All CPRs Are Not Created Equal: Two Important Physical Characteristics and Their Relation to the Resolution of Commons- Dilemmas

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ABSTRACT

Policy prescriptions offered in the now-voluminous literature on common-pool resources (CPRs) frequently focus upon the strategic situation of resource users, paying relatively less attention (or none at all) to the characteristics of the common-pool resources themselves. In short, most contributions to the policy literature presume that all CPRs are alike. Based on our reconsideration of the strategic situations users face, and our empirical observation of three kinds of CPRs — fisheries, irrigation systems, and groundwater basins — we conclude that two physical characteristics of CPRs have vital implications for the likelihood of successful resolution of difficulties over resource use, and for the types of resolutions users develop. Those physical characteristics are the degree of stationarity of flow units and the existence of storage capacity. Speaking generally, fisheries are CPRs with fugitive flow units and without storage capacity, irrigation systems have fugitive flow units but possible availability of storage, and groundwater basins have relatively stationary flow units and storage capacity. Using comparisons among these types of CPRs, we analyze the effects of these physical characteristics upon the. prospects for the emergence- of successful cooperation in resource use.

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Common-pool resources (CPRs) have been distinguished from so-called "private goods" and "public goods." CPRs differ from private goods in that the former are jointly accessible by multiple users. CPRs are distinguishable from public goods by the former's subtractibility in use (also referred to as "rivalry in consumption"). The combination of joint accessibility and subtractability in use characterizes a wide array of resources, including wildlife and fisheries, minerals and underground oil deposits, ambient air and water systems, groundwater basins and irrigation systems, wilderness areas and grazing lands.

Because the characteristics of joint accessibility and subtractability in use suffice to distinguish CPRs from private or public goods (Ostrom and Ostrom, 1978), some analysts understandably might assume that these two characteristics also fully specify CPRs. Such an assumption would appear to be reinforced by numerous observations that the distinguishing combination of joint access and subtractable uses also is what renders CPRs vulnerable to problems of overuse, depletion, and degradation.[1] Joint access by multiple users whose actions are rivalrous defines for several authors what has been named "the tragedy of the commons" (G. Hardin, 1968), "the problem of the common" (Dasgupta and Heal, 1979), and "the commons dilemma" (Dawes, 1973).[2]

As first analyzed by Gordon (1954), the "problem of the common" is rent dissipation. The economic value accruing to the use of the resource (i.e., rent) diminishes as a result of excessive use. Excessive use may be caused by the presence of too many users, too high a use rate, or both, suboptimal resource use occurs, in the absence of corrective institutional arrangements, because the costs of individual resource users' actions are diffused across multiple users rather than being borne fully by each individual user. As individual users capture for themselves the benefits of their resource use while bearing only a portion of the costs, the collective outcome can be repeated overuse that diminishes or destroys the value of the resource.

From an economic perspective, the CPR problem is one of inefficient resource use. From an ecological perspective, popularized by Garrett Hardin (1968), the CPR problem is one of natural resource destruction, deterioration of the quality of life due to resource destruction and human overcrowding, and ultimately, endangerment of the sustainability of life on the planet.

The Principal Policy Recommendations of Past CPR Literature

Since assessments of the severity of CPR problems range from inefficient resource use to the potential destruction of the planet, it is not surprising that there has been a strong normative element to the literature on CPRs. Gardner, Ostrom, and Walker (1990: 336-337) make the existence of a preferable and feasible alternative part of the definition of a "CPR dilemma," since, as they observe, if there is no preferable and feasible alternative to the existing suboptimal situation, users do not actually face a dilemma. Many authors have concentrated on competing conceptions of the "preferable" alternative (the "solution" to "the CPR problem"). Somewhat lesser attention has been given to feasibility.

The principal recommendations issuing from the past literature on CPRs are the imposition of central public management and control or the transformation of the common-pool resource into individual parcels of private property. Either way, a single owner or administrator is believed necessary for the efficient use of the resource (or each individual parcel thereof). Gordon (1954: 135) crystallized the policy recommendations in the following statement:

> Common-property natural resources are free goods for the individual and scarce goods for society. Under unregulated private exploitation, they can yield no rent; that can be accomplished only by methods which make them private property or public (government) property, in either case subject to a unified directing power.

Garrett Hardin later echoed Gordon's assertion that CPRs must be brought under a "unified directing power," presenting the alternatives as "a private enterprise system" or "socialism." (1978: 314)

Although Gordon and Hardin were ambivalent on the <u>form</u> the "unified directing power" should take, the recommendations of CPR analysts settled into two primary groups. As Elinor Ostrom (1990: 8-15) summarizes, the first group argued for centering the coercive power over the commons in a public authority, and the second group argued for the privatization of the commons and the creation of "full-ownership property rights." (Welch, 1983; see also Ciriacy-Wantrup, 1956)

The privatization advocates have been relatively consistent in the substance of their policy recommendations, viz., the transformation of the commons into private property with owners holding specific and transferable property rights. On the other hand, the substantive policy recommendations of the advocates of public control have evolved in interesting ways.

The principal initial recommendation for governmental intervention to "manage" CPRs was to limit access to them.

However, experience with limiting access, particularly in the case of fisheries, proved "sobering." (Copes, 1986: 288) Limiting access alone did not suffice to eliminate rent dissipation. Often, those resource users who were fortunate enough to gain access to a government-issued access license merely accelerated their rate of use and continued to dissipate rents and threaten the sustainability of the resource. (Anderson, 1977; Fraser, 1979; Pearse and Wilen, 1979: Rettig, 1984)

Subsequently, advocates of public control of CPRs modified the substance of their recommendations. Policies currently recommended, and frequently pursued by public agencies with jurisdiction over CPRs, involve defining, allocating, and enforcing quantity restrictions, or quotas (preferably transferable ones) . Quantity restrictions, especially individual quotas, have the advantages of limiting access and use. (McGartland and Oates, 1985; Neher et al., 1989) Assuming that the initial quantities are appropriately determined, transferable quotas should eliminate rent dissipation in CPRs. (Maloney and Pearse, 1979)

Having accepted public control as the only means of ensuring efficient use of CPRs, advocates turned their search to the optimal regulatory device to be used by the state. As Copes (1986: 288) writes: "The individual quota, indeed, seems to have replaced limited entry licensing as the new 'conventional wisdom.'" Regardless of what type of CPR is involved, and regardless whether problems of overuse or insufficient provision are occurring, the policy currently in vogue is to assign individual, transferable quotas.

For our purposes, what is noteworthy about the policy literature on CPRs is not whether the advocates of privatization or the advocates of public control have been right, or whether the evolution among public control advocates from recommending access limitations to recommending individual quantity restrictions has been progress. To us, what is noteworthy is that these policy recommendations have been set forward without apparent regard for whether some types of CPRs might be particularly well-suited, or particularly unsuited, to access limitations, or the imposition of quotas, or privatization. *What is remarkable to* us, in *other words, is the fact that virtually the entire policy literature on CPRs has assumed that all CPRs are identical.*

This "have CPR, will travel" approach is notably out of sync with actual experience. Having examined several actual settings, we have found diversity in the strategies pursued by users in designing institutional arrangements, as well as in the institutional arrangements they designed.

