WATER TRANSFERS IN WATER RESOURCE SYSTEMS

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ABSTRACT: Water transfers are a common component of many regional water systems, and are increasingly being considered for meeting growing water demands and for managing the impacts of drought. Water transfers can take many forms and can serve a number of different purposes in the planning and operation of water resource systems. However, to be successful, water transfers must be carefully integrated with traditional water supply augmentation and demand management measures. This integration requires increased cooperation among different water-use sectors and resolution of numerous technical and institutional issues, including impacts to third parties. This paper identifies the many forms that water transfers can take, some of the benefits they can generate, and the difficulties and constraints that must be overcome in their implementation.

INTRODUCTION

Historically, advances in water system management have been motivated by socioeconomic and environmental considerations. Since the 1970s, the increasing expense and environmental impact of developing traditional water supplies (e.g., reservoirs) have encouraged innovative use of existing facilities (e.g., conjunctive use and pumped storage schemes), and have led to expanded demand-management efforts. In recent years, growth in water demands and environmental concerns have caused even these innovations to yield "diminishing marginal returns." These economic and environmental conditions, combined with recent droughts, have spurred further efforts to improve traditional supply augmentation and demand management measures, and have motivated the recent consideration and use of water transfers. The use of water transfers in many parts of the country, especially in the West, can be seen as a natural development of the water resources profession, which is seeking to explore and implement new approaches in water management.

This paper identifies the many forms of water transfers available to water managers and their uses in the engineering of water resource systems. Some important technical and planning problems in implementing water transfers in real water resource systems are also presented. The overall intent of the paper is to provide a conceptual basis for moving the use of water transfers beyond the fundamentals provided by economists and lawyers, and toward a more engineered integration of water transfers into water resource systems. The basis for this work is an in-depth analysis of recent water transfer activity in California (Lund et al. 1992). The paper begins with brief reviews of existing examples and economic aspects of water transfers.

Existing Examples of Water Transfers

Although water transfers and water marketing are currently controversial in many parts of the country, they have existed in one form or another in many parts of the United States since early in this century. For example, many metropolitan areas have some form of water market in operation. Most of these transfers involve a single large seller, typically a large central city or utility company, selling water to numerous large and small suburban cities and water districts. The motivations for these sales arise from the economies of scale of urban water supply acquisition, conveyance, and treatment, as well as the historical legacy of central cities being the first to acquire most of the better, larger, and least expensive water supplies in many regions. Both central city and suburban parties to these transfers and sales accrue significant advantages from this arrangement, in the form of lower water supply costs, higher supply reliabilities, and greater capability and certainty in regional water supply planning. Still, there is often some degree of controversy and conflict between parties to these transfers (Lund 1988).

Water marketing and transfers within agricultural regions is an ancient practice. Maass and Anderson (1978) describe a very effective water marketing arrangement that has been in effect in one area of Spain since the 15th century. In addition, there are almost countless water trades

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and sales between farmers throughout much of the Western United States. The majority of these transactions occur within mutual irrigation companies. These companies are typically informally constituted cooperatives of farmers, with no governmental status. Each farmer has a share of the total amount of water available to the company. Water is then transferred by rental or sale of these shares to other farmers within the venture (Hartman and Seastone 1970). It has been estimated that there are roughly 9,200 such mutual water companies in the Western United States, with roughly 1,300 of them in California (Revesz and Marks 1981).

Other examples of existing water transfers are presented by MacDonnell (1990), who reviews recent transfers of water and water rights in six western states between 1975 and 1984. This review found that almost 6,000 water-right change applications were filed, primarily in Colorado, New Mexico, and Utah. The vast majority of these applications were approved by state authorities. There are untold additional cases in which transfers have been effected without legal need for State approval. For example, water transfers within the Bureau of Reclamation's Central Valley Project (CVP) generally do not require State review, since the Bureau is the holder of very general and flexible water rights. Between 1981 and 1988, CVP contractors were involved in over 1,200 short-term transfers involving over 3.7×10^9 m^3 (3,000,000 acre-ft) (Gray 1990).

Most of the transfers just described are confined to specific water sectors and to individual metropolitan areas or irrigation systems. However, more recent interest in water transfers, fueled by the economic and environmental conditions noted previously, has broadened the scope of traditional transfers to include transfers between different water use sectors, e.g., agriculture-to-urban. These transfers may involve many parties with diverse views, facilities, and water demands that are more geographically separated. They may also require the use of conveyance and storage systems controlled by parties who are neither selling nor purchasing water. The controversies and complexities of effecting water transfers under these conditions may have initially deterred water managers from pursuing this option. However, in light of the changing economic and policy environment of water management, water transfers offer engineers a new choice for enhancing the performance and flexibility of their systems (Lund et al. 1992).

