

Chapter 5: Integration Models

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Introduction

Federal lands cover about 78 percent of the Great Basin region, and are managed to provide for multiple societal values including potentially conflicting goals such as supporting cattle grazing and protecting habitat for endangered species. Many decisions required to achieve these goals, such as when to remove cattle from an allotment, require that local managers evaluate information from a larger spatial and longer temporal context than what is directly under local control. In particular, habitat quality over large spatial extents is important for some species of concern. For example, home ranges for the Greater Sage-grouse commonly encompass multiple management units and several seasonally variable habitat needs such as meadows for chick rearing and sagebrush for nesting (Connelly and others, 2000). A broad landscape-level perspective also is necessary for evaluating processes such as disturbance, fragmentation, and connectivity that affect the local extent but are detectable only from an extensive view. Temporal extents are important because landscape patterns are created by the time-dependent transport of energy, matter, and organisms (Farina, 2000). Consequently, decisions made by local managers are improved with knowledge about management actions in adjacent or similar areas beyond their local jurisdiction and by observations over time frames longer than individual growing seasons or annual budget cycles. Local decisions also are affected by policy changes that impose additional constraints on allotments, for example by allowing higher ORV use levels. Hence, land-management agencies also must understand how multiple management activities and decisions covering various spatial extents will be impacted by events happening at other spatial extents and over various timeframes.

In addition to improving decisions with knowledge from spatial and temporal contexts larger than the typical individual management unit, managers also must consider the concurrent effects of multiple drivers. For example, the local manager's decision regarding a grazing allotment depends not only on the effects of cattle, but also on an evaluation of other stressors and drivers that impact the condition of the allotment. The capacity for the allotment to maintain an expected level of productivity following a given level of grazing depends on soil properties, local precipitation, disturbance regimes, prior conditions, and human activities, among other factors. This complicated estimate may become more difficult to make in the face of unpredictable climate or other environmental change, which may invalidate previously understood

relationships. Conceptual models assist in developing a capacity to anticipate future management opportunities and constraints by identifying the most important relationships among multiple drivers of ecosystem function. This document has described these relationships for subsystems; now the goal is to describe how to combine subsystems and to scale up to the region.

A major challenge to scaling is the mismatch between ecosystem structure and function and the human institutions that are available to manage and study them. The spatial scales at which habitat features are perceived and used typically differ among organisms in relation to body size and mobility, and they often do not correspond to the scales at which researchers and land managers focus their efforts ([fig. 5.1](#); Wiens and others, 2002). A diagram similar to [figure 5.1](#) could be produced for temporal scales because ecologists commonly sample and describe the environment at spatial and temporal scales that are not directly relevant to most organisms and management decisions. This document attempts to bridge these gaps by providing a regional or landscape view to help inform the decisions that are required at multiple scales across the Great Basin. A region-wide understanding of the interacting ecosystems of the Great Basin derived from conceptual modeling helps us develop a predictive capability to evaluate the cumulative effects of multiple stressors on target resources. Predictions, in the form of landscape change hypotheses, become the basis for a monitoring strategy to detect the predicted changes. Accomplishing this goal for the Great Basin involves linking the stressor and control models, described in [chapters 3](#) and [4](#), with analytical models to facilitate the compilation of data from multiple scales and to simulate landscape change.

Integrated Ecosystem Framework

Spatial Structure

In previous chapters, the Great Basin ecoregion was deconstructed into 10 subsystems ([fig. 1.3](#)), each of which represents groups of related ecological elements. Discrete, generalized conceptual models were presented of the significant interactions among environmental drivers, stressors, and biotic components and processes *within* these subsystems ([Chapters 3](#) and [4](#)). The next step in integration is to recognize that subsystems are distributed across the landscape in predictable patterns based on biophysical conditions and previous management actions,

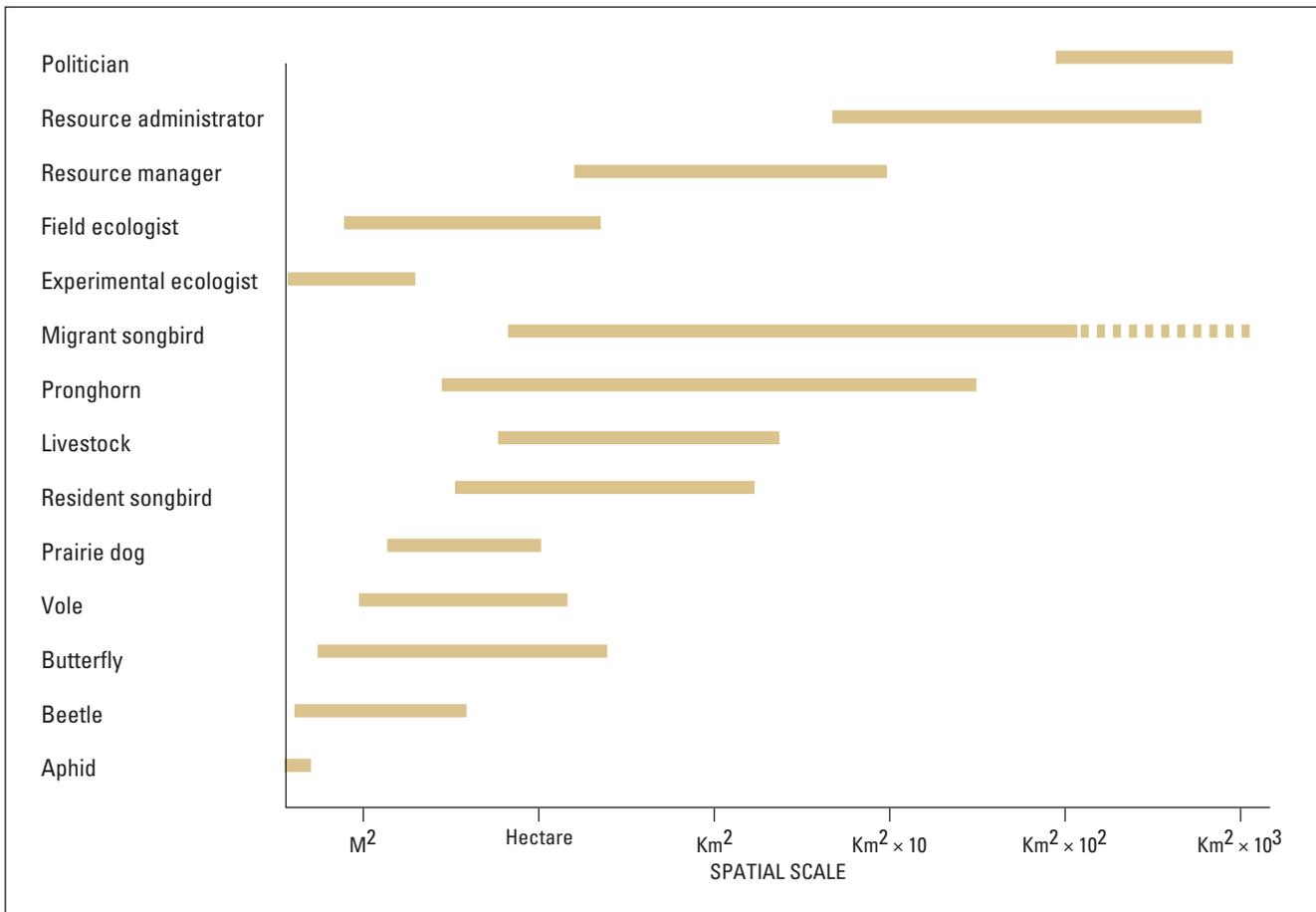


Figure 5.1. Diagram illustrating how scaling windows differ among species that use, investigate, or have management responsibilities for sagebrush steppe ecosystems. A scaling window is defined by the minimum resolution at which organisms perceive spatial variation and the maximum spatial domain experienced by organisms over a fixed period of time (after Wiens and others, 2002).

and that multi-scale, multiple-driver linkages exist *among* subsystems. Supporting effective management decisions by predicting ecosystem responses requires developing tools that address these patterns and model these linkages. The spatial foundation for such a model is a digital representation of the subsystems in their mosaic arrangement across the Great Basin (figs. 5.2 and 5.3; see fig. 2.1).

