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Water Use and Value

We can distinguish between several benefits that may be provided by water resources.

First, we should distinguish between consumptive use which includes, agricultural and industrial uses and non-consumptive uses. For example, in stream benefits associated with kayaking, fishing, and hydroelectric generation are non-consumptive uses of water. Water provides environmental benefits with some are consumptive as water feeds trees and supports wildlife. But mostly environmental benefits are non-consumptive uses. Some individuals may value the existence of bodies of water, say lakes or rivers, even though they don't necessarily visit or utilize them. But this existence value may motivate support for policies regarding water restoration and water resource conservation.

The value of water depends on the use of the water, the location, the time, and the quality of the water. For example, during drought periods water may cost twenty times more than during wet years. In the same region you may have years where the price of water is zero, or even negative because of flooding, while in other years the price is extremely high because of drought.

The value of water can be modified through projects that include storage facilities and conveyance facilities and through water management strategies.

Water Around the World/Virtual Water

There is significant dis-equality in the distribution of water across locations. Annual water availability in Canada, for example, is more than 5,000 M³, while annual water availability in Jordan is approximately 70 M³ per person. One approach to compare water situations across locations is to establish a certain minimum level of water per capita and consider locations with less water per capita to have water shortages. The determination of this minimum water level is according to the amount needed to produce food for an individual, as well as the amount needed for personal and per capita and industrial use. Some of the United Nations organizations consider 1,000 M³ to be the minimum requirement per capita, and using this measure, many parts of the world have water shortages.

But, regions can survive and prosper with less than this minimal amount of water per capita if they are importing low value water consuming crops and exporting high value crops. By importing food you actually import virtual water, namely the water content that was needed to produce the food. To some extent, water shortage is not so much a physical problem but an economic problem. If a region can export its food it can overcome the shortage problem. Furthermore, in regions that border seas and oceans, one can produce any amount of water through desalinization, and in this case, again, water scarcity is really an economic problem.

Water Rights Systems

It's useful to distinguish between surface and ground water. Surface waters include lakes, rivers, etc. The allocation of water among users in many regions is according to systems of water rights.

In many regions, water allocation has been based on **queuing systems** rather than on markets. Queuing systems are sets of laws defining property rights regarding who has priority to use water, when water may be used, how water may be used, and how much water may be used. Although **queuing systems** are still the norm throughout the world, and are going through change. A typical queuing system is a use-it-or-lose-it system of water property rights based on the principle "first come first serve."

Queuing systems were established to encourage settlement of land and development of water resources. In early periods water was abundant, governments were poor and they wanted to encourage people to develop water resources so they gave individuals a right to the water that they divert, as long as they use it. Note, markets are the best allocation mechanisms when there is scarcity, but queuing can be very effective when scarcity doesn't exist. The

biggest problem of water systems demands increase and suddenly scarcity emerges and in this situation water reforms are needed.

Queuing systems are not efficient because they do not allocate water across users in such a way as to balance the marginal benefits and marginal costs of water use. Although it appears that a slow move toward market-oriented mechanisms is occurring, queuing systems are still the norm. We next discuss two queuing systems commonly found around the world.

Riparian Water Rights (Developed in England)

Areas adjacent to rivers, streams, and lakes are called riparian areas. Under common law, ownership of riparian land entitles the landowner to the use of the adjacent water on an "equal" standing with other riparian landowners. Each riparian landowner has the right to "reasonable use" of the water. A riparian landowner does not lose their riparian water right if they do not use the water.

Under a system of Riparian Rights, individuals upstream hold rights to a "reasonable use" of water before individuals downstream receive rights. Priority of water use is thus not established among riparian users. Since water rights are not based on any economic criteria, the water does not "flow to the highest valued user."

Under Riparian Water Rights, the **common property problem** may arise. This common property problem can lead to inefficiencies.

Another source of inefficiency arises from the fact that, under Riparian Water Rights, water may not be diverted from the water body for use outside the watershed. The watershed of a lake, river or stream is defined as the area of land contributing water to the lake, river or stream. Hence, Riparian Water Rights **cannot be traded freely**. If trade cannot occur, inefficiencies can arise.

For example, suppose agricultural land within a watershed is poor and land just outside the watershed is rich. Suppose:

- Farmer A owns the land within the watershed and
- Farmer B owns the land outside the watershed.