Economic Theory of Water Transfers

The literature espousing the merits of water markets and voluntary water transfers is vast and well-developed (Milliman 1959; Hartman and Seastone 1970; Howe et al. 1986; Brajer et al. 1989). Although the economic theory of water transfers has been addressed extensively elsewhere, some of the more relevant issues for water managers and planners contemplating the use of water transfers are reviewed.

First, although water market transfers are often desirable, the economic efficiency of water markets is likely to be imperfect when compared to the performance of an ideal market. The conditions required for a perfectly efficient market are difficult to attain, especially for a commodity such as water. Some problems that one might encounter are as follows (Howe et al. 1986; Brajer et al. 1989)

1. Water rights are often poorly defined.
2. Water transfers can have high transaction costs.
3. Water markets will often consist of relatively few buyers and/or sellers.
4. Water is often costly to convey between willing buyers and sellers.
5. Communication between buyers and sellers may be difficult.

Yet, these difficulties are often found for other goods and services commonly provided through market mechanisms with great success. These imperfections are not so much barriers to the use of water markets as sobering aspects for engineers and policy makers to consider in their appraisals of water transfers.

Second, the transfer of water can significantly affect third parties not directly involved in the transfer. In fact, the greatest challenge for implementing water transfers in the future may lie in properly identifying the affected parties and adequately mitigating the impacts. All water use sectors can be adversely affected by water transfers. Some potential third parties to water transfers are as follows:

1. Urban

- Downstream urban uses
- Landscaping firms and employees
- Retailers of lawn and garden supplies

2. Rural

- Farm workers

- Farm service companies and employees
- Rural retailers and service providers
- Downstream farmers
- Local governments

3. Environmental

- Fish and wildlife habitat
- Those affected by potential land subsidence, overdraft, and well interference
- Those affected by potential ground water quality deterioration

4. General

- Taxpayers

The impacts can be direct, as in the case of reduced in-stream flows below the diversion point for a transfer, or secondary, as represented by the loss of farm-related jobs in an agricultural region in which farmers chose to transfer their water supplies. More detailed discussions of the third-party impacts of water transfers appear in *Water* (1992), Howe et al. (1990), and Little and Greider (1983).

Primary impacts on third parties sometimes may be reduced through legislation. For example, potential third-party effects due to changes in return flow quantity are commonly eliminated by state regulation allowing the transfer of only consumptive water use (Gray 1989). Nevertheless, difficulties in assessing consumptive use may cause impacts to users of return flows (Ellis and DuMars 1978). Likewise, the relative magnitude of secondary impacts is often difficult to determine accurately, but their presence is undeniable. Under ideal economic conditions of full employment and perfect labor and materials markets, such secondary impacts should be self-canceling in the aggregate. However, the common presence of significant unemployment, imperfect labor and capital mobility, and potentially important equity impacts have raised these secondary economic impacts of water transfers to prominence.

Paradoxically, water transfers might aid members of a group in one region while harming other members of the same group in another region. Water transfers from one farming region to another will lower farm employment and demand for farming services in the selling region and increase them in the purchasing region. Similarly, transfers of surface water from farms to cities can both help and harm fish and wildlife. By reducing application of water to farms, water quality downstream of the farm might improve, to the benefit of fish and perhaps other downstream water users. Also, there is a likely reduction in fish kills at the farm intake pumps because of the decreased withdrawals. However, although the on-farm application of water served as a habitat for migrating waterfowl, the removal of this water could be harmful to bird populations.

Several mechanisms have been suggested to ameliorate the impact of or to compensate groups harmed by water transfers. These mechanisms include (*Water* 1992; "Open" 1992)

1. Taxing transfers to compensate harmed third parties
2. Requiring transferors to provide additional water for environmental purposes
3. Using State compensation to help economic transitions in water-selling regions
4. Requiring public review and regulatory and third party approval of transfers
5. Requiring prior evaluation of third party impacts of transfers, similar to an environmental impact report
6. Requiring formal monitoring of third party impacts
7. Restricting transfers to "surplus" waters

A third important point is that water transfers can emerge from various forums: bipartisan or multilateral negotiations, several forms of brokerage and bidding, and other means (Hartman and Seastone 1970; Saleth et al. 1989). There is, of course, the potential to mix the use of different forums in the water transfer process, using one forum to set a price and quantity, with other forums performing technical and legal review of transfer proposals. The forum or institutional mechanism under which water transfers are developed, reviewed, and approved can substantially affect the number, type, and details of transfers that actually take place, and is particularly important for the consideration of third party impacts (Nunn and Ingram 1988; Little and Greider 1983).