Hierarchical Structure

Ecologists recognize that ecological systems can be viewed as being organized hierarchically, with larger slower-changing units composed of smaller units with faster process cycles (Allen and Hoekstra, 1992; Holling, 2001). Examples of commonly useful hierarchies include individual

→ population → community → biome, and site → drainage → watershed → basin → region. Each hierarchical level has novel emergent properties that arise from the combination of its subunits. For example, erosion-driven changes to small drainages occur frequently during a season and affect the establishment of individual plants. Over several seasons, these changes can accumulate and lead to changes at a larger extent such as mass wasting, which alters not only topography and soil quality, but also land cover with consequent changes in movement patterns of migratory species or new opportunities for invasive colonizers. This example shows how the smaller scale can be viewed as providing the mechanism for changes at the next larger scale (Allen and Starr, 1982; Giampietro, 2003) and shows how temporal and spatial scales are hierarchical. These properties of hierarchical structure can be used as a framework for the integrative model.

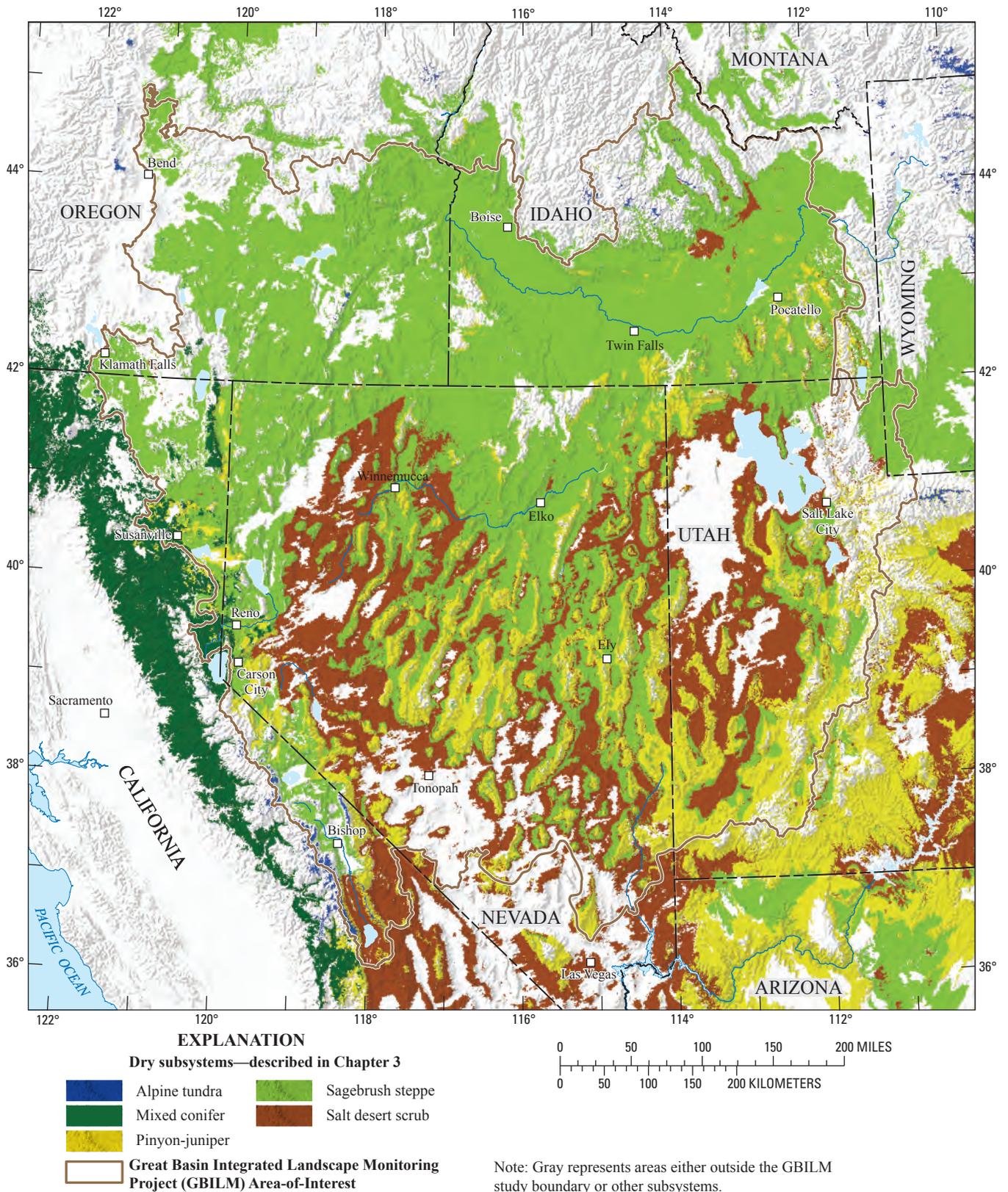


Figure 5.2. Map of dry subsystems described in Chapter 3 (see fig. 2.1) and also salt desert scrub.

