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## Complex Landscapes

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### WATERSHEDS AND INSTITUTIONS

Every watershed has a physical landscape—a complex terrain of landforms, water resources, vegetation, animals and their habitats, human beings and the structures they have built. Every watershed has an institutional landscape, too—a complex but largely invisible terrain of rules and organizations that govern and affect human choices about the making of decisions, the use of resources, and the relationships of people to nature and one another. This book considers the institutional landscapes of watersheds, not in isolation from the physical world but in connection to it, recognizing that watersheds have both physical and institutional landscapes.

Institutions are political—not in the limited sense of Democratic or Republican, conservative or liberal, or labor and so forth, but in the larger sense of involving choices about who may participate in decision making and how, what actions can be taken and under what conditions, what issues fall into which jurisdictions, and how and by whom current actions and past decisions can be examined, critiqued, and modified. Political scientists are fond of saying that politics is about power, which is true. “Power,” however, is not necessarily employed in this book as the word is used in ordinary conversation, where it makes many people uncomfortable and suspicious. Politics is about power because politics is about who can do what and when and under what conditions and under what limitations. In that broad sense, politics is about all of us in all the landscapes of our lives. Politics is even part of how people relate to nature, and so it matters in watersheds.

Without question the institutional arrangements in most watersheds in the United States are complicated. There are nongovernmental components (associations, councils, trusts, etc.) as well as governmental ones. The governmental components are themselves complex, being embedded in a political system that features the separation and sharing of powers as well as federalism and its web of intergovernmental relations. Furthermore, neither governmental nor nongovernmental elements of the institutional landscapes of watersheds remain fixed for long. Organizations and the rules governing them change. Like their physical counterparts, institutional landscapes shift, sometimes almost imperceptibly and at other times dramatically.

How, then, to understand the institutional as well as the physical landscapes of watersheds? Much has been gained recently in understanding the physical dimensions of watersheds and other ecosystems by viewing them as complex adaptive systems. That view can be applied also to understanding institutions relating to watersheds. First we will summarize briefly the view of watersheds as complex adaptive systems, and later in the chapter we will connect that view to the understanding of institutions and what these complexities mean for organizing the management of watersheds.

## COMPLEX ADAPTIVE SYSTEMS I: ECOSYSTEMS AND WATERSHEDS

The idea and study of complex adaptive systems emerged in connection with rising interest in ecosystems. A significant literature on ecosystems as complex adaptive systems has developed (Holling 1978, 1986; Walters 1986;

Lee 1993; Grumbine 1995; Gunderson, Holling, and Light 1995; Stanley 1995; Carpenter 1996; Haueber 1996; Lackey 1998; Levin 1999; Low et al. 2003). The concept of complex adaptive systems is encapsulated elegantly by Low and colleagues (2003, 103), who write that “complex adaptive systems are composed of a large number of active elements whose rich pattern of interactions produce emergent properties which are not easy to predict by analyzing the separate system components.” The connection between complex adaptive systems and ecosystems is that ecosystems also consist of multiple interacting elements, the conditions and behavior of which change over time in ways that can yield unpredictable shifts and outcomes.

### Ecosystems, Watersheds, and Complex Adaptive Systems

The literature on ecosystems has had many points of overlap with the literature on watersheds. Watersheds fit the conception of ecosystems noted above and are often employed as examples of ecosystems (but this is not a one-to-one match since a watershed may be home to multiple ecosystems and a given ecosystem could contain more than one watershed). Although the ecosystem literature is not entirely about watersheds and not all contributions to the watershed literature include a discussion of ecosystems, each concept has contributed to the development of thought about the other.

When analysts and policy advocates try to apply the ecosystem concept to actual settings, they often use watersheds as examples. Ecosystems can be difficult to identify in a way that finds agreement among many people. As Ruhl (1999, 519) stated provocatively, “The term ‘ecosystem’ is much like Darwinism and Marxism, in that everybody ‘knows’ what it means, but after not very much discussion of the subject it turns out everybody’s meaning differs to some degree.” Barham (2001, 183) connects this difficulty with ecosystems to the attention that watersheds receive: “Setting precise boundaries around an ‘ecosystem’ has proven difficult. . . . For planners and policymakers in the public arena, the result has often been the adoption of the watershed or catchment basin as an ecosystem proxy. Watersheds, defined by the ridgetops that separate drainage basins from one another, provide ecosystem boundaries that are not as open to dispute in terms of their physical location.” Ruhl too advocates watersheds as proxy ecosystems for exactly this reason: “It is imperative . . . that policy decision

makers undertake a concerted effort to agree upon a single predominant controlling factor for ecosystem delineation. Of the realistic candidates for that purpose, watersheds stand out as the most suitable [and] most viable planning unit available” (1999, 521–522). With some satisfaction, then, Ruhl observes that “the use of watershed based planning as a foundation for ecosystem protection has grown steadily throughout the 1990s to the point of predominance” (522).<sup>1</sup>

Watersheds thus are not merely examples of ecosystems; they are seen by advocates of ecosystem management as near-substitutes for ecosystems and as an appropriate physical landscape on which to put ecosystem management concepts into practice.<sup>2</sup> Although we will have much more to say about the matter of watershed boundaries, it suffices here to note that the topographical manifestation of watersheds has pragmatically reinforced the conceptual link that already existed between watersheds and ecosystems.

Accordingly, the literature on complex adaptive systems may be seen as relating not only to the broad category of ecosystems but also to watersheds as ecosystems. Writing about watershed management projects in language compatible with the language of complex adaptive systems, Kerr and Chung (2001, 539) observe:

Spatial interlinkages related to the flow of water are inherent in watersheds. Water pollution upstream may harm downstream uses of land and water, while conservation measures upstream may benefit downstream use. Coordination or collective action is often required, which may be difficult because benefits and costs are distributed unevenly. . . . Since the extent of such complexity will vary by case, a project that works in one location may not work well in another. Subtleties in underlying differences can make it difficult for researchers to understand causal relationships governing project success.

