

Chapter 4: Hydrologic Processes Influencing Meadow Ecosystems

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Introduction

The hydrologic regime exerts primary control on riparian meadow complexes and is strongly influenced by past and present geomorphic processes; biotic processes; and, in some cases, anthropogenic activities. Thus, it is essential to understand not only the hydrologic processes that operate within meadow complexes but also the interactions of meadow hydrology with other processes that affect these ecosystems. Regional- and watershed-scale analyses have contributed to the understanding and management of meadows. However, investigation of meadow-scale characteristics and processes have shown that local factors can override larger-scale influences and that some processes, especially those related to groundwater hydrology, cannot be fully explained by topographically defined watershed-scale characteristics (Montgomery 1999; Winter 2001; Devito and others 2005). In this chapter, we provide an overview of the hydrologic setting within the Great Basin and describe and explain key aspects of meadow hydrology for specific sites within selected watersheds in central Nevada. Next, we discuss generalities in the hydrologic characteristics of 56 meadows that were assessed in these upland watersheds. We conclude by providing an approach for characterizing hydrologic conditions based on hydrologic setting, groundwater conditions, vegetation patterns, and stream connections.

Hydrologic Characteristics and Processes

General Hydrologic Setting

The geomorphic and hydrologic characteristics of the Great Basin provide a framework to understand general hydrologic processes and patterns at both watershed and meadow scales. The geology, topography, and climate of the Great Basin are highly variable across the region and, consequently, the hydrology of the area is complex. Regional groundwater flow patterns are strongly controlled by southwest-northeast trending fault-block mountain ranges and, in some locations, include deep, interbasin flow through permeable bedrock units that connect basins (Mifflin 1988; Plume 1996; Maurer and others 2004). In general, mountain ranges and flanking alluvial fans are groundwater recharge areas, whereas the centers of many basins are groundwater discharge zones (Maurer and others 2004). The types of geologic units that underlie the basins and that form the adjacent mountain ranges exert strong controls on groundwater flow

rates and paths. Most bedrock units have low permeability. Intrusive igneous rocks and metamorphic rocks generally exhibit low permeability and act as barriers to groundwater flow (Plume 1996; Maurer and others 2004). However, highly fractured basalt, a volcanic rock, may have hydraulic conductivity values up to about 400 m/day. Sedimentary rocks have a wide range of permeabilities; at the high end, some carbonate rocks with fractures widened by solution have hydraulic conductivity values up to 1000 m/day (Maurer and others 2004). Unconsolidated deposits are commonly of fluvial origin, and although their hydraulic conductivity is highly variable, it may be as high as 670 m/day. Faults can differ in permeability from surrounding earth materials by up to several orders of magnitude. In general, faults in unconsolidated materials restrict groundwater flow, and faults in bedrock enhance flow (Maurer and others 2004).

The locations, volumes, and timing of groundwater recharge and discharge are critical to sustaining montane riparian meadow complexes. The interactions of groundwater and stream water are important to understanding these systems (Winter 1999; Jewett and others 2004; Newman and others 2006; Stonestrom and others 2007). Groundwater recharge in the arid- to semi-arid southwestern United States tends to be focused in stream beds and limited areas of headwater regions of mountains rather than over broad, diffuse areas as is common in more humid regions (Wilson and Guan 2004; Constantz and others 2007; Prudic and others 2007). Perennial streams, springs, and wetlands are generally groundwater discharge sites that are supported by deeper, regional groundwater flow systems (Jewett and others 2004; Anderson and others 2006; Newman and others 2006; Patten and others 2008). Conceptual models of groundwater and stream water interaction in the Great Basin show that streams gain in the mountains and lose in the basins (Mifflin 1988). At smaller scales, however, the patterns are more complicated. A given stream channel may change between gaining and losing over short distances or seasonally (Jewett and others 2004; Newman and others 2006; Prudic and others 2007).

General Relationship of Meadow Vegetation to Hydrology

Montane riparian meadow complexes of the central Great Basin are characterized by herbaceous wet and mesic plant communities dominated by sedges, rushes, and grasses (Weixelman and others 1996; Chambers and others 2004). Meadow vegetation patterns are partly controlled by geomorphic setting, soil type, and human uses, but the depth to

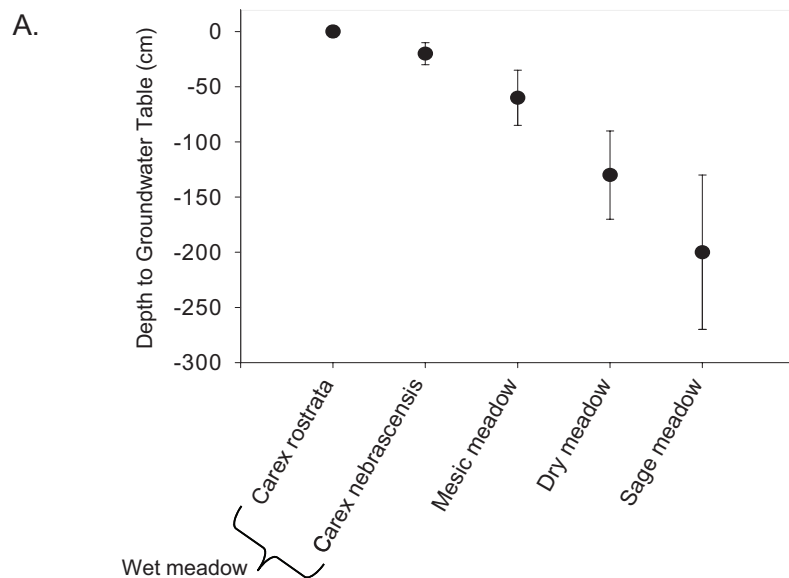
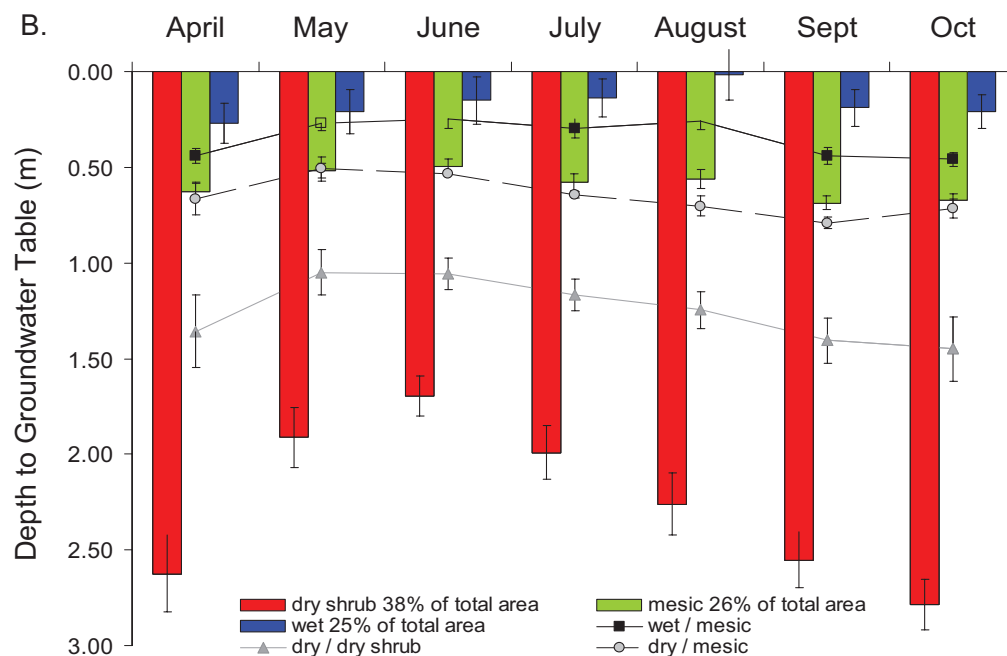


Figure 4.1. (a) General relationship between depth to groundwater table and vegetation type; both *Carex* species are part of the wet plant community (Chambers and others 2004). (b) Seasonal relationship between water table depth and vegetation type at Kingston 3 meadow, 2003 to 2006.



the water table is the dominant controlling factor at most sites (Allen-Diaz 1991; Chambers and Miller 2004). Different meadow plant communities tend to occur along gradients that are controlled by water table elevation (or depth) (Castelli and others 2000; Jewett and others 2004; Dwire and others 2006). The relationships between depth to groundwater and meadow vegetation types are well-defined for upland meadows in the central Great Basin (fig. 4.1a; Castelli and others 2000; Martin and others 2001; Chambers and others 2004). In general, wet meadow communities require water table depths during the growing season of less than 30 cm, mesic meadow communities require about 55 cm, and dry meadow communities require about 120 cm (Castelli and others 2000; Jewett and others 2004). Widespread stream incision of meadow ecosystems is considered the most important threat to this scarce, ecologically important resource

that supports a high percentage of the Great Basin's biodiversity. The magnitude, location, and frequency of stream incision are influenced by climate, bedrock geology, alluvial stratigraphy, vegetation, groundwater-stream water interactions, and anthropogenic activities (e.g., Germanoski and Miller 2004; Weissmann and others 2004). Stream incision often results in declines in meadow water tables and can cause shifts in plant community types from wetter to drier (Chambers and others 2004). The response of plant communities to stream incision is largely controlled by the meadow groundwater hydrology, especially the traits of interaction between groundwater and stream channels. Understanding the linkages among stream, hydrologic, and vegetation processes in meadow complexes is fundamental to effective management, stabilization, and restoration of these riparian ecosystems.