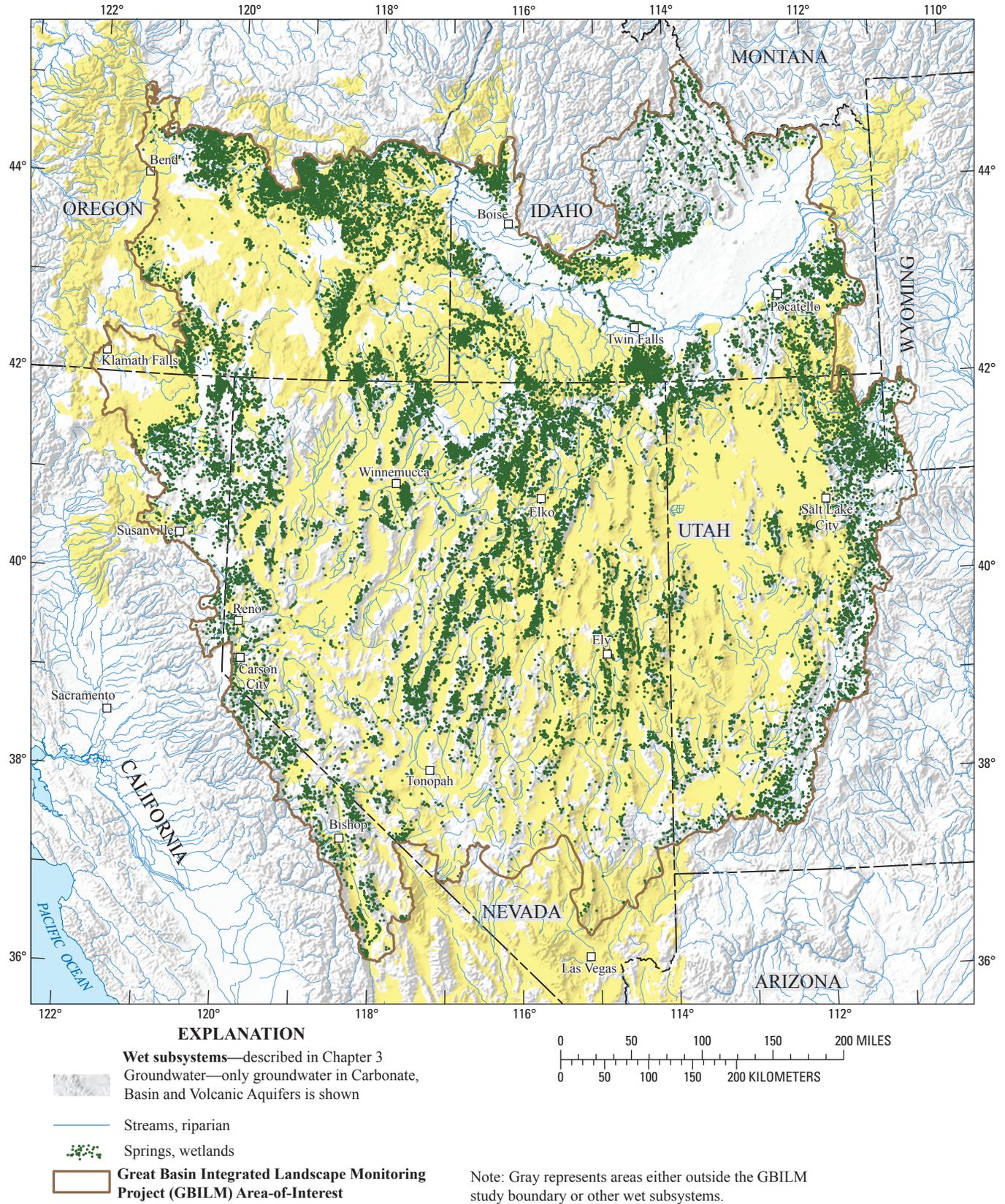


Figure 5.3. Map of subsystems described in Chapter 4 (see fig. 2.1) and also lakes and discharging (wet) playas.

Different hierarchical systems can be used to describe the same set of resources and spatial extents depending on the process of interest and the management or research question. When describing the generic scaling process linked to the GBILM hierarchy of system models (fig. 1.2), a three-tiered hierarchy (fig. 5.4) is used: sites within each subsystem → mosaic of site classes within subsystem → mosaic of subsystems (or landscapes). The smallest hierarchical unit in this system is a site, which can be viewed as a study plot, transect, or an allotment. The next hierarchical unit, the site mosaic, is used to describe the aggregation of different site conditions for areas with similar vegetation potential (a function of the underlying ecological conditions of soil, geomorphology, and climate). For example, sites with the same ecological potential for Wyoming big sagebrush may have different site conditions. due to different disturbance regimes acting at the site over time. Sites that are within their ecological resilience capacity can be found as Wyoming big sagebrush with a high percent cover of perennial and annual

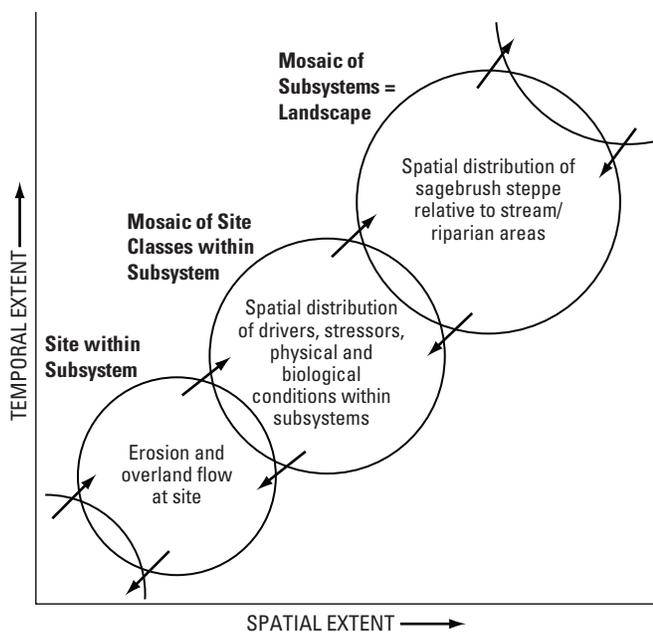


Figure 5.4. Domains of scale from site to landscape including properties and processes especially relevant to determining the effects of erosion from sagebrush steppe on adjacent riparian areas. Examples at the site level include differential infiltration, runoff, and erosion because individual plant, animal, and microbial species affect site-specific soil conditions. At the level of the mosaic of site classes within the sagebrush steppe subsystem, mass wasting and other geomorphic changes in drainage areas are important. At the mosaic of subsystems, or landscape, level, differential precipitation and infiltration due to land cover and topography affect regional drainage patterns.

native understory—this is the reference condition. Sites that have been stressed by excessive grazing and subject to exotic plant exposure may become Wyoming big sagebrush with a cheatgrass understory. Sites that have experienced an extremely hot fire may have no Wyoming big sagebrush, just herbaceous cover, but they still have the ecological potential for Wyoming big sagebrush, in the absence of further disturbance. Site classes are a result of both the ecological potential of the site and the stressors the site is subject to over time. A mosaic of site classes is aggregated to describe the sagebrush steppe subsystem; the mosaic of subsystems is aggregated to form the landscape level of the three-tier hierarchy. The approach that is taken is to scale across hierarchical levels—either upscaling, going from the site to subsystem to landscape, or downscaling—depends on the management question(s) and data availability. For example, when satellite data such as Landsat are the best available data, or the goal is to conduct a stratified random sampling design across a landscape, a downscaling approach is called for. Figure 5.4 uses an example of a three-tier spatially and temporally defined hierarchical structure to illustrate the model. Specific management questions may require more hierarchical levels depending on the temporal and spatial scales of the driving variable(s).

