to Sustain Salmon and Other Native Fish in the Pacific Northwest." *Contemporary Economic Policy* 20(4): 366-80.

Levine, G., R. Barker, and C.C. Juang. 2007. "Water Transfer from Agriculture to Urban Uses: Lessons Learned, with Policy Considerations." *Paddy and Water Environment*, 5(4):213-22.

Molle, F., and J. Berkoff. 2006. *Cities versus Agriculture: Revisiting Inersectoral Water Transfers, Potential Gains and Conflicts*. Comprehensive Assessment Research Report 10. Comprehensive Assessment Secretariat. Colombo, Sri Lanka.

Molle, F., and J. Berkoff. 2009. "Cities vs. Agriculture: A Review of Intersectoral Water Re-Allocation." *Natural Resources Forum* 33:6-18.

National Water Commission (Australia). 2010. *Australian Water Markets Report 2009-10.* Commonwealth of Australia, Canberra.

Roe, T., Dinar, A., Tsur, Y., and Diao, X. 2005. "Feedback Links between Economy-wide and Farm-level Policies: Application to Irrigation Water Management in Morocco." *Journal of Policy Modeling* 27(8): 905-928.

Scheierling, S.M., G.E. Cardon, and R.A. Young. "Impact of Irrigation Timing on Simulated Water-Crop Production Functions." *Irrigation Science* 18:23-31.

Scheierling, S.M., R.A. Young, and G.E. Cardon. 2004. "Determining the Price-Responsiveness of Demands for Irrigation Water Deliveries versus Consumptive Use." *Journal of Agricultural and Resource Economics* 29(2): 328-45.

Scheierling, S.M., R.A. Young, and G.E. Cardon. 2006. "Public Subsidies for Water-Conserving Irrigation Investments: Hydrologic, Agronomic, and Economic Assessment." *Water Resources Research*, 42, W03428, doi:10.1029/2004W003809.

Scheierling, S.M. and R.A. Young. 2010. "Measuring Foregone Direct Benefits of Irrigation Water Transfers:The Effect of Model Specification." Presentation at the 2010 Annual Meeting of the Agricultural and Applied Economics Association, Denver, CO, July 25-27, 2010. http://agecon.lib.umn.edu

Seung, C.K., T.R. Harris, T.R. MacDiarmid, and W.D. Shaw. 1998. “Economic Impacts of Water Reallocation: A CGE Analysis for the Walker River basin of Nevada and California.” *Journal of Regional Analysis and Policy* 28(2): 13-34.

Seung, C.Ck. T.R. Harris, J.E. Englin, and N.R. Netusil. 2000. “Impacts of Water Reallocation: A Combined Computable General Equilibrium and Recreation Demand Model Approach.” *Annals of Regional Science* 34:473-87.

Sunding, D., D. Zilberman, R.E. Howitt, A. Dinar, and N. MacDougall. 2002. “Measuring the Costs of Reallocating Water from Agriculture: A Multi-Model Approach.” *Natural Resource Modeling* 15(2): 201-25.

Taylor, R.G., and R.A. Young. 1995. “Rural-to-Urban Water Transfers: Measuring Direct Foregone Benefits of Irrigation Water under Uncertain Water Supplies.” *Journal of Agricultural and Resource Economics* 20(2): 247-62.

U.S. National Research Council. 1992. *Water Transfers in the West: Efficiency, Equity, and the Environment*. Washington, DC: National Academy Press.

Wollman, N. 1963. *The Value of Water in Alternative Uses*. Albuquerque: University of New Mexico Press.

World Bank. 2004. *Water Resources Sector Strategy: Strategic Directions for World Bank Engagement.* Washington, DC: World Bank.

World Bank. 2010. *China: Xinjiang Turpan Water Conservation Project*. Project Appraisal Document. Washington, DC: World Bank.

Young, R.A. 1986. “Why Are There so Few Transactions among Water Users?” *American Journal of Agricultural Economics* 68(5): 1143-51.

Young, R.A. 2005. *Determining the Economic Value of Water. Concepts and Methods*. Washington, DC: Resources for the Future.

Young, R.A., and S.L. Gray. 1985. “Input-Output Models, Economic Surplus and the Evaluation of State or Regional Water Plans.” *Water Resources Research,* 21(12):1819-23.