The closing sentences of that observation underscore the roles of uncertainty and surprise that characterize complex adaptive systems, including ecosystems and watersheds. The difficulties of predicting watershed or ecosystem behavior are not merely a matter of intellectual curiosity: they are vitally connected with the challenges of management. We therefore turn to the topic of uncertainty and its relation to the understanding of complex adaptive systems such as watersheds and ecosystems.

## Complex Adaptive Systems and Scientific Uncertainty

“Uncertainty” is used in several contexts. Often it signifies a lack of complete information (insufficient data). Sometimes it means the presence of “noise” or risk due to the stochastic, or randomly varying, nature of some process. Underlying these standard or familiar definitions of “uncertainty” is an “assumption that we know or believe we know the basic cause-and-effect relationships—the system structure—in . . . whatever we are studying” (Wilson 2002a, 333), we just lack enough data to be more precise and accurate, or our predictions contain errors because of variability in the system. We might call these kinds of uncertainty “system uncertainty.”

By contrast, “scientific uncertainty” involves more than a lack of reliable data. Scientific uncertainty involves a lack of knowledge or absence of agreement among scientists about the nature of the resource system and its dynamic behavior, about what elements of the system are the best indicators of its overall condition, and about what changes in those indicators mean. By themselves, more or better data would not necessarily diminish or eliminate this kind of uncertainty.

Because the problem of scientific uncertainty has been discussed in the context of complex adaptive systems, people may think uncertainty is the same as complexity. As Emery Roe has usefully and clearly articulated, however, uncertainty and complexity are distinct. “Issues are uncertain when causal processes are unclear or not easily understood. Issues are complex when they are more numerous, varied, and interrelated than before” (2001, 111). Seeing this distinction helps avoid a misconception that underlies standard modern (often engineering-based) approaches to environmental management; namely, that the accumulation and integration of additional information will allow us to understand the complex processes better, which will reduce the uncertainty. Roe continues:

It is commonly said that, since ecosystems are complex, many of their causal processes are uncertain, which in turn requires learning more about these processes if the ecosystems are to be managed more optimally. Hence, the implicit notion is that complexity leads to uncertainty, which, if reduced, would allow for more complete management. . . . As ecologists remind us, it is also true that a deal of uncertainty remains, even after scaling down from the ecosystem to the site, where presumably the components are fewer if not less varied or interrelated. (2001, 111–112)

Uncertainty of this type is particularly troublesome for understanding or managing complex adaptive systems (Holling 1986; Lee 1993). Ecologists have struggled for some time with the challenge of being able to describe and predict ecosystem processes (Jordan and Miller 1996). With respect to the management of ecosystems in particular, Carpenter (1996, 118–119) observed that “a host of scientific uncertainties about the behavior of ecosystems under anthropogenic and natural perturbations continue to frustrate statistically reliable biophysical measurements and ecologic understanding.”

Wilson (2002a) contrasts the Newtonian world of controllable non-adaptive systems with the ecosystem world of complex adaptive systems. A problem with the latter is the pervasiveness of nonlinear relationships, making it difficult to trace the particular course of movement of one object in the system and, from that information, predict the reactions of other objects. In Carpenter’s words, “Almost all real systems, and certainly all ecosystems, are nonlinear (small change in a parameter can lead to a sudden large change in behavior)” (1996: 134). Past approaches to managing ecosystems have typically assumed “relatively complete (if stochastic) biological knowledge operating in a Newtonian world” (Wilson 2002a, 342). Actual experiences (more bluntly, observed failures) in ecosystem management suggest that the Newtonian view does not apply readily to complex adaptive systems, and perhaps not at all.

Why is scientific uncertainty of this sort particularly associated with complex adaptive systems such as ecosystems? The literature on uncertainty in ecosystem management discusses at least three distinct but interrelated reasons: differential rates of change among system components, scale differences, and disturbance processes.

The factors that make up a complex adaptive system such as an ecosystem typically change at different rates. Species populations within the system change at different rates. A host of ambient environmental conditions connected with ecosystem conditions (e.g., temperatures, air or water quality, soil composition) change at different rates. Anthropogenic impacts on the system (e.g., harvesting behavior or technologies) change at different rates as well. In and of themselves, differential rates of change present a complexity problem rather than an uncertainty problem. The uncertainty problem arises from the fact that in a complex adaptive system, elements respond to changes in other elements so the differential rates of change yield alterations that are not mere linear extensions of trends. Relationships and effects are

contingent. “State shifts” occur among system elements as the configuration of other elements changes. Thus, a one-degree temperature change in combination with one configuration of ambient conditions produces little effect on a species population, but an additional degree of temperature change occurring in combination with a slightly different configuration of other ambient conditions produces a crash or a surge in that population, which triggers shifts in other populations, and so on.

Interactions and effects also occur across space and time scales in complex adaptive systems. Problems are not always fixed to specific areas, nor can a change of condition in one portion of the system be automatically “scaled up” to predict system-level effects (Gunderson, Holling, and Light 1995, 531). In part because of heterogeneities within resource systems, the effects of a condition change in one part of the system may be relatively insulated from the rest, whereas the same change occurring in a different part of the system translates more directly into system-level transformations. Discontinuities in the relationships between system elements and system effects make it “very difficult to extrapolate results from one scale—frequently the plot scale—to higher spatial scales” (Swallow, Johnson, and Meinzen-Dick 2001, 451).

Furthermore, particularly in the ecosystem context, system processes are interrupted by disturbances. In biological systems, these include effects of infestation and disease, natural disasters, and shifts in the ambient environment. In the case of natural resources, such as water, disturbance processes clearly include droughts and flooding but also climate change and even landscape transformations caused by events such as earthquakes (which in addition to effects such as tidal waves have been known to alter the courses of surface streams and the geologic features of aquifers). Disturbance processes introduce an element of uncertainty—not merely complexity—into the challenge of resource management. Combined with the natural variability of the resource systems themselves, uncertainty allows for “unknowable responses, or true surprises [due to] the self-organizing, ever-changing character of ecosystems and their response to perturbations that are unprecedented (at least to the current ecosystems)” (Carpenter 1996, 120). Rapid and adverse changes may occur for reasons that are unforeseen and poorly understood.