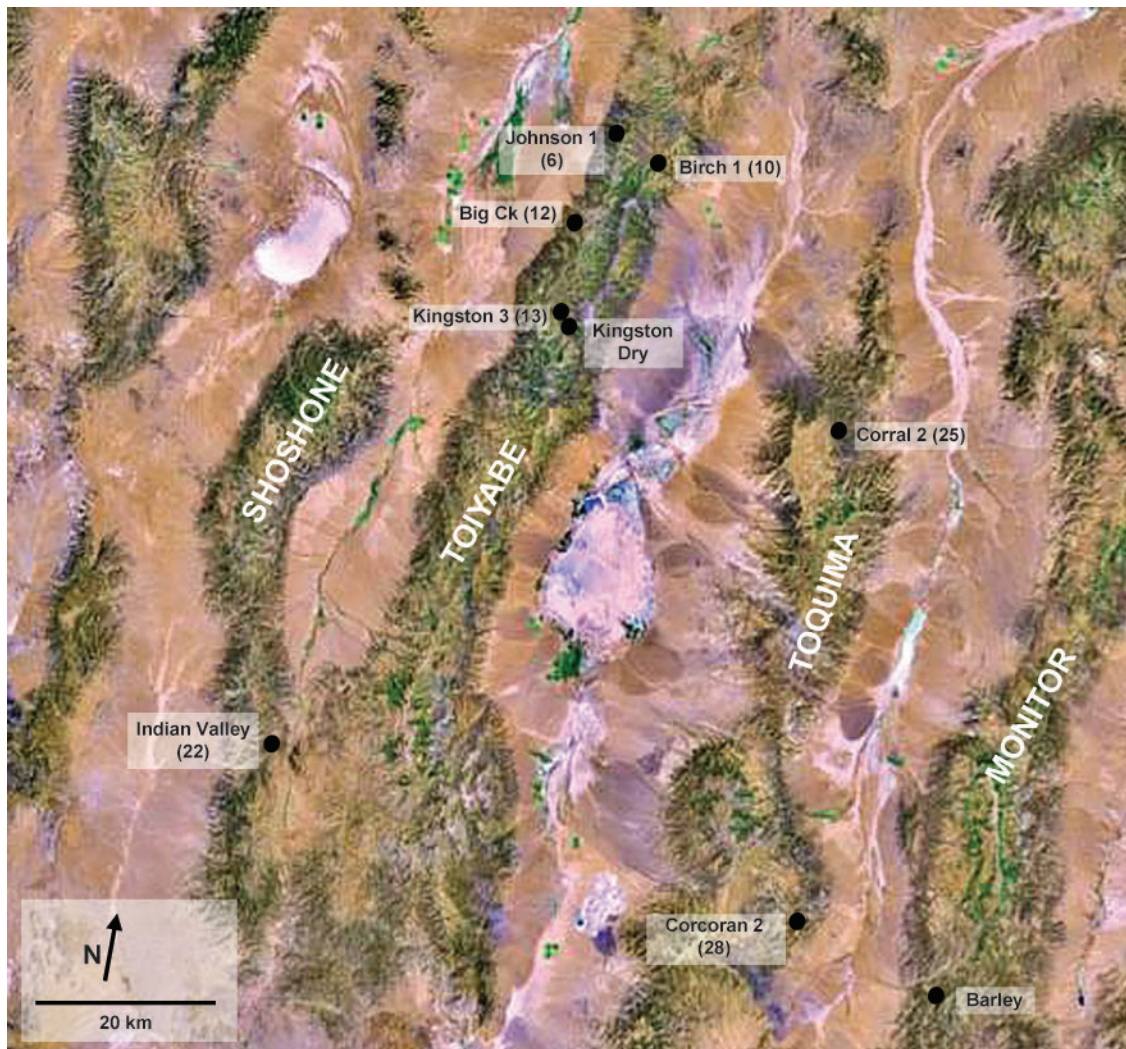


Figure 4.2. Satellite image of central Nevada mountain ranges showing locations of three heavily instrumented meadow sites (yellow circles) and other meadows referenced in this chapter. Meadow names and number in parentheses match the study site map in fig. 1.7.

Hydrologic Study Approach

The characterization of meadow hydrology was conducted using (1) data collected at meadows that are dispersed across the Great Basin of central Nevada, and (2) intensively monitored and studied meadows that were chosen to represent the larger meadow population. The study population included 56 meadows located in 33 watersheds over 6 mountain ranges in the central Great Basin (fig. 1.7). All of the meadows that were studied are located in the mountains; range in elevation from 2023 m to 2631 m; and, with few exceptions, are located within the Humboldt-Toiyabe National Forest. Detailed hydrologic, stratigraphic, and geomorphic data were collected at six meadows to document processes, test hypotheses, establish causal relationships, and provide a basis for interpreting the hydrology of the entire meadow population (fig. 4.2; table 4.1). Three of the six meadows (Kingston 3, Big Creek, and Indian Valley) were studied intensively; data were collected on water table depth, stream discharge, stream and channel bed temperature, geophysical

properties, stratigraphic layers from sediment cores, and plant species and communities. These three sites were chosen because they are representative of other meadow complexes and because multiple years of physical and vegetation data were available. The Kingston 3 meadow, which was established as an experimental site in 2003, was the most studied site. Water table depths were collected monthly during the growing season from 1997 to 2008. Well depths ranged from about 0.5 m to 8 m. Groundwater levels and water temperature were measured hourly in 24 wells using automated water level loggers (pressure transducers). These data were used to document diurnal and seasonal variations in groundwater levels and longer-term patterns in groundwater flow.

This chapter summarizes data from the three intensively studied sites and integrates results with information that was collected at other meadows. Collectively, an improved understanding has emerged of meadow processes; hydrologic, geomorphic, and vegetation interactions; and management implications.

Table 4.1. Types of data collected at eight sites in the central Great Basin (figs. 4.2 and 1.7). Two sites, Barley and Kingston Dry, were studied to examine the formation or destruction of meadows; Barley did support a meadow prior to stream incision.

Topic	Data type	Meadow							
		Big Creek (12)	Indian Valley (22)	Kingston 3 (13)	Barley	Birch 1 (10)	Corcoran 2 (28)	Johnson 1 (6)	Kingston Dry
Geology	Sediment cores (stratigraphy, texture, % organic)	3	3	14	4	2	0	4	2
	Down-hole geophysics (resistivity)			•					◦
Ground-water	Water chemistry	◦	◦	•		◦			◦
	Groundwater well level data (monthly)	54	60	99	4	4	3		4
	Continuous water level and temperature	•	◦	•					
	Hydraulic conductivity data (slug/bail tests)	◦	◦	•					
Stream water	Longitudinal and cross section repeat surveys	◦	◦	•					
	Stream water and stream bed temperature surveys	◦	◦	•		◦			
	Water chemistry	◦	◦	•		◦			◦
	Continuous water level and temperature data	•	◦	•					
	Stream gaging	•	◦	•		◦			
Meadow	Plant community maps	X	X	X		X	X	X	
	Spring location, size, and type maps	X	X	X		X	X	X	
	Ground-penetrating radar survey data	•	•	•	•	•	•	•	•
	Seismic survey data	•	•	•			•		•
	Geomorphic map	X	X	X					

Number of wells and sediment cores at meadow
• Extensive at meadow (>6 locations in meadow)
◦ Minimal at meadow (<6 locations in meadow)
X Data were collected and mapped at meadow for listed topic

Hydrogeologic Settings of Kingston 3, Big Creek, and Indian Valley Meadows

The general hydrogeologic settings where meadows have formed were discussed in Chapter 2. Briefly, the major factors required for meadow formation are a sufficient supply of water and a hydrogeologic setting that detains groundwater, thereby creating a shallow water table. There are a number of geologic and geomorphic settings that have created these conditions, but a pervasive trait is the occurrence of fine-grained (low hydraulic conductivity) sediments in the down-valley portion of the meadow, which are commonly present where there is a local reduction in the cross section of axial valley fill. Whereas low-permeability sedimentary materials detain groundwater flow to support wet meadow vegetation, most meadows terminate down-valley where unconfined, high-permeability sedimentary layers permit rapid draining and lowering of the groundwater table.

A common geomorphic setting for meadow complexes is immediately upstream of where side-valley alluvial fans project across axial valleys (Chapter 2; Miller and others 2001).

Because the three intensively studied meadow complexes are discussed extensively in this chapter, their geomorphic settings are described here. The valley of Kingston Canyon has numerous side-valley alluvial fans (fig. 4.3a). However, some have created the hydrogeologic conditions necessary to support meadow complexes (such as Kingston 3) while others have not. One such area (Dry Kingston, fig. 4.3a) was studied to understand how the hydrology of this “dry” site differs from those that support wetlands (table 4.1). Within Kingston 3, the channel is locally incised by as much as 2 m below the valley floor. Stream incision is deepest immediately upstream of the side-valley alluvial fan and decreases upvalley.