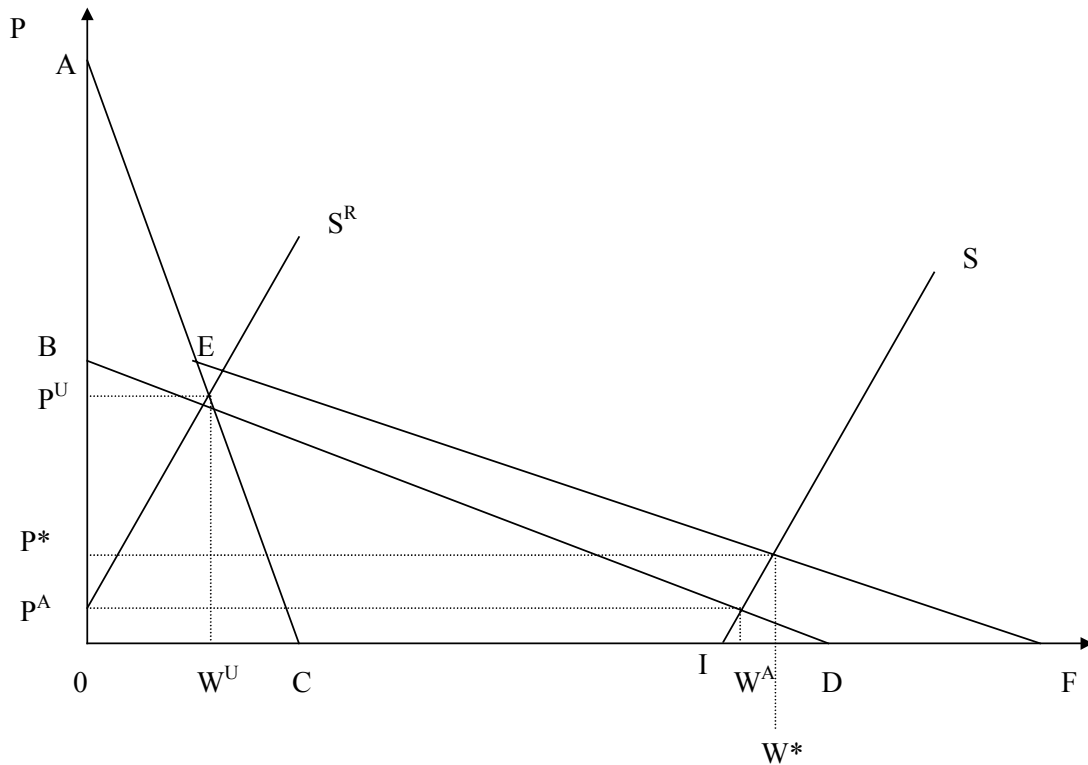
In this case, it might be efficient for Farmer A to sell water to Farmer B, since water would have a higher value (produce more crops) when used on the better quality land. This type of trade would not be allowed under Riparian Water Rights. Also, under Riparian Water Rights, senior owners (at the upper end of the watershed) are given rights before junior owners (at the lower end of the watershed). Water trading may be welfare enhancing between senior owners and junior owners as well.

Prior Appropriation Water Rights

Under prior appropriation water rights law, the right to use water is acquired by discovering or "possessing" the water. In contrast to a riparian water right, a prior appropriation water right is "absolute," the owner of the prior appropriation water right does not share the right with anyone else. Also in contrast to a riparian water right, a prior appropriation water right may be lost if the owner of the right does not put the water to beneficial use. Although the prior appropriation approach formally assigns water rights, because poor records were kept when water was being discovered many years ago, there are often legal battles over who actually owns the rights. As is the case under riparian water rights, under prior appropriation rights water trading is also often prohibited. Hence, water may not be allocated to its highest valued uses and economic inefficiencies may arise.

Example of Prior Appropriation Water Rights and Inefficiency

In California, many agricultural users hold prior appropriation water rights. Thus, they have priority use of the water supply. As the urban population in California has grown, the urban demand for water has grown, and it would be efficient to reallocate some water from agricultural uses to urban uses. Because water trading is not allowed, this reallocation cannot occur and the market for water is not efficient. We can analyze this situation with the figure on the next page.