TYPES OF WATER TRANSFER ARRANGEMENTS

Water transfers can take many forms.

1. Permanent transfers

2. Contingent transfers/dry-year options

- Long term
- Intermediate term
- Short term

3. Spot market transfers
4. Water banks
5. Transfer of reclaimed, conserved, and surplus water
6. Water wheeling or water exchanges

- Operational wheeling
- Wheeling to store water
- Trading waters of different qualities
- Seasonal wheeling
- Wheeling to meet environmental constraints

The specific needs of the purchasing and selling parties may dictate the type of transfer sought and the forum through which transfer arrangements are made. However, existing legislation and recent transfer experiences will also be important in selecting the most appropriate form of transfer. Each transfer form can have a different use in system operation, and has different advantages and disadvantages for water buyers, water sellers, and other groups (Lund et al. 1992). The various uses and associated benefits of water transfers are as follows:

1. To directly meet demand and reduce costs

- Use transferred water to meet demand, either permanently or during drought
- Use purchased water to avoid higher cost of developing new sources
- Use purchased water to avoid increasingly costly demand-management measures
- Use seasonal storage of transferred water to reduce need for peaking capacity
- Use drought-contingent transfers to reduce need for overyear storage facilities
- Wheel low-quality water for high-quality water to reduce treatment costs

2. To improve system reliability

- Directly use transferred water to avoid depletion of storage
- Use overyear storage of transferred water to maintain storage reserves
- Use drought-contingent contracts to make water available during dry years
- Use water wheeling to make water available during dry years

3. To improve water quality

- Trade low-quality water for higher quality water to reduce water quality concerns
- Purchase water to reduce agricultural runoff

4. To satisfy environmental constraints

- Purchase water to meet environmental constraints
- Use water wheeling to meet environmental constraints
- Use transferred water to avoid environmental impacts of new supply capacity

In addition, water transfers, like many forms of water source diversification, increase the flexibility of a water system's operation, particularly in responding to drought. This flexibility allows new forms of operation that could not be accomplished without transfers and, in many cases, allows modification of system operations on a rapid time-scale. The following discussion on transfer types focuses on the possible uses and associated benefits of each.

Permanent Transfers

A permanent transfer of water involves the acquisition of water rights and a change in ownership of those rights. Permanent transfers are a form of supply augmentation, and serve many of the same needs as capacity expansion projects, including direct use to meet demands and improved system reliability. In some instances, the direct use of permanently transferred water can delay the implementation of increasingly costly demand-management measures or the need for system expansion. This in turn has the advantage of avoiding, or at least delaying, potential environmental impacts associated with construction.

The majority of permanent transfers involve the purchase of agricultural water rights by urban interests. These transfers can involve reversion of the farmland to dryland agriculture, the immediate or gradual fallowing of farmland, the replacement of the farm's water supplies with an alternate supply source of possibly lower quality (from an urban use perspective), or the lease of the transferred water back to the farmer in wet years when urban supplies are plentiful. Another form of permanent water transfer, common in Arizona, is for the developer to acquire ground-water rights associated with recently developed, formerly agricultural suburban lands. Some Arizona cities have made the provision of such rights to the urban water supplier a prerequisite for annexation of new suburban developments to urban water systems (MacDonnell 1990). This ties permanent changes in water use to changes in land use, and does not require water rights to be severed from the land, which is in some cases a political and legal difficulty.

Contingent Transfers/Dry-Year Options

In many cases, potential buyers of water are less interested in acquiring permanent supplies than in increasing the reliability of their water supply system during drought, supply interruptions due to earthquake, flooding, contamination, or mechanical failure, or during periods of unusually great demand. For these cases, temporary transfers contingent on water shortages may be desirable. The appropriate time horizon and conditions for a contingent transfer agreement will depend somewhat on the particular source of unreliability that the buyer would like to eliminate. For example, the timing of the "call" mechanism for earthquake supply interruptions would likely be very different from the "call" mechanism for responding to drought. Nevertheless, drought-contingent contracts for water are probably best made with holders of senior water rights, since they are the least likely to be shorted during drought. However, the increased reliability of water from senior rights tends to raise its market value (Lund et al. 1992; *Water* 1992). An important benefit of contingent transfers is that longer term arrangements allow for more thorough analysis and mitigation of potential third party impacts.