Differentiating CPR Problems

Before we explore the differences in characteristics of CPRs, we draw upon a fuller account of CPR problems and the barriers to their resolution. Gardner, Ostrom, and Walker (1990) have attempted to distinguish CPR problems more definitively. They distinguish first between decisions about appropriation and decisions about provision. Appropriation decisions govern users' demands for flow units generated by a CPR. Provision decisions concern the protection or enhancement of the supply of flow units generated by a CPR. Either type of decision is problematic.

Appropriation Problems. The most common problems affecting appropriation are assignment problems, stock externalities, and technological externalities (Gardner, Ostrom, and Walker, 1990) . Assignment problems involve allocating spatial, temporal, or quantity restrictions on demand across users. Unless flow units are absolutely evenly distributed throughout a resource and over time, assignment problems are likely to arise, because some spaces or times will be less productive or more vulnerable than others. Allocations of quantity restrictions also entail complications, such as (a) whether quantities should be allocated equally among users, or on some other basis such as need, historical use, etc. and (b) whether the sum of the quantities allocated matches the sum available. Inappropriate allocations generate unnecessary conflicts among users.

Stock externalities reflect the effects of users' current activities upon the future availability of flow units or ease of obtaining them. Increased appropriation of flow units in a given period diminishes the remaining stock, which may raise the costs of appropriating flow units in future periods (e.g., increased harvesting effort, longer pumping lifts). In a CPR, the increased costs fall not only upon the user(s) whose actions generated them, but are externalized to other users.

Technological externalities are the harms CPR users visit upon each other through physical interference with one another's appropriation activities. Wells located too close together may cause one pumper to interfere with another, fishers may tangle or damage each other's gear, and so forth, apart from the question of whether the CPR generates adequate flow units for all.

Provision Problems. Provision problems generally arise from deficient investments in the development, maintenance, and protection of common-pool resources, or what Gardner, Ostrom, and Walker (1990: 340) refer to as "creating a resource, maintaining or improving the production capabilities of the resource, or avoiding the destruction of the resource." Within the class of provision problems, we distinguish development failures, maintenance problems, and degradation problems.

Opportunities foregone to make a CPR more productive of flow units are development failures. A resource may be far from being threatened with depletion or destruction, and nevertheless fall short of optimal productivity. A grazing area can be fertilized, the storage and distribution capacity of a surface water or irrigation system can be enhanced, a groundwater basin can be artificially replenished and operated conjunctively with surface water supplies, and so on. Such actions, however, typically will require coordinated contributions of labor and capital. Development failures occur when contributions are not forthcoming or are inappropriately coordinated.

While development failures represent opportunities foregone, deficient investments in maintenance can result in erosion of a CPR's productive or regenerative capacity and deterioration of the status quo. The yield of flow units generated by a resource may decline because of maintenance failures, apart from appropriation-side issues of overuse. Failure to adequately protect spawning or nesting areas, seedlings and saplings, recharge zones, etc., eventually results in the loss of flow units regardless of appropriators' behavior. Failure to maintain the physical facilities of human-made CPRs such as irrigation or surface water supply and distribution systems produces similar results. As Gardner, Ostrom, and Walker (1990: 346) point out in discussing what they call "extinction problems," without adequate maintenance, the flow-unit yield of a CPR diminishes each period and may eventually collapse. Adequate maintenance requires coordinated contributions of labor and capital, and therefore is problematic.

Degradation problems comprise a third category of provision problems. Both the productive capacity and the flow-unit yield of a resource may be maintained, but the quality and value of the flow units diminishes if they are not protected adequately from a variety of threats. Coastal aquifers can be replenished by sea water rather than fresh water if proper balances are not maintained. Surface and underground water supplies can become valueless if contaminants are allowed to reach them. Fish and other animals may remain numerous but become inedible, eliminating one of the principal forms of their value to human users. Avoiding degradation problems involves protection of the resource, necessitating coordinated contributions of labor and capital, and/or regulation of users' behavior, either or both of which is problematic.

Barriers to Resolution. Neither appropriation nor provision problems can be expected to resolve themselves. Ordinarily, actions must be taken to overcome these difficulties. Yet, the process of resolution of any CPR dilemma itself is problematic. Among the difficulties encountered in resolving CPR dilemmas are information inadequacies and costs, uncertainty, barriers to communication, asymmetries

of interest and capacity, transaction costs, and lack of assurance.

The information possessed in a given period about a resource of sufficient size to be accessed by multiple users and of sufficient complexity to run the risk of assignment problems, stock externalities, technological externalities, development failures, maintenance problems, and degradation problems can be expected to be inadequate for reaching a fully successful resolution of a CPR dilemma. The boundaries, capacity, yield and other properties of a given CPR (including the identities of all relevant users whose actions must be coordinated) are likely to be imperfectly known at best, and acquisition of additional needed increments of information is likely to be costly.

Uncertainty surrounding a CPR is not merely a subset of information problems. The uncertainties that complicate appropriation and provision decisions in a CPR context cannot be eliminated through the acquisition of additional information. Changes in migratory patterns due to climatic shifts, droughts, floods, forest fires, and the like are matters of uncertainty rather than inadequate information. Nevertheless, these sorts of uncertainties compound the difficulties users face in reaching successful and sustainable resolutions of CPR dilemmas.

Even under conditions of greater information availability and lesser uncertainty, communication barriers among resource users present obstacles to resolving appropriation and provision problems. In some instances, communication barriers are institutional, such as the lack of a regular forum for communication about the nature of problems and the alternatives for their amelioration. In other instances, the factors inhibiting communication are social, having to do with attributes of the community of users, such as linguistic or religious differences that prevent members of one group from communicating with another. In especially problematic instances, there may be both social and institutional barriers to communication. In any event, policy prescriptions that are built upon assumptions of immediate or costless or error-free communication neglect the fact that communication barriers must be overcome (see Blomquist and Ostrom, 1985) .

Asymmetries of interest and/or capacity among users of a CPR can complicate the process of resolution, as well, even in the relative absence of information, uncertainty, or communication problems. Users may be situated differently with respect to. their dependence upon or use of a particular CPR. For some, reliance on the CPR may be nearly total; for others, use of the CPR may be a convenience they can take or leave. Gardner, Ostrom, and Walker (1990: 345-346) discusss the importance of users' rates of discounting the future for the likelihood that a resource will be driven to extinction; of considerable significance also are the implications of different rates of discount among resource users for the prospects of arriving at any collective decisions governing appropriation or provision. Differences in asset ownership and/or technological capability also bear implications for the relative difficulty of reaching resolutions about appropriation or provision. Users in favored positions may be reluctant to agree to patterns of use that do not permit them to exploit their advantages. Alternatively, users in favored positions may be more willing to exploit a CPR to the edge of its regenerative capacity than users who cannot as readily sustain the more intensive efforts needed under those circumstances to capture the same quantity and quality of flow units.

Except for the extremely rare case of "privileged groups" (Olson, 1965), overcoming any appropriation or provision problems in a CPR will require the coordination of multiple users' efforts and activities. Thus, transaction costs present an additional barrier to resolution. Even if one could imagine a CPR in which information availability, uncertainty, and communication were not problematic and users were identical in their interest in the resource and their capabilities to use it, the transaction costs involved in obtaining, implementing, monitoring, and enforcing any agreed-upon coordination of appropriation and provision still would complicate the process of resolution.