The Big Creek basin is located in the Toiyabe Range of central Nevada, to the west and across the divide from the Kingston Canyon basin (fig. 4.2). Like Kingston 3, the meadow at the Big Creek field site is located upstream of a valley constriction that was created by coalescing alluvial fans that nearly extend across the entire width of the valley floor to the north (fig. 4.4). Another side-valley alluvial fan enters the axial valley near the southern end of the site. The Big Creek site is approximately 250 m long and ranges from 20 to 60 m wide. The site has a perennial stream,

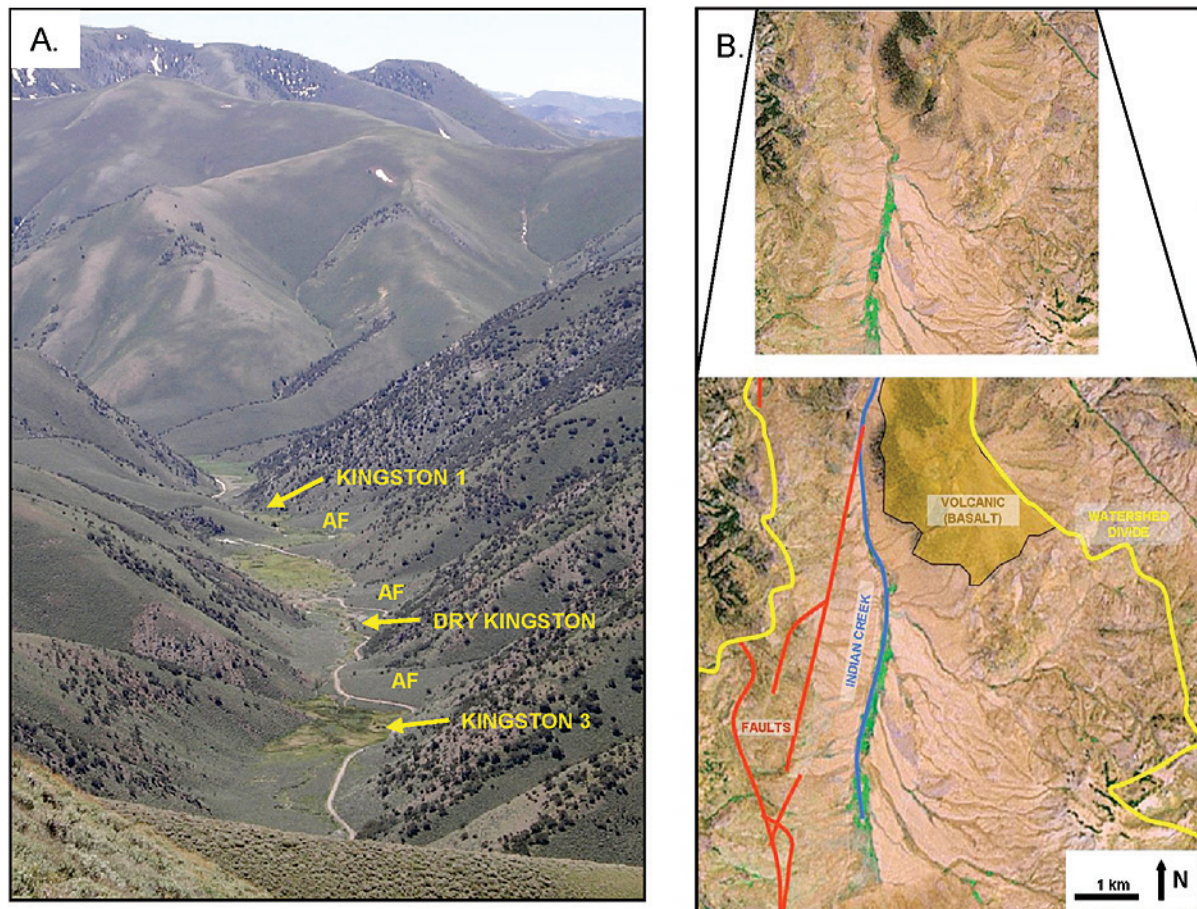


Figure 4.3. (a) Southerly view of Kingston Canyon showing setting common to many meadow complexes, with meadows immediately upstream of a side-valley alluvial fan (AF). The Kingston 3 meadow has 99 groundwater wells and a stream gage; it was the site of many detailed geologic, hydrologic, and vegetation studies (table 4.1). (b) Satellite image of Indian Valley showing meadow upstream of valley constriction caused by a volcanic mountain. Geology modified from Kleinhampl and Ziony (1985).

flowing south to north, in a channel incised up to approximately 1 m below the valley floor. The channel traverses the entire meadow system and links upstream and downstream reaches of the basin. Six small, spring-fed gullies flow across the wet meadow to the incised axial channel. The site is bounded laterally by steep hillslopes that rise sharply above the valley floor (fig. 4.4).

The Indian Valley meadow complex (fig. 4.3b) occurs in a different type of setting than Kingston 3 and Big Creek (fig. 4.4). Its origin is due to a remnant of a basaltic volcanic mountain located upslope of Black Mountain. Upvalley (south) of Black Mountain, a series of broad meadow complexes are present that developed on a relatively thin (about 8 m) sequence of primarily fine-grained alluvial sediments underlain by low-permeability volcanic rocks: rhyolite and tuffs (Kleinhampl and Ziony 1985; Jewett and others 2004). The meadow complex diminishes completely downvalley due to well-developed, incised channels underlain by coarser-grained alluvium and higher-permeability basaltic bedrock (Jewett and others 2004). In some locations in the meadow, incision exceeds 4 m. Source areas of water for this meadow complex are broad, old alluvial fans and faults (fig. 4.3b).

Groundwater Hydrology of the Study Meadows

Groundwater Spatial Patterns. Groundwater flow rates, seasonal patterns, and flow directions vary within a meadow and among meadows and reflect the geologic complexities discussed previously. The primary controls on groundwater conditions at a given location are: (1) stratigraphy (i.e., the type, geometry, continuity, and sequence of underlying geologic units); (2) hydraulic conductivity of subsurface materials; (3) the water source, particularly whether it is part of a local or regional aquifer groundwater flow system; (4) whether the source waters that directly support the meadow complex are diffuse or discrete (that is, derived from a thick, sedimentary unit or through faults and fractures in bedrock); and (5) the relationship of groundwater to stream channels. The Kingston 3 meadow was used to demonstrate groundwater flow patterns because of the extensive stratigraphic and hydrologic data available for this site. Information also was used from the Indian Valley site (fig. 4.2).

Like many Great Basin meadows, the hydrologic sources of Kingston 3 are springs and artesian conditions, and these

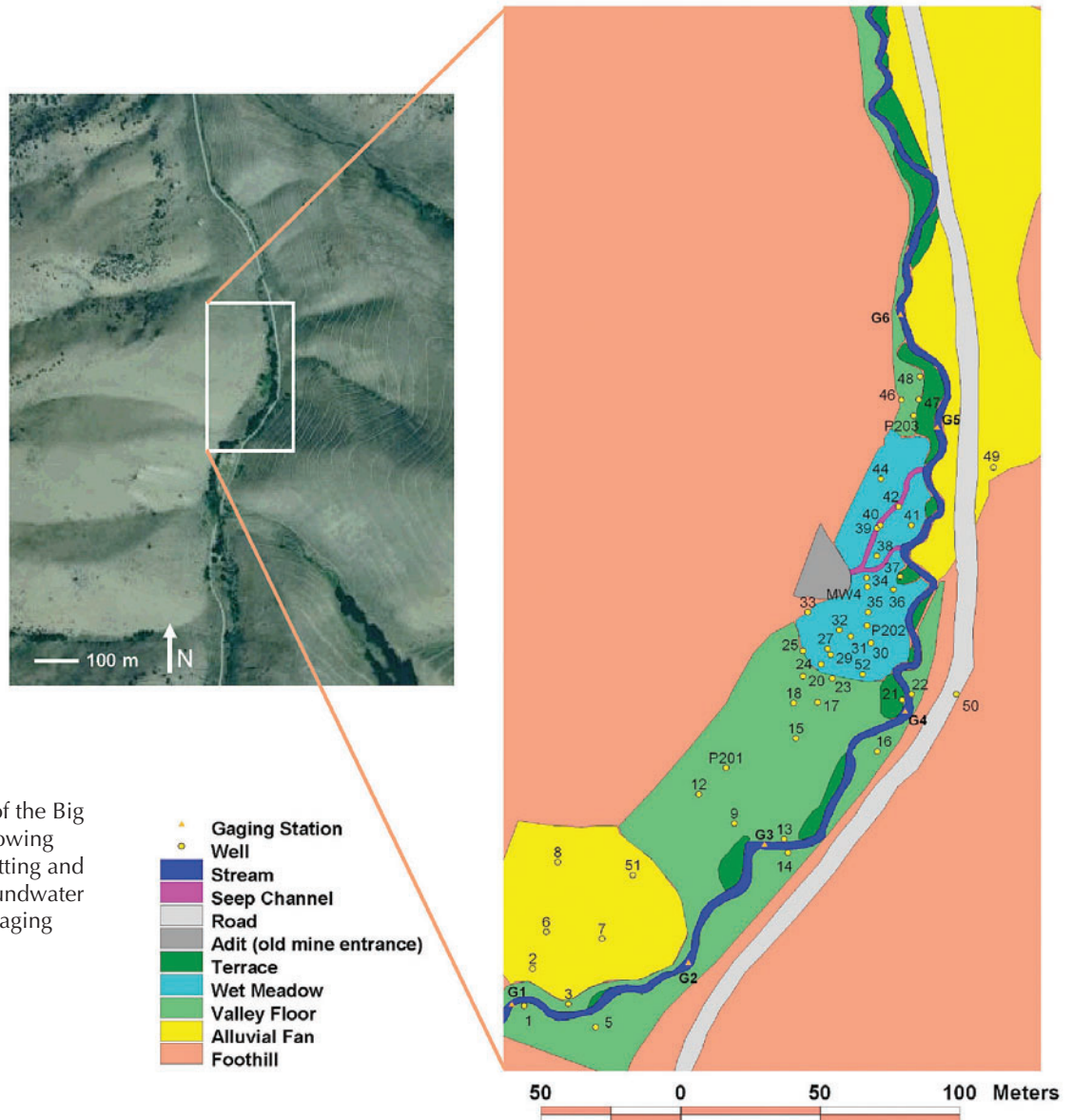


Figure 4.4. Site map of the Big Creek meadow showing the geomorphic setting and distribution of groundwater wells and stream gaging sites.

directly reflect the complexity of the subsurface geology. The water table depth at the Kingston 3 meadow is shallowest at valley floor edges and slopes toward the stream; the water table drops about 12 m in elevation over the length of the meadow (about 350 m) (fig. 4.5). An examination of the longitudinal, hydrogeologic cross-section demonstrates the influence of geology on groundwater flow patterns (fig. 4.6). In the upstream portion of the meadow, sediments are mostly fine-grained alluvial deposits created by axial valley streams. Down-valley, the coarse-grained sediments deposited by side-valley fans become more dominant. The interfingering of axial valley deposits with side-valley fan deposits resulted in many discontinuous sedimentary units with strongly contrasting hydraulic conductivities, which contributed to confining layers, artesian conditions, and points of emergence (or discharge) for springs. Discontinuous units also were produced by channel avulsion processes. Slug tests, an in-well method, were used to determine hydraulic conductivity of subsurface materials. The tests showed values that ranged over three orders of magnitude (10^{-2} to 10^{-5} cm/s) but

that probably under-represented the variability because in establishing the well field, groundwater wells were preferentially screened in coarser-grained sediments. The meadow's down-valley terminus coincides with the occurrence of continuous sand and gravel deposits (well 10.1; fig. 4.6), which permit more rapid groundwater flow and a lowering of the water table depth. The influence of stratigraphy of the valley fill and groundwater is indicated by the relationship of the shallow groundwater table and groundwater head levels from deeper wells (about 8 m). For example, as seen in fig. 4.6, the water table slopes down-valley and becomes more shallow downstream. The deep wells, however, are bound by fine-grained stratigraphic units, causing the head levels to become increasingly artesian down-valley, reaching levels up to 2 m above the ground surface, before continuous gravel layers are encountered and water pressure is released.