Interactions Within and Among Subsystems

Interactions within major subsystems of the Great Basin are described by their control models (Chapters 3 and 4). The dominant processes illustrated in the control models are those that contribute strongly to the biophysical structure of each subsystem. The responses of subsystems to stressors are outlined in the stressor models. Just as the entire ecoregion was deconstructed into subsystems to more easily understand and articulate the dominant controlling processes, the control and stressor models can be further disassembled, using spatial hierarchical levels (or scales), to describe the dominant processes occurring within subsystems. An illustration of the cross-scale approach for understanding subsystem controls and stressors will be described, from an upscaling perspective, using the sagebrush steppe and stream/riparian subsystems and the processes of overland flow and erosion across hierarchical scales. Factors relating to the specific example of soil hydrology, runoff, and erosion in the sagebrush steppe subsystem can be organized using domains of scale (fig. 5.5). At the site level, one can measure the number and depth of rills caused by erosion, which will depend primarily on soil characteristics, vegetation, and weather patterns. These site-based data describe the results of overland flow and erosion at specific places with a specific combination of variables, and can be statistically used to quantify relationships among them. At the next higher spatial domain, the sagebrush steppe subsystem consists of a mosaic

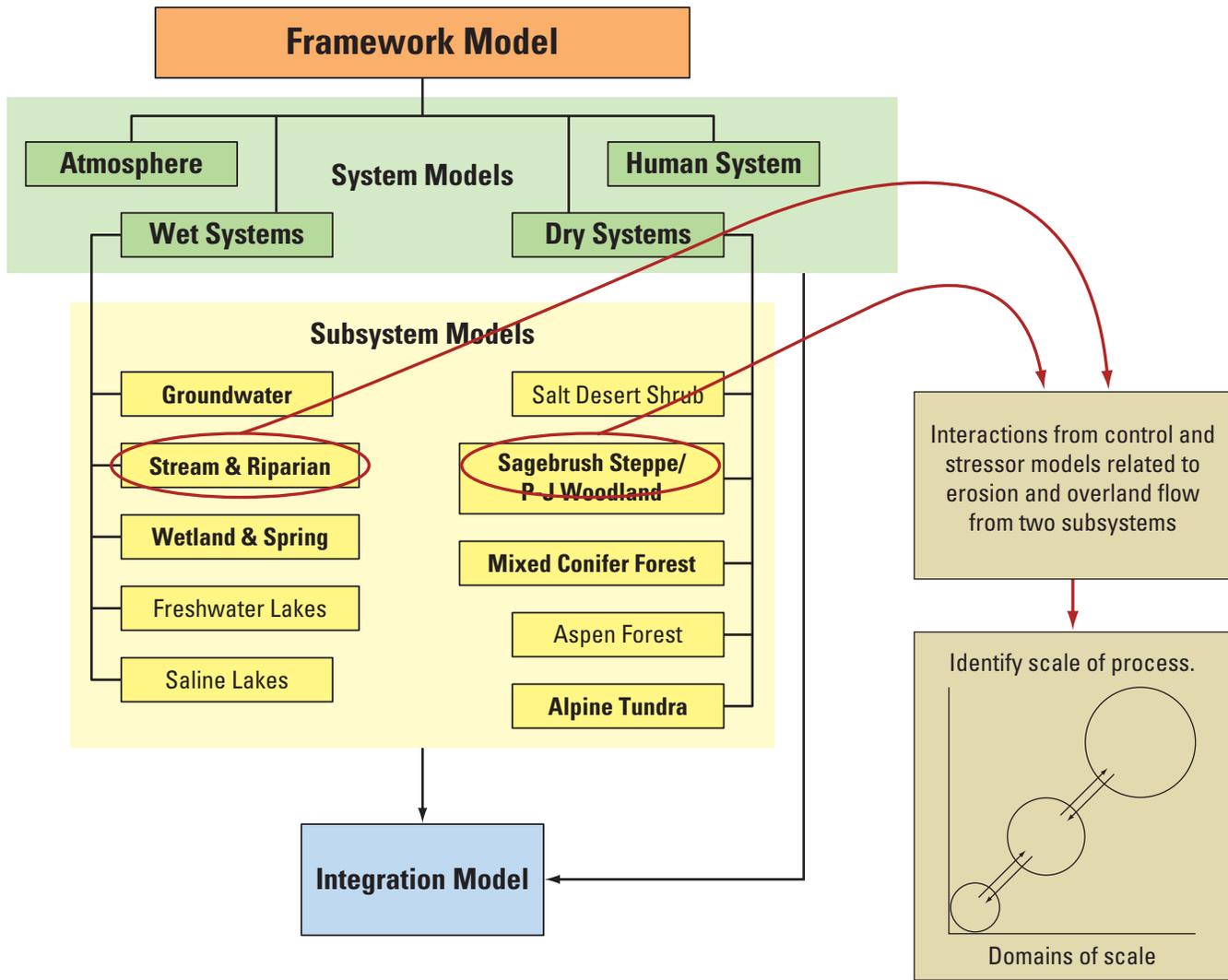


Figure 5.5. Context for example in text explaining how site-based data and conceptual models (control and stressor) from two subsystems are spatially and temporally identified within the appropriate hierarchical scale for analysis.

of vegetation community states (site classes), whose pattern depends on broader environmental factors, such as soil patterns and topographic features, as well as relict impacts of anthropogenic stressors, all of which determine the pattern of erosion among the mosaic of site class units. At the landscape scale, the aggregated patterns of erosion within the sagebrush steppe subsystem can be quantified as they interact with other subsystems (for example, riparian and aquatic), depending on the spatial pattern of subsystems as well as the pattern of erosion within the sagebrush steppe subsystem. As is shown in [figure 5.6](#), cross-scale interactions occur within subsystems, as this example describes, or across subsystems.

A model of interactions among subsystems begins to address the complexity of an integrated landscape approach to monitoring because patterns and processes at spatial scales

larger and smaller than the area of interest are relevant. The comparable statement with respect to temporal scales also holds. An important step in this conceptual approach is to select the appropriate spatial and temporal domains for the processes represented by the control and stressor models ([fig. 5.5](#)). Cross-scale interactions then can be categorized, as illustrated using the sagebrush steppe and stream/riparian subsystems for the processes of runoff as overland flow and erosion. For graphing purposes, space and time are combined on the vertical axis reflecting increases with each higher domain of scale ([fig. 5.6](#)). In this way, multiple subsystems can be displayed on the horizontal axis.

To keep this example simple, only uni-directional water flow from sagebrush steppe to stream/riparian areas is considered, but we recognize that other relationships exist