Abbreviations and Acronyms

AC	Alternative costs
CC	Conveyance costs
CGE	Computable general equilibrium
DB	Direct (economic) benefits
ESW	Economic and Sector Work
FDB	Foregone direct (economic) benefits
FIB	Foregone indirect (economic) benefits
FNB	Foregone nonuser (economic) benefits
FSB	Foregone secondary (economic) benefits
IB	Indirect (economic) benefits
IEG	Independent Evaluation Group
NB	Nonuser (economic) benefits
SB	Secondary (economic) benefits
TPC	Transaction and planning costs

Glossary[22]

At-site value The value of water calculated as at the site of use (such as the farm). By convention, this is the value used in investment evaluations, to be compared with cost of supply. See *at-source value*.

At-source value The value of water calculated as at the source (such as the stream or aquifer).. A derived demand less than at-side value by any costs of capture, transport, and treatment for use. See *at-site value*.

Benefit, economic A monetary measure of preference, satisfaction, or welfare improvement from some change in quantity or quality of a good or service; the maximum amount a person would be willing to pay to obtain the improvement.

Computable General Equilibrium (CGE) model Empirical model of a region, political entity, or subdivision designed to determine domestic prices, supplies, and incomes jointly with a system of nonlinear simultaneous equations.

Consumptive use In the context of measuring water use, the amount of water that is actually depleted, i.e. lost to the atmosphere from evaporation and transpiration from plant and soil surfaces, embodied in plant products, or otherwise removed from the immediate water environment.

Contractual inputs In analyzing producer goods, those productive inputs purchased by the firm at known prices, including materials purchased from other firms, hired labor, and other inputs whose costs are known. See owned inputs.

Deductive techniques Valuation methods (including residual imputation methods) which primarily use deductive reasoning, i.e. from general principles and assumptions to specific conclusions using logical or mathematical rules. Conclusions are only as valid as the initial assumptions.

Delivery Amount of water delivered to the place of use (such as the farm). Defined as the difference between *withdrawal* and the amount of water lost in transit from the point of withdrawal to the point of delivery.

Direct benefits The value accruing to the actual users of a resource.

Econometric methods The combination of economic theory and mathematical statistics to inductively infer general economic relationships from observations on producer or consumer behavior, from experimental data, or from responses to questionnaires.

Foregone benefits The value sacrificed when one resource use option is chosen over another.

Indirect benefits The value accruing to third parties beyond the actual users of a resource.

Inductive techniques Valuation methods which use inductive reasoning, i.e. from specific empirical observations to broader generalizations, usually employing statistical methods. The accurateness depends, among others, on the representativeness of the observations used, the appropriateness of the assumed statistical distribution, and the functional form on which the inference is based.

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[22] For further details, see the glossary in Young (2005).

Input-output model A static economic model of production, usually portraying a geographic region or political subdivision, for understanding the structure of the regional economy and for making *short-run* predictions of the effects of exogenous changes in final demands on such economic variables as output, employment, and income.

Long-run The situation in which plant and equipment capacity is assumed to be variable, rather than fixed as it is in the *short-run*. Short-run and long-run are distinguished not by the actual time in days, weeks, or months, but by the degree to which economic actors can adapt to changing conditions.

Noncontractual inputs See *owned inputs*.

Non-market valuation The study of economic behavior (such as production, supply, consumption and demand relationships) for the purpose of assigning economic values in contexts when market prices are absent or distorted.

Nonuser benefits The value accruing to non users of a public good resource by knowing that it exists, even though the good may never be directly experienced.

Owned inputs The productive inputs owned by a firm, including the firm's equity capital, some human inputs (such as management and entrepreneurial creativity), and some natural resources (such as land). Cost of *owned* (or *noncontractual*) inputs are important in residual evaluation of producers' uses of water. Because their prices are uncertain, i.e. determined by the outcome of prior management and investment decisions rather than being priced on markets, any method of pricing owned inputs creates uncertainty in residual valuation of producer uses of water. See *contractual inputs.*

Rent, economic Nonobservable income imputed to an input in limited supply; represents payment made to an input over and above the amount needed to attract any of that input to be supplied to its present employment.

Residual imputation methods Methods used primarily for valuing nonmarket producers' or intermediate goods; approximates the net rent or value marginal product of a nonpriced productive input by subtracting all other estimated costs of production from forecasted total value of output. The remaining (residual) value is assigned to the nonpriced input (such as water)

Return flows Difference in the amount of water between *withdrawal* and *consumptive use*.

Secondary benefits The value accruing due to market links to suppliers of inputs and processors of outputs.