The time horizon of contingent transfers is important. Contingent transfer agreements can be established to cover a period of several decades. This provides each party with long-term assurance of the terms and conditions of water availability. Such long-term agreements can help an urban water utility modify release rules for reservoir storage in order to maintain less drought storage than would otherwise be desired or to reduce the need for new source development. Long-term arrangements also can provide flexibility where future water demands may not meet expectations. However, long-term leasing of water does entail risk for water buyers if water demands meet or exceed current forecasts. Long-term leasing or contingent contracts allow water-right owners to retain long-term investment flexibility in anticipation of potentially greater future values for water leasing or sale of a water right.

Intermediate-term (3–10 yr) contingent transfer contracts might be employed to help reduce the susceptibility of the buyer's system to drought during periods prior to the construction or acquisition of new supplies. Short-term (1–2 yr) contingent transfer contracts might be utilized in the midst of a drought by a water agency with depleted storage, preparing for the possibility that the drought might last a year or two longer. This type of short-term contingent transfer contract would enable the buyer to have committed water supplies when their system might be extremely vulnerable.

Advantages of contingent transfers for the seller, typically agricultural interests, are the immediate infusion of cash when the contract is made, the infusion of additional revenues if the contingent transfer option is "called," and an increased ability to predict the conditions and timing of transfers, rather than relying on the vagaries of timing, price, and quantity of a water spot market.

The potential sale of water by farmers during a drought affects the need for ground-water management (if available as an alternate supply of water) and the special operation of conveyance and storage facilities. The ability of farmers to sell water might also affect the operation rule curves used by agricultural water suppliers for allocating water from storage to farmers over multiyear droughts. Perhaps additional hedging or overyear storage by agricultural water suppliers will increase farm incomes more than adherence to current reservoir operating rules, by creating a greater scarcity of water and higher water transfer incomes during drought years. Similar issues relate to the overyear use of ground-water storage.

Spot Market Transfers

Spot market transfers are short-term transfers or leases, typically agreed to and completed within a single water year. However, there is nothing to prevent formation of a "futures market" for water in which water is leased on a short-term basis for the following year. Spot market transfers are typically established by some sort of bidding process, often with some of the conditions for transfer being fixed (e.g., price, quantity). However, spot market transfers can arise from negotiations between individuals or groups or buyers and sellers. A wide variety of bargaining rules for the operation of spot markets have been examined on a theoretical basis and through the use of simulation (Saleth et al. 1991). These results illustrate the importance of bargaining rules when the numbers of buyers and sellers are small, fewer than about a dozen participants. For large spot markets, the effects of particular bargaining rules are quickly overshadowed by competition among buyers and sellers.

Spot market purchases can be advantageous in both dry and wet years. During periods of drought, short-term transfers may be sought to directly meet demands, especially demands still not met after implementation of drought water conservation and traditional supply augmentation measures. As with permanent transfers, temporary transfers used to meet demands directly can have the advantage of delaying or avoiding the costs of developing new supply sources or implementing more stringent demand-management measures.

In wet years, water purchased through a spot market can be stored in reservoirs or aquifers as overyear storage. This enhances the yield of the system during drought years by increasing the amount of stored water available upon entering a drought. Overyear storage of transferred water is particularly well suited to acquiring water from junior water rights holders. Junior water rights are typically less expensive than senior water rights, although they may only be available during relatively wet years. However, storage of transferred water during wet years may require additional surface or ground water storage capacity, and is subject to evaporative and seepage losses and any costs associated with storage. This approach may also work for within-year storage.

Water Banks

Water banks are a relatively constrained form of spot market operated by a central banker. Here, users sell water to the bank for a fixed price and buy water from the bank at a higher fixed price. The difference in prices typically goes to covering the bank's administrative and technical costs. Each user's response to the bank and involvement in the market is largely restricted to the quantity of water he or she is willing to buy or sell at the fixed price.

The California Drought Emergency Water Banks of 1991 and 1992 are examples of water banks or spot markets in which the terms and price of transfer were relatively fixed, with the State acting as a banker (*1991 Drought* 1992; Howitt et al. 1992). A similar, but smaller, water bank was established in Solano County, California (Lund et al. 1992). In agricultural regions, it is common for water banks or pools to exist within large irrigation systems. For many existing water pools, sellers avoid only the cost of purchasing unneeded water from the system. Water buyers in these pools pay the system normal wholesale water prices, plus some administrative cost (*Water* 1992; Gray 1990).

Where spot market or water bank transfers have become established, as in California, agencies of all types are likely to plan on these markets being available for either buying or selling water (Lund et al. 1992; Israel and Lund, in press). The existence of spot markets and water banks during droughts provides incentives for urban water suppliers to rely somewhat less on the more expensive forms of conventional water supply capacity expansion and urban water conservation in planning. It also may encourage different designs for new facilities and modified operation of existing facilities. For agricultural water districts, the existence of water banks and spot markets during a drought has implications for the wording of water supply contracts and the management of water and cropland during a drought.

