Chapter #16: Surface Water Economics

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<u>Economic Characteristics of Water</u>

Recall that economics is concerned with the allocation of scarce resources. Although water may seem relatively abundant from a global perspective, in some geographic locations water is quite scarce. Furthermore, in most areas, water of the appropriate quality is scarce. We can see that two important characteristics of water as an economic good are *Location and Quality.* Thus, society undertakes many large-scale and expensive investment projects in the attempt to exert control over the location and/or quality of water.

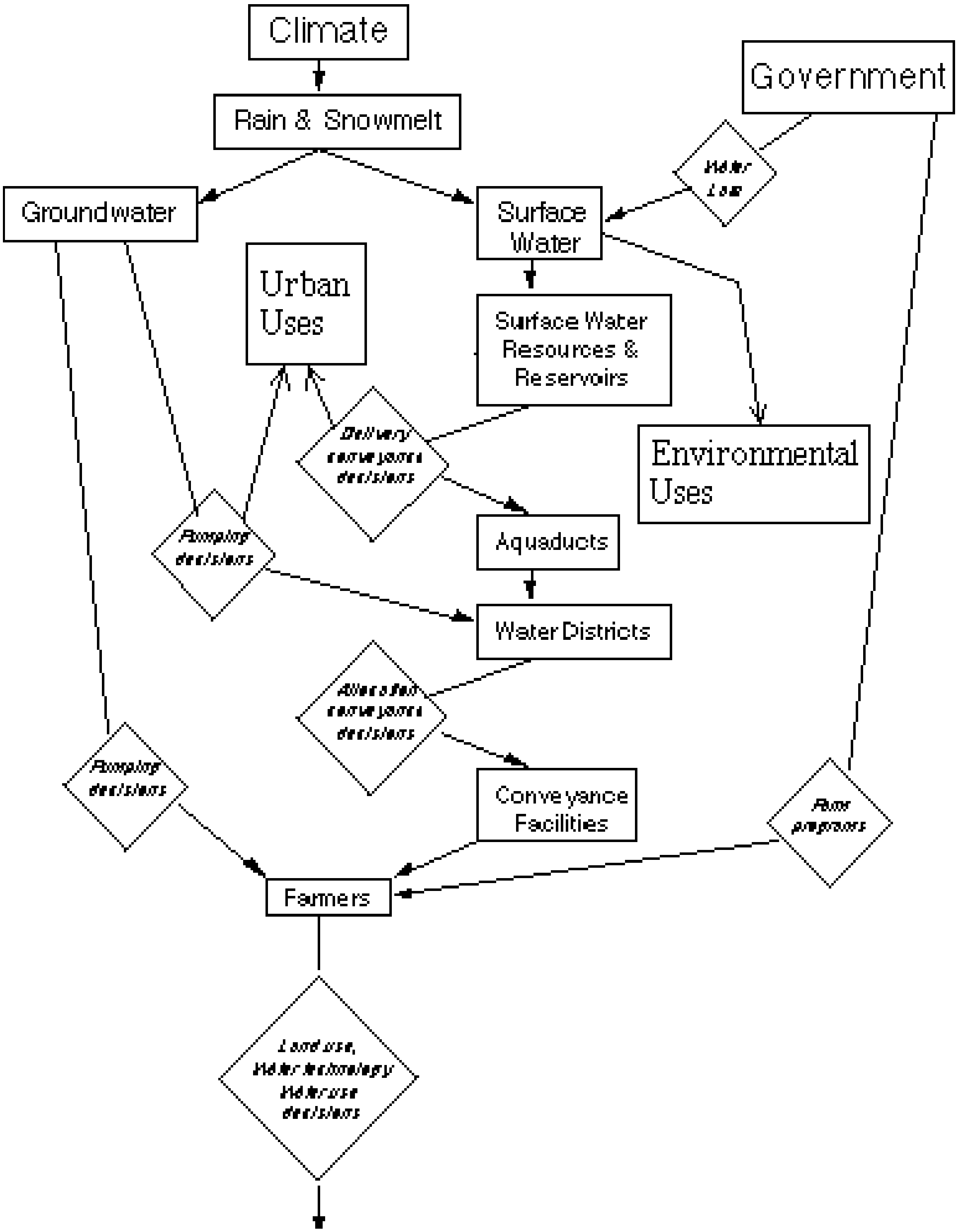
Examples of Surface Water Systems

Reservoirs and Dams
Rivers and Lakes
Drinking Water Supply Facilities
Waste Water Treatment Facilities
Irrigation Projects
Hydroelectric Projects
Transportation Canals