Finally, as Runge (1984) has described, there remains the problem of assurance in coordinating CPR use. Even overcoming the transaction costs barriers to reaching an agreement governing appropriation and provision will not suffice if that agreement fails on assurance grounds. The assurance problem is the unwillingness of participants to commit and follow through on a cooperative strategy unless they are convinced that all other relevant participants will do so. That problem — and its manifestations in terms of "holdouts" and "free riders" — still can remain, even (albeit less likely) among relatively homogeneous, well-informed, well-communicating users of a CPR under conditions of relative certainty.

Physical Characteristics That Make a Difference

The previous section, borrowing heavily from Gardner, Ostrom, and Walker (1990) and others, has attempted to distinguish more thoroughly among CPR problems, and to identify the principal categories of problems users encounter in attempting to overcome CPR problems. Even so, the essential presumption noted earlier about the policy literature on CPRs was retained, namely, that all CPRs are alike. At this point, we depart from that presumption.

All CPRs are not alike. Systematic differences in users' strategies and in the institutional arrangements developed to overcome these problems appear to us to emerge around two important physical characteristics that differentiate CPRs. One of these is whether the flow units that resource users capture and use are stationary or

fugitive; the other is whether the resource itself exhibits storage capacity.

By "stationarity," we mean that flow units yielded by the resource- (usable amounts of water, oil, fish, timber, etc.) remain spatially confined, or at least travel so slowly as to be static for all practical short-term purposes of users. For our purposes, the opposite of stationary is "fugitive." Examples of stationary flow units include water in a groundwater basin, most forest products, grasses, and shellfish. Fugitive flow units include water moving in a surface stream or canal, wild animals, and most fish.

Resources with storage capability possess the physical capacity to collect and hold flow units. Storage permits variations in the flow to be regulated. Stored units can be appropriated as needed, rather than being appropriated only when available. Examples of resources with storage capability include surface and underground water reservoirs and some irrigation systems. Examples of resources for which storage is infeasible include fisheries, forests, and grazing areas.

CPRs differ along these two important dimensions of stationarity and storage.[3] The characteristics of stationarity and storage can be combined to show a typology of CPRs, as in Figure 1. This typology classifies CPRs according to whether flow units are stationary and whether storage is feasible. The cells in Figure 1 contain examples of each CPR type.

		Flow Units	
		Fugitive	Stationary
Storage	Infeasible	Cell 1 (Fisheries)	cell 2 (Grazing Areas)
	Feasible	Cell 3 (Irrigation)	Cell 4 (Groundwater)

Figure 1

A Typology of CPRs

We do not contend that institutional arrangements are "determined" or "induced" by physical characteristics. Resource users face a number of interacting constraints in devising arrangements to coordinate their use of CPRs. Rather, we believe that the physical characteristics of stationarity and storage shape the opportunities and constraints that resource users face in important ways that have not been taken into account adequately in the literature to date.

Stationarity and Storage and Barriers to the Resolution of CPR Dilemmas

In two subsequent sections, we shall address how stationarity and storage each relates to appropriation and provision problems. In this section, we discuss stationarity and storage together, and their relation to barriers to resolution.

We do not claim that the physical characteristics of stationarity and storage affect every identifiable barrier to the resolution of CPR dilemmas. Specifically, barriers to communication among resource users and asymmetries in their interests and capabilities seem to us to result from and to be aggravated or ameliorated by characteristics of the user group or physical characteristics <u>other than</u> stationarity and storage.

Stationarity and storage <u>do</u> affect several other barriers to resolution. Perhaps the most obvious is uncertainty. All other things being equal, users of CPRs that yield fugitive and/or unstored flow units will face greater difficulty in devising acceptable regimes for governing the resource and overcoming dilemmas.

If flow units are fugitive, variability in the flows available from one period to another is likely to be greater, and more difficult for users to understand and anticipate. If storage of those fugitive flow units is infeasible, users lack a principal means of reducing this uncertainty of flow availability. On the other hand, the variability of flows from one period to the next is likely to be smaller in CPRs with relatively stationary flow units, even though stationarity does not eliminate uncertainty (e.g., a drought way reduce the supply of grazing fodder or a fire may decimate a forest). And if flow units — fugitive or stationary — can be stored within the resource, uncertainties about flow units can be reduced sharply. The reduction of uncertainty associated with the availability of storage is, in our view, probably the greatest effect of storage on barriers to resolution of CPR dilemmas.

Stationarity and storage also affect information inadequacies and costs. All other things being equal, adequate information about the quantity and quality of flow units, and about patterns or trends in quantity or quality, will be more costly to obtain in CPRs with fugitive flow units. Stated simply, stationary and/or stored flow units can be identified, inventoried, and monitored more easily than fugitive flow units. Therefore, agreement among users about the incidence and causes of problems, and the appropriate behavioral or institutional changes to resolve those problems, will be attained wore easily in CPRs with

stationary and/or stored flow units than in CPRs with fugitive and unstored flows.

However, it should be noted that in CPRs with storage capability, users who intend to take advantage of that storage capability must learn about it as well as about the flow units. Acquisition of information about that storage capability and its relation to the flow also will be costly. Therefore, the presence or feasibility of storage is likely to reduce some information costs but raise others.

In a similar vein, while we anticipate that the transaction costs involved in reaching resolutions of CPR problems will be principally affected by such characteristics as the size and heterogeneity of the user group and the nature of the legal and institutional environment, the presence or feasibility of storage in a CPR will add some increment to transaction costs. If users of a CPR choose to take advantage of the storage capability of a resource in which storage is feasible, the regulation of the storage capacity and the allocation of stored flow units are additional items about which the users will have to reach some resolution.

Finally, assurance problems are likely to be reduced by stationarity and storage. Users who are aware that flow units are stationary, and especially users who are aware that flow units can be stored within the resource for later appropriation, should be more willing to agree to proposed resolutions that limit their use of the CPR in a given period (by limiting access, restricting quantities, etc.) than users appropriating fugitive and/or unstored flows. All other things being equal, we would anticipate that users of a CPR with fugitive, unstored flow units are substantially more likely to reject resolutions that restrict their use, and instead to pursue "first capture" (or "use it or lose it") strategies. For all practical purposes, the very definition of fugitive flow units is that those units one does not appropriate today are available to someone else tomorrow. In addition, absence or infeasibility of storage means that users cannot "bank" units in the resource. In a CPR with fugitive and unstored flows, the levels of trust — i.e., assurance — users must reach about one another's actions (or restraint of actions) are substantially higher, and consequently more difficult to attain.

Stationarity and Appropriation and Provision Problems

Stationarity affects not only the prospects for the emergence of cooperation, but also the types of CPR dilemmas resource users are likely to address. Users facing fugitive flows are more likely to address CPR dilemmas that arise in relation to the resource as opposed to dilemmas that emerge in relation to flow units. Because the resource is likely to be more stable than the fugitive flow units, users possess more information, face less uncertainty, and can exert greater control over a resource than over the fugitive units flowing through it.

The principal appropriation problems that arise in relation to the resource (as distinguished from the flow) are technological externalities and assignment problems (Gardner, Ostrom, and Walker, 1990; Schlager, 1990). These dilemmas are caused by multiple users interacting within a resource's finite space — interfering with each other's appropriation efforts, or conflicting over access to particular locations. These problems primarily concern how the space within a particular CPR is to be allocated.