Wheeling and Exchanges

In the electric power industry, power is often wheeled through the transmission system between power companies and electric generation plants to make power less expensive and more reliable. Water can be similarly wheeled or exchanged through water conveyance and storage facilities to improve water system performance. Again, such movements of water involve the institutional transfer of water among water users and agencies. There are a number of forms of wheeling water or water exchanges (Lund et al. 1992).

Sometimes the cost of conveying water or the losses inherent in water conveyance can be reduced by wheeling water through conveyance and storage systems controlled by others. An example would be the use of excess capacity in a parallel-lined canal owned by another agency, rather than the use of an agency's own unlined canal to convey water. Differences in pumping efficiencies might also motivate wheeling between conveyance facilities. Similar considerations might apply to decisions on where to store water during a drought, when different reservoirs have different seepage or evaporation rates (Kelly 1986), or if the distribution of hydropower heads is considerable for different storage options.

Seasonal wheeling of water is common in agricultural regions in which different subareas have complementary demands for water over time. This can provide opportunities for one water user to exchange water with another user during the former's low-demand season, with repayment coming in the form of additional water during the user's high-demand season.

Also, by paying farmers not to use their rights to water, the foregone consumptive use becomes available for instream demands downstream. This mechanism is particularly applicable to riparian rights, which cannot be legally transferred for use away from the riparian lands (Lund et al. 1992). Another application of wheeling to meet environmental constraints could involve the use of storage facilities to release water for instream flows when desired, while meeting demands before this time from other reservoirs or ground water.

In many cases, historical happenstance has left agricultural users with rights to high-quality water for irrigation while new urban development is left with remaining water sources of lesser quality. In such cases, the additional costs of treating low-quality water for urban use is usually much greater than the costs of slightly lower crop yields from use of the lower quality water. Given reasonable conveyance costs, it therefore becomes desirable for water-quality based trades between agricultural and urban users. Urban users can often afford to make these trades on an uneven basis, trading more low-quality water for less high-quality water or providing a monetary inducement for a volumetrically even trade of water. Lesser-quality waters might also be traded for environmental uses of aquifer recharge or habitat maintenance (Lund et al. 1992).

Transfer of Reclaimed, Conserved, and Surplus Water

Although not always recognized as such, the purchase of water made available by reclamation or reductions in water demand is a form of water transfer. Numerous urban water utilities have become involved in purchasing water back from their retail customers. Such schemes usually involve rebates to customers for installing low-flow toilets or removing relatively water-intensive forms of landscaping (*Landscape* 1988). Some cities have developed clever schemes in which water transfers are made within their customer base. For instance, Morro Bay, California has a program whereby developers can receive water utility hook-up permits if they cause a more than equivalent reduction in existing water demand through plumbing retrofits, landscaping, or other measures (Laurent 1992).

Urban areas have taken an interest in financing the conservation of irrigation water to make additional water available for urban supplies. This has primarily been accomplished through the lining of irrigation canals. For example, the transfer of water between the Imperial Irrigation District (IID) and the Metropolitan Water District of Southern California (MWD) involves a 35-yr contract for MWD payments for canal lining and other system improvements in IID's irrigation infrastructure, in exchange for the water saved by these improvements. The savings are estimated at 123.3×10^6 m^3/yr (100,000 acre-ft/yr) from IID's Colorado River water supplies (Gray 1990; Sergent 1990). This approach can have additional benefits where agricultural seepage and drainage water has led to water quality problems or high water tables, but can create additional problems where canal seepage is used to recharge ground water.

IMPLEMENTING WATER TRANSFERS

Perhaps the most important implication of water transfer planning is the need to increase integration and cooperation among diverse water users. For economic reasons, most water for water transfers will probably come from agricultural users, and much of this water will go to urban and perhaps environmental users; therefore, any planning for water transfers implicitly integrates urban, agricultural, and environmental water supplies. As the tendency to seek and implement water transfers continues, it will become less possible, and less desirable, for individual urban or agricultural water districts or regions to plan and operate their water supplies independently. This necessary coordination of planning and operations between functionally diverse water agencies will imply potentially protracted, and probably controversial, negotiations, at least for long-term transfer arrangements.

Additionally, if intersectoral and interregional water transfers are to become significant long-term components of water resources planning, they must be integrated with traditional water supply augmentation and demand-management measures. Given the complex nature of many water resource systems and the wide variety of different possible water transfer designs, it seems apparent that some form of water-supply-system computer modeling will be required to achieve this integration of water transfers with other water management measures.

