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The Great Lakes can be classified as a common property resource, although consumptive water use from the lakes is, at best, "loosely" managed. Contributing to the complexity of the problem are the eight U.S. states, two Canadian provinces, and two federal governments involved in managing the lakes. At certain control points, such as the water diversion out of Lake Michigan at Chicago and the locks at Sault St. Marie, there are specified rules and procedures for determining water releases. In contrast, there is little regulation of consumptive uses from the lakes. Thus the problem is two fold: (1) there is no single entity in charge of managing the Great Lakes, and (2) it is technically difficult to closely manage the lake levels, particularly consumptive uses.

This paper focuses on the management problems involving water diversions that are created by inter-dependencies among water users. What are the likely effects of different entities using the Great Lakes when their use will have impacts on other entities? This is the classic problem posed by open access resources or a common property resource with inadequate institutional arrangements. The Great Lakes system is characterized by a situation where action by one state or users influences other states or users. Mohring and Boyd (1971) called this type of problem, "asset utilization". That is, all the individuals utilize an asset where there are no well-defined use, in this case, water withdrawal from the Great Lakes.

Recent dry weather conditions show how rapidly the issues concerning lake levels and diversions can change. In 1988, the emphasis abruptly changed from a concern about high lake levels and shore line erosions to low lake levels and the impacts of water diversions on hydropower production and navigation. During times of high lake levels, water diversions would have mostly positive external effects (reduce erosion). However, if lake levels are low, water diversions could have significant negative externalities through reductions in hydropower production and higher shipping costs.

From the standpoint of water users in other river basins (such as the lower Mississippi), they wonder why a little more water cannot be released through the Chicago diversion during drought periods. This would supplement the river flow on the Illinois and lower Mississippi Rivers and improve navigation. Such an increase was widely discussed during the 1988 drought, but was not supported by most Great Lakes states and provinces. Would this situation change if the lower Mississippi river basin states were willing to pay Illinois to allow more water to be released, and would there be anything wrong with allowing the sale? The answer is both political and economic and involves the interdependency of users and the possible impacts on water users in the Great Lakes.

Model of Interdependencies

Suppose there are N exploiters on the lake. Each one of them can extract q_i from the lake. All the other factors are conditionally optimized, thus production y_i can be represented as a function of q_i alone:

$$y_i = f(q_i) \ \forall_i = 1, \dots, N \tag{1}$$

The cost function, however, is a function of both q_i and the lake level L:

$$C_i = C_i \ (q_i, L) \tag{2}$$

The interdependence can be demonstrated by comparing the equilibrium water withdrawals when no well-defined property rights exist, with the case where withdrawals are determined by a social planner (sole owner).

The first equilibrium is derived by solving the following maximization problem:

$$\Pi = p.f(q_i) - C_i(q_i, L) \tag{3}$$

where p is the output price. The first order condition for this maximization problem is:

$$\frac{\partial \Pi}{\partial q_i} = p \cdot \frac{\partial f(q_i)}{\partial q_i} - \frac{\partial C(q_i, L)}{\partial q_i} = 0 \tag{4}$$

or

$$p \cdot \frac{\partial f(q_i)}{\partial q_i} = \frac{\partial C_i(q_i, L)}{\partial q_i} \tag{5}$$

However, (5) is not a socially optimal solution, since lake levels are an argument in the objective function over which players have no control.

The social planner problem (sole owner) is given by the following objective function:

$$\text{Max.}\Pi = \int_o^\infty e^{-rt} \sum_{i=1}^{n} [p.f(q_i) - C_i(q_i, L)]dt \tag{6}$$

s.t.

$$\dot{L} = R_t(L) - \sum_{i=1}^{n} q_i$$

where r = social discount rate, R_t = recharge rate of water into the lakes, and $\dot{L}$ = change in lake level.

This intertemporal problem can be solved by formulating the following current value Hamiltonian:

$$H = \sum_{i=1}^{n} [p \cdot f(q_i) - C_i\,(q_i, L)] - \theta(t)[F(L) - \sum_{i=1}^{n} q_i] \qquad (7)$$

where $\theta(t)$ is the co-state variable.