(a) Water supply projects (dams, canals, etc.) have high initial fixed costs associated with construction and low marginal costs of supplying water up to the capacity of the project, at which point the marginal cost of water supply rises steeply because additional projects would be required in order to supply additional water. Thus, we get marginal cost of water supply curve OIS .

(b) Assume that agricultural water demand is given by curve BD .

(c) Assume that urban water demand is given by curve AC .

(d) Aggregate demand for water is given by curve AEF , if water markets exist. Under water markets, the equilibrium level of water consumed is W^* and the equilibrium price is P^* .

(e) Prior appropriation rights allocate water to different users at different times. Demand is not aggregated, but discriminated by time in the residual demand curves BD and AC . Agricultural users are senior rights holders and purchase water first. They purchase an amount of water equal to W^A , which is where agricultural water demand equals the marginal cost of water. The price of water in agricultural uses is P^A .

(f) Once the W^A units of water have been consumed by agricultural users, urban users face residual water supply S^R , and therefore consume W^U units of water and pay a price of P^U . The price of water in urban areas is higher than in agricultural regions.

Because the agricultural and urban prices are unequal, the marginal benefits are unequal. Since the marginal cost to supply each type of user is essentially the same, social welfare may be increased by reallocating water from agricultural users to urban users. Thus, the current situation is inefficient. Under Prior Appropriation Rights, water cannot be traded between agricultural and urban users, which ensures that this inefficiency persists. Social welfare could be improved by establishing a market system. Allowing water to be freely traded would lead to water transfers from agricultural areas to urban areas.

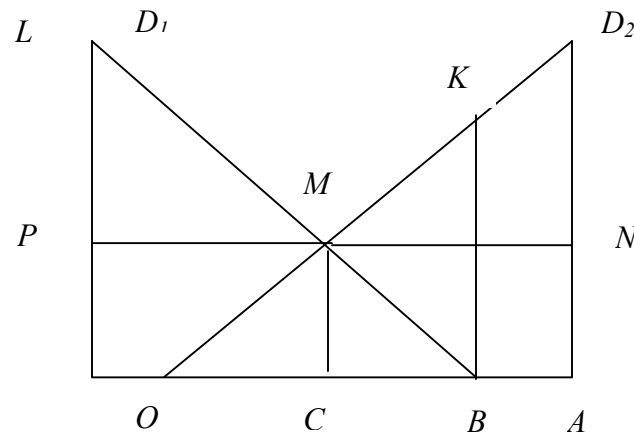
Notice also that the total level of water consumed is inefficiently high under a system of Prior Appropriation water rights, $W^A + W^U > W^*$. Thus, moving to a market oriented system of water allocation can lead to greater water conservation. A major goal of water reform is to make water transfers legal and to lower the transaction costs associated with water transfers.

Transitions from Water Rights to Water Markets

As water scarcity increases there is a tendency to introduce water reform that allows trading in water. In many cases, for example California, water trading was introduced during drought periods. The transition from queuing to market may involve redesign of the water allocation system, building a system for the monitoring of water use, and protection against theft, and all this entails high transaction costs. If the gains from transition are smaller than the transaction costs, reform will not occur. In some cases, the reform may require moving water ownership from the farmers with senior rights to the state. In this case all the users will have to pay for the water. Such reform will encounter objection as senior rights owners will have to pay a higher price. Therefore, an alternative design is to introduce transferable rights and to enable individuals to sell their water rights.

This system of transferable rights will make senior rights holders better off. To illustrate this point let D_1 be demand of senior rights holder, let D_2 be demand of junior rights owners, and total water to be given by OA . If conveyance cost is 0, then senior rights owners are using OB and junior rights owners are using BA . Introduction of water markets will result in the price of P , with senior rights owners using OC and junior rights owners using CA . If the senior rights owner has to pay for the water their economic surplus is given by LMD . But if there is a regime of transferable rights the economic surplus is given by $LMNAO$. This area is greater than the area LBO , which was the welfare of the senior rights owners under the prior appropriation system.

The overall welfare gain associated with transition to the market is equal to the area MKB and society will benefit from the reform if this area is greater than the transaction costs.