Most major water supply agencies already possess significant conventional water modeling capability. However, most models are specific to individual water systems, in accordance with the needs of traditional water supply and water conservation measures that can be implemented by a single system. The integration of water transfers will likely require significant modifications to these single-system models to allow explicit examination of long- and short-term water transfers and exchanges. Water transfers also encourage more explicit consideration of the economic nature of water supply operations in system modeling. System models that examine water transfer options as well as supply source and water conservation expansions and modifications might usefully provide economic measures of performance (component and net costs) in addition to traditional technical measures of performance (e.g., yields and shortages). Various agencies and academic researchers have already begun such efforts (Lund and Israel, 1995; Smith and Marin 1993).

The economic nature of the design of water transfers and their integration with other water-supply-management measures encourages the use of optimization models, in which the model itself suggests promising combinations of water transfers, construction, and water conservation. Although technically more difficult and still somewhat inexact, optimization modeling can aid in identifying promising solutions, which can then be examined in more detail with simulation models. Performance of economically-based optimization (or simulation) of water resource systems with water transfers requires technical studies estimating the value of and the willingness-to-pay for different water uses and different water quantities.

During California's 1987–1992 drought, in which water transfers were actively pursued and implemented, both traditional supply infrastructure and demand-management strategies continued to have important, albeit modified roles in water management (Israel and Lund, 1995). Some hints of how the integration will fare, and several specific areas of concern for implementing water transfers, are discussed.

Legal Transferability of Water

The legal transferability of water is a major consideration in designing water transfers. Legislation pertaining to the transferability of water will vary between states, and can vary over time within a given state as the state's water law evolves. California has strong statutory directives to promote water transfers (Gray 1989; Sergent 1990), yet legal constraints still pose a significant threat to water transfer activity. Legal considerations are particularly important when a proposed transfer involves changes in conditions stipulated by the original water right, such as changes in type of use, place of use, or timing of withdrawals. The type of water right to be transferred is also an important consideration. Riparian rights, for instance, are generally nontransferable from their initial location of use, and the transferability of ground water rights varies substantially by state.

Also, different types of water contracts impose different transferability requirements. In California, many water contracts stipulate that any water not used by the contractor reverts to the contractee, while others may stipulate that water cannot be transferred outside of a district and can only be transferred within a district at cost. These types of provisions reduce the ability and incentive of contractors to sell surplus or conserved water (Sergent 1990; Gray 1989).

Short-term, emergency water transfer may be able to gain relatively easy approval and rapid implementation, given sufficient flexibility in the conveyance and storage system and sufficient professional flexibility and readiness on the part of water managers. Legislation often exists that reduces or eliminates barriers to transfers during drought or other emergency conditions. This was certainly the case for the 1991 and 1992 California Drought Emergency Water Banks (*1991 Drought* 1992). On the other hand, long-term, planned transfers, such as dry-year option contracts and permanent water transfers, typically face more difficult legal and economic constraints. Many of the longer-term transfers that require the storage of surplus water during wet years also involve complex legal issues (Getches 1990), particularly for ground water storage (Kletzing 1988). The costs, delays, and risks involved in overcoming these constraints can induce agencies not to consider or participate in water transfers.

Real versus Paper Water

Where water transfers are motivated by real water shortages, the transfer of water by contract must correspond closely with the transfer of water in the field. This is sometimes known as the distinction between real and paper water. Associating quantities of paper water to real water is a difficult technical problem. In the case of transfers from farms, farmers typically do not know with certainty how much water they use or how much real water would become available if land were to be fallowed or cropping patterns altered (Ellis and DuMars 1978). Even where such flow measurements are made, they are often inexact.

As water moves through a complex conveyance and storage system, there are seepage and evaporation losses, withdrawals by or return flows from other users, and natural accretions downstream. All these factors complicate the estimation of how much water is physically available to the receiver of a water transfer, given that the sender has relinquished use of a given amount. Another problem with linking paper water to real water is establishing the hydrologic independence or interdependence of water sources. This is a common problem where pumped ground water may induce recharge from nearby surface water.

Particularly where there are many potential buyers and sellers of water, there would seem to be some need for standards or governmental involvement in tying real water to paper water transfers (Blomquist 1992). Without such standard accounting, amounts of paper water are likely to exceed amounts of wet water available, leading to excessive withdrawals by water users to the detriment of downstream users and those not party to transfers. This will be true for transfers of water for both consumptive and instream uses. Litigation and calls for greater regulation of water transfers would be the likely result.