The first order condition with respect to q_i is given by:

$$\frac{\partial H}{\partial q_i} = p \cdot \frac{\partial f(q_i)}{\partial q_i} - \frac{\partial C_i(q_i, L)}{\partial q_i} - \theta(t) = 0 \qquad (8)$$

or:

$$p \cdot \frac{\partial f(q_i)}{\partial q_i} = \frac{\partial C_i(q_i, L)}{\partial q_i} + \theta(t) \qquad (9)$$

Thus, we see that under the common property equilibrium, players fail to take into account the additional cost $\theta(t)$. This difference is the user cost or the value of an additional unit of lake level or the future cost saving that is lost because water is used now. At a social optimum, the value of the marginal water unit as a flow and as a stock must be equal.

Once a steady state is reached under both situations, the withdrawal rates will be the same and equal to inflow, otherwise the equation of motion is violated. Yet lake levels will be higher under the social optimum equilibrium as compared to open access. This can be seen by comparing equations (5) and (9) where the difference is the user cost caused by differences in lake levels.

Factors limiting overuse

There are several factors which limit the overuse of the Great Lakes. The first mitigating factor is the number of firms that surround the lakes. The previous analysis is accurate only if N approaches ∞. If not, notice in equation (3) that a firm's decision will affect its profit through the L variable. As N approaches ∞, the effect of a firm's withdrawal upon its own profits (through lower lake levels) approaches zero. Assuming that $\frac{\partial \Pi}{\partial L} > 0$ and $N < \infty$, the private firms will have an incentive to withdraw less than is suggested by equation (5).

The expectations of each decision maker regarding the other players (firms) may limit the amount withdrawn from the lakes. Notice that this situation can be formulated as a game, with N identical firms and each one choosing q_i as its decision variable. The aggregate withdrawal is given therefore by: $Q = \sum_{i=1}^{N} q_i$. If we denote the withdrawal of the others besides i by $Q_{-i} = \sum_{j \neq i} q_j$ then: $Q = q_i + Q_{-i}$.

Total cost to each player is given by:

$$TC_i = TC_i(q_i, Q, L) = q_i \cdot A\,(Q,L) \tag{10}$$

where A is the external effect caused by the overall withdrawals on the lake level.

The marginal cost is therefore:

$$\frac{\partial TC}{\partial q_i} = q_i \cdot \frac{\partial A}{\partial Q} \cdot \frac{\partial Q}{\partial q_i} + A\,(Q,L) = MC_i \tag{11}$$

using the symmetry property we get:

$$MC_i = \frac{Q}{N} \cdot \frac{\partial A}{\partial Q} \cdot \frac{\partial Q}{\partial q_i} + A(Q,L) \tag{12}$$

Every exploiter faces the following maximization problem:

$$\max_{q_i} \; \Pi_i = q_i\,[P - A(Q,L)] \tag{13}$$

$$\text{s.t.} \quad q_i + Q_{-i} \leq L$$

$$q_i \geq 0$$

for every time period.

A Nash equilibrium occurs if each player treats the other player's actions as given and maximizes his or her profits with regard to only his or her actions. In our case, this is done with respect to q_i and not to Q_{-i}.

However, a more realistic assumption is to use a non-Nash behavior. A non-Nash solution is characterized by a non-zero conjectural variation with respect to the effect that one agent expects his or her own behavior to have on the other player's activities. In our case, agent i expects $\frac{\partial Q_{-i}}{\partial q_i}$ to be other than zero. We are especially interested in the case where this term is greater than zero. That means that player i expects that his or her activity will cause the other players to increase their activity. If we assume in addition that: $\frac{\partial \Pi_i}{\partial Q_{-i}} < 0$, then q_i under this kind of expectation will be smaller than in the Nash case. This follows because it shows that each firm, by taking into account the other firms' reaction, will not divert as much as when the other firms are assumed not to react. The self-limiting behavior reduces the negative externalities since it shifts the solution towards the socially optimum withdrawal and resulting lake levels.

Another factor that may limit the amount of water diverted is the element of reciprocity (see Sugden, 1984). Over use of the resource arises partly because of the uncertainty concerning what other states will do. This is the reason that the shared cost is commonly ignored. If, however, a system of conditional commitments can be established, we can move toward the socially optimum withdrawal and lake level. Assurance concerning the action of other states and provinces is needed, nevertheless, to achieve these coordinated activities. A conditional commitment occurs when others are contributing, and individual group members feel obligated to contribute the same (see Runge, 1984).