Technological externalities and assignment problems occur within the bounds of a single resource, involving only the users of that resource (Wilson, 1982). Even in a CPR with fugitive flows, users possess (or through experience can gain) information about the incidence and causes of these two types of appropriation problems. Users experience these problems repeatedly under similar conditions, so their diagnosis is a relatively straightforward process.

For instance, assignment problems may arise because some locations within a CPR are more productive than others. Productive locations within a fishing ground usually correspond to feeding grounds or to areas that provide shelter from predators. The productive areas within a fishery remain constant over long periods, and within a given fishing ground, the same fishers compete for the most productive spots. Repeated use of a fishing ground allows fishers to determine the most productive areas, and thus to develop an understanding of the incidence and causes of assignment problems.

Even resource users appropriating fugitive flows can develop a necessary base of information concerning technological externalities and assignment problems that may allow them to develop and adopt resolutions of these problems. In addition, because these two types of problems normally arise within a single resource and among a set of users, the benefits from resolving these types of problems can be captured by those whose cooperation must be secured.

It is with regard to stock externalities that the difference between stationary and fugitive flow units is most apparent, and the problems created by fugitive flows most acute. Stock externalities are more directly related to the flow units of a CPR than to the resource space itself. Stock externalities arise from excessive appropriation of flow units, drawing down the amount of units available for appropriation in the future. In order to resolve stock externalities, the appropriation behavior of users must be regulated, rather than their use of the resource space.

As stated in the previous section, users of CPRs with fugitive flows experience greater assurance problems, information inadequacies and costs, and uncertainty. It is more difficult for users to understand whether a decline in

flow is merely a temporary deviation or evidence of a longer-term phenomenon. Even if users become convinced that the stock externality is not merely a temporary deviation, diagnosis of the cause of a decline in the flow of fugitive units is itself problematic. The effects of users' appropriation activities in one period on the flow of units in another period is not clear. Other plausible hypotheses present themselves: perhaps some migratory patterns or precipitation patterns have shifted, perhaps some infestation or pestilence is at work, perhaps someone or something outside the resource has affected the flow, and so on.

Users face serious difficulties in crafting acceptable solutions when the cause of their problems cannot be determined clearly. Users in these situations have greater incentives to reject, or cheat upon, agreements to limit appropriation. At a minimum, the incentive for any user to attempt to restore the stock and reduce the externality by limiting appropriation activity is severely diminished in CPRs with fugitive flows.

In some instances, these difficulties in ascertaining and addressing the incidence and causes of stock externalities are compounded by the fact that the fugitive flow units actually exit the boundaries of one resource and flow through multiple resources. This may be the case with wildlife or aquatic species that migrate beyond the bounds of a single resource. In such instances, groups of users exist and operate within systems of linked or nested CPRs, and the users in any one resource cannot control the flow even if they act collectively. Users therefore may generate stock externalities not only for their fellow users within the confines of a given resource, but for users of other resources that share the common fugitive flow, even though these other users may appropriate flow units from a resource hundreds or even thousands of miles away, across national borders, etc. In addition to the greater transaction costs and communication barriers created by the larger and more heterogeneous user group in such situations, the fugitiveness of the flow units aggravates the stock externalities problem in two ways: first, users in any one of the resources sharing a common fugitive flow may (indeed, are likely to) attribute flow declines to the behavior of users elsewhere in the system; second, because no one group can control the flow and capture the benefits of collective action, users in any one resource are less likely to provide benefits for users elsewhere in the system by restraining their own appropriation activities.

Parallel observations apply to the effect of stationary or fugitive flows on provision problems and users' prospects for overcoming them. First, users are more likely to engage in provision-side activities — development, maintenance, or protection against degradation — if those activities relate to the resource from which users appropriate rather than to the flow units appropriated. Second, users are less likely to commit to or engage in provision activities that relate to fugitive flow units. Third, users are least likely to engage in provision-side activities that will enhance, maintain, or protect the flow in the case of fugitive flows that pass through multiple resources.

Generally, development or maintenance efforts will be more likely to be directed toward the resource rather than the flow units themselves. Several such options may be feasible even when the flow units yielded by the resource are fugitive. Fishers may place fish shelters in a fishing ground or protect feeding or spawning areas, and irrigators may line irrigation canals or maintain diversion ditches.

On the other hand, maintenance efforts directed toward preserving the flow units may be more difficult to achieve in CPRs with fugitive flows. An example in a biological resource would be restrictions on the harvesting of units that are capable of reproduction. Maintenance failures regarding the flow are more likely in CPRs with fugitive flow units for the same reasons stock externalities are more difficult to overcome: assurance problems, information inadequacies and costs, and uncertainty are greater when flows are fugitive. It is more difficult for users to diagnose what is going on in a CPR with fugitive flows — e.g, whether declining result from excessive appropriation, maintenance failure, or neither — and thus whether increased maintenance efforts will mean that flows will exist or be more abundant in future periods.

Resource users are more likely to address development or maintenance failures if by enhancing or maintaining the resource they are able to capture the benefits from such investments. If fugitive flows exit the resource and pass through multiple resources, users are substantially less likely to engage in development activities that will enhance the flow or maintenance activities that would avert depletion. Moreover, as with stock externalities, the presence of multiple resources sharing a common fugitive flow compounds the uncertainty about the incidence and causes of flow declines.

Finally with respect to provision problems, fugitive flows may have their most deleterious effect on degradation problems. The incentives for users to take actions or make contributions to protect a fugitive flow — whether to protect the quality of water in a surface stream, a wetlands area or other habitat of migratory species, etc. — are sharply attenuated relative to those incentives when flow units in a CPR are stationary. The negative consequences of degradation are (literally, from an individual user's viewpoint) passed on to others.

Storage and Appropriation and Provision Problems

The availability of storage in a CPR relates to virtually the entire range of appropriation and provision

problems identified above. In fact, because the availability of storage in a CPR allows users to capture and contain flow units, at least temporarily, storage can help users of CPRs with fugitive flows overcome some of their appropriation and provision problems.

Among appropriation problems, the possibility of storing flow units within a CPR most clearly affects stock externalities. The ability to store flows lessens the uncertainty that aggravates stock externalities. Storage can smooth the pulses of flows in a CPR, deferring surpluses for later use. Under those circumstances, users may be able not only to understand better the relationship of current appropriation activities to future flows, but to exercise a greater degree of control over that relationship. As stated earlier, storage also alleviates the assurance problem, reducing the incentive to follow "first capture" or "use it or lose it" strategies that drive stock externalities in many CPRs. If users can store flows, cycles of depletion may be interrupted before they pass a critical threshold and move toward extinction.

Storage also has profound effects on assignment problems. The availability of storage enlarges the range of assignment options from which users may choose in allocating access to and use of a CPR. Users may be more reluctant to accept allocation schemes based on individual quotas or quantity restrictions in the absence of storage. Without the ability to "bank" flow units, the availability of flow units to any one user is likely to be (or at least to be perceived as being) a function of space and time — i.e., who gets to be where and when. Storage makes use of the resource less space-and-time dependent by making flow availability less space-and-time variant, ensuring to a greater degree that flow units will be available to a given user in a specified quantity. In a resource with storage, quantity assignments may not only be feasible, but may even be made variable, depending on the availability of stored units — e.g., quantity assignments may be increased in time t to draw down the number of units in storage, and decreased in time (t + i) to replenish the number of units in storage.