Water Management

Water management involves several related issues (see Figure 16.1) that include *Water Provision, Storage, Conveyance* (either by irrigation or by natural river systems)*, Allocation,* and *Quality Control.*

Figure 16.1: Water Systems and Decision Junctions



Water provision is the economic problem of determining the optimal total supply of water. Due to variations in climate and weather, the total supply of water is usually somewhat uncertain. The cyclical nature of climate and weather results in the cyclical behavior of water dependent systems. Although water managers may not have complete control over the total water supply, they can:

- adjust the location of the water supply (by **conveyance**)
- adjust the timing of water supply use (by **storage**).

Water allocation is the economic problem of deciding how the total supply of water will be allocated among potential users. There are many alternative (competing) users of water: *Residential, Industrial, Agricultural, Forestry, Fisheries, Recreational, Hydroelectric,* and *Transportation.*

The first four are mostly **consumptive users**, meaning they withdraw water from the total water supply (a process generically known as "diversion") and "consume" the water by:

(a) transforming it into water vapor (where it is "lost" to the atmosphere)
(b) letting it seep into the ground
(c) significantly degrading its quality.

These users treat water as a non-renewable resource.

The last three are **non-consumptive users**. These users either leave the water in the water supply or return the water to the water supply. In either case, in general, they do not degrade water quality.

- Fisheries use water as a *medium* for fish growth.
- Hydroelectric users extract energy from the water.
- Recreation may involve using water as a medium (example: swimming) and/or extracting energy from the water (examples: white-water rafting, surfing).

These users treat water as a renewable resource.

U.S. Water Rights History and Property Rights Law

Competitive markets for surface water often fail or may not exist because of the peculiar nature of surface water property rights, or "water rights." The development of water rights law in the United States paralleled the development of land allocation rules during the “squatter period” of U.S. history.

United States: Land and Settlement Policy

1600-1700: Experimentation in developing appropriate technology.

1700-1800: Establishment of modes of agricultural production on the East Coast.

1800-1900: Movement to the West.
Growth in agricultural output through increase in land use.
Yield per acre stabilized.
Overall, yields increased, but because settlements spread West.
Very little biological innovation.
Land allocated by first-come, first-own basis.
Railroads lowered costs of westward expansion.

We are now at the same point with water and air resources as we were 100 years ago with land, since air and water quantity and quality are becoming scarce.

Water Policy

Historically, water rights allocation in the United States has been based on legal property rights mechanisms known as **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 in the United States, they are truly artifacts of the U. S. Homesteading. A queuing system is a use-it-or-lose-it system of water property rights based on the principle “first come, first serve.” A queuing system:

- Assigns water rights according to the sequence of previous uses.

- Encourages the rapid use of a resources, the “Settle the West” mentality. Homesteading for land rights is equivalent to the queuing system. It is aimed to increase settlement with the lowest cost to the government.

The main difference between the economic implications of a queuing system today and those of the Homesteading period is that, under conditions of water scarcity: *Markets are the best mechanism for allocating resources!*

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 in the United States.

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 her riparian water right if she does 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.