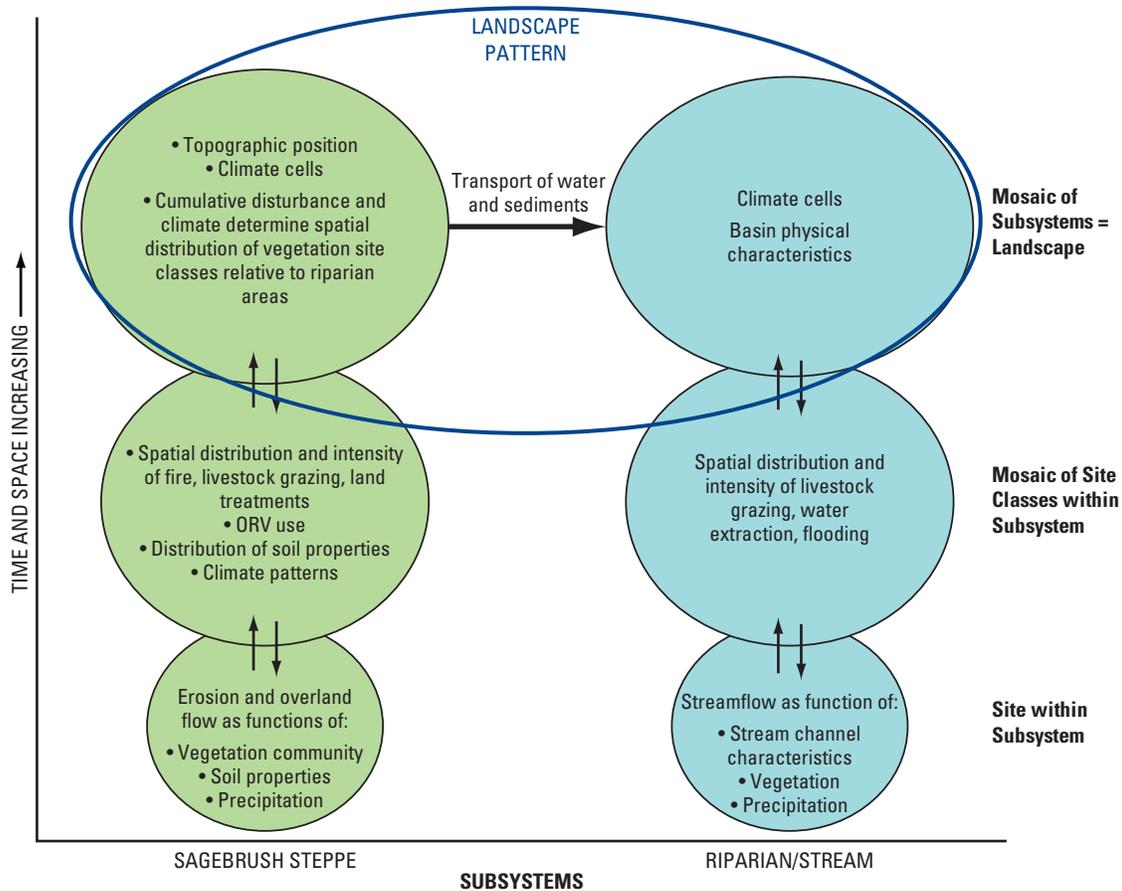


Figure 5.6. Example of interactions between two Great Basin subsystems regarding erosion and overland flow.

(for example, flow from stream-riparian to sagebrush steppe due to flooding). For a given rainfall event, vegetation cover, topography, and soil structure determine rate of overland flow, and streamflow rate determines residence time of sediment for the stream/riparian subsystem. The spatial pattern of site characteristics that influence overland flow can be overlaid with data about the occurrences of stressors and drivers (for example, fire, invasive species, local disturbance). The result is a spatial representation of patches having different properties relative to erosion and overland flow. A spatial model (see section “[Models for Monitoring Landscape Change](#)”) then can be used to predict how this specific configuration of patches will respond, for example, to a given rainfall event or changes in climate pattern, depending on the specific management concern.

Changes at the landscape level in response to system drivers are described in terms of changes to the spatial distribution of sagebrush steppe relative to stream/riparian areas. These changes will, in turn, affect the processes of erosion and overland flow at all other scales ([fig. 5.7](#)) and feedback loops within and across scales likely will need to be addressed.

Many processes and management issues in the Great Basin involve more than two subsystems ([fig. 5.8](#)). Some interact more directly than others and interactions can involve various combinations of hierarchical levels. A comprehensive model of the Great Basin would include all subsystems. However, many priority management questions likely can be answered by focusing on the details of a few key subsystems.

By integrating the effects of multiple stressors and drivers across multiple subsystems, the integrated spatial modeling should improve decision-support for land managers. Predicting the consequences of changes in particular system drivers and stressors, including management actions, will help managers direct resource management decisions in the context of a large spatial extent, potentially as large as the entire Great Basin. In addition, assumptions and hypotheses about change will help identify the most effective indicators in which to invest monitoring efforts. Monitoring results can alert managers to changes resulting from changes in global, regional, and local drivers. As changes develop, they also can be used to improve model parameterization, and therefore the predictive ability, of the models.

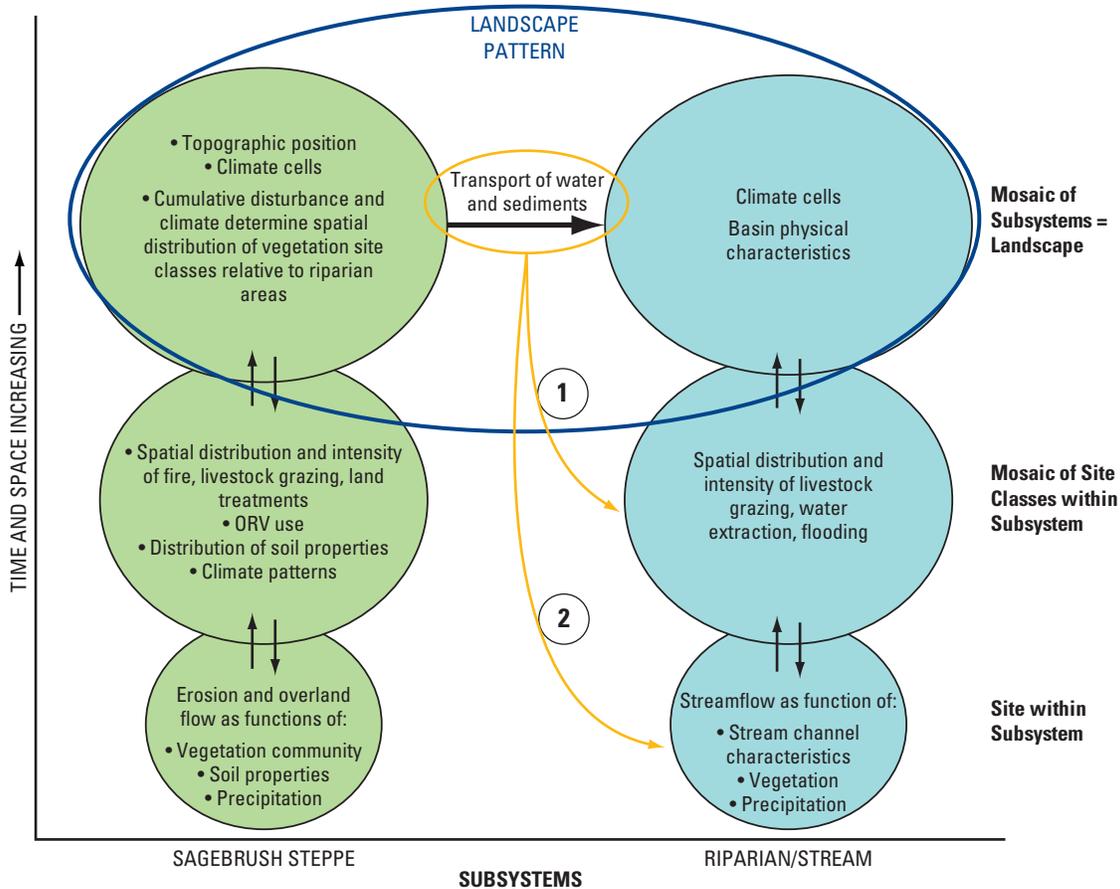


Figure 5.7. Landscape-level processes will have effects at other hierarchical levels. Arrow 1 could indicate the role of water and sediment transport to alter the spatial distribution of riparian and stream site classes, for example, by changing the spatial distribution of new surfaces for colonization by vegetation. Arrow 2 could indicate the effect of sediment transport to scour riparian vegetation and change the stability of a particular streambank.