The effect of storage on technological externalities is less clear, but appears to us to relate to the reduction in the space-and-time dependence of resource use. In resources with storage, users may be less likely to conflict with each other's appropriation activities, and more willing to defer or relocate their appropriation activities if they do conflict, because the availability of flow units is less a function of space and time.

With respect to provision problems, the relationship of storage to degradation problems is also less clear than its relation to development or maintenance failures. The willingness of users to engage in or contribute to efforts to protect the quality of flow units does not appear to us to be clearly a function of the presence or absence of storage.[4]

With respect to both development and maintenance failures, the principal effect of storage in a CPR is upon the certainty that users will be able to capture and enjoy the benefits of their efforts. In resources with storage, users can be more certain that actions taken to augment or maintain the resource and the flows it generates will provide them with greater availability of valued flow units in the future. The connection between actions taken in the present and benefits reaped in the future is less tenuous under these circumstances.

With particular reference to development, feasibility of storage enlarges the range of augmentation options. Users of CPRs where storage is feasible (such as a canal irrigation system) have more options for augmenting the flow of units (in this case, the amount of water in their canals) than do users of CPRs where storage is infeasible (such as a fishery).

With particular reference to maintenance, it must be observed that, while storage enhances users' prospects for overcoming some maintenance failures, it also adds to the number of aspects of the system that must be maintained. Storage facilities (natural or human-made) in CPRs themselves must be maintained, which increases the possibilities for some kind of maintenance failure to occur. We do not offer an a priori estimation of whether the maintenance benefits of storage in a typical CPR will outweigh the additional maintenance costs.

Evidence from Empirical Studies of Three of the Four CPR Types

In earlier individual efforts, we have conducted research on three of the four types of CPRs identified in Figure 1. Unfortunately, we do not have empirical evidence to relate concerning examples in cell 2 — CPRs with stationary units but for which storage is infeasible, such as grazing areas and forests. We can relate evidence from fisheries as examples of CPRs in cell 1 (fugitive, storage infeasible), canal irrigation systems as examples from cell 3 (fugitive, storage feasible), and groundwater basins as examples from cell 4 (stationary, storage feasible).

Cell 1; Fisheries. Since storage is infeasible in many fisheries, fishers do not have access to the many ameliorating effects storage has upon fugitive flows. Consequently, the defining characteristic of many fisheries is their fugitive flows. The ability of fishers to cooperate and the types of common-pool dilemmas that they will attempt to address are heavily influenced by this characteristic. That is, fishers are more likely to address dilemmas that arise in relation to fishing grounds, and much less likely to address dilemmas that arise in relation to the fugitive flows of fish through their fishing grounds.

Data collected from in-depth case studies of twenty-four different inshore fishing grounds located around the world will be used to test the above research question.[5] These inshore fisheries are located in fourteen different countries, and are utilized by thirty-seven distinct subgroups of fishers (see Table 1). The subgroup is the unit of analysis and refers to a group of fishers who harvest from the same fishing ground and who are relatively similar in relation to the following five characteristics: 1) their legal rights to appropriate fish, 2) their withdrawal rate of fish from a fishing ground, 3) their exposure to variation in the supply of fish, 4) their level of dependency on fish withdrawn from the resource, and 5) how they use fish, i.e., for consumption, for sale, etc. Thus, a group of fishers must share similar circumstances, as just defined, in relation to commonly shared fishing grounds to be a subgroup.

The average number of fishers constituting a subgroup is 189, with the smallest group having 33 members and the largest group consisting of 387 member. The members of each subgroup are relatively homogeneous. Most groups consist of men who share similar racial, ethnic, linguistic, and religious backgrounds. In addition, fishers within each subgroup have access to meeting places, that provide forums to discuss problems they confront in fishing. Given the cultural homogeneity of the fishers of each subgroup, the regular interaction of their members, and the fact that the fishers of each group are similarly situated in relation to their fisheries, the primary barriers to cooperation that most subgroups face are information problems, uncertainty, and assurance problems.

The types of common-pool resource dilemmas that the thirty-seven subgroups of fishers have faced or continue to face are technological externalities, assignment problems, declines in stocks of fish which may indicate stock externalities or maintenance problems, and declines in the quality of fish harvested which may indicate maintenance or degradation problems (see Table 2).[6] The distribution of dilemmas across subgroups includes fourteen subgroups that have faced a single dilemma, eighteen subgroups that have faced more than one dilemma, two subgroups that have faced all dilemmas, and three subgroups for which there is insufficient data to determine whether they have faced any of the dilemmas.

Among the 34 subgroups that have faced one or more of the common-pool resource dilemmas, fishers of 27 subgroups have cooperated to devise rules that govern their use of their fishing grounds. Before examining the types of rules fishers have devised it is necessary to first examine the types of rules fishers do not utilize. The types of rules fishers have not devised, and hence do not utilize, are as informative as the types of rules that they have devised and utilized.

Among the 27 subgroups that have devised rules, no subgroup has devised rules that limit the amount of fish that fishers can harvest. Fishers have not devised quota rules that would limit their catch levels (see Table 3). By limiting the amount of fish (i.e., fugitive flow units) that may be harvested, quotas are the most direct means of addressing stock externalities and maintenance failures that arise in relation to the flow units. Yet, fishers have not derived such rules, nor have they devised other rules that could address maintenance failures in relation to fish stocks, such as rules establishing fishing seasons. Fishing seasons typically prohibit harvesting during spawning periods so that fish have an opportunity to reproduce before they are captured, thus ensuring future flows of fish. The only rules that fishers have devised and utilized that are directed at managing the flows of fish in their fishing grounds are minimum size rules. Only fish larger than a specified size may be harvested. Minimum size rules operate in a similar manner to fishing season. Typically, fish above a certain size have had the opportunity to spawn at least once. Only four subgroups, however, have adopted minimum size rules, and the effects of such rules have been mixed. Two of the subgroups have, over time, experienced declining flows of fish, whereas two subgroups have not experienced declining flows.

The lack of rules directed at dilemmas that arise in relation to fugitive flows, such as stock externalities, provides evidence that fishers are unlikely to cooperate to govern the fugitive flows of fish in their fishing grounds. Flows of fish vary within a single year and from year to year, often unpredictably. The causes of variability of fish flows are many, and include human actions and environmental events. Consequently, it is not always clear to most fishers that their harvesting activities have any impact on the availability of fish.[7] Also, because so many fishing grounds share common flows of fish, fishers within any particular fishing ground are uncertain whether any actions they would take to limit their harvesting levels would have any positive effects.

On the other hand, the 27 twenty-seven subgroups of fishers who have devised rules, overwhelmingly have devised rules that govern their use of the space of their fishing grounds. All 27 subgroups have faced technological externalities, assignment problems, or both, and they have attempted to address and resolve those dilemmas. All 27 subgroups require that fishers engage in harvesting activities in specific areas, or spots, of fishing grounds. In some instances different types of gear are relegated to different areas of the fishing ground, in part, as a method of minimizing technological externalities. For example, the cod fishers of Fermeuse, Newfoundland, as discussed by K.O. Martin (1973, 1979) have

> divided their own fishing grounds, as have many inshore fishing communities, by setting aside certain fishing areas (usually the most productive) for the exclusive use of certain technologies. (Martin 1979,:285)

The fishers of Port Lameron Harbour, Nova Scotia, have done the same. "A rectangularly shaped area stretching from the Gate Rocks to the Half Moons and out to the Fairway Buoy is reserved primarily for herring and mackerel gillnets," whereas the area around Brazil Rock is reserved for handlining for cod (Davis, 1984, 141-143).