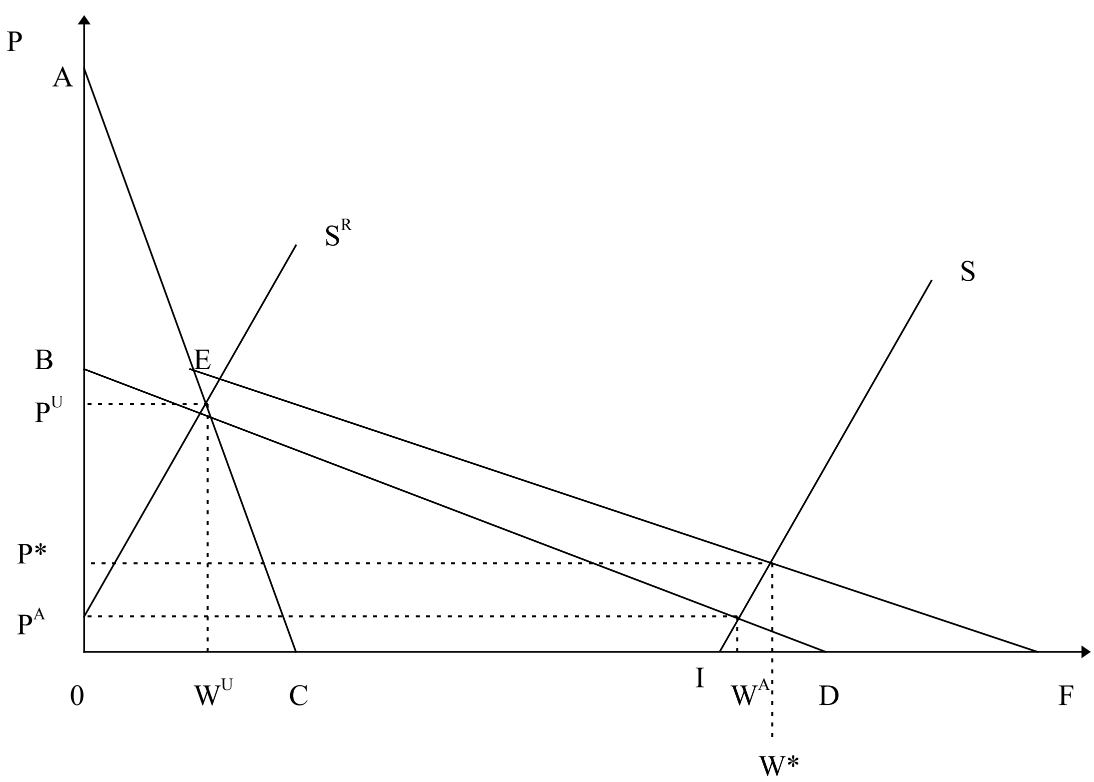
Prior Appropriation Water Rights

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 below.

Figure 16.2



(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 in 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.

<u>The Role of Water Districts</u>

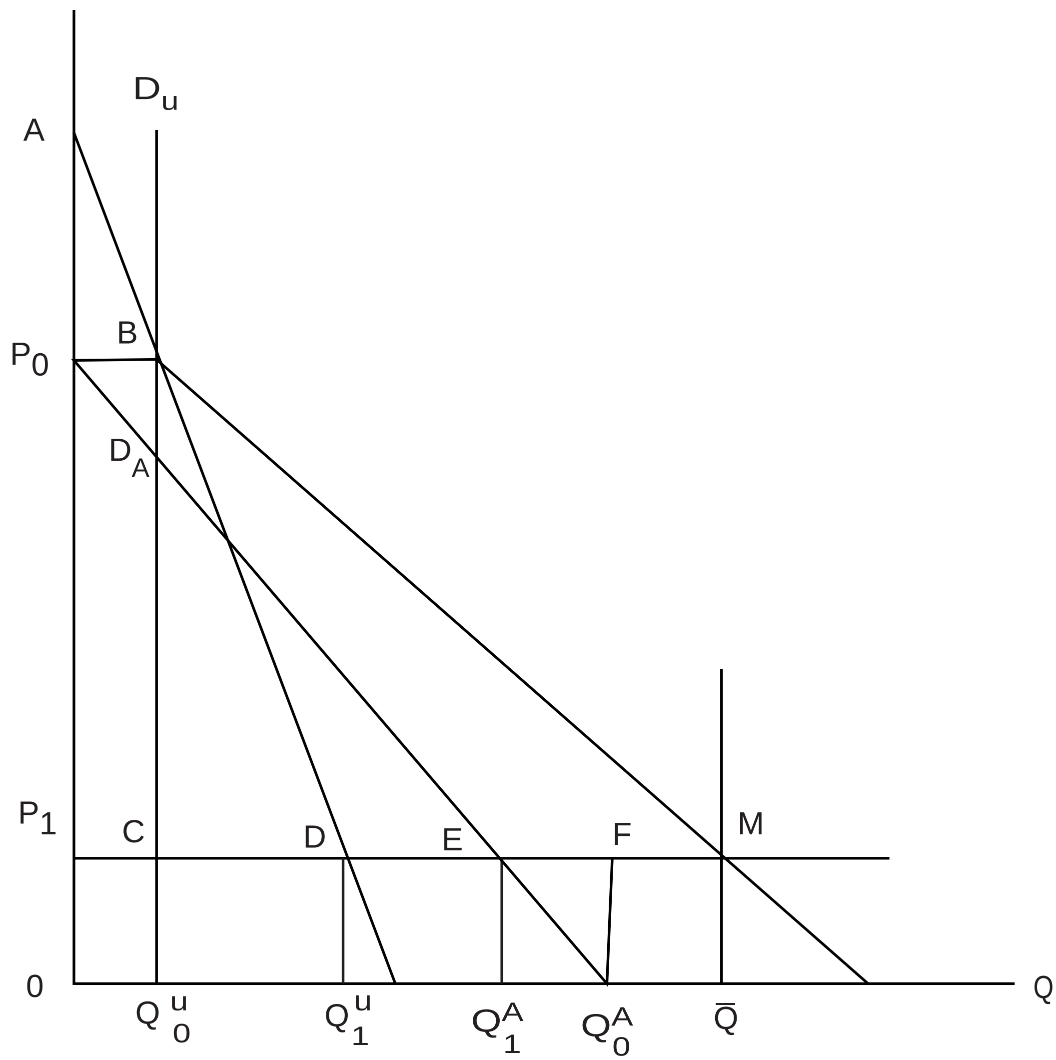
In the United States, special local governmental agencies called Water Districts build dams and canals to supply water to agriculture and to supply hydropower to local municipalities. The goal of Water Districts is to supply water for the public good. Water Districts also generally supply hydro-electric-power from dams and sell the electricity to power companies. Revenue from the sale of electricity is then used to cross-subsidize the price of water. The justification for keeping water prices artificially low is:

- water is necessary for everyone, rich and poor alike
- cheap water lowers the cost of producing agricultural commodities, which should have the effect of lowering food prices to consumers.
- low water prices get senators votes from agricultural constituencies

It is against Federal and State law for a Water District to make profit from the sale of water and electricity. In many cases, water laws require the water district to operate in a budget-balancing manner, (i.e., the NPV of profits equals zero). This is called a rate of return constraint. In economics the rate of return on regulated industries is usually equal to a constant greater than zero. In the United States, utilities are limited to a 5% return over costs.

Transitions from Queuing to Markets

Under the water rights systems, trading among groups is disallowed.



A region has $\overline{Q}$ acre-feet (AF) of water. Assume that the demand for water in agriculture is D_A and the urban demand is D_u. Farmers have senior right and consumers under the prior appropriation Q_0^A pay the price of 0. The urban sector consumes $Q_o^u = \overline{Q} - Q_0^A$ and assumes trading within the urban sector. The price per AF for urban user is P_0.

Under the Traditional System

The welfare of the farmer is represented by area $P_0 Q_0^A 0$. The gross welfare of the urban sector is measured by $0ABQ_0^u$ and the utility that owns the water earns $P_0 B Q_0^u 0$ and net consumer surplus is AP_0B.

Suppose trading is introduced. Let it first be transferable trading. The new price of water is P_1. The urban sector will consume Q_1^u and agriculture Q_1^A. The net gain for the urban sector is measured by the area BCD. Agriculture will lose $EQ_1^AQ_0^AF$, so that the net gain to agriculture is EFQ_0^A.

The net impact on social welfare is $BQ_0^uQ_1^u - FQ_1^A EQ_0^A = BCD + EFQ_0^A$. The transition to markets improved social welfare and, under transferable rights, both groups benefit.

Now suppose the government takes ownership of the water and sells it for P_1. The urban sector gains from the transition $BCD - P_1COQ_0^u$. Agriculture loses $P_1EQ_1A_0 + EQ_1^AQ_0^A$. Obviously, agriculture will oppose this reform, while supporting the transferable rights approach. A transition from water rights to water market improves water-use efficiency but may involve significant transaction cost (for example, cost of developing, monitoring, and managing water systems; establishing a legal framework for trading; establishing **exact** water rights, etc.). Over time, the urban demand for water increases, so that the gain from reform increases. At some point, these gains exceed the transaction cost and reform is justified.

In most regions, we do not have trading because water is not scarce to justify reforms. Water supply is random; and scarcity may first occur in periods of drought. Trading may be introduced, first in drought periods and then expanded to other periods.

When new water projects that expand supply are built, there are fewer incentives for reform. On the other hand, a reform with trading will reduce the pressure for new projects.

If new projects harm the environment, introduction of water markets that will reduce perception of scarcity may reduce the likelihood of new water projects and protect the environment.