Models for Monitoring Landscape Change

Converting the knowledge embodied in the conceptual models of the Great Basin subsystems into a form that is useful to management decisions is the key to the landscape monitoring challenge (fig. 5.9). One useful approach, which we expand upon below, is to use frame-based simulation models (Starfield and others, 1994) to integrate plot-level data collected by local managers along with expert knowledge and measures of uncertainty to provide alternative predictions of the effects of multiple stressors over time. Predictions (results) from the simulation models provide a means for selecting indicators that track ecosystem responses over time and that serve as early warnings of possible altered ecosystem function. The results of the simulation model can be used to extrapolate the knowledge gained with site-specific conditions to explore management options across a landscape (fig. 5.10). An advantage of using spatially explicit frame-based simulations

to inform indicator selection is that they map the conceptual model results to expected changes at actual locations on the ground. Identifying indicators using status and trends analysis of ecosystem elements or control and stressor models is an important first step, but indicators developed without addressing geography are likely to overlook significant aspects. Surprising relationships arise as a direct result of processes that are spatially and temporally cross-scale dependent. To increase the possibility of uncovering these surprises, and to do so before significant time and resources have been invested in indicator sampling design and implementation, the GBILM team proposes the use of landscape level simulation models to explore spatially and temporally explicit conceptual model results. The simulation models can facilitate an iterative planning—or at least increased dialogue—to ensure common purpose among the stakeholders responsible for funding and implementing an integrated landscape-level monitoring effort.

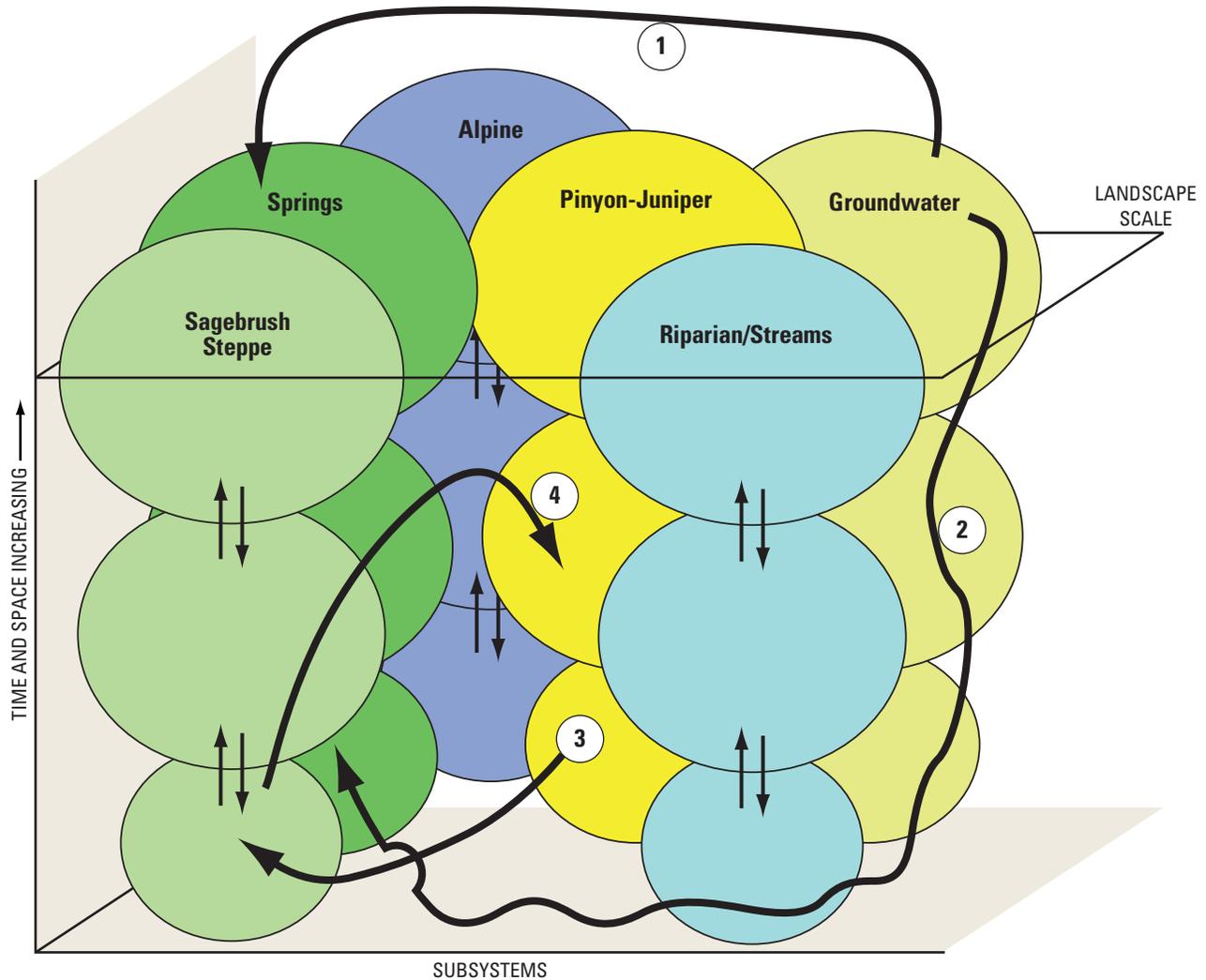


Figure 5.8. Multiple subsystems interacting on the landscape. Arrows indicate that a hierarchical level of one subsystem may interact with one or more levels of another system. Arrow 1 represents the landscape level interaction where groundwater levels control spring discharge. Arrow 2 represents how spring discharge at a particular site depends on the spatial pattern of groundwater level (which may be altered by urban withdrawal). Arrow 3 represents the site-to-site interaction between sagebrush steppe and pinyon juniper because they are usually adjacent on the landscape, and spread of pinyon-juniper into sagebrush steppe. Processes represented at the local scale are plant dispersal mechanisms and effects of recent fire. Arrow 4 shows that a pattern of vegetation within the pinyon-juniper subsystem can affect site level sagebrush steppe vegetation. These arrows are just a few examples of the important interactions.

Frame-based models are dynamic versions of state-transition models, such as those described in Chapter 3, section “[Ecosystem Dynamics](#).” They are based on the same idea that a site’s state is maintained by a number of interacting processes until a threshold of change is reached, which precipitates a switch to a different system state. For example, a sagebrush steppe-bunch grass site can be converted to sagebrush steppe-cheatgrass with the frequent occurrence of fire ([fig. 3.6](#)). Frame-based models incorporate site-specific ecological accounting, which means that these models keep track of and account for the prior or existing

condition, the causative factors altering these conditions, and, if the conditions cumulatively cross a threshold, the subsequent changed condition. This ecological accounting is conducted at regular time steps (frames) defined by the management decision (question) that structures the model itself. The management questions also define which states and drivers must be tracked. Spatially explicit frame-based models use geographic information systems (GIS) to include measures of the site’s geographic relationships that affect the ecological processes such as landscape patterns and measures of adjacency, proximity, diffusion, and fragmentation. Until