In other instances, rules requiring fishers to harvest from specific spots within a fishing ground allocating scarce productive spots and thereby resolve assignment problems. Often times specific spot rules will be combined with other types of rules such as "harvest in a specific order" or "harvest during a fixed time slot" so that all fishers have equal opportunities of harvesting from the most productive spots over the course of a year. For instance, the fishers of the estuary adjacent to Valenca, Brazil, would draw lots to determine the order in which each boat would harvest from a productive spot. Each boat crew was permitted to cast their net once and then they were required to move off of the spot so that the next boat in turn could harvest from the spot (Cordell, 1972: 42).

One of the most elaborate arrangements for assigning productive spots, however, has been devised by the fishers of Alanya, Turkey (Berkes, 1986). Prior to 1960, the fishers of Alanya did not experience assignment problems. There were fifteen fishers and fifteen productive spots utilized. After 1960, the number of fishers increased and severe conflict erupted as fishers competed for a limited number of spots. Over a period of fifteen years the fishers developed a lottery and rotation system as a method of allocating the best fishing spots. At the beginning of the fishing season a list of fishers who want to participate in the fishery and a list of the named fishing spots are drawn up. Fishers then gather at the coffeehouse to draw lots for the named spots. Since the number of fishers exceeds the number of spots some fishers draw blanks. That does not mean they cannot fish, rather they are rotated into the system.

> From September to January each fisherman moves to the next site east each day. The "excess" fishermen are rotated in, and those who hold the blanks can rest or mend nets off go long-lining. After January, as the fish reverse their migration from west to east, the fishermen also reverse their movements and shift one site to the west each day, until the end of the season. (Berkes, 1986:17)

Thus, the fishers of Alanya combine spot rules with time and turn rules to create an intricate system in which each fisher has an opportunity to fish from all of the productive spots over the course of a season.

The use rules that fishers have devised to address technological externalities and assignment problems have been relatively successful. Among the twenty-four subgroups that have experienced technological externalities, thirteen have stabilized or reduced the level of technological externalities, and there was insufficient data for two of the subgroups to determine their outcome. Among the seventeen subgroups who have experienced assignment problems, thirteen have resolved those problems whereas four have not.

Nearly all of the 27 subgroups of fishers who have cooperated to devise use rules have done so by addressing problems related to the physical structure of their fishing grounds, as opposed to problems related to the flows of fugitive fish through their grounds. They have almost exclusively focused upon resolving technological externalities and assignment problems. Fishers can readily identify the causes of these problems. Most of the fishers harvest from the same set of fishing grounds over their lifetimes, the same set of fishing grounds that their fathers and grandfathers harvested from (Davis, 1984). Consequently, they possess extensive knowledge of the structure of their grounds. Given the daily interactions among fishers, and their extensive knowledge concerning the problems that arise in relation to their use of their fishing grounds, fishers can more easily devise and experiment with rules to resolve such problems.

Cell 3: Canal Irrigation Systems. Cell 3 CPRs are characterized by fugitive flow units and the feasibility of storage. Canal irrigation systems are an example. The water in a canal irrigation system is a fugitive flow, but it is possible to capture the units within such storage structures as reservoirs and water tanks.

Because of its fugitive nature, the water flow in an irrigation system may vary drastically, depending on the configuration of various physical and ecological factors. However, once water is captured and stored, its flow can be evened out and appropriated as needed. In general, users can inventory the water flow and estimate the amount available for appropriation at particular times.

In canal irrigation systems, an important task is water control. Water control is the ability of the users to apply the right amount of water to crops at the right time. This requires the proportioning of supply to demand from the crops. The ability of irrigators to control the water is affected by many physical factors, including the pattern of water flow and the availability of storage facilities.

•The availability of information and the degree of predictability of water flow are significant factors

affecting cooperation among users. To develop productive agricultural practices, irrigators need to have a certain degree of assurance about water availability, especially during crucial growth stages of the crops. If water flow is highly unpredictable, users have few incentives to cooperate with one another in tackling appropriation and provision problems.

Farmers' vulnerability to scarcity and uncertainty in the water flow and its effects on their incentives for collective action have drawn special attention in the irrigation literature. Wickham and Valera (1979), in a study of irrigation projects in the Philippines, observe that in order to induce farmers to cooperate in managing their watercourses, an effective system-wide management program is a prerequisite. In other words, farmers have less incentive to organize if they lack a predictable or sufficient flow of water into their watercourses in the first place. This observation seems to contradict that of Wade (1988a) who, drawing on experiences in South India, argues that the greater scarcity and uncertainty of the water supply, the greater the likelihood that a community of cultivators will develop collective arrangements for appropriation and provision.

Although these two arguments appear to be directly contradictory, they may be consistent when presented in a more general context. Irrigators' vulnerability to scarcity and uncertainty in water supply may be related in a curvilinear fashion to their incentives for cooperation (see Uphoff, Wickramasinghe, Wijayaratna, 1990). Farmers have to be sure of at least some minimal availability of water before they are willing to invest in collective efforts in water allocation and maintenance. On the other hand, if the water supply is abundant, investments in water allocation and maintenance make little sense. But under conditions of moderate scarcity, keeping regular appropriation and maintenance schedules may strongly affect the amount of water available to farmers' fields. Thus, little cooperation by farmers can be expected under conditions of either extreme abundance or scarcity. Most cooperative activities will occur in situations where water is barely sufficient or moderately scarce and farmers believe that their cooperative efforts can improve their chance of securing a more reliable supply of water.[8]

An inadequate and uncertain supply of water, however, could create barriers for cooperation. As the supply of water decreases,.the temptation for free-riding in water acquisition increases. Monitoring and sanctioning efforts must be increased in order to enforce discipline in water allocation. Furthermore, more conflicts are likely to arise among irrigators as they compete for a scarce source of water. In some situations, farmers may be able to increase the water flow to their fields by damaging the canal embankment. This again increases maintenance difficulties for the irrigation system. All of these could increase the barriers to resolving commons dilemmas in irrigation systems.

Thus, in situations between extreme abundance and extreme scarcity, farmers expect both potential benefits and costs in their participation in collective action. On the one hand, if they are successful in collective action, they may be able to receive a more adequate and reliable supply of water; there is a "demand" for collective action. On the other hand, the potential costs created by water scarcity and uncertainty make their cooperation with one another more difficult, thus inhibiting the "supply" of collective action. One may expect that in the real world many irrigation systems fall within this middle range, and whether farmers in these systems will be successful in governing and maintaining their systems depends on the balance between the benefits and costs they face (Tang, forthcoming).

The prospects for cooperation in canal irrigation systems is affected by another common characteristic of water flow — the difference in flow volume between the headend and the tailend of a canal. In most canal irrigation systems, headenders have a natural advantage over tailenders in access to water. Because of their more favorable location relative to tailenders, headenders may have little incentive to cooperate with tailenders in water allocation. As documented by many authors, unless irrigation systems are well organized, headenders tend to take more water than is necessary for the growth of their crops to the detriment of tailenders (Bromley, 1982; Chambers, 1977).