<u>Response to Variability</u>

Precipitation is random. There are periods of droughts as well as periods of floods. The key element in water policy is managing this instability. One important feature of the queuing systems is that it determines who is entitled first to water during drought periods. For example, if in normal time a river carries a million AF of water, suppose that a user with senior right has 800,000 and the junior right has 200,000 AF of entitlement. During drought periods where only 900 AF of water are available, the junior right holder will receive only 100 AF of water.

The key element of a policy in dealing with variability is storage. Water is stored during wet years and distributed during dry years. Sometimes the storage is done through dams and, in other situations, ground water is used as storage. Building dams to store water may entail significant water cost but provides quite a lot of benefits during periods of droughts. Let *D* be the demand for water. Suppose that 50% of the time the supply is S_w (wet year), and 50% of the time the supply is S_d (dry year). Suppose we have a storage that stabilizes water at $\overline{S}$. During wet years, the loss of welfare because of storage is the area $A\overline{S}S_wC$. During dry years, the gain from storage is $BS_d\overline{S}A$. The average gain from storage is $1/2 \cdot \left(BS_d\overline{S}A - A\overline{S}S_wC\right)$.

Of course, drought may last several years, and management of drought is quite complex. Obviously, the decision about storage design also has to take into account the benefits in terms of water productivity gains versus the environmental and economic costs. For example, the optimal size of the dam has to be at the point where marginal benefits are equal to marginal cost.

The response to drought situations consists of several activities. First, we have user storage. Second, we have increased use of ground water, which is another form of storage. Third, during drought situations, it may be worthwhile to introduce water trading. It may be that the transaction cost does not justify water trading during wet periods, but there is significant gain from trading during dry years. Finally, during dry years, the price of water increases and farmers may reduce water use by adopting conservation strategies and fallowing land in low-value crops. These were the elements of a strategy that California used in response to the drought.

Water Projects and the Government

Water rights systems as well as homesteading systems are mechanisms where governments provide ownership rights to people who develop a resource. When the U.S. government was relatively young, the Treasury didn't have a lot of money, but the government controlled assets. It used land grants as mechanisms to induce investment in infrastructure. The railroads were built by private individuals who received ownership of lands adjoining the tracks. Similarly, the first developers of water projects were groups of farmers or miners who diverted water to develop farming or mining. In many developing countries today, we still see the use of resource grants as an incentive for developers or international corporations to develop resources. Obviously, this approach, which provides ownership of resources to rich individuals or organizations to develop these resources, may lead to significant neglect to environmental quality and negative equity effect.

Established governments that are able to assemble resources through taxation would not rely as much as on resources grants to develop resource systems, especially in situations that may entail externality problems. The government may invest public monies instead in infrastructure projects. That is the situation today in California with the modern federal and state water projects that developed with taxpayer money. When governments do not have the resources to pay for development projects, they have to rely on private developers. Organizations like the World Bank may provide a third alternative to developing countries to use cheap bank funding for development projects. The bank now insists on meeting environmental objectives in project design and considers both environmental benefits and costs in designing new projects.

A Static Version of a Rate of Return Constraint

Say a water district is regulated to make some rate of return "r" in period 1 based on a fixed investment that was made in period 0 (i.e., a dam).

Let:

- Electricity from a dam be: $E = kQ$
  where Q is the volume of water released from the dam and k is a constant
- Price of energy = v
- Price of water = p
- Regulated rate of return = r

Then the rate of return constraint is:

$$vE + pQ = C(Q)(1+r)\text{, subject to } E = kQ\text{, or}$$

$$vkQ + pQ = C(Q)(1+r)$$

or,

$$p = \frac{C(Q)}{Q} + r\frac{C(Q)}{Q} - vk$$

The price of water is equal to the Average Cost of building the dam plus the allowed rate of return on AC less average revenue from electricity sales. There are two key elements to this type of solution:

- The price of water does not arise from maximizing behavior.
- The price of water is cross-subsidized by electricity revenues

These two components together imply that the price of water is set artificially low!

How the Need for Explicit Water Rights Might Arise

Suppose a water district wants to maximize social welfare by building dams and canals to handle the optimal amount of water per year, Q^*. Suppose the total cost of the project is given by:

$$TC(Q) = bQ^{\beta} + cQ/r$$

where bQ^{β} = the fixed cost of building the dams and canals, $B > 0$, and
cQ/r = the present value (using a discount rate of r) of annual operation, repair and administration costs cQ.

Assume that after construction, maximum Q is fixed at Q^*.