Natural variability, the presence of disturbance processes, and the lack of understanding of the causal processes underlying the resource system mean



that additional data—the usual solution recommended by standard modern approaches—will not always or necessarily reduce the uncertainty or make the problem more tractable. Jordan and Miller (1996, 110–115), for example, describe some ecological situations (e.g., the Everglades, Yellowstone National Park) where, in theory, “further study and data collection should help improve ecological predictions, but where in practice, improvement in predictions is unlikely.”

In complex adaptive systems, there are changes in conditions that are not trends, but there are also changes in conditions that *are* trends. Among other things, scientific uncertainty with respect to complex adaptive systems means that we lack a clear way of knowing which changes are trends and which are not.

Despite all this, ecosystems are not completely beyond our comprehension and their behavior is not entirely random. But our ability to see and understand the order and predictability of complex adaptive systems is different: we can observe patterns that repeat within systems over time even though they do not repeat in exactly the same way each time, and sometimes system or subsystem conditions shift in ways that set into motion a different set of patterns. Understanding those patterns is useful science. Still, that science may allow us only to make qualitative and conditional predictions rather than quantitative and precise ones (Wilson 2002a, 335), and that affects our decision making.

### Elements and Implications of Uncertainty in Contemporary Watershed Management

Much of the literature on complex adaptive systems has dealt with biological ecosystems, such as fisheries, that “may be uniquely vulnerable ecosystems” (Carpenter 1996, 132). Professionals engaged in the study or management of non-biological resource systems, such as watersheds, may wonder whether the difficulties described above affect them too. There are two reasons for answering yes: (1) the frequent use of watersheds as near-substitutes for ecosystems, as noted already, and (2) some recent and emerging issues in watershed management. These issues are the incorporation of species and habitat protection into water management, the river restoration movement, and the greater recognition of human-environment interactions.

The promotion of integrated watershed management has meant incorporating the protection of biological systems (most often riparian and aquatic species and their habitat) into the set of management priorities and tasks. Some of this has been a response to, and embracing of, the integrated water resources management literature's advocacy of drawing together all water uses. Some of it has been forced by public policy—such as species listings under the Endangered Species Act, habitat protections stipulated in natural resource conservation plans, site-specific litigation—which is part of the institutional landscape in almost any watershed. By whatever means, ecosystem considerations have become a more common element of watershed management.

The incorporation of ecosystem protection and/or recovery tasks necessitates some replacement of engineering-based hydraulic water management with a broader, less precise, and less controlled approach. Borrowing Wilson's language, integrated watershed management exchanges the Newtonian world, where water was understood as a physical mass—to be captured, diverted, stored, and delivered in particular quantities with required qualities at specific locations and times—for a new and more uncertain world in which water retains all those physical properties and yet is a habitat at the same time.

Over the same period that ecosystem elements have been integrated into watershed management, other ideas have emerged and been adopted concerning the physical dimensions of the water resource. Stream and river channel restoration—ripping out concrete channels and returning streams to meandering courses with soft beds—is being undertaken in a number of locations and advocated in others as a means of re-balancing flood control objectives with other considerations, such as reduced runoff and erosion and enhanced groundwater replenishment. Restoration efforts also have been supported by communities rediscovering the economic and aesthetic value of waterfronts and stream courses. Wetlands are being constructed and restored to achieve in situ water quality improvement in preference to standard divert-and-treat methods. As sound as these water resources management ideas are, they do reduce the engineering-based control of the physical water resources in a watershed.

Of course, the presence of human societies in the watershed adds another complex adaptive system component. Carl Walters, the early advocate of adaptive ecosystem management, pointed out that focusing resource

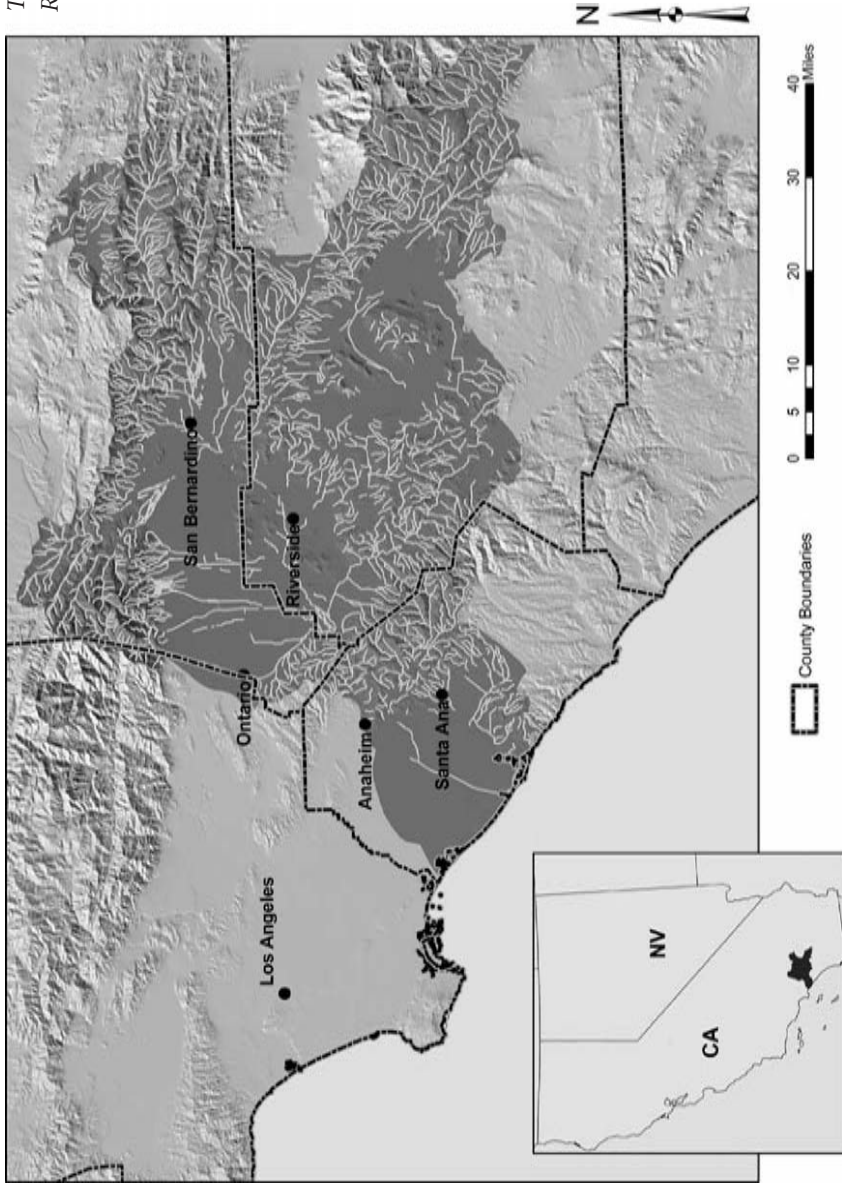
management on the physical landscape alone overlooks “the socioeconomic dynamics that are never completely controlled by management activities.” The presence of human beings in the watershed creates the potential for unexpected dynamic responses as well. Walters (1986, 2) analogized the human-environment relationship to a “predator-prey” relationship and cautioned us not to limit our attention to the “prey,” “because the predators don’t sit still either.” (In the watershed context, see also Swallow, Johnson, and Meinzen-Dick 2001.)