Conveyance, Storage, and Treatment

The mere purchase of water is usually insufficient to effect a water transfer. Transferred water must typically be conveyed and pumped to a new location, often stored, and commonly treated. Since both emergency short-term transfers and long-term transfers may require modifying the operation of existing water infrastructure, considerable work may be required in order to coordinate the use of conveyance, storage, and treatment systems. This can be particularly challenging because these facilities are often designed for very different operations. Occasionally, canals must be run backwards, water must flow backwards through pumps, and treatment plants must treat waters of a quality different from their design specifications. Construction of additional conveyance interties or other facilities may be required in some cases.

The difficulties encountered by San Francisco illustrate well the traditional engineering limitations and concerns with the use of water transfers in system operations and planning (Lougee 1991; Lund et al. 1992). San Francisco purchased 50,000 acre-ft from the 1991 California Drought Water Bank, but their water treatment plant was unable to accept more than a limited rate of transferred water from the Sacramento–San Joaquin Delta. Delta water is of lower quality than San Francisco's normal Sierra supply, and the mixing of waters in the treatment plant beyond certain ratios increased the likelihood of trihalomethane formation. This limitation forced much of the transferred water to be stored in State-owned facilities and slowly released into San Francisco's treatment plant. California's East Bay Municipal Utility District (EBMUD) faced similar quality limitations on the treatability of transferred water, which, combined with other difficulties in effecting transfer, led EBMUD not to use transferred water and to rely more on urban water conservation measures.

Water transfers are likely to be more successful in regions with an extensive system of conveyance and storage facilities and well-coordinated operations. Locations with restricted conveyance and storage infrastructure are likely to have limited potential for effecting water transfers unless creative operations or new conveyance and storage facilities can be developed. The coordination and physical completion of water transfers will be more difficult, and perhaps impossible, if agencies controlling major components of a region's water conveyance and storage system choose not to participate in transfers, are legally restrained from participating, or participate only in a limited way.

Contracts and Agreements

The legal transfer of water is typically effected by contracts that must specify a number of logistical and financial conditions of the transaction. Among the logistical and fiscal details that must be specified are: (1) The location and timing of water pick-up from the seller; (2) the fixed or variable price of the water; (3) the fixed or variable quantity of water; and potentially (4) the quality of the water. The responsibilities for contract execution and liabilities for failure to completely execute the contract might also be included.

In situations where transferred water cannot be conveyed directly between the buyer and seller, agreements with other entities are often required, either to make use of their conveyance facilities (pumps or aqueducts) or to coordinate the conveyance of transferred water through natural waterways, within environmental limitations (Lougee 1991). Similarly, facilities owned or operated by entities not directly involved in the transfer may be necessary in order to store transferred water until it can be used. This will often require agreements or contracts for the storage of water with agencies that oversee storage facilities. When water is stored in aquifers, recharge and pumping facilities will be required, and legal arrangements with overlying landowners are common (Kletzing 1988). Likewise, contractual arrangement may be required for the treatment of transferred water.

Price, Transaction Costs, and Risks

As demonstrated by the 1991 and 1992 California Drought Water Banks, both sellers and buyers can be quite sensitive to the price established for water (Lund et al. 1992). At lower prices, there are fewer willing sellers and greater demand for water from agricultural users. Higher prices encourage sellers but tend to exclude most potential agricultural buyers. The price set by the market, through negotiations, or by a governmental water bank has important implications for the character and number of resulting transfers.

The cost of water to a user includes more than its purchase price. As noted previously, much of the work in establishing successful transfers of water lies in arranging for the conveyance, storage, and perhaps treatment of the transferred water. In some cases, the costs of these activities may exceed the cost of the water itself. For example, in 1991 San Francisco purchased 18.5×10^6 m^3 (15,000 acre-ft) from Placer County at a price of \$36 per 1,000 m^3 (\$45/acre-ft). However, total costs including wheeling charges through state and federal facilities and storage costs were between \$203 and \$284 per 1,000 m^3 (\$250–\$350/acre-ft). Also, the final delivery cost of water purchased by San Francisco from the Water Bank was nearly double the purchase price of \$142 per 1,000 m^3 (\$175/acre-ft).

Water transfers are also subject to numerous other transaction costs, including legal fees, costs of public agency review, costs of required technical studies, and costs involved in settling claims from third parties. MacDonnell's survey (1990) found that transaction costs averaged several hundred dollars per acre-ft of transferred perpetual water right, with averages of \$308 per 1,000 m^3 (\$380/acre-ft) of perpetual right in Colorado and \$149 per 1,000 m^3 (\$184/acre-ft) in New Mexico. These transaction costs can add substantially to the purchase price of water, which in Colorado and New Mexico ranges from \$243 to \$1,216 per 1,000 m^3 (\$300 to \$1,500 per acre-ft). The unit costs for transactions commonly decrease for larger transfers and increase with the controversy of a transfer. Still, transaction costs are highly variable between transfers.