The dam is built to supply both hydropower, E, and also to supply water for agriculture. Assume that hydropower production E is related to water supplied by:

$$E = kQ.$$

Assume that the marginal benefit of water to agriculture is:

$$MB(Q) = aQ^{-\alpha}$$

and that the price per unit of hydropower in the competitive energy market is \$v. The Social Welfare problem is:

$$\max_Q SW(Q) = \sum_{t=0}^{\infty}\left[\frac{\int_0^Q MB(Q)\,dQ}{(1+r)^t}\right] - TC(Q)$$

and the FOC is:

$$\frac{dSW(Q)}{dQ} = \sum_{t=0}^{\infty}\left[\frac{MB(Q)}{(1+r)^t}\right] - MC(Q) = 0$$

In each period, *MB*(*Q*) = *MB* to agricultural users + *MB* of power generated by the dam. Thus, *MB* in a single period is:

$$MB(Q) \;=\; [aQ^{-\alpha} + vk]$$

and the value of MC is given by:

$$MC(Q) \;=\; [\beta \cdot bQ^{\beta-1} + c/r]$$

Using the annuity formula to compute the value of the infinite sum of *MB*(Q):

$$\frac{[a \cdot Q^{-\alpha} + v \cdot k]}{r} - [\beta \cdot b \cdot Q^{\beta-1} + c/r] = 0$$

which implies that: $a \cdot Q^{-\alpha} = r \cdot \beta \cdot b \cdot Q^{\beta-1} + c - v \cdot k$

However, the water district must choose the per unit price of water to agriculture, \$W, that will meet the zero rate of return constraint, i.e., that will exactly balance its budget (given the choice of Q^* it has chosen for capacity). The basic problem that the water district needs to solve is to find \$w such that: $NPV\left[\Pi\left(w;Q^*\right)\right] = 0$

where, $$NPV\left[\Pi_t\left(w_t;Q^*\right)\right] = \sum_{t=0}^{\infty}\left[\frac{TR_t\left(w;Q^*\right)}{(1+r)^t}\right] - TC\left(Q^*\right) = 0$$

We can decompose $TC(Q^*)$ into fixed and variable cost components, then move the fixed costs of building the dam to the other side to get:

$$\frac{TR_t\left(w_t;Q^*\right)}{r} - VC\left(Q^*\right) = FC\left(Q^*\right)$$

where we have applied the annuity formula to compute the value of the infinite sum. We can now substitute in for *TR*, *VC*, and *FC* from above to get:

$$\frac{w\cdot Q^* + v\cdot k\cdot Q^*}{r} - \frac{c\cdot Q^*}{r} = b\cdot\left(Q^*\right)^{\beta}$$

which can be simplified and re-arranged to yield:

$$w + v\cdot k = r\cdot b\cdot\left(Q^*\right)^{\beta-1} + c$$

or, $$\boldsymbol{w^* = r\cdot b\cdot\left(Q^*\right)^{\beta-1} + c - v\cdot k}$$

Comparing this equation to the conditions for a maximization of the Social Welfare function above, we find that:

If:	Then:	So that:
$\beta = 1$	$MB(Q) = aQ^{-\alpha} = w$	Market for *Q* clears.
$\beta < 1$	$MB(Q) = aQ^{-\alpha} < w$	Surplus water capacity exists.
$\beta > 1$	$MB(Q) = aQ^{-\alpha} > w$	Shortage of water exists.

We can now understand that water rights are important since when a surplus capacity or market clearing outcome arises, there are no longer problems with ill-defined property rights. Without property rights, we may deal with two unexpected outcomes:

- Surplus water, which can always be managed by building up stock behind the dam or by releasing excess water into rivers.
- Water shortage, which means that water should be rationed.

Say that water is rationed due to shortage, the natural question is who gets first priority? Priority still has to be determined by property rights! Without water markets, it is unlikely that water will flow to the highest valued user to achieve the highest level of social welfare.

From an economic perspective, the water authority would sell water until the MVP of water is equated across all use-types: urban, residential, and agricultural. But there are more problems at this point. The water district cannot sell water for profit, and sets an inefficient price. Also, revenues from hydroelectric generation are used as a form of cross-subsidization that lowers the price of water. We have yet to discuss the fact that the price of water to agriculture is also indirectly subsidized by taxpayers, because it is often taxpayers who pay the fixed costs to build the water supply projects.