Third Party Effects and Trading in Water

Some of the applied water in agriculture is not used by the crop but rather ends up as deep percolating water or run-off. This water is then re-used for agricultural, environmental, and in many cases, municipal purposes. Introduction of trading in water that would transfer water away from a region will prevent the third party to benefit from the residual water. Therefore, in many regions where individuals who transfer water are restricted to sell the amount of water that is actually consumed by their activities. For example, if a farmer has 75% water use efficiency, he can sell 75% of the water.

Trading in water has many forms. In some cases, transferable rights implies that farmers can allocate their water to others one season at a time. This is really water rental. In other cases, farmers can sell some of their water rights permanently, but only within a basin. Many regions limit, or bar, inter-regional transfers. Chile is one country where transfer between basins is allowed. This enabled the building of high value agriculture in dry areas, but at an environmental cost to the original area.

In many cases, where water trading is not allowed, but water rights are attached to land, people will obtain water by buying land. In the past many water transfers were feasible because the environmental effects were not considered. At the present, some reasonable transfers may not occur because of high transaction costs associated with environmental regulation. We are challenged to develop reasonable methods to assess possible water transfers for the overall effects to determine when they are socially desirable.

Water Allocation over Space

Water is being moved from its source region to a destination where it's being used. Sometimes conveyances are done by a river and in other cases through a canal. Generally, upstream producers may have the power to control water flow and determine the water use by downstream users. When canals are constructed, upstream users do not take into account the need to transfer water downstream and may under invest against conveyance losses. Therefore, management of water over space requires intervention that will improve the situation of downstream users. Canals have to be constructed to take into account the interest of all users. Of course, both the dimension and the quality may decline further away from the source. Moreover, water prices have to take into account locational differences and downstream producers have to pay higher water prices that take into account higher transfer costs (both in terms of energy and construction).

Thus, there are two sources of efficiency in water systems. In some cases, the interests of downstream users are under-represented and canals are under-built and the conveyance losses are high. In other cases, decision makers may impose uniform pricing of water, regardless of location, and that may result in excessive water use downstream. Effective spatial pricing of water may increase efficiency significantly and increase productivity of water.

Collective Action in Water Districts

Water management is a regional problem. Most water users are too small to invest water projects and water diversion facilities. Negotiations with government agencies are quite time consuming and expensive and therefore, there is a gain from collective action. Finally, effective management of water over space requires regional management.

Water Districts (or water user associations) were established to construct water projects, to represent water users, to purchase water, and to allocate it among users. These organizations have the power to tax users and constantly monitor the water system (to protect against theft). Of course, the actual action of water districts varies according to voting rule (in some cases, one user is one vote and in other cases one acre is one vote). In the latter case, big farmers may dominate the policies of the district.

Most districts manage agricultural and municipal water use. But, in some cases there are districts that are also engaged in the management of recreational activities, for example, a lake or a fishing pond. In some regions where there is a water logging problem, namely where deep percolating water hits a barrier and starts rising, which may lead to salinization, there is a need to establish drainage facilities to protect productive capacity of the land. In this case water districts are

involved in construction and management of drainage facilities, in some cases, there are regional agencies that are solely concerned with drainage or flood management. In the case of floods they obtain and maintain reserve lands for buffering floods and in some cases construct and maintain dams.

Water Projects

Water resources have reconstructed through a wider array of water projects that includes dams, canals, artificial lakes, etc. Projects come in all forms. There are many irrigation projects, hydroelectric projects, flood control projects, and recreational and environmental projects. Benefit-cost analysis is a technique that was designed to assess water projects. It compares the expected discounted benefits of the project with the expected discounted cost. When net benefits are positive the project should be built.

Many projects have been built in the past without the use of benefit-cost analysis, or when the benefit cost ratio was smaller than one. Because water projects are determined politically, and when the gainers are not paying fully for the project they may use political power to obtain a project. The requirement to use benefit-cost analysis before a project is approved, has prevented many projects from being executed. Nevertheless, benefit cost analysis can be misused. Some of the issues associated with benefit-cost analysis:

- Finding the right interest rate. When a high interest rate is being used, future benefits are discounted heavily and projects with high initial investment and delayed benefits are less likely to be built.
- Accounting for environmental benefit and cost. In some cases, some of the non-market environmental benefits of a project are being taken into account, while the non-market costs are ignored. This is wrong; all non-market impacts have to be monetized and considered.
- There is a tendency to emphasize structural solution in project design. In many cases it may be useful to consider non-structural solutions, mainly use incentives to address a problems. For example, instead of building bigger canals to dispose waste that contaminates bodies of water, policy makers could use anti-pollution tax to reduce the generation of waste.