Short-run The situation in which plant and equipment capacity is assumed to be fixed, rather than variable as it is in the *long-run*. Short-run and long-run are distinguished not by the actual time in days, weeks, or months, but by the degree to which economic actors can adapt to changing conditions.

Value-added The difference between the value of a firm's output and the value of inputs purchased from other firms, i.e. the value contributed by the firm's production process. Labor, land, and capital are treated as owned or internal, rather than externally purchased inputs. Sometimes used incorrectly as a measure of net rents of an increment of water in production.

Withdrawal The amount of water diverted from a surface of ground water source.

Annex

Estimates of Unit Net Returns for Corn Silage with and without Owned Inputs
1 hectare, 4 irrigations (each with a net infiltration of 7.6 cm) per season with flexible pipe

			Without Owned Inputs			With Owned Inputs		
	Description	**Unit**	**Units per ha**	**Price/Cost per Unit**	**Value/Cost per ha**	**Units per ha**	**Price/Cost per Unit**	**Value/Cost per ha**
A.	**Total Revenue**	ton	61.25	21.66	**1326.68**	61.25	21.66	**1326.68**
B.	**Variable Costs**							
a.	Seed 1,000 seed		90.00	1.00	90.00	90.00	1.00	90.00
b.	Fertilizer							
	1. Anhydrous Nitrogen	lb	190.00	0.12	22.80	190.00	0.12	22.80
	2. 10-34-0 w/zn	gal	15.00	1.25	18.75	15.00	1.25	18.75
c.	Chemicals							
	1. Lasso II 15 G (Herbicide)	lb	13.75	0.99	13.61	13.75	0.99	13.61
	2. Banvel (Herbicide)	pt	1.25	9.31	11.64	1.25	9.31	11.64
	3. Counter (Insecticide)	kg	22.50	1.75	39.38	22.50	1.75	39.38
d.	Irrigation Operation & Maintenan	ha	1.00	35.63	35.63	1.00	35.63	35.63
e.	Machinery/Equipment (Custom)							
	1. Disc	ha	1.00	15.00	15.00	1.00	15.00	15.00
	2. Plow	ha	1.00	37.50	37.50	1.00	37.50	37.50
	3. Apply Anhydrous Nitrogen	ha	1.00	15.00	15.00	1.00	15.00	15.00
	4. Apply Herbicide	ha	1.00	10.00	10.00	1.00	10.00	10.00
	5. Plant	ha	1.00	25.00	25.00	1.00	25.00	25.00
	6. Row Crop Cultivation	ha	1.00	15.00	15.00	1.00	15.00	15.00
	7. Row Crop Cultivation	ha	1.00	15.00	15.00	1.00	15.00	15.00
	8. Ditch	ha	1.00	20.00	20.00	1.00	20.00	20.00
	9. Combine	ton	61.25	4.00	245.00	61.25	4.00	245.00
	10. Truck	ton	61.25	0.50	30.63	61.25	0.50	30.63
f.	*Management*	*5% of total revenue*			*0.00*			*66.33*
g.	Interest on Variable Costs	9% for 4 months			19.80			21.80
	Total Variable Costs				**679.72**			**748.05**
C.	**Net Return over Variable Costs**				**646.95**			**578.63**
D.	**Annual Overhead and Annualized Capital Costs**							
a.	Real Estate Taxes	ha	1.00	25.00	25.00	1.00	25.00	25.00
b.	Irrigation Equipment	ha	1.00	29.98	29.98	1.00	29.98	29.98
c.	*Land Charge (Non-Irr. Winter W*	ha	*1.00*		*0.00*	*1.00*	*56.98*	*56.98*
d.	Overhead Costs	5% of total variable costs			33.99			37.40
	Total Overhead and Capital Costs				**88.96**			**149.35**
E.	**Net Return (over Variable, Overhead and Capital Costs)**				**557.99**			**429.28**
F.	**Annual Cost of Water Supply**							
a.	Variable Cost of Water Supply	ha	1.00	50.45	50.45	1.00	50.45	50.45
b.	Fixed Cost of Water Supply	ha	1.00	78.75	78.75	1.00	78.75	78.75
	Total Cost of Water Supply				129.20			129.20
G.	**Net Return to Water**				**428.79**			**300.08**
	Water Delivery	m3	7709.38			7709.38		
H.	**Net Return per m3 of Water Delivery**			**0.06**			**0.04**	
	Consumptive Use	m3	4656.46			4656.46		
I.	**Net Return per m3 of Consumptive Use**			**0.09**			**0.06**	