A three-dimensional understanding of the stratigraphy was obtained by detailed ground penetrating radar (GPR) surveys (Sturtevant 2007). As suggested by the core data, a facies map produced from the GPR surveys showed that

Figure 4.5. Kingston 3 meadow groundwater table and well sites. The stream is mostly gaining through the meadow, except at the downstream end where it is losing; the water table drops about 12 m over the length of the meadow. Groundwater table map is for August 2003, but overall patterns change little with time. The meadow is instrumented with groundwater wells (circles); most well sites have nests of piezometers (n = 99; schematic lower left). Green line (center) is location of water table profile in fig. 4.10. Stream flow is south (right).

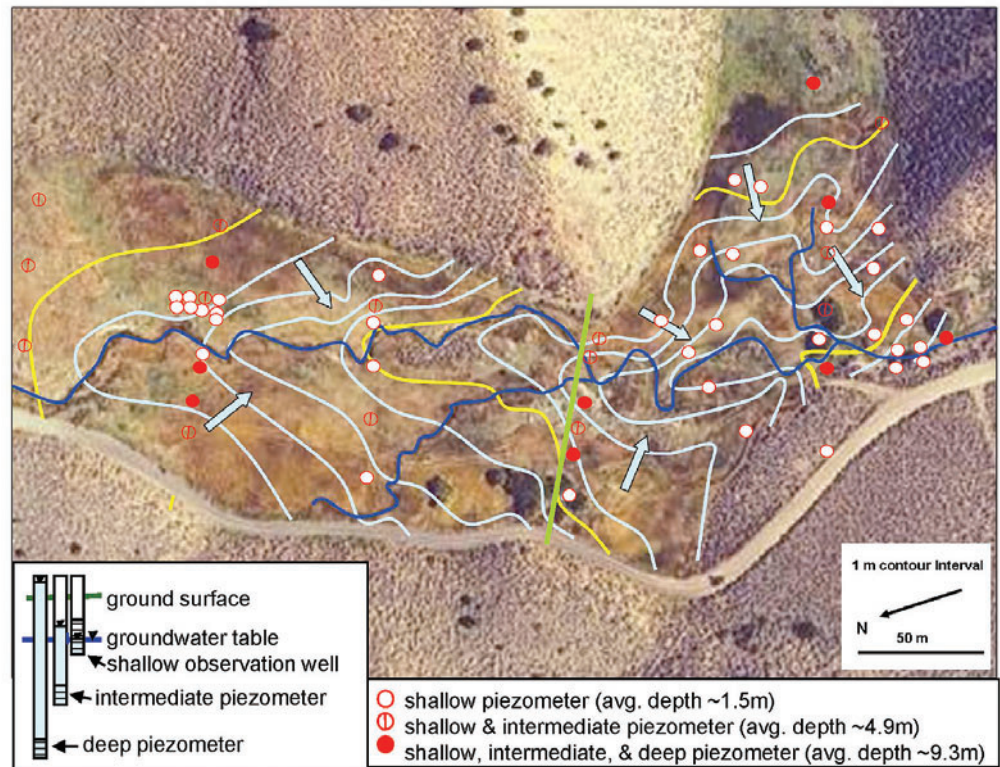
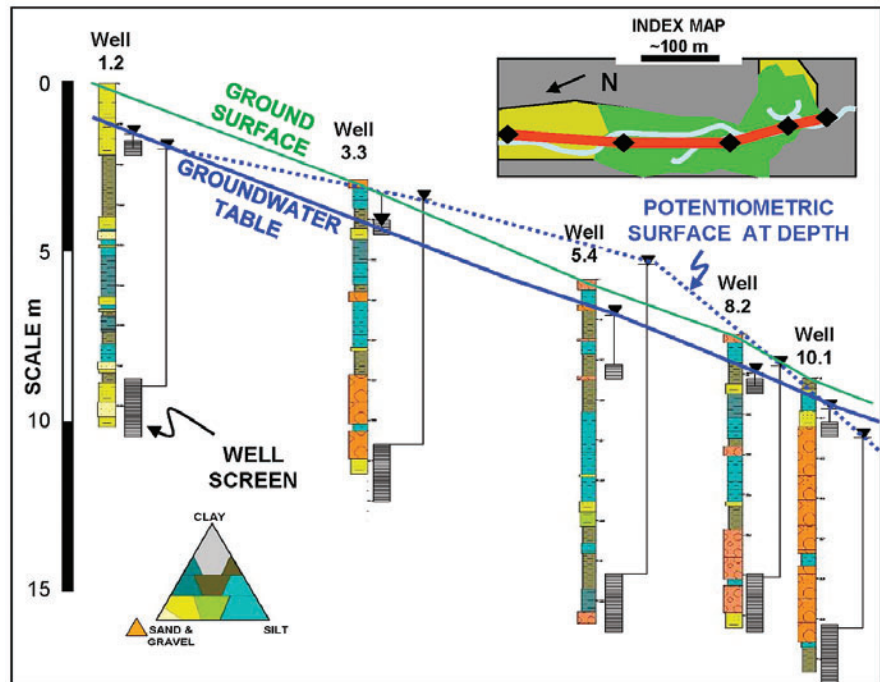


Figure 4.6. Longitudinal hydrogeologic section of down-valley axis of Kingston 3 meadow. Lithologic columns show a coarsening down-valley; about three-quarters of the most downstream core in the meadow (well 10.1) is composed of gravel. The water table, determined from the shallow wells, becomes closer to the surface down the meadow. The deep groundwater shows an increase in artesian conditions (see potentiometric surface) down the valley, up to the point where the meadow terminates around well 10.1.



the valley fill is characterized by many discontinuous layers that generally coarsen down-valley (fig. 4.7). The map also showed the occurrence of gravel deposits along the eastern valley floor margin, where numerous springs discharge to the surface.

Groundwater table and flow patterns in the meadows also vary along the valley floor before reaching the side-valley fan deposits. In the Kingston 3 meadow, the variability of groundwater levels decreases down-valley in both shallow and deeper groundwater systems (fig. 4.8). Over a five-year period, groundwater levels at the upstream end of the meadow varied about an order of magnitude more than at

down-valley sites. The opposite pattern is present at the Indian Valley meadow complex (fig. 4.9), where down-valley wells show much more variability than upstream sites. This contrast reflects differences in the hydrogeologic settings of the two sites. At Indian Valley, the stratigraphy is less complex than at Kingston 3 meadow and the conditions contributing to shallow water tables are gradually lost over about 1 km (Jewett and others 2004). At the Kingston 3 meadow, marked changes in hydrogeology occur over just a few meters in some places.

The characteristics of the connection between groundwater and surface water are strong determinants in how the