Depending on how plots are distributed along the main canal in a watercourse, irrigators face different incentives for cooperation. Ascher and Healy (1990) document the problems associated with the Jamua Irrigation Project in India. The designers of the project presumed that once water began to flow in the main canal, farmers would jointly construct field channels to divert water from the canal to their fields. This spontaneous cooperation did not happen because farmers located near the canal had little incentive to devote their efforts in constructing channels that would deliver water through their own fields into those of others.

Mirza and Merrey (1979), in a study of ten watercourses in Pakistan, find that a watercourse is likely to be better maintained if there is a concentration of power and influence at the tail or at the tail and middle of the watercourse. This is because the powerful and influential people have resources as well as incentives to help organize water allocation and maintenance activities in the watercourse so that sufficient water can reach their fields located in the middle and tail portions of the watercourse.

While the pattern of water flow and the positioning of irrigators along the system affect incentives for cooperation, irrigators may achieve better control over the water flow if storage facilities such as reservoirs and

water tanks are available at the watercourse level. These intermediate storage facilities are especially important because, at the watercourse level, water begins to move from the public into the private domain. It is at this point that various appropriation problems arise. The existence of storage may help to smooth the water allocation process at this level.

A potential contribution of storage facilities is to increase users' control of water, that is, to reduce uncertainty in the water flow. Farmers will be more confident in their irrigation practices if there is a local water tank to serve as an inventory buffer. Even though the amount of water delivered to their watercourse may suddenly drop, farmers can still rely on the tank water to irrigate their crops for a while. This inventory buffer is especially important during certain stages of the crop growth when insufficient water will be detrimental to crop yields.

Storage tanks at the watercourse level help to reduce the coordination load of the system-level management (Wade and Seckler, 1990) . With these tanks, irrigators are able to match water supplies to local irrigation needs more precisely, which may not be possible if the system-level management has to bear the information and transaction costs needed to fine-tune water supplies to various watercourses.

Storage facilities also induce irrigators to conserve water because the water can be retained for future uses. Irrigators have less incentives to pursue "first capture" if they can be assured that they have a reliable access to a certain amount of water. With their increased ability in water control, irrigators are more likely to cooperate in water allocation and maintenance activities in their watercourses. Wade (1988b) indicates that canal irrigation systems in East Asia normally consist of linked series of small reservoirs and canals, which are mostly absent in irrigation systems in South Asia. This may partly explain why irrigation systems in East Asia tend to be better managed than those in South Asia.

Although storage facilities may increase confidence among irrigators, they also create additional provision problems. For example, whenever the flow of water is interrupted or banked, silt accumulates. Without efforts to remove silt regularly, the storage facilities will cease to function. Regular maintenance of the storage facilities becomes another commons dilemma for irrigators. Furthermore, although storage may facilitate water control, the actual utility of the storage facilities depends on the proper operation of gates and other physical devices that control the flow of water. Sometimes, such control potentials generate other types of governance problems: who is to be responsible for opening and closing of gates? Unless a system exists to ensure whoever operating the gates will do so in accordance with the needs of irrigators, such facilities may be counterproductive.

In conclusion, the pattern of water flow and the availability of intermediate storage facilities are two major physical characteristics that affect the incentives for cooperation among irrigators. Although these two characteristics create no deterministic effects on cooperation among irrigators, they create constraints and opportunities that irrigators have to consider when attempting to develop their cooperative arrangements for appropriation and provision.

Cell 4: Groundwater Basins. Cell 4 CPRs, such as groundwater basins, have relatively stationary flow units plus feasible storage. The subterranean movement of water into, out of, and through a groundwater basin is so slow as to be relatively stationary from a user's perspective. Groundwater basins also have capacity to store water, although the amount and usefulness of that capacity differs among basins.

The evolution of institutional arrangements in seven southern California groundwater basins demonstrates the effects of stationarity and storage on the collective decisions taken by users. All seven basins experienced severe CPR problems, which became most acute in the middle decades of this century, as irrigated agriculture competed with, and ultimately yielded to, the rapid development of the southern California metropolis.

Collective action to address severe overdraft problems began in two of the basins during the 1930s. In the Orange County basin (Blomquist, 1987d), users initially organized for the provision-side activity of augmenting the supply of water to the basin, by increasing the inflow of the principal surface stream that replenished the basin water supply and by improving the stream channel to raise the rate of replenishment. Users created a public jurisdiction — the Orange County Water District — to pursue these development activities. Those activities reflected the opportunities created by the stationarity and storage capacity. Users perceived the advantages of taking fugitive surface water flows and moving them underground, where they could be appropriated as needed by pumpers. In the 1950s, water users further institutionalized these arrangements by authorizing the Orange County Water District to tax groundwater pumping in order to finance purchases of replenishment water.

Users chose a different approach in the nearby Raymond Basin in Los Angeles County (Blomquist, 1987a). No collective efforts were made to augment the basin flow. Instead, an adjudication resulted in the determination of specific pumping rights based on historic use. Total pumping rights were limited to a fixed estimate of the basin's annual "safe yield." The overdraft ceased, and the decline in underground water levels halted, and even reversed. After a few years' experience under the pumping restrictions, it appeared to pumpers that the estimate of the basin's safe yield had been too low. Individual and total pumping rights were adjusted upward slightly, and have remained at that modified level for 35 years.

Water users in two other Los Angeles County groundwater basins followed the Raymond Basin example between the mid-19403 and the mid-1960s. Adjudications in the West and Central basins produced determinations and limitations of pumping rights based on historic use (Blomquist, 1987b, 1987c). However, users in these two basins went beyond mere quantity restrictions in three important ways. First, they authorized the leasing or sale of pumping rights, so individual quotas were transferable. Second, they adopted a program of taxing pumping to pay for imported water for basin replenishment, which facilitated users' willingness to accept the pumping restrictions. Third, because West and Central basins are coastal basins, they faced serious degradation problems due to salt-water intrusion from the ocean, which users addressed by constructing and operating fresh-water injection barriers along the coast. (Subsequently, the Orange County Water District, which also governs a coastal basin, constructed barrier projects, too.)

New concepts in groundwater basin management, focusing on the active use of basin storage capacity, appeared during the 1960s. Thereafter, three more major groundwater basins in and around the Los Angeles area were adjudicated, but on a substantially different basis. The Main San Gabriel and San Fernando Valley basins in Los Angeles County were adjudicated during the 1960s and 1970s (Blomquist, 1988, 1990a), and the Chino Basin in the west end of San Bernardino County in the 1970s (Blomquist, 1990b). In these basins, instead of being assigned fixed pumping rights aggregating to a fixed safe yield, pumpers are assigned shares or proportions in a variable "operating safe yield" set each year in each basin by court-appointed watermasters. The "operating safe yield" is determined on the basis of both the basin's normal yield and water storage conditions within the basin. Watermasters are obliged to monitor the basin's available storage capacity and to maintain water in storage within desirable ranges. Furthermore, certain types of water users (overlying water districts in the Main San Gabriel Basin, municipalities in the San Fernando Valley Basin, and municipalities and other appropriators in the Chino Basin) are authorized to enter into agreements with their respective watermasters to store water in the basin for later use. Users in the Chino Basin may even sell their stored water to other pumpers.