The trends described above can be illustrated using a particular watershed. In March 2003, a federal district court ordered the U.S. Fish and Wildlife Service to designate a critical habitat protection area within the Santa Ana River watershed in Southern California for the Santa Ana sucker, a fish native to several Southern California streams but now found in dramatically diminished numbers and in only a few stretches of the river. The Santa Ana sucker has been a subject of considerable attention within the watershed in recent years (especially since its designation as a threatened species in 2000), and a recovery plan was developed through the collaborative efforts of the Santa Ana Watershed Project Authority and the Orange County Water District in consultation with the U.S. Fish and Wildlife Service and the California Department of Fish and Game.

The Santa Ana River watershed is already an intensively managed resource system, with dense networks of physical facilities and institutional arrangements developed to address flood control, wastewater treatment and disposal, drinking water quality, the allocation of water supplies across sub-watershed basins and communities, restraint of water use and assignment of water rights to individuals and organizations, and the conjunctive management of surface water flows and storage with groundwater yields and storage. In large measure, those management approaches reflect an intent to minimize variability of flows and reduce vulnerability to familiar (though unpredictable) hazards of drought and flooding by maximizing the ability of agencies to store, release, move, and deliver water within the watershed while maintaining water quality parameters within limits needed to serve human consumptive purposes.

The additional feature of managing the watershed in order to avert the elimination of the sucker, and even try to restore the sucker population, is affecting the watershed management challenge in ways not yet fully calculable. Urbanization of the watershed landscape and changes in river

The Santa Ana River Basin.



water quality are the most frequently mentioned causes of the decline in the sucker population and its current threatened status, but in fact no one is certain whether those factors alone have caused the decline, or whether and how they have interacted with other causes. After all, the sucker has vanished from all other urbanized Southern California streams in which it was once found but has remained in certain stretches of the Santa Ana River, which is sometimes described as the most urbanized watershed in North America. In addition to puzzling over why the sucker population continues to decline in the Santa Ana (and, just as intriguing, why it has survived there despite dying out everywhere else), scientists have yet to determine exactly what water quality and riverbed conditions the sucker requires in order for its decline to be arrested and its recovery to begin.

No consensus exists, therefore, on what the indicators or targets for sucker recovery policy should be. What is almost certain is that the water quality and river condition indicators and targets that will be appropriate for the goal of sucker protection and recovery will differ from those indicators and targets that have been developed and used for the flood control, conjunctive management, wastewater treatment and disposal, and drinking water protection practices in the watershed to date. Combining the policies and practices for species and habitat protection with the current and long-standing watershed management practices will add complexity but also increase uncertainty, that is, greater prospects in the watershed for surprise, for unanticipated population shifts and other state changes.

The Santa Ana River watershed has been changing from a hydraulically managed watershed, where the emphasis was on physical control of the water, to a watershed that also has to be managed as an ecosystem, with all that implies in relation to complex adaptive systems. Even though the particular circumstances of each watershed are distinct, in some respects the case of the Santa Ana River illustrates how watershed management has been changing in the United States and elsewhere for the past couple of decades, adding not only to its complexity but also to its uncertainty. These changes raise important questions. How do these changes relate to decision making within and about watersheds? What kinds of institutional arrangements might people use when attempting to manage and protect watersheds as complex adaptive systems? Answers to these questions require us to consider the uses and properties of institutions.

## COMPLEX ADAPTIVE SYSTEMS II: WATERSHEDS AND INSTITUTIONS

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The view of watersheds as ecosystems—and of both as complex adaptive systems—has substantial and far-reaching implications for decision making. Those implications have ramifications of their own for the kinds of organizational and governance structures human beings devise and employ. Most importantly, the creation and adaptation of decision-making arrangements bring the kinds of political considerations we mentioned at the outset into the heart of the watershed.

### Uncertainty, Complexity, and Decision Making

Complex adaptive systems pose a substantial challenge to twentieth-century engineering-based decision models, such as rational-comprehensive decision making. With its requirements for specification of objectives, evaluation of alternatives, and selection of the alternative that achieves the desired objectives at least cost, rational-comprehensive decision making presumes that underlying system processes and cause-effect relationships are understood. In the face of scientific uncertainty, this presumption may not hold.

Not only does rational-comprehensive decision making (or any comparable approach) require predictions of the system-level effects of alternative actions, it also requires agreement on which indicators are valuable for assessing system-level effects. As already noted, however, scientific uncertainty implies a lack of consensus over what elements of a system are the best indicators of its overall condition. It also implies a lack of agreement on what a change in one or more of those indicators at any particular time signifies. Under such circumstances, the selection of policy “targets” becomes especially unclear, and so does our understanding of how alternative policy actions relate to those targets. Furthermore, if resource managers focus their attention on a few selected policy targets, undesired and undesirable results may occur as other elements of the system shift in unanticipated ways (Carpenter 1996, 147).