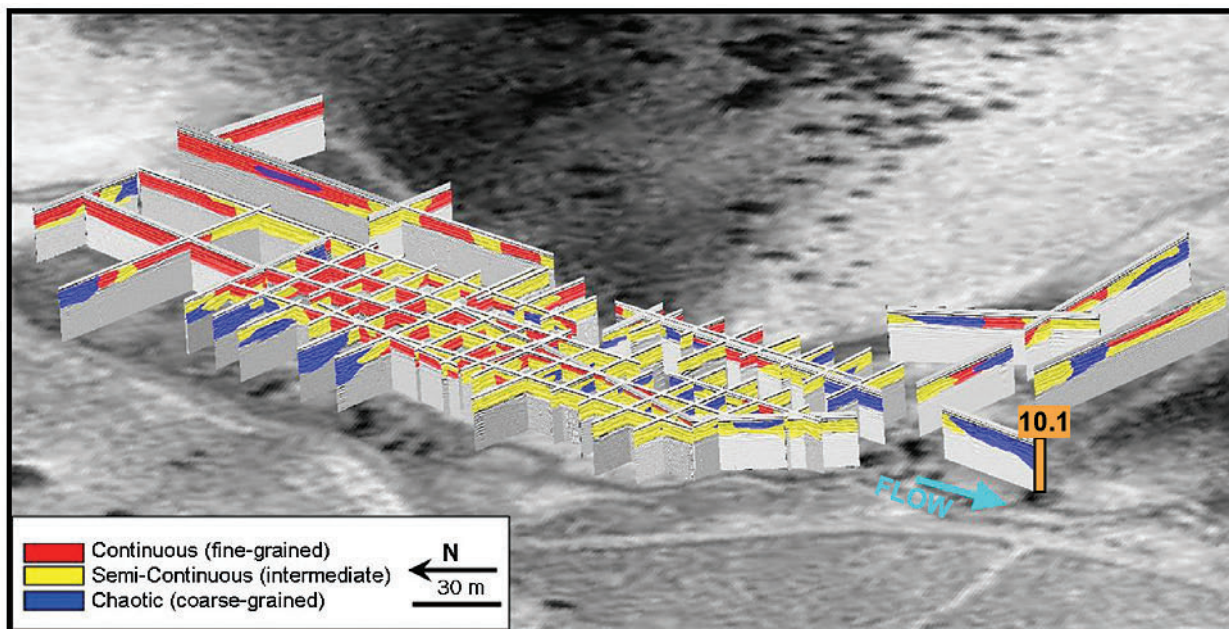
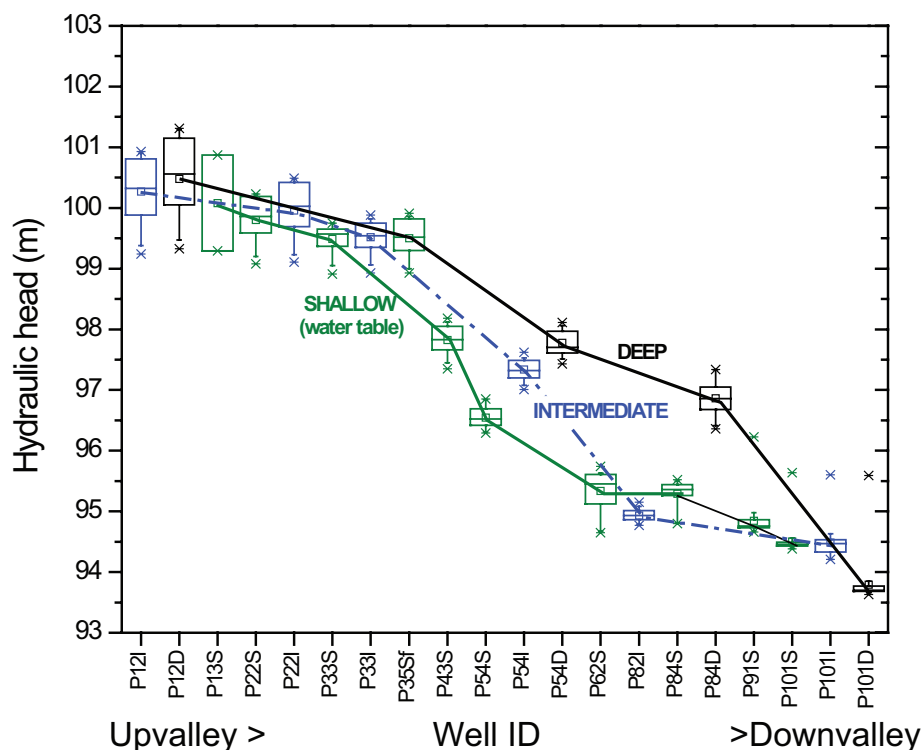


Figure 4.7. Ground-penetrating radar facies map of Kingston 3 meadow (from Sturtevant 2007). Upstream units are generally fine-grained and continuous, whereas downstream units are coarser-grained and discontinuous. The coarse-grained area at well site 10.1 (see longitudinal section of fig. 4.6) coincides with the down-valley meadow terminus, a loss of artesian conditions, and groundwater with a downward flow direction. These changes in conditions are attributed to the continuity of the coarse-grained sediments that permit rapid drainage of groundwater that supports the meadow upvalley.

Figure 4.8. Water levels in nested piezometer sites along the down-valley axis (fig. 4.5) at Kingston 3 meadow; elevation is relative. Groundwater levels at all depths are most variable upvalley. Water levels in the deep wells are above the groundwater table throughout most of the meadow and have heads up to 3 m higher than the water table in the lower part of the meadow (e.g., P84D). The increased artesian conditions down the meadow are caused by fine-grained, confining stratigraphic units, which lead to high fluid pressure.



water table and, therefore, vegetation types respond to stream incision or migration (Chapter 5). Streams can be viewed as gaining or losing depending on whether the groundwater flows toward the stream or drains away from the stream. At Kingston 3 meadow, much of the stream is fed directly by shallow groundwater, thus the groundwater table adjacent to the stream slopes to the level of the stream (fig. 4.10a). In

a losing reach, stream water drains into the groundwater so that the water table slopes away from the channel. This is the case for some reaches of the stream in Indian Valley (fig. 4.10b), where the hydrogeologic conditions no longer support shallow water tables.

The source area of the groundwater supporting meadows also controls the spatial characteristics of the groundwater

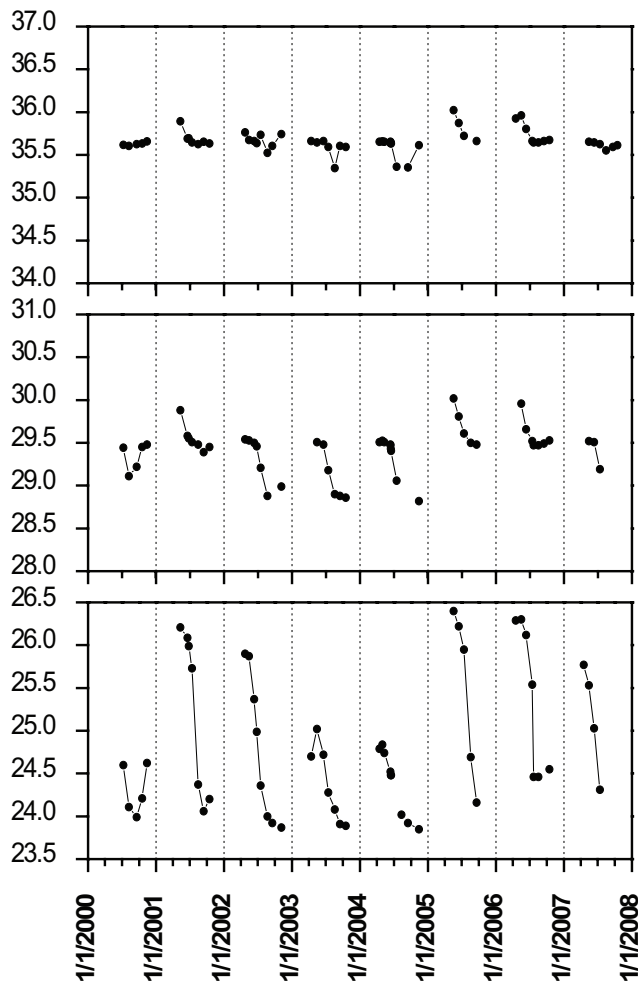


Figure 4.9. Groundwater table elevations in floor of incised trench, from upstream (well 8B), midstream (well 5B), and downstream (well 3B) reaches at Indian Valley; elevation is relative. Note that seasonal water table variations increase downstream from less than 0.5 m to over 2 m.

table and flow patterns in meadows. Overall, meadow complexes are groundwater discharge sites, though patterns vary depending on the size of the groundwater catchment area and when the recharge occurs for that groundwater body. For example, discharge areas of regional (large-scale) groundwater flow systems tend to have less variation in head levels at daily and seasonal scales and are important to sustaining many springs and wetlands (Mifflin 1988; Wilson and Guan 2004; Anderson and others 2006; Winter 2007; Patten and others 2008). The influence of different groundwater sources is evident at Kingston 3 meadow. The upstream portion of the meadow is fed by groundwater moving downstream through the valley fill. These areas show strong seasonal and diurnal variations in water levels (well 33; fig. 4.11). In the mid- and downstream portion of the meadow, water table depths show little seasonal variation and, in some cases, have trends opposite to those in the upstream portion of the meadow (fig. 4.11). These traits are indicative of regional groundwater discharge sites (Winter 2004; Jewett and others 2004; Newman and others 2006; Prudic and others 2007). Based on the groundwater level and water chemistry data at

Kingston 3 meadow (Tennant and others 2006), the meadow complex has three primary groundwater sources: axial valley water; alluvial tributary water that joins the meadow from the east; and, as indicated by seismic data, water from a subsurface fault that outcrops under a portion of the west margin of the valley side. The influence of these sources also is reflected in fig. 4.5, which shows contours of relative water table depths throughout the meadow.

Groundwater Interaction with Stream Water. Evidence for multiple groundwater sources supporting meadow complexes can be found by examining the interaction between groundwater and stream water. In fig. 4.11, the discharge pattern of the stream in Kingston 3 meadow (Stm, bottom graph) reflects a complicated composite of different groundwater sources. The stream is perennial within the meadow but it is intermittent immediately upstream of the meadow and typically flows from late spring to mid-summer during snowmelt runoff. Interactions between surface water and groundwater were evaluated by repeated, detailed stream discharge measurements of the stream and its tributaries (fig. 4.12a). Hydrologic budget analysis of stream discharge showed that axial valley groundwater feeds the upstream end of stream (above gage station K4) but that the spring-fed tributaries are the primary source of flow downstream. When tributary inputs to flow are subtracted, the stream is losing in some reaches of the meadow, especially downstream of gage station K2. For example, for the 2004 data shown in fig. 4.12a, the stream loses over 30 percent of its flow between stations K2 and K1.

Spatial changes along the stream within the meadow also were evaluated by installing temporary piezometers directly in the stream bed to a depth of 0.5 m. This simple method can be used to determine if the stream is gaining or losing by comparing the water level in the piezometer to the stream water level (Wanty and Winter 2000). The collected data are consistent with stream discharge measurements. The vertical hydraulic gradient was 0.3 m/m upward at the upstream end of the meadow and 0.06 m/m downward in the downstream portion of the meadow.