On the other hand, it must be stated that water storage in a basin adds to the complexity of the basin management system, with potential for erroneous calculations. In the Chino Basin, for example, the Chino Basin Watermasters increased the amount of water in storage so much that water in the lower portion of the basin rose near the land surface, and users in that area complained that their water supplies were being contaminated by nitrate concentrations in the upper soil layers.

The relative stationarity of groundwater and storage capacity of groundwater basins has influenced the evolution of institutional arrangements for managing these basins in southern California. Users in six of the seven basins assigned rights to specific quantities of pumping from the basin, a flow allocation scheme that is substantially easier to devise, implement, and enforce with stationary flows. In the seventh basin, Orange County, pumpers are not limited to specific quantities of pumping, but are required to record and report their water production to the Orange County Water District and to pay taxes upon it. The district uses differential tax rates on pumpers to encourage conservation as necessary.

Conservation (i.e., restraint on pumping) in all seven basins is facilitated by the stationarity of flows and the availability of storage capacity. All seven basins authorize users to engage in "in lieu replenishment" of the basin (withholding pumping from the groundwater basin in certain periods in exchange for a reduced price on purchases of surface water when it is available in adequate quantities), and the six adjudicated basins permit users to "carry over" unused pumping rights from one year to the next. Neither of these management options would be as feasible if flows were fugitive or could not be stored within the basin.

Finally, the availability of storage has encouraged users to engage in provision-side activities for CPR management in addition to appropriation-side activities. In most of the basins, programs have been instituted for replenishing and storing water within the basin to augment future flows. In the three coastal basins (West, Central, and Orange County) , users have financed very expensive barrier projects to halt the degradation of water quality resulting from sea-water intrusion. These options also would be considerably more problematic were flows not relatively confined, making users more confident that they would reap the benefits of their provision actions.

Conclusion: Stationarity, storage, and the Prospects for Resolution of CPR Dilemmas

Thus far, our conjectures about the effects of stationarity and storage on the prospects for resolution of CPR dilemmas have been relatively tentative and qualified. In this concluding section, we offer some bolder conjectures as well as some directions for further research.

A summary statement of our conclusions, based on analytical and empirical contemplation of CPR problems and their resolution, is this: the physical characteristics of stationarity and storage affect (1) the types of CPR problems resource users are most likely to attempt to

resolve; (2) the relative ease or difficulty with which users will be able to reach resolutions of those types of problems; and (3) the kinds of resolutions they are likely to adopt. If this conclusion holds, efforts to find a single institutional reform or policy alternative for the resolution of CPR dilemmas are misdirected. At a minimum, we believe this conclusion is sufficiently well supported to warrant further research.

Our somewhat bolder conjectures involve our four-celled typology of CPRs based on the stationarity and storage characteristics. A first proposition is that the four CPR types may be linked with the typology of appropriation and provision problems to indicate which types of problems users of which types of CPRs are more likely to attempt to resolve. Recognizing that characteristics of CPRs condition, but do not induce or determine, the choices of users, we propose the following figure. In general, we conclude that stationarity encourages users to address stock externalities and provision problems while fugitiveness discourages them from doing so, and that storage encourages users to attempt to resolve provision problems (though it may create additional provision problems for them to resolve). Together, stationarity and storage enlarge the range of appropriation and provision problems users are likely to address.

	Cell 1	Cell 2	Cell 3	Cell 4
Appropriation Problems:				
Technological externalities	+	+	+	+
Assignment problems	+	+	+	+
Stock externalities	-	+	-	+
Provision Problems:				
Development failures	-	-	+	+
Maintenance problems	-	+	+	+
Degradation problems	-	?	?	+

Figure 2 (+ = users more likely to address; - = less likely)

A second proposition is that the four CPR types we have identified can be arrayed along a spectrum that reflects the relative ease or difficulty users will experience in trying to reach resolutions of CPR problems. Figure 3 below is based on the effects of stationarity and storage on the barriers to resolution discussed earlier. Barriers to

cell 1 — Cell 3 — Cell 2 — Cell 4

← Greater difficulty ——— Lesser difficulty →

Relative difficulty of reaching resolutions

Figure 3

resolution tend to be exacerbated by fugitive flows and the absence or infeasibility of storage. Further, the presence of feasibility of storage can ameliorate some of the difficulties created by fugitive flows.

A third proposition is that the four CPR types can be related to the kinds of resolutions of CPR problems, particularly appropriation problems, users are likely to reach. In attempting to resolve appropriation problems, users of some CPRs will be more likely to rely on access limitations, or spatial or temporal restrictions on use of the CPR. In other CPRs, users will be more likely to devise individual quotas or quantity restrictions on use. Our anticipation about these relationships is shown in Figure 4. Users of CPRs with stationary flows should be more likely to reach resolutions involving quantity restrictions than users of CPRs with fugitive flows, and users of CPRs with storage should be more likely to reach resolutions involving quantity restrictions than users of CPRs without storage.

Cell 1 Cell 3 Cell 2 Cell 4

Access limitations/ Spatial/temporal restrictions on use — Quantity restrictions on use

Types of resolutions of appropriation problems

Figure 4

Our suggestions for further research are obvious; we will not belabor them. None of us has yet done research on Cell 2 CPRs; this plainly is necessary. Empirical research on other examples of Cell 1, Cell 2, and Cell 3 CPRs also is necessary to confirm or disconfirm the typology's usefulness. Another interesting area of exploration would be the interaction of the physical characteristics we have discussed with other physical characteristics of CPRs, such as those mentioned in Footnote 3. Each of these endeavors would advance the effort to understand the processes and the prospects of resolution of CPR dilemmas.

NOTES

1. As Gardner, Ostrom, and Walker point out (1990: 338), it should not be assumed that all common-pool resource situations are necessarily problematic. There may be instances where no problems have arisen. There may be other instances where resource users have collectively resolved problems that have arisen. See also Berkes (1989) and McCay and Acheson (1987).

2. Several authors use the term "common property" rather than "common pool." Howe (1979), observes that the term "common property" is used to refer to a particular type of property regime in which a defined group of individuals manage and use a resource collectively. He warns that common property (res communes) should not be equated with the absence of property rights (res nullius). Berkes (1987), Runge (1987), and others also have attempted to reclaim the term "common property" as referring to a particular type of property regime rather than to a situation of "open access." Bromley and Cernea (1986: 6) emphasize:

> Our primary purpose here is to challenge the fallacy of what has been passing as received doctrine about group-managed natural resources in the developing world. Among these regimes, common property carries the false and misplaced burden of 'inevitable' resource degradation that instead has to be causally attributed to situations of open access.

For an attempt to differentiate among types of property systems, including "common property," see Schlager and Ostrom (1990).

3. Of course, common-pool resources differ on other physical characteristics, as well. As Howe (1979) and others have observed, an important physical feature of CPRs is whether they are renewable. Another important physical characteristic is whether flow units are distributed unevenly throughout the resource, making some "spots" better than others (this is not the same as the fugitive/stationary distinction, since either fugitive or stationary flow units could be distributed unevenly). Another noteworthy feature is whether the resource is hidden from view (as with oil deposits or groundwater), which plainly affects the availability of information about its dimensions and capacities. Thoughtful readers undoubtedly will be able to bring to mind other physical characteristics that differentiate among CPRs. Four our purposes, we explore the implications of stationarity and storage, without implying in any way that these are the only two physical