In addition to challenging our ability to pursue comprehensive decision making generally, scientific uncertainty poses problems for the role of science itself in policy making. When underlying system structures are known (or believed to be known), remaining uncertainties result from lack of data

or from insufficient specification of the stochastic processes at work. Those kinds of uncertainty can be reduced by directing scientific effort toward the problem, with a justified confidence that science will facilitate or improve comprehensive decision making. But in the protection and management of complex adaptive systems, where our uncertainty concerns the underlying system processes themselves and we do not entirely understand the basic relationships that make up the system or drive its transformations over time, both the scientific problem and the policy problem are not just harder—they are different.

Wilson (2002b) points out that much of environmental policy making and management (at least in the United States) is performed through the delegation of authority to regulatory agencies. This is done with the underlying presumptions that science will be employed in regulatory decision making and will also be available to check or correct regulatory errors. In light of uncertainty about system processes and cause-effect relationships, science loses some ability to provide policy makers with specific predictions through its usual methods of professional criticism and consensus development (Jordan and Miller 1996, 97, 108) or to check the mistaken exercise of policy-making authority.

This change in the role of science and in its relationship to decision making poses two serious problems. One is that science's eroded role in guiding decision making opens the field for the use of regulatory instruments to serve other political and economic purposes, including the ability of some interests to use scientific uncertainty as an excuse to delay action (Caldwell 1996, 394; Wilson 2002b, 6). Another problem is "error proneness," as scientific uncertainty expands the prospects for regulatory decision making to produce misguided or maladaptive policies.

In the effort to manage and protect complex adaptive systems, failure to recognize and acknowledge uncertainty can magnify the error proneness of management efforts. Low and colleagues (2003) have observed that decision makers tend to underestimate the uncertainty and overestimate their understanding of problems. This makes error correction even more important. Error correction depends upon error detection, and as Caldwell (1996, 404) points out, "Uncertainty unacknowledged is a factor that handicaps efforts to discover whether error has occurred." Wilson (2002a, 332) adds that failure to acknowledge uncertainty, or pretending it does not exist, lessens our ability to develop and implement management practices that have learn-



ing elements deliberately designed into them, exposing us to more “catastrophic” errors that can result from an incomplete understanding of the resource system.

With this catalog of difficulties, it is important to insert a caveat. Just as uncertainty does not mean that natural systems behave randomly or are incomprehensible, uncertainty additionally does not mean that scientific research on natural systems is useless to policy makers. Despite its limits and imprecision, science concerning complex adaptive systems such as ecosystems has value. Even this limited vision “is far more valuable than a sense that the future is totally unpredictable and not subject to influence” (Caldwell 1996, 400).

Instead, the limited vision that is possible with respect to complex adaptive systems “is the basis for forward-looking adaptive management” (Wilson 2002a, 339; see also Walters 1986). In light of the contemporary tasks of watershed management (integrating species and habitat protection, restoring streams and constructing wetlands, and taking more seriously the dynamic and adaptive human communities within watersheds), adaptive management warrants consideration in the watershed context. Lee (1993) has argued this point effectively. (See also Swallow, Johnson, and Meinzen-Dick 2001, 451.)

Adaptive management has high information requirements too, of course, but of a different sort than those required by a comprehensive decision-making model. In the management of complex adaptive natural resource systems, the general predictions underlying policy actions must be closely and continually compared with observations of the resource system. Furthermore, this close monitoring and comparison will need to be done at multiple scales and with respect to multiple indicators.

Arrangements are therefore needed that will enhance information collection, error detection, and the opportunities for adaptation. Further advances are difficult if scientists and policy makers do not engage questions of organization—such as what institutional arrangements may be able to counteract unacknowledged uncertainty, closely check general predictions against actual physical conditions, and “substitute for the hoped for role of science” (Wilson 2002b, 6) as a check on decision making. These questions about organizing decision making are of great interest to political scientists and others in the social sciences. The physical complexity of watersheds, and certain characteristics of people and institutions, however, will frustrate



any effort to identify and follow a best way to organize the governance and management of watersheds.

### Decision Making, Governance, and Institutions

Noting the inapplicability of the Newtonian paradigm to complex adaptive systems, resource economist James Wilson has stated the implications broadly but emphatically: “We have wrongly characterized our knowledge of the natural environment and, consequently, have viewed the uncertainty and learning problem as if it were a typical engineering problem. As a result, we have created institutions and administrative procedures ill adapted to a solution of the conservation problem” (2002a, 351). Those ill-adapted institutions and procedures include efforts at comprehensive regulation through integrated agencies.

In the preceding section, we discussed the applicability of comprehensive decision making in complex adaptive systems. Some readers may have perceived this to be a kind of straw-man approach, since the model of rational-comprehensive decision making has been subject to so many thorough critiques in the latter half of the twentieth century that it appears to have few remaining advocates. Yet, we believe the desire for comprehensive decision making still holds significant attraction in the literature on integrated ecosystem management and integrated watershed management, even if obliquely. Comprehensive decision making is implicitly associated with the notion of an integrated decision-making apparatus. Advocacy of integrated decision-making organizations, such as unified river basin agencies or watershed authorities, is often justified in terms of the need for comprehensive decision making that encompasses all affected interests and addresses all inter-related resources within a watershed or ecosystem.

Other authors whose work we find useful for anyone contemplating the complexities of watershed management are skeptical of using an integrated decision-making organization for the management of complex adaptive systems. Their rationale appears to comprise three common themes—recognizing scale diversity, reducing error proneness and promoting learning, and overcoming limitations on human information-processing capabilities.

In complex adaptive natural resource systems, organizations of multiple scales may be useful to gather and exchange information about resource conditions (e.g., Berkes 2006). Gunderson and colleagues (2002, 262) observed

that “resource systems that have been sustained over long time periods increase resilience by managing processes at multiple scales.” Such arrangements are likely to include relatively small local organizations that can focus on particular locations or subsystems, thereby approaching a complex adaptive system as being modular or decomposable, made up of smaller albeit interrelated elements (Simon 2005).