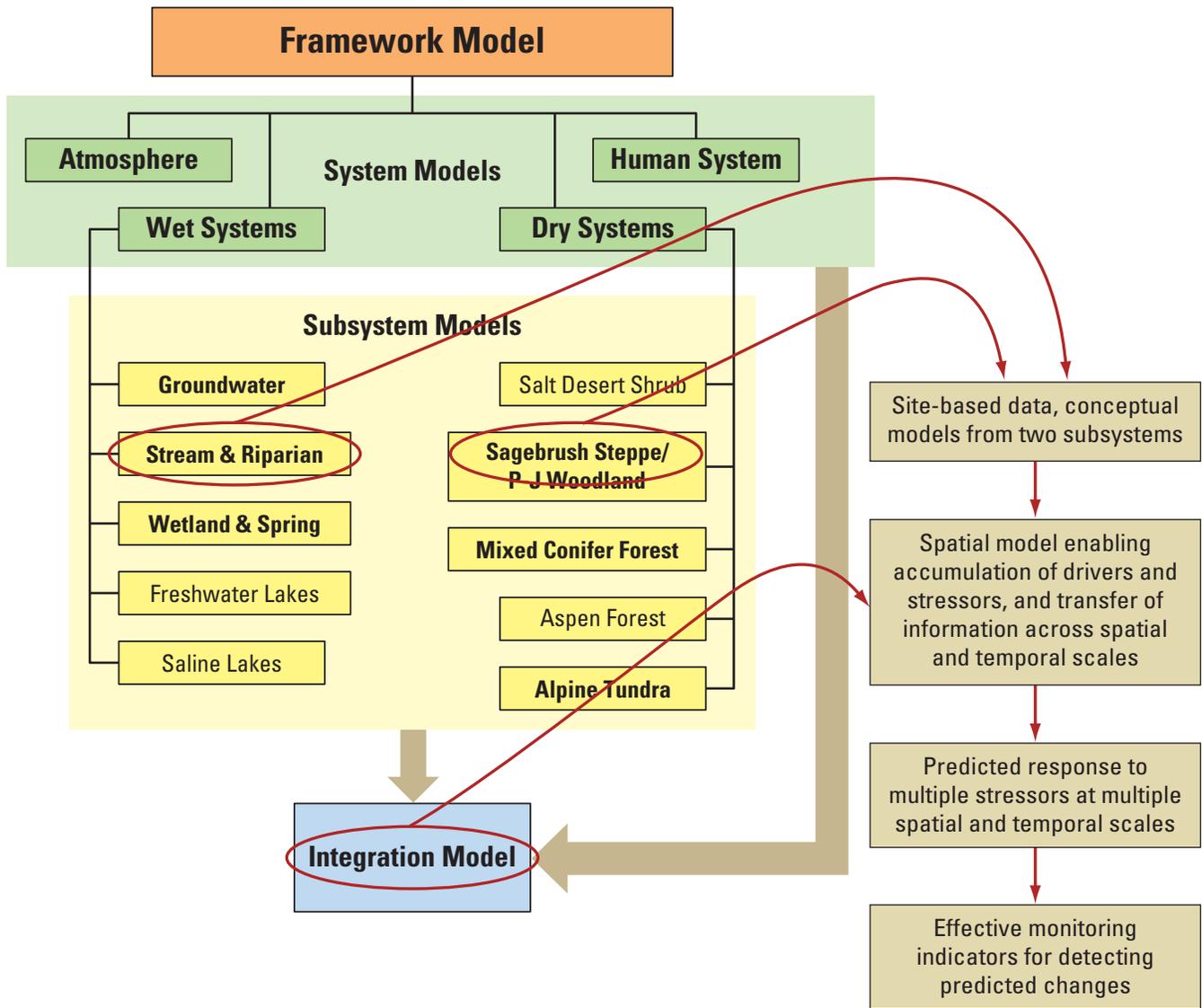


Figure 5.9. Overview of the relationship between outcomes from subsystem models, the integration model, and specific management needs. The diagram provides context for the example in the text explaining how site-based data and conceptual models (control, stressor, and integration) are identified spatially and temporally within the appropriate hierarchical scale for analysis.

recently, compiling an ecological accounting framework for an area the size of the GBILM was unrealistic. However, with advances in GIS, remote sensing, digital archiving, computer technology, and networking, it is feasible to develop the required framework.

A necessary step for ecological accounting is to distill the information embodied in the control and stressor models. Model relationships must be compiled into a library of probabilities that can be used for the frame-based model in the form of parameters. The parameters represent the probability of occurrence of the agents of landscape change. For the example used in this chapter, the most common agents of

change are fire return intervals, rates of invasion of exotic species, relative intensity of biological pests, anthropogenic aquifer drawdown, and climate parameters used to model the probability of droughts and floods. Within frame-based models, these probability parameters are the switches from one state to another. When the probability of an occurrence is high enough that a tipping point is reached, the system switches to an alternative state (fig. 5.11).

Each land unit has its own particular set of conditions that is part of its legacy within the landscape. Prior conditions that led to a degraded current condition can hold for parcels occurring adjacent to parcels with healthy reference