Repeated surveys of stream water and stream bed (15 cm deep) temperatures were conducted along the length of the stream and its tributaries (fig. 4.12b) to identify gaining and losing stream segments and changes in groundwater sources (Constantz 1998; Kalbus and others 2006). The temperature profile data showed three distinct patterns in stream water temperature: warming in the upstream segment of the meadow, cooling to the middle segment of the meadow, and subsequent warming downstream (fig. 4.12b). The locations of the pattern changes are consistent with the flow data on gaining and losing reaches.

Many studies have documented the importance of understanding the exchange between groundwater and surface water on stream biotic productivity, the hyporheic zone, and biogeochemical cycling (e.g., Hunt and others 2006; Newman and others 2006). However, as seen in Kingston 3 meadow, changes in this interaction can occur over short distances and time intervals, so generalizations about a stream reach being gaining or losing may oversimplify

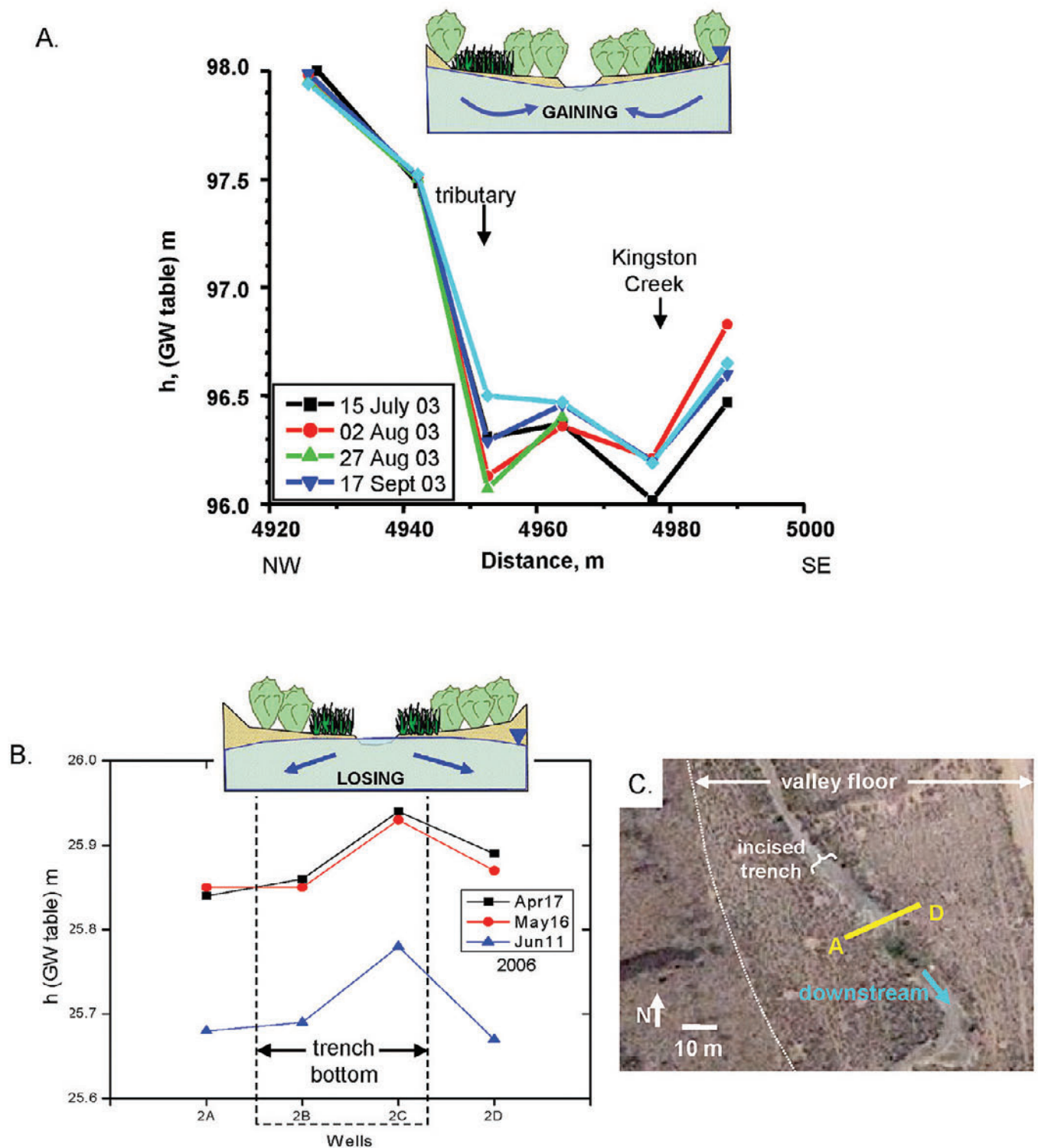


Figure 4.10. Groundwater table profiles across a gaining and losing channel reach. Schematic diagrams show relationship of water table and flow directions to stream. (a) Gaining reach at Kingston 3 meadow; water table slopes toward channel (profile location shown by green line on fig 4.5). (b) Losing reach at Indian Valley meadow; water table slopes away from channel of incised trench. (c) Aerial photograph shows geomorphic setting. Upstream portions of Indian Valley are mostly gaining but become losing down-valley with distance from the water sources and as the permeability of the subsurface materials increases.

reality. Newman and others (2006) indicated that small-scale changes in the type of exchange between groundwater and surface water are relatively common in semi-arid systems and can result from changes in geology and variations in runoff inputs.

Meadow Hydrology Temporal Patterns. While some temporal patterns relate to spatial controls were discussed previously, natural events (precipitation, snowmelt, occurrence and length of growing season, climatic change, etc.) also have significant effects on hydrologic processes. We

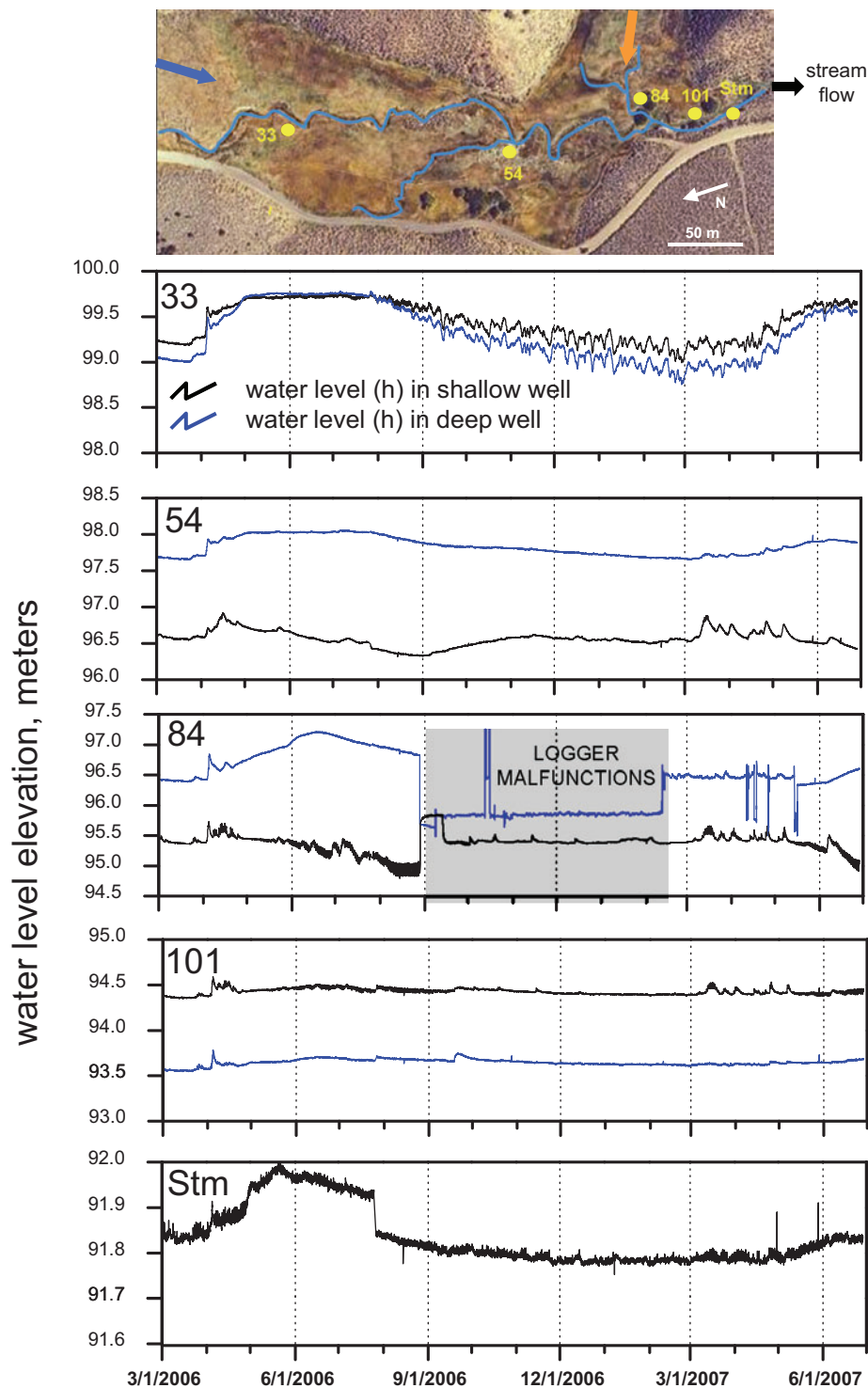


Figure 4.11. Groundwater and stream water levels (Stm) of Kingston 3 meadow sites. Groundwater plots show water levels of deep and shallow wells in successively down-valley wells, from top to bottom. Well site 33 shows a smooth seasonal signal, fed by axial valley groundwater (index map, blue arrow), while well sites 54 and 85 are more flashy and are influenced strongly by groundwater from the high-gradient tributary valley (orange arrow). Vertical hydraulic gradient is small at well site 33, strongly upward at sites 54 and 84, and downward at site 101.

use the hydrologic and hydrogeologic data from the Big Creek study site to illustrate short-term and long-term temporal patterns in meadow hydrology. The Big Creek site has been continuously monitored since it was instrumented with 54 piezometers in 1997 (Jewett and others 2004).