The risk of a transfer not being completed may also dissuade potential partners in transfers. The risk of a proposed transfer being stopped entirely is particularly palpable where a substantial part of the transaction costs must be expended before a transfer agreement is finally approved, or if there are high costs to delaying implementation of other water supply alternatives while transfers are being negotiated. This would be the case where large expenditures for technical and legal work must be made before final approval of a transfer is in place (Lund 1993).

Evaluation of Impacts to Third Parties

Evaluating the third-party impacts of water transfers can be formidable and inexact, involving difficult ecological and economic studies (*Water* 1992). There is currently little technical work quantifying physical, environmental, economic, and social impacts from water transfers (Howe et al. 1990; *California* 1993). Less is known about how these impacts would vary with different specific transfer cases and mechanisms, and how effective different approaches to mitigating third party impacts might be.

Some of the technical issues in managing third party impacts are illustrated by the case of Yolo County, California. Farms in Yolo County contributed about 185×10^6 m^3 (150,000 acre-ft) of water to the 1991 California Drought Water Bank. Some of this water came from fallowing farmland and transferring the surface water rights. However, most of the surface water was replaced by increased ground water pumping. Yet the county does not employ a water engineer or ground water specialist dedicated to county-wide water supply problems who could assess and manage the long-term impacts of these transfers (Jenkins 1992). There is also little legal authority for counties to assume this role. Furthermore, rural county governments may lack the expertise needed to estimate the economic impacts of different types of transfers. Without an understanding of the economic and physical effects of water transfers, water-exporting regions are likely to be suspicious of and somewhat resistant to water transfers.

This same lack of a technical basis for assessing and managing impacts of water transfers takes on a more important role at the state-wide level, where water transfer policies are made. Technical studies are needed to support policies, and perhaps specific cases should be investigated of when and how water transfers are made and how any third party impacts should be managed (Howitt et al. 1992).

ROLES FOR GOVERNMENT IN WATER TRANSFERS

The role of state and federal government is so important in many cases that it must be considered part of the system engineering. In California, for instance, a significant part of state and federal involvement in water transfers is due to the technical role required by their ownership and operation of major conveyance and storage facilities and their requirements and responsibilities under various environmental regulations.

A number of roles for federal, state, and local governments can be identified for facilitating water transfers, some of which may require modification of existing regulations, legislation, and local agency enabling legislation. Perhaps the most appropriate role for government in water transfers is that of an arbiter of technical and third party disputes and a regulator of the market. This role is needed to ensure a close tie between trades of paper water and real water and the coordination of the movement of transferred water with environmental regulations (Blomquist 1992). State or regional governments would also seem to have a useful role in the collection and analysis of data for monitoring and resolving external and third party impacts. Regional governments can also act as bankers in the formation of regional water markets, taking advantage of the regional hierarchy of governmental water jurisdictions commonly found in water management.

Government involvement can improve the prospects for water transfers by

1. Improving information regarding transfers and transfer impacts
2. Establishing a process for managing third party impacts
3. Reducing the transaction costs of arranging and implementing water transfers

4. Increasing the probability that efforts between parties to arrange a water transfer will be successful, and reducing the risks to parties from involvement with transfers

Individual agencies have their own agendas and will continue to pursue short- and long-term contracts regardless of the existence of government-sponsored water banks. However, government involvement can greatly accelerate the development of water transfer agreements by initial sponsorship of transfers through the establishment of water banks or by other means. The development of transfers as part of a larger water resource system is likely to continue after government sponsorship of water banks has ended.

CONCLUSIONS

Water transfers have far-reaching implications for water resource planning and management. In addition to contributing to the "bag of tricks" available to water managers, transfers require a broader conceptualization of water-management problems. Unlike traditional supply augmentation and demand-management measures, which can be typically accomplished by a single water agency, water transfers require coordinated planning and operations between both groups party to the transfer. Also, water transfers often require the use of storage and conveyance facilities belonging to or operated by entities not directly involved in the buying or selling of water. The evaluation of transfers demands a more explicit economic perspective on the purposes of water resource systems and more detailed economic measures of operation performance. The water acquired by transfers can serve a variety of operational, environmental, and economic purposes. Overall, the multiple forms of water transfers and their flexibility, combined with legal, third party, and technical issues in implementing transfers, make water transfers one of the more promising, yet complex, techniques for improving water management.

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