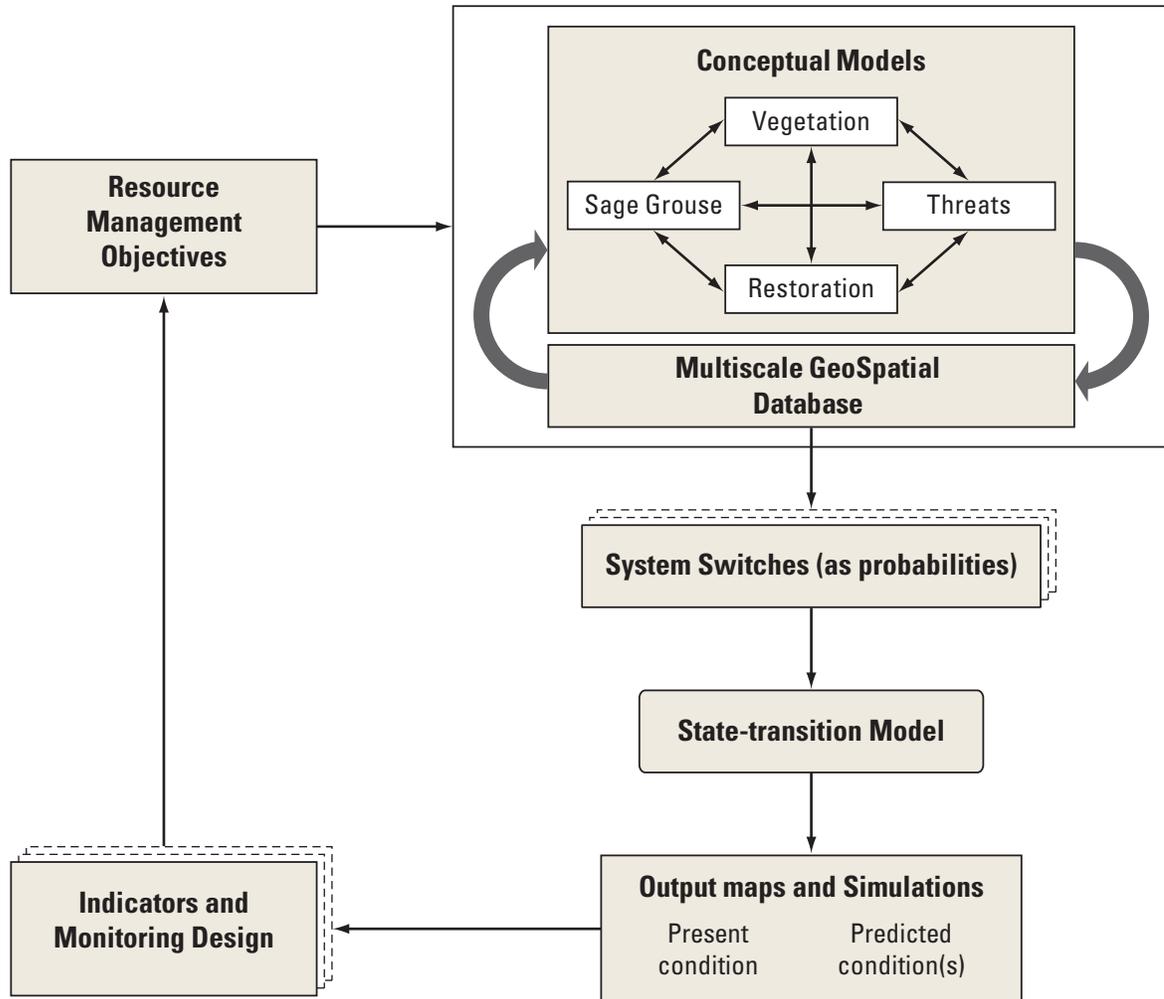


Figure 5.10. Overview of Integration Model. Depending on the objectives defined by resource managers, a subset of conceptual models is selected that provides a mechanistic understanding of the social, hydrologic, and ecological processes relevant for understanding management options. The conceptual models inform the development of a geographic information service (GIS) database to “map” the mechanisms onto a spatially explicit multi-scale framework. Using information from the mechanistic models and, if lacking, from sensitivity analysis or other techniques, probabilities are derived and used in frame-based state-transition models to begin to explore the effects of stressors on the focus areas. The outputs from the frame-based state-transition models are mapped back into the GIS to provide spatially explicit predictions to be tested as hypotheses. Results from the hypothesis testing provide information for management consideration for issues such as selecting indicators.

conditions. The frame-based model predicts the changes for one land unit area in a specific initial condition given differing scenarios of probable occurrences. Frame-based models are made spatially explicit by merging them with GIS geodatabases where each polygon (or pixel) on a map can be categorized with the condition of its vegetation community and other attributes. In addition to the drivers/stressors shown in [figure 5.11](#), other probabilities of occurrences associated with spatial patterns are included such as distance to a neighboring polygon with cheatgrass, distance to road

features, relative topographic position, and measures of fragmentation or connectivity. The model is run on each individual land unit to produce landscape level change predictions.

Running the simulation over time and across space can provide a systematic framework to explore the responses of various sagebrush steppe sites to drivers and stressors. Using regionwide site-based data will help to quantify the relative influence of site conditions and drivers to expected changes in climate and other anthropogenic impacts.

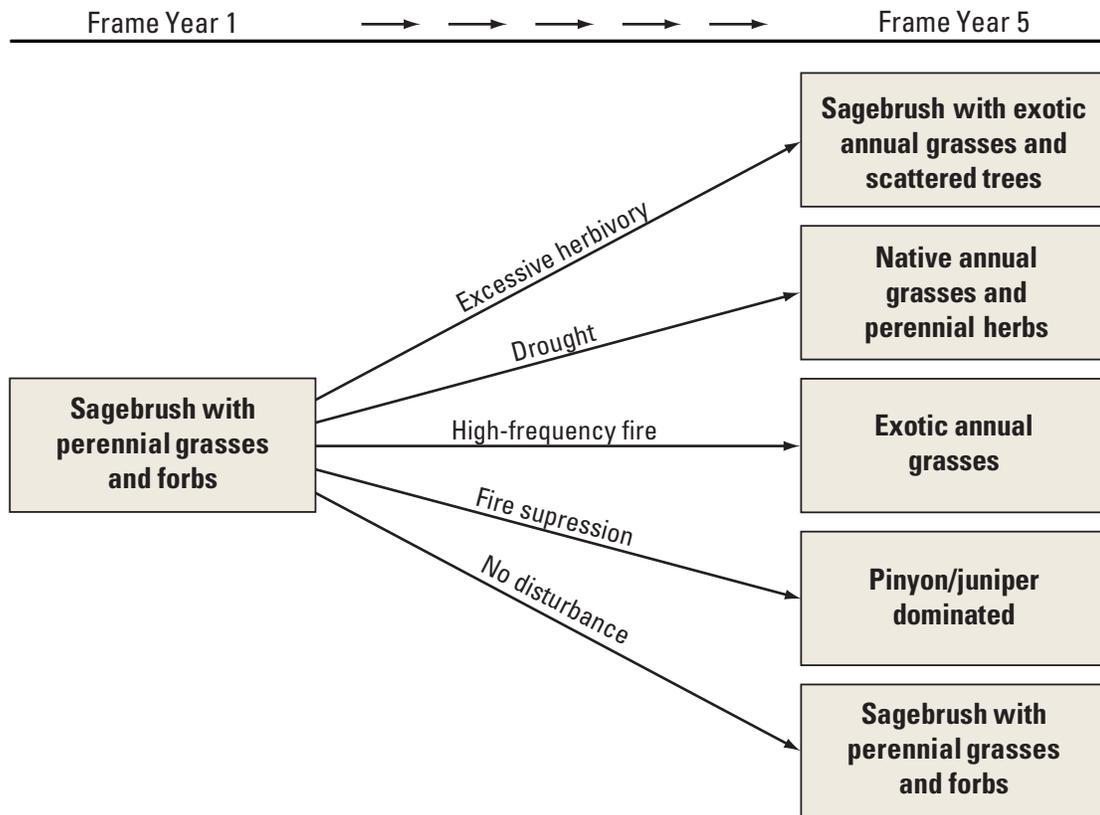


Figure 5.11. Frame-based model for simplified sagebrush steppe example. The single box on the left represents the state of one specific area of the map that was classified (for example, in year one, the initial condition) as “Sagebrush with perennial grasses and forbs.” The five boxes on the right represent the condition of the site after five yearly time steps (frames) under five scenarios each represented by a different driver. For simplicity, each driver is assumed to operate for the full 5 years and the transition result (for example, Frame YR 5) for each scenario is the result of a single driver.

Summary Points

The integration model described in this section seeks to link the components of the Great Basin within a multi-scale framework to provide insights for management decisions. A three-tiered hierarchical structure in which the ecological systems and the associated processes that structure these systems—described through control and stressor models—forms the spatial and temporal skeleton of the integration model. The model is intended to improve understanding of cross-scale interactions and cumulative effects.

The model approach assumes that simulation model results from frame-based state-transition models (or other kinds of models) are hypotheses that summarize the current state of scientific knowledge and project these into the areas of management interest. These hypotheses then must be evaluated to validate the model. Evaluating hypotheses requires access to monitoring data, which in turn requires resources to extract and convert these data into the parameters that drive the model. Archived data such as remotely sensed imagery or land treatment data, for example, could be useful for generating and testing the hypotheses.

Many issues related to data development will continue to challenge model integration. Data compilation, aggregation, and transformation are being advanced through informatic, geostatistical, and mathematical research. Keeping abreast of and incorporating innovative methods to integrate data from different sources will be important.

As ecosystems continue to respond to anthropogenic pressures, novel conditions may arise that our current model categories have not captured. Maintaining flexibility in our ecological accounting framework will be an important design element so that new categories can be added as needed. Unexpected synergistic effects, either between stressors or as feedback loops between drivers and ecosystem responses, also are a category of surprise that a flexible accounting structure can accommodate.

Much research effort from many organizations is pointed toward creating model-based applications to work more effectively with changing geographic units over time. Given the resources, the challenge will be to communicate among land managers, scientists, modelers, computer application designers, and database designers to create systems that provide results and then develop visualization tools to share the results with society.