Surface Water Economics

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. Although water managers may not have complete control over the total water supply, they can:

- adjust the location of the water supply (by **conveyance**) and,
- 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.

consumptive users withdraw water from the total water supply (a process generically known as "diversion") and "consume" the water through either:

- transforming it into water vapor
- letting it seep into the ground, or
- significantly degrading its quality.
- These users **treat water as an non-renewable resource**.

non-consumptive 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

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.

- they are an Artifact of the Homesteading Period of U.S. History
- 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 resource: the "Settle the West" mentality (increase settlement with the lowest cost to Gov't)

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.

two queuing systems commonly found in the U.S.:

- Riparian water rights
- Prior Appropriation water rights

Common Queuing Systems in the U.S.

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 land owner to the use of the adjacent water on an “equal" standing with other riparian land owners. Each riparian land owner has the right to "reasonable use" of the water. A riparian land owner does not lose her riparian water right if she does not use the water.

- upstream users are given rights before downstream users
  --water does not “flow to the highest valued user”

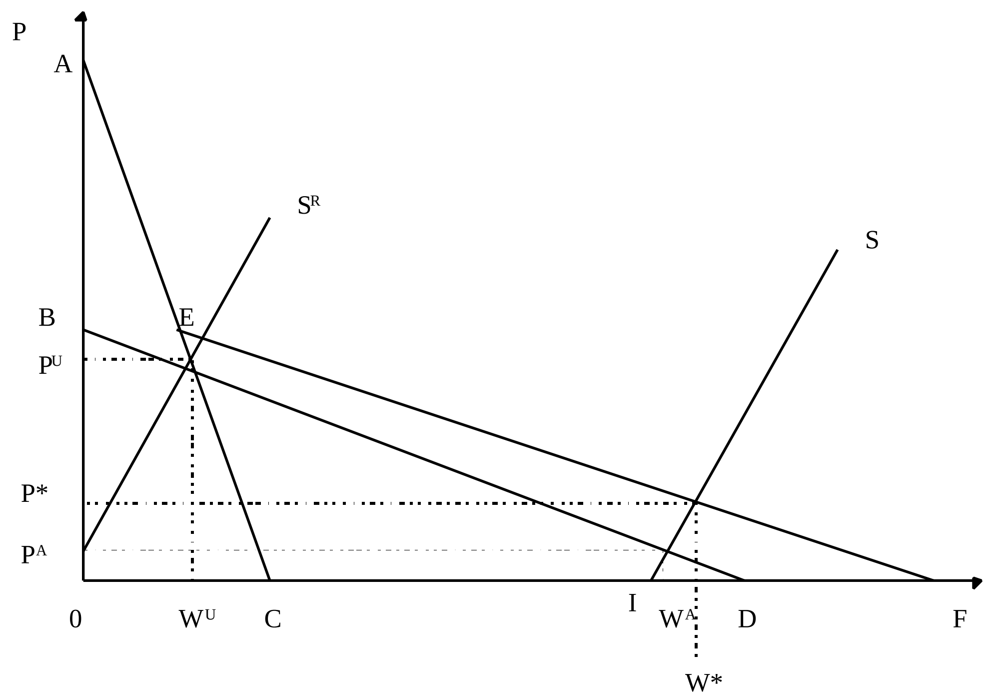
Inefficiencies:
- common property problem
- water may not be diverted for use outside the watershed
- Hence, **riparian water rights cannot be traded freely**.

Prior Appropriation Water Rights*:*

Under **prior appropriation** water rights law, the right to use water is acquired by discovering or "possessing" the water.

- water right is **"absolute,"** the owner of the prior appropriation water right does not share the right with anyone else
- right may be lost if the owner of the right does not put the water to beneficial use.
- water trading is also often prohibited.
  --water may not be allocated to its highest valued uses

Prior Appropriation Water Rights and Inefficiency



- MC of water supply curve OIS (due to high fixed costs)
- agricultural water demand is given by curve BD.
- urban water demand is given by curve AC.
- Aggregate demand is given by curve AEF (if markets exist) the --equilibrium solution is water, W* and price, P*
- Prior appropriation rights: demand is not aggregated, but discriminated by time in the residual demand curves BD and AC. Agricultural users purchase first.
  --they buy W^A, at price P^A.
- 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
- Since the MC to supply each type of user is the same, social welfare could be increased by reallocating water from agricultural users to urban users (inefficient)
- Notice $W^A + W^U > W^*$ => a market oriented system of water allocation can lead to greater water conservation.

The Role of Water Districts

water districts build dams and canals to supply water to agriculture and to supply hydropower to local municipalities.

- Revenue from the sale of electricity is 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 food
  - Low water prices get senators ag. votes

In many cases, water laws require the water district to operate in a budget-balancing manner, (NPV =0). called **a rate of return constraint**

A Static Version of a Rate of Return Constraint:

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

- Electricity from a dam be: E = kQ (Q is volume of water)
- Price of energy = v; Price of water = p
- Regulated rate of return = r

Then the rate of return constraint is:

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

$$vkQ + pQ = C(Q)(1+r) \;=>\; p = \frac{C(Q)}{Q} + r\frac{C(Q)}{Q} - vk$$

The price of water is equal to the AC of building the dam plus the allowed rate of return on AC less average revenue from electricity sales => **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:

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

- bQ^{β} = the fixed cost of building the dams and canals, $\beta>0$, and
- cQ/r = the PV of operation, repair and administration costs cQ.

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

hydropower production E is related to water supplied by:

$$E = kQ.$$

the MB of water to agriculture is:

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

price per unit of hydropower is \$v.

The Social Welfare problem is:

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

FOC :

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

In each period, MB(Q) = MB to agricultural users + MB of power generated by the dam:

Example (cont.)

Thus, MB in a single period is: $\quad \text{MB(Q)} = [a\ \ Q^{-\alpha} + v\ \ k]$

the value of MC is given by: $\quad \text{MC(Q)} = [B\ \ b\ \ Q^{\beta-1} + c/r]$

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

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

However, the **water district must choose the per unit price of water to agriculture that will meet the zero rate of return constraint**, (**given the choice of Q*** it has chosen for **capacity**):

Problem: Find $w such that $\quad NPV\left[\Pi\left(w; Q^*\right)\right] = 0$

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:

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

Example (cont.)

the previous expression can be simplified and re-arranged to yield:

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

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 capacity
$\beta > 1$	$MB(Q) = aQ^{-\alpha} > w$	Shortage of water

Now we can see why water rights are important:

- When a surplus capacity or market clearing outcome arises, there are no problems with ill-defined property rights
- However, if a shortage of water exists, then water must be **rationed**.
  - Priority is determined by **water rights**!

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.

- The water district cannot sell water for profit, and so sets an inefficient price.
- Also, revenues from hydro-electric generation are used as a form of cross-subsidization that lowers the price of water