The argument for smaller local organizations attending to particular subsystems does not presume that uncertainty disappears at small scales—in other words, it is not a “complexity” argument in disguise. Rather, it acknowledges that complex systems are usually composed of subsystems, and subsystem levels are more nearly amenable to close monitoring and to the development of improved understanding of patterns of activity. Especially for geographically extensive systems with multiple and heterogeneous local subsystems, smaller organizations are likely to be better suited to monitoring and managing those local conditions, noticing changes rapidly, and notifying others of them. Of course, small local arrangements are not all that is needed (Costanza et al. 2001, 8). Overlapping organizations at larger scales can serve as forums for communication across local subsystems and as a check on local structures that behave in ways detrimental to other subsystems (Low et al. 2003, 106).

A second theme is the importance of reducing error proneness and promoting learning, an effort that may be aided by some degree of duplication and redundancy of organizational structures. In the kind of adaptive management that has been advocated for complex adaptive systems like ecosystems (Walther 1987; Lee 1993), the real key to progress is learning. Learning is likely to be maximized and accelerated in a diversified institutional setting where multiple interventions are being undertaken and compared within the same system simultaneously with opportunities to exchange results and observe others’ experiences (Wilson 2002a, 345–347; see also Holling 1986; Ostrom 2005).

We noted in the preceding section the danger of limited attention to a few selected indicators of system conditions, but this is exactly what a comprehensive organization trying to monitor and manage a complex system will be prone to do. Polycentric structures of overlapping organizations—networks, federal systems, and other multiple-organization arrangements—are one organizational option that can increase the likelihood of checks on the persistent maintenance of maladaptive policies and practices. Such

safeguards might exist within a single comprehensive resource management agency as well, but a century of organizational behavior research suggests that more nearly centralized organizations are susceptible internally to distortions of information and communications that can allow poor policies and practices to persist for undesirably long periods.

It may therefore be especially important to avoid organizational integration where information distortions and losses may cascade into dramatically erroneous decisions and actions. Low and colleagues (2003, 103) cite Landau's (1969, 354) critique of integrated hierarchical structures: "Organization systems of this sort are a form of administrative brinksmanship. They are extraordinary gambles. When one bulb goes, everything goes." More directly in relation to the ecosystem management challenge, Wilson (2002a, 347) adds: "Perhaps the only reasonable institutional response to this problem is to maintain independent (nearly decomposable) local governing units. Their ability to probe different policies and to remain skeptical without great cost is one of the few ways there might be to constrain persistent maladaptive policies, or viewed more positively, to assure the continuing evolution of the institution." Ludwig, Walker, and Holling (2002, 23) agree, employing the metaphor of a raft (representing institutions for managing ecological systems) withstanding unexpected or unpredictable waves or shifts of weight (representing the changeability of complex adaptive systems):

Another possible response to disturbance might be to restructure the raft itself. If it were constructed of several loosely coupled subunits, then excessive weighting or a strong disturbance might flip one part of the system but leave the rest intact. Such a structure might not require as much vigilance as the single raft, and it might be able to withstand a greater variety of external disturbances. On the other hand, if the bindings that link the subunits become stiff, then the structure may become brittle and, hence, more prone to failure.

The concept of decomposability and the metaphor of the single raft bring us to a third theme, which is the limited information-processing and decision-making capabilities of single systems, a theme that applies concepts such as bounded rationality (a characteristic of individuals) to organizations. The problems of limited understanding and cognition may not be solved merely by the often-prescribed organizational fix of "scale matching,"

that is, creating organizations to correspond with the boundaries of a complex resource system (Gunderson, Holling, and Light 1995, 531). Herbert Simon (1996, 178) advocated “nearly decomposable” rather than centralized organizational structures to deal with complex systems, balancing the need for close interaction and specialized expertise against the need for communication and integration. Because of the complexity of systems and the uncertainty associated with large numbers of adaptive components in multiple relationships that vary continuously and discontinuously over space and time, “no one individual or group could hope to adequately address the learning problem” (Wilson 2002a, 341). With particular reference to managing water resources, Gilbert White (1998, 25) has reflected that “truly comprehensive analysis” is challenging. He maintains that “the constraints of professional training and competence, the limits of organizational authority and the ignorance of the outcomes of many actions, past and future, impede the balanced formulation of all potential solutions and options in dealing with such aims as efficient use of water for food production, or for transportation, or for ecosystem health.”<sup>3</sup>

Managing and protecting complex adaptive resource systems are challenging enough even if human uses, interests, and values are not at stake. The addition of human beings brings an additional set of multiple scales (Lebel, Garden, and Imamura 2005; Berkes 2006). Just as the physical dimensions of a watershed or other ecosystem appear at different scales, so do the multiple human uses and behaviors that occur in a watershed, complicating further the tasks of decision making, monitoring, and enforcement (Adger, Brown, and Tompkins 2006). Once we contemplate individuals and communities interacting with the natural resources within a watershed, the “how” questions about decision-making arrangements are compounded by “for whom” questions (Hooghe and Marks 2003, 241). When we think about how to make decisions and for whom, boundary issues (e.g., who belongs “in” and who does not) are not only complex but take on added intensity. The implications of these complexities for water resources management were conveyed well by Blatter and Ingram (2000, 464):

Common goods such as water are multidimensional (drinking, shipping, power generation, irrigation, recreation, ecological functions, economic development, et al.). For this reason, [a single principle] does not work very well as an instrument to define the one best size of a geographical area for governing water. Instead of applying economic criteria or

markets to the task of creating boundaries, a political process of trading values off against one another must take place. It is necessary to determine the most important function(s), create the government structure(s) corresponding to these functions, and find some mechanisms to deal with the interdependencies and spillovers between these functions.

As countless authors have observed, human communities have rarely been organized to coincide with ecosystem boundaries or even the more visible boundaries of watersheds. As a result, “achieving coordination often requires *reconciling* socially defined boundaries like villages with physically defined boundaries like catchments. . . . Organizing collective action along strict hydrological boundaries is difficult” (Swallow et al. 2004, 1, emphasis added). The communities that matter most to people, and where established decision-making structures already exist, typically are either smaller than the watershed or straddle watershed boundaries. Neither form of organization is likely to displace the other, and reconciling them adds further complexity to the task of institutional design.