The Big Creek meadow is located upstream of a valley constriction that is created by coalescing alluvial fans that extend nearly across the entire width of the valley floor to the north (fig. 4.4). Another side-valley alluvial fan enters the axial valley near the southern end of the site. Sources of

water to the groundwater system at the Big Creek site are subsurface flow moving down-valley in the valley-fill sediments, the side-valley alluvial fan located near the southern boundary of the site, and discharge from the stream. Contour lines of water table surface (fig. 4.13) indicate that the main direction of subsurface groundwater flow is down-valley in a southwest to northeast direction. The largest component of groundwater flow is water moving through the thick valley-fill sediment sequence. The lateral constriction caused by narrowing of the valley on the north end of the site combined

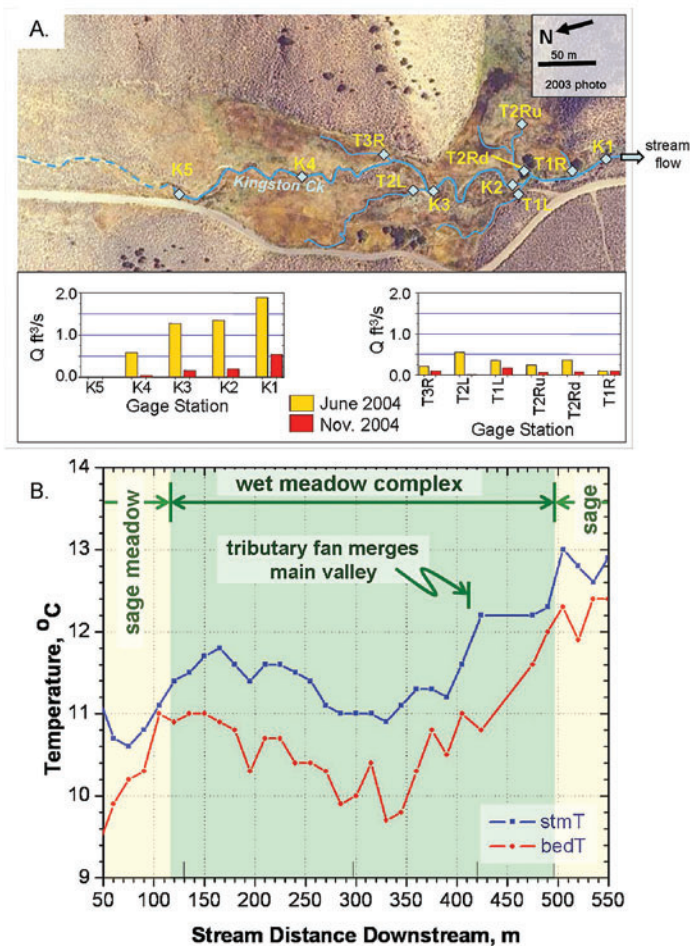


Figure 4.12. (a) Stream discharge data in Kingston meadow for summer and fall 2004. Data show strong seasonality, with flow in the main channel that is over three times greater in June than in November. In the upstream, flow in the main channel is primarily from groundwater; downstream from mid meadow, most flow is from tributaries. (b) Stream water and stream bed (depth ~15 cm) temperature plot shows increased temperature at about 350 m, reflecting warmer groundwater contribution from the east tributary valley.

with a vertical thinning of the valley-fill sediments creates a bottleneck for subsurface flow. This flow constriction produces saturated soils and groundwater discharge zones that are characteristic of the meadow complexes. The configuration of the water table (fig. 4.13) also suggests that the side-valley alluvial fan in the southern area of the site as well as the stream influence groundwater flow patterns. The pattern of the water table near the side-valley alluvial fan indicates it is a source of subsurface flow. The water table contours slope toward the stream (gaining) in some places and away from the stream (losing) in others (fig. 4.13, arrows).

The impact that different water sources have on the groundwater system varies over time due to seasonal changes and fluctuations in timing and amounts of annual precipitation. Figure 4.13 presents water table maps for both a wet season monitoring event (that is, high water table conditions; 25 June 1998; fig. 4.13a) and a dry season

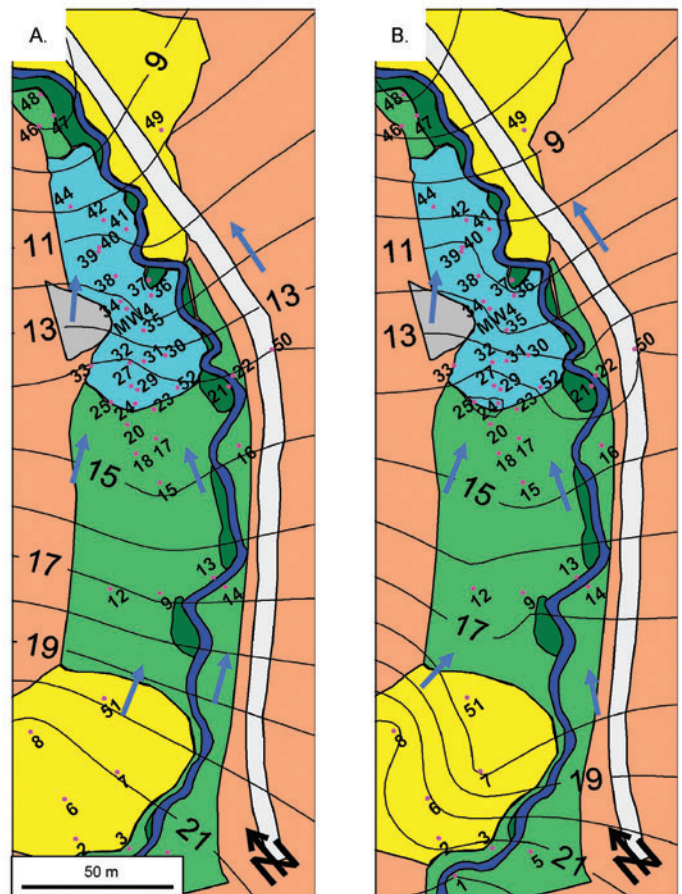


Figure 4.13. Big Creek water table maps illustrating (a) high water table conditions (25 June 1997) and (b) low water table conditions (09 August 2000). Water table elevation values are relative; 1 m contour interval. Arrows show groundwater flow directions; stream flow is northerly (top). Base maps are fig. 4.4.

monitoring event (low water table conditions; 09 August 2000; fig. 4.13b). During wetter conditions, the water table is higher across the site, with the greatest increases in the sage meadow zone located in the upper region of the site (for example, water levels near piezometer No. 7 increased by approximately 3 m). Water table elevations in the wet meadow zone also increased but not by nearly as much. The water table in the wet meadow zone is at or near the ground surface, and higher water levels (greater hydraulic heads) result in increased groundwater discharge, which flows across the ground surface in small channels and eventually enters the stream. Field observations revealed that the area of saturated soils, indicating groundwater discharge, was greatest when the water table was high.

Both maps of the water table (fig. 4.13) show that the side-valley alluvial fan in the southern area of the site and the stream traversing the entire site have an influence on groundwater flow patterns, but that influence is less pronounced when the water table is higher. During wet conditions (fig. 4.13a), water level contours only deflect slightly down-valley near the side-valley alluvial fan, suggesting that the fan supplies flow to the subsurface. However, the magnitude of subsurface flow that was contributed by the

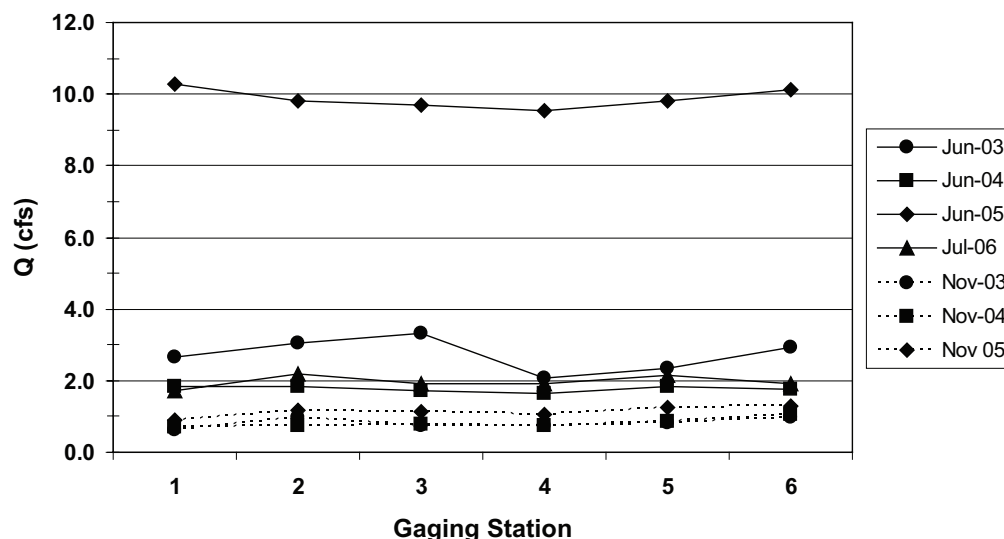


Figure 4.14. Stream discharge (2003 to 2006), Q (in cfs), measured at six gaging stations located along the stream at the Big Creek study site. See fig. 4.4 for gaging station location G1 to G6.

fan relative to the contribution provided by subsurface flow in the valley-fill sediments is greater during drier conditions (fig. 4.13b). The impact of groundwater flow to and from the stream channel also is more evident during drier conditions. The downstream reach of the stream adjacent to the wet meadow (fig. 4.13; light blue) is gaining during both wet and dry conditions. However, upstream the influence of the stream on groundwater flow patterns increases as site conditions become drier and the water table elevation decreases (fig. 4.13b).