An excellent example of this kind of conditional commitment is the Great Lakes Charter that was signed by the eight Governors of the Great Lakes states and the Premiers of the two Canadian Great Lakes provinces. The Charter states that no diversion or other new consumptive use above a given level will be allowed unless all eight states and two provinces have given their permission. However, it is not binding until enacted into law by each individual state and province. The primary reason for abiding by the Charter appears to be the reciprocity element. The existence of this Charter is purely dependent on the assurance the states receive from this kind of policy. The policy has more chance of surviving if the impacts on all states and provinces are similar, i.e., the impacts should be similar for them to all enact the Charter. So far, four states and the two provinces have essentially enacted the Charter's provisions. Only Michigan, Indiana and Pennsylvania have not taken action. New York tried to pass the needed legislation in 1987, but failed [Frerichs and Easter].

The lack of homogenous impacts may explain the difference in legislative response. States that need the water as a stock (for navigation and hydropower purposes) are not the same states that have an incentive to withdraw the water. The state of Illinois, for example, has an incentive in drought times to divert water from Lake Michigan to the Chicago and Illinois rivers in order to raise their flows. Transportation and hydropower production on the Chicago and Illinois rivers are important to the state's economy, as is the water disposal function of the rivers.

Other states do not have the same incentive, and especially not during drought periods, when the lake levels are low enough without increasing the Chicago diversion. There is also a much lower concern about lake levels in states such as Indiana and Pennsylvania, which have only a small amount of shoreline and lake use. Michigan is the only state whose lack of legislative action, in regard to the Charter, is hard to explain. They would seem to have the most to lose from increased water transfers.

Options for Regulating Water Use

If open access to the Great Lakes causes overuse of the lake water, as shown in figure 1, can government action bring about an improvement?

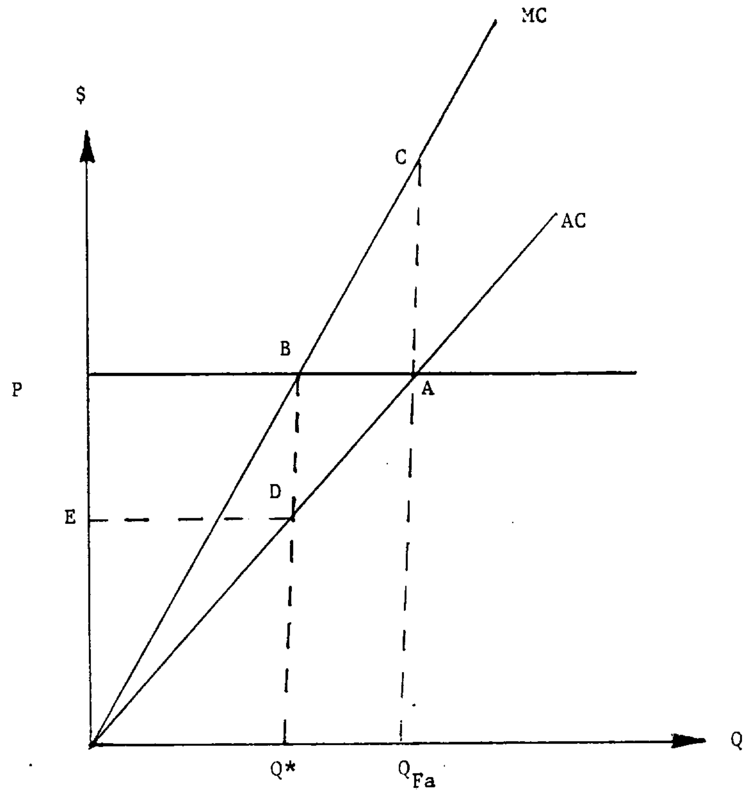

Figure 1: Optimum Withdrawals from the Great Lakes

The horizontal axis (q) represents withdrawals from the Great Lakes at the margin, while the vertical axis shows the costs. With free access, the firms will withdraw water until the average cost of diverting one more unit of water will be equal to the marginal revenue (which is constant and equals to p in our case). This will result in Q_{fa} being diverted, while the optimal amount of water to divert is Q* where MC=p. The loss because of excessive withdrawals is given by ABC.