Neither a single decision-making principle nor a single organization at a single scale is therefore likely to suffice. As a result, institutional arrangements suited to decision making about complex adaptive systems may themselves need to exhibit some features of complexity and adaptability (Berkes 2006). The cases we describe in this book provide a few illustrations of how complex institutional arrangements have evolved in watershed contexts in the United States.

In the uncertain world of complex social and ecological systems, institutional richness may be preferable to institutional neatness. Multi-scale institutional arrangements, including small and local organizations linked horizontally with each other and vertically with larger-scale organizations, may be able to achieve (1) close monitoring of local (subsystem) conditions; (2) representation of diverse interests associated with different physical components of the system as a whole; (3) error correction when management practices undertaken with respect to one element of the system create unanticipated negative effects elsewhere in the system; and (4) opportunities to communicate and exchange information across subsystem elements and to discuss subsystem interactions and system-wide conditions without necessarily trying to manage all parts of the system with a comprehensive organization.

In a useful article distilling decades of theoretical development about the organization of governing jurisdictions, Hooghe and Marks (2003) have distinguished between “Type I” and “Type II” governance structures. Type I structures are *constituency-defined multi-service or multi-function organizations*—that is, general-purpose governments, such as a municipality, that encompass a defined group of residents and provide an array of services (police patrol, trash pickup, parks, and so on). In the United States, Type I governance structures typically exhibit the familiar branches of government, with a legislative body, a judicial forum, and an executive capability. Type I structures may be nested—cities and counties encompassed by states, states within a nation, even regional and international organizations arranged in meso or supra levels—but they do not overlap horizontally (i.e., the territory and population of one city or state does not extend into those of another city or state), and each Type I jurisdiction is a multi-function mechanism for governance within its own domain. Type I governmental structures facilitate bargaining and trade-off decisions (e.g., whether to devote more resources this year to policing or to street maintenance).

Type II governmental structures are *functionally* defined, and their boundaries vary from one service or function to another. Type II structures are established at whatever geographical scale may be suited to funding and delivering a particular service—hence, a library district or regional transportation authority covering a metropolitan area, an irrigation district serving a collection of farmers, and so forth. These structures do not necessarily feature legislative, executive, and judicial branches—rarely in the United States do Type II structures have a judicial function, for example. Type II governments can and often do overlap horizontally, and many may operate in the same location because their functional responsibilities are distinct (Hooghe and Marks 2003, 236–240). They have the advantages of flexibility in jurisdictional size and specialization of function. On the other hand, because of that specialization they are usually not engaged in trade-offs or bargaining among service priorities. Conflicts involving their policies or performance generally must be resolved in the judicial systems associated with Type I structures.

Although these governance forms “represent very different ways of organizing political life,” Hooghe and Marks point out the compatibility and complementarity of the two:

Type I governance reflects a simple design principle: Maximize the fit between the scale of a jurisdiction and the optimal scale of public good provision while minimizing interjurisdictional coordination by (a) creating inclusive jurisdictions that internalize most relevant externalities and (b) limiting the number of jurisdictional levels.

Type II governance also limits the transaction costs of interjurisdictional coordination, but it does so in a fundamentally different way, by splicing public good provision into a large number of functionally discrete jurisdictions. (2003, 241)

In most (perhaps all) watersheds or other ecosystems, combinations of Type I and Type II governance structures will exist, additional ones may be created and existing ones modified, and the relationships among them adjusted from time to time. Overall, then, the institutional arrangements in a watershed may themselves be thought of as a kind of complex adaptive system (perhaps more accurately, a complex adaptable system) composed of multiple elements at differing scales and operating both independently and interdependently.

For reasons already noted—scale differences, disturbance processes, the importance of reducing error proneness while increasing error detection and learning—complex adaptable systems of institutions may be well-suited to the management and protection of complex adaptive natural resource systems. Swallow and colleagues (2004, 2) have reached such a conclusion with particular reference to the management of watersheds:

The scale at which the physical environment is optimally managed may not correspond to any one decision-making body in a community. In that case, collective action within existing institutions or through the creation of new institutions becomes critical for managing watershed resources. Decisionmaking does not have to be embedded in only one body at one level, but different management responsibilities can be devolved to different bodies. These options vary according to the size of the watershed, the populations occupying the watershed, and how the scale and interaction of resource flows affect people.

Returning to our watershed example, fortunately for Santa Ana River water users and for the Santa Ana sucker, that watershed already has developed a network of institutional arrangements that includes relatively small sub-watershed communities and agencies and some watershed-scale rules and organizations. Water quality is already monitored intensively in the

watershed, and river flows are managed under rules that were agreed to by upstream and downstream organizations and made part of a stipulated judgment enforceable in court. The two largest groundwater basins in the watershed are governed by court judgments and by agencies that try to manage the basins' storage capacity while balancing annual yields with demands. There are numerous special water districts and municipal water and wastewater utilities in the watershed that look out for their local concerns and monitor their conditions. There are five larger water districts that acquire supplemental supplies for those smaller districts and utilities and engage in several planning and resource management activities. And there have been two forums for watershed-scale communication and coordinated action—the Santa Ana Watershed Project Authority mentioned earlier, which is a joint-powers agency of five water districts within the watershed, and the Santa Ana River Watershed Group, a nongovernmental entity convening organized stakeholders and interested individuals to discuss issues of concern within the watershed and seek cooperative solutions.

There is in the Santa Ana River watershed a rich mix of Type I and Type II organizations. Rather than impeding effective management, this institutional richness may aid policy making in the Santa Ana River watershed as its components adapt to the complex tasks of managing for ecosystem survival and stability.

## COMPLEXITY, CHOICE, AND POLITICS

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Institutional arrangements are human creations; they are matters of choice. There have been recommendations to try to match organizational boundaries to watershed boundaries and create comprehensive jurisdictions since the time of John Wesley Powell. Relatively few examples of comprehensive watershed or river basin agencies exist, however, and even where watershed-scale entities have been created, they are intricately interconnected with smaller and larger jurisdictions of both Type I and Type II characteristics.