Ground Water as a Common Resource

Ground water has been used for irrigation and other activities throughout the world. To a large extent the Green Revolution in India was facilitated by ground water irrigation. In some cases, aquifers are removable resources and the amount found is replenished by rainfall but in many regions there is over pumping and ground water is depleted.

Ground water requires investment in pumping and pumping costs increases the deeper the ground water. When ground water resources are being depleted,

irrigation may stop or reduce as the depths to the aquifer is increasing because of the higher pumping costs. One reason for over pumping is that irrigators may share the same aquifer and as a result "tragedy of a commons" occurs in a sense, in that none of the irrigators take fully into account the costs for future periods associated with current pumping. Therefore, there is a need for social intervention and regulation of pumping through taxation, or restriction of quantity pumped. In India, in addition to the lack of regional control of aquifers, energy for pumping is subsidized and that provides an extra incentive for over pumping.

Over pumping is not the only important policy issue of groundwater management. Pumping is capital intensive and may not be affordable for individual farmers. In some regions farmers establish collective action to collectively pay for pumping a well. In other areas, entrepreneurs may pump wells and may use their monopoly power to overcharge farmers. This calls for intervention that has a flavor of antitrust activity.

Conjunctive use of Ground and Surface Water

Because of variation of precipitation a key element of water policy is the build up of storage. Generally, water accumulates in wet years and storage is depleted during dry years. In some cases, ground water aquifers are used for storage. During wet years farmers may use surface water and sometimes even divert surface water to fill the aquifers and in dry years they will pump.

Availability of storage is especially important when long term investment in water consuming activities, for example, perennial crops is desirable. The value of stored water is increasing as the likelihood of dry periods is increasing and as the value of incremental water during dry periods is increasing.

Irrigation

Up to 80% of the water is used for irrigation in many regions. Water use for irrigation varies by crop and innovation technologies. Irrigation efficiency defines as a percentage of water consumed by crops varies according to technology and land quality. Traditional technologies are gravitational and have irrigation efficiency of .9 in heavy leveled soil and may be .1 in steep hills or sandy soil. Modern irrigation technologies such as drip and sprinkler require investment but increased water use efficiency. For example in California typical water use efficiency is .6 with traditional technologies and increases to .85 with sprinkler and .95 with drip. Adoption of modern technologies tends to increase yield per acre and reduced water use per acre but that has to be compared to the extra cost.

Introduction of water markets or trading is likely to increase adoption of modern technologies as opportunity costs of water increases. Adoption of modern technologies can be encouraged by subsidies, as well as water taxes

One advantage of modern technologies is that they generate less residue and thus contribute less to the drainage problem. In regions with water logging problems policy makers may use incentives of various kinds to encourage adoption and reduce water logging.

Water Quality

There is a wide array of water quality. Some are caused by soil erosion associated with farming, others with the disposal of pollution that may include, sewage, residue chemicals, etc. In regards to water quality problems it is important to distinguish between point and non-point source problems. Point source problems are dealt with by taxes or subsidies based on observed pollution levels. Non-source problems may be dealt with by collective punishment or regulations of activities that are correlated with the pollution.

In many developing countries the major water quality problems are major public health problems and build up of sewage is a key solution to improved water quality and improved health. Sewage has to deal with industrial, residential, and agricultural waste. The last problem is especially difficult and in most cases the optimal solution is to reuse animal waste as fertilizer. However, intensive use of fertilizer may lead to increased nitrate concentration in the water. Governments are experimenting with a wide array of regulations and incentives that reduce application of chemicals close to bodies of water to improve water quality.

One major issue is a measurement of water quality. While chemical concentration measures are effective in describing the content of water we may need to measures that are related to the use of the water. Water that is used for fisheries is of a high quality if the appropriate temperature needed is kept to sustain the fish population. In this case, the measurement of quality is by indicators of population or representative species survival.

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