Is Q* preferable to Qf_a? The answer depends upon the expense required to reach Q*. Will the Charter's provisions, if adopted by all eight states, improve water use in the Great Lakes and move withdrawal to Q*? If enforced, the Charter provisions would essentially stop any new water diversions and limit other major new consumptive uses. This would improve water use only if the current levels of use are near to or above the optimum level of consumption, i.e., Qf_a. If it is below the optimum level of consumption, the Charter could cause losses in benefits that exceed any cost savings.

Another alternative would be a tax equal to the marginal user cost, which is given in figure 1 by BD. This will result in equilibrium at Q* and tax revenues of BDEP. If the tax payments collected by the monitoring agency are not distributed back in some form, it will result in a net welfare loss to each of the resource users--that is, the area BDEP is greater than ABC (for a proof, see Weitzman, 1974). If redistribution of taxes are considered, they should not be connected to the amount diverted, otherwise the tax program will not provide an incentive to reduce diversions at the margin.

In contrast to the tax solution, efficient quotas (property rights to divert water) can result in the benefits to the users, if quotas are assigned such that the marginal social cost of diverting one more unit of water is equal among all users. This would be possible, however, only in the case of identical users of the lakes. Otherwise, opposition can be expected from various groups of users who receive lower quotas than others.

A new approach is to control water use with a marketable permit system (see Tietenberg, 1980). The advantage of this system is that it can provide cost-effective solutions for a given lake level. However, there is a possibility that some resource users will be worse off under this management policy than under one where no property rights are assigned (free access). This may be why New York and Michigan have not approved the Charter and suggests that they would oppose a permit system.

Benefits and Costs of Regulation

The benefits and costs to the different states and provinces are not only a function of their decision concerning how much to divert or consume, but is also dependent on what other parties do on the lake. The additional costs imposed on other parties comes, primarily, from losses to hydropower production and commercial navigation while shoreline property probably benefits from lower lake levels. The major loser from a large diversion would be the hydropower industry, which would suffer a loss of about $10 million per 1 inch drop in the lake level. An additional 1 million dollars will be lost by the navigation industry on the lakes (David, et. al., 1988). This total cost will be slightly reduced by the benefit to shoreline property.

Depending on how the diverted water is used, its value can range from $10 to $400 per ac. ft. The only feasible uses for large quantities of water appear to be irrigation, and, in dry years, navigation. Agriculture, however, cannot pay much more than $50 per ac. ft. for imported water. The only users that can pay prices high enough to cover the $200-$300/ac.ft. cost of new water diversions are municipalities and hydropower producers (Buckley, et. al., 1984, David, et. al., 1988). Thus, from an economic stand point, new large water diversions should not be tried.

However, political considerations and the unequal distribution of costs and benefits from water diversions keep the option open. While navigation is spread more or less equally around the Lakes, the hydropower is mainly located in two states (Michigan and New York) and the two Canadian provinces (Ontario and Quebec). These parties will put more weight on water as a stock rather than as a flow commodity to be sold. This raises the question of who gets paid for the diverted water, since not all lake states have similar interests. States that do not own hydropower facilities and want to sell water face only the commercial navigation damage, which is not high for an individual state. Thus, they can reap much of the benefit from a water sale, while imposing most of the external costs on others.

Downstream users, especially New York and Quebec, cannot affect the upper stream users without some kind of a well-established agency to monitor diversions. The results appear to be biased significantly in favor of the U.S. states, especially those on the western Great Lakes, who do not use hydropower facilities as an energy source. They are the ones most likely to pursue water diversions. Yet contrary to expectations, the three western most states have already implemented the Charter provisions to control consumptive water use and transfers.

Conclusions

The outcome under free access is just one possibility; it is the upper boundary of the inefficiency. However, the number of users is finite and the user expectations do not necessarily form a Nash solution. In fact, the Great Lakes experience would suggest this is the case, as the western Great Lake states and provinces have taken the lead in opposing diversions out of the lakes and supporting the Charter. Support for the Charter is beneficial to the Great Lakes States as long as current withdrawals are at or above the optimum level.

However, whether or not withdrawals are near optimum in the Great Lakes cannot be ascertained, given our state of knowledge. To determine this, research is needed concerning the aggregate and individual firm demand curves for water from the Great Lakes. This will be dependent on what additional sources of water are available, the technical water needs and any government water conservation policies that may be implemented (demand management). With this information and different assumptions concerning lake water supplies, estimates can be made concerning the optimum water withdrawals from the Great Lakes.

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