The impressive empirical analysis reported by Lubell and colleagues (2002) found that collective action in America's watersheds is being attempted and accomplished instead through literally thousands of "watershed partnerships" and network-style structures involving numerous private and public organizations of varied sizes and functions. Why is this so? Why have we so rarely chosen to create comprehensive organizations based



on hydrological boundaries? Is the partnership approach merely the path of least resistance? Are watershed stakeholders relying on these complex, polycentric arrangements because it is too difficult to create the comprehensive watershed agencies that, deep down, they really would prefer?

The final report of the National Watershed Forum, held in 2001, is interesting in this regard. After three days of meetings, the hundreds of participants—some of the Americans most intensively involved in watershed management—generated several pages of “key recommendations and findings.” These included five pages of findings and recommendations concerning watershed governance, organization, and participation. Not one of those findings or recommendations called for the establishment of more centralized and comprehensive watershed-scale agencies. Rather, most of the recommendations emphasized maintaining a variety of organizations at a variety of scales while enhancing their exchange of information and coordination of activities (National Watershed Forum 2001, 15–17, 37–38).<sup>4</sup> Indeed, the participants recommended the establishment of even smaller, sub-watershed “stream teams” to monitor local conditions more closely. Altogether, the forum’s findings and recommendations displayed an intriguing congruence with the analysis in this chapter about the relationship between nature’s complex adaptive systems and humans’ complex adaptable systems. Even individuals closely involved in and committed to watershed management did not recommend the creation of integrated watershed agencies, and they were inclined toward greater organizational complexity rather than less.

Nature has many complex adaptive systems—watersheds, continents, lakes and seas, prairies, tropics, wildlife habitats, and so forth, from the micro to the intercontinental scale. Human beings still have to choose how (and around what) to organize their activities. We do not get to just let nature do the choosing for us, pointing to topographical boundaries or other physical features as a way of defining communities of interest and crafting decision-making processes. Despite their importance and visibility, it is not clear why watersheds or river basins should have primacy in the shaping of human decision-making systems.

Furthermore, even if people chose to organize decision-making arrangements around watersheds, that would hardly be the end of the choices to be made. For good or ill, nature’s watershed boundaries have been altered by human actions in many cases all over the planet. So even if we zero in on

watersheds and river basins, we still have to choose how to bound the decision-making arrangements. Is Los Angeles in the Owens Valley or not (not *should* it be, but *is* it)? Is Denver in the Colorado River basin or not? Are San Diegans in the Sacramento River watershed? Should San Franciscans get to participate in decisions about the Hetch Hetchy Valley? One could pose an almost endless list of such questions, and they are not idle ones—they must be addressed in order for watershed management to proceed. As Walther (1987, 443) observed, the effort to establish integrated resource management in any location confronts “institutional environments that are ruled by culture, politics, and tradition and that have a history.” Communities of interest already exist in and for many watersheds, and topographical features do not go far in telling us who they are or how they should be involved.

Who is “in” and who is “out”? Who gets to decide what we are going to do? How do we decide? These are political questions, and they are inescapable no matter what natural boundaries we try to employ and no matter what organizational structures we try to construct. Michael McGinnis (1999, 499) sagely observed: “Watershed policymaking is both a scientific and a political enterprise. The mythical separation of politics from administration will not suffice in watershed policymaking because of the diverse values held by policymakers and the scientific uncertainty endemic to physical sciences in this policy area.” In the chapters that follow, we will explore the politics of watershed policy making and management as it has evolved in the United States (primarily), with particular attention to the choices that have been made about how to connect institutional landscapes with physical ones.

Complex systems of institutional arrangements can appear chaotic to some observers—and understandably so. The institutional landscape of a watershed, like its physical and ecological landscape, can be and often is complicated. Although there are ways to make sense of that landscape (such as the distinction between Type I and Type II structures), we understand that institutional arrangements in a watershed are likely to be complicated and, on initial view, even confusing. Institutional complexity in a watershed can be viewed as an intrinsically undesirable trait to be minimized, an intrinsically desirable trait to be maximized, or a phenomenon that is intrinsically neither good nor bad but a fact of life and where the extent and kinds of complexity will vary from one watershed to another. Those variations to greater or lesser degree will reflect the physical, biological, and human terrain. In some ways they may work well to reduce environmental

damage and achieve sustainable human-environment relationships, and in other ways, poorly. Because our goal is not to prescribe a best way to organize water resource management, we do not have a model organization to hold up before our readers.

Instead, we proceed to the remaining chapters, operating from the premise that there may be sound reasons for institutional complexity in the watershed, but the questions of what institutional forms that complexity takes and how institutional arrangements operate are empirical ones. They are also political questions—it is not only a physical watershed, it is a political one too. Questions about the institutional landscapes of watersheds are questions about the social and political tools people use to govern and manage themselves and their relationships to one another and to nature.

## NOTES

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1. That observation coincides with Milon, Kiker, and Lee's comment (1998, 37) about the rise in attention to ecosystem management during the same decade: "Within the past decade ecosystem management has become a central theme in state and federal environmental resource management and a powerful issue in environmental policy debates. A recent survey [Yaffee et al. 1996] showed that more than 600 projects related to ecosystem management are underway around the U.S. Under the Clinton Administration, a high level of federal commitment to an ecosystem management approach has developed despite many obstacles."

2. "A watershed is a complex ecosystem" (Brandes et al. 2005, 87).

3. In a comparison of two cases, for example, Slaughter and Wiener (2007) found that the concentration of decision making in a single agency was less effective in detecting and solving complex problems in a watershed than polycentric arrangements in another one.

4. Participants even suggested *replacing* watershed coordination teams organized at the federal and regional scale with ones organized along state boundaries (National Watershed Forum 2001, 37). Since almost no state boundaries in the United States match watershed boundaries, this recommendation is a notable departure from the watershed management literature's emphasis on superseding traditional political jurisdictions in favor of regional-scale entities.