To examine the temporal and spatial interaction between surface and subsurface flow, stream discharge was measured at six gaging stations during the spring/summer and fall seasons from 2003 to 2006. The locations of the gaging stations are shown in fig. 4.4. Figure 4.14 shows the discharge measured at each gaging station (in cubic feet per second, cfs) for seven dates over three years. Stream flow ranged from 0.6 to 3.3 cfs, except during a high flow event recorded in June 2005 when discharge measured 10.3 cfs. During this event, a gradual decline in streamflow was observed from stations G1 to G4 indicating losing conditions upstream. Stream discharge gradually increased from stations G4 to G6, suggesting gaining conditions downstream. Stream flow recorded during the other spring/summer measurement events ranged from 1.7 to 3.3 cfs. In June 2003, gaining conditions occurred upstream (between G1 and G3) followed by losing conditions mid-stream (between G3 and G4) and gaining conditions downstream. The length of the upstream segment that exhibited gaining conditions decreased as stream discharge decreased. Stream flow was lowest during the fall (November 2003 to 2005; 0.6 to 1.3 cfs) following the dry summer season. Fall gaging records showed that flow in the stream increased only slightly from location to location in the downstream direction.

Water table depth data that were collected over time provide a glimpse of the hydroperiod, or the frequency and amplitude of water-level fluctuations (Winter and others 1998), for different portions of the Big Creek meadow. Figure 4.15a illustrates the water table depth (mean depth $\pm$ 1 standard deviation) from 1997 to 2006 for piezometers

located in the sage, dry, and wet meadow zones. Water table depth is greatest in the sage meadow zone. Average water table depths in the sage-dominated meadow range from 2.5 to 3.5 m below the ground surface, but depth to the water table varies greatly across this zone (as depicted by the error bars). Average water table depths in the dry meadow zone range from 0.5 to 1 m and are less variable. The water table is closest to the surface in the wet meadow, with the average depth generally less than 0.5 m. Water table depths in the wet meadow are the least variable. As the hydraulic head in this zone increases, the water level can only rise to the ground surface, after which further increases in the hydraulic head are marked by increases in groundwater discharge.

Average depth to water table also reflects the amount of precipitation received in the Big Creek watershed (fig. 4.15b). The water table was highest (that is, the depth to water was at a minimum) during the wet years of the late 1990s, and it was lowest from 1999 to 2004 in response to lower than average precipitation. Groundwater levels increased in 2004 and 2005 as annual precipitation increased. Water table depths generally reflected the influence of evapotranspiration during the growing season for both the dry and wet meadow zones. During most years for which data are available, water table depths declined during the growing season in the dry and wet meadow zones. This trend was likely due to increased plant transpiration and evaporation from the wet meadow surface. Water levels showed a rebound in the fall when evaporation was less, plants became dormant, and transpiration was minimal.

Hydrographs (time series data of water table depths from piezometers and the stream), also exhibited these seasonal and annual trends and fluctuations (fig. 4.16). Three piezometers (P-201, P-202, and P-203) were instrumented with water-level loggers to obtain continuous water level records. P-201 was located in the sage meadow zone, P-202 was in the wet meadow zone, and P-203 was just down-gradient of the wet meadow at the northern end of the site (fig. 4.4). The stream also was instrumented with a datalogger that was located at gaging station G5 (fig. 4.4). The hydrographs for P-201, P-202, and P-203 exhibited the same annual pattern.

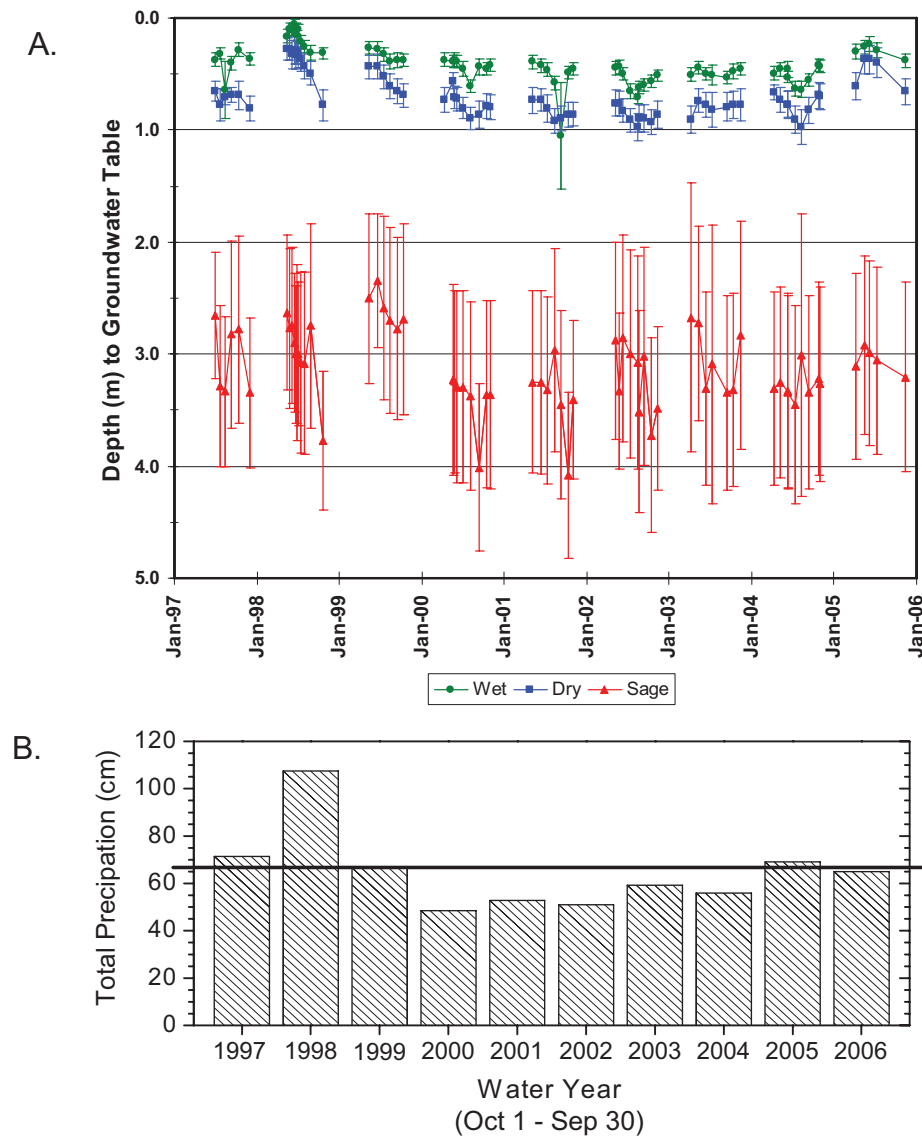


Figure 4.15. (a) Average depth to groundwater (± 1 SD) in piezometers located in wet, dry, and sage plant communities of the Big Creek meadow, January 1997 to January 2006. Water level measurements were taken monthly during growing season, five to six times per year. (b) Total water year precipitation at Big Creek SNOTEL site; line is 27-year average (66.8 cm).

Water-level elevations were at their highest during the spring snowmelt, which usually occurs in May (fig. 4.16). Water levels decreased throughout the growing season probably due to reduced rainfall in the summer months and the loss of water through increased evapotranspiration. As the growing season ended, water levels increased. Water table elevations also showed a slow increasing trend throughout the period of record (2003 to 2006). This corresponds to the general increase in annual precipitation since the 2000 water year (fig. 4.15b). In addition, the hydrographs showed the influence of storm events on the water table. P-202 and P-203 were responsive to precipitation events because they were located in or near the wet meadow, where the water table is near the ground surface. P-201 was not as responsive to precipitation events because it was located in the sage meadow where the water table depth was greatest. Large precipitation events

still affected the water table in the sage meadow, but the change in the water level was not as rapid as where the water table was closer to the surface.

Although not measured, plant transpiration and surface evaporation appeared to affect the water table depth in and around the meadow complex. Water level fluctuations were greatest during the growing season and least during the non-growing season (fig. 4.16). These fluctuations were more pronounced in piezometers located in or near the wet meadow (P-202 and P-203). The daily periodicity of the water level fluctuations was evident when portions of the hydrographs were enlarged in order to better observe the diurnal fluctuations during portions of the growing season (June to July 2004) and the non-growing season (November to December 2004) (fig. 4.17). During the growing season, water levels began to drop about the time sunlight hit the meadow. The water table declined throughout the day and reached the lowest levels in the evening when the meadow became shaded from the sun by the surrounding steep terrain. The level of the water table then recovered (rose) overnight. The hydrograph for P-202, which was located in the wet meadow, showed the greatest fluctuation in water levels, up to 17 cm daily from October 2003 to 2006. The same periodicity in water level

fluctuations was present in the hydrograph for P-203, but the magnitude of the diurnal change was less. This piezometer was located just outside of the wet meadow zone and was probably affected by different soil:plant water relations. The P-201 (sage meadow) hydrograph showed minimal change, but the daily periodicity was still evident. Diurnal fluctuations also were evident in the stage records for the stream and were probably due to a daily decrease in baseflow to the stream from subsurface sources because of evapotranspiration demands.

Daily water level fluctuations in the hydrographs were minimal or nonexistent during the non-growing season (fig. 4.17). Diurnal fluctuations occurred in piezometer P-202, but the magnitude of change was less than that observed during the growing season. These fluctuations may have been due to evaporation of water from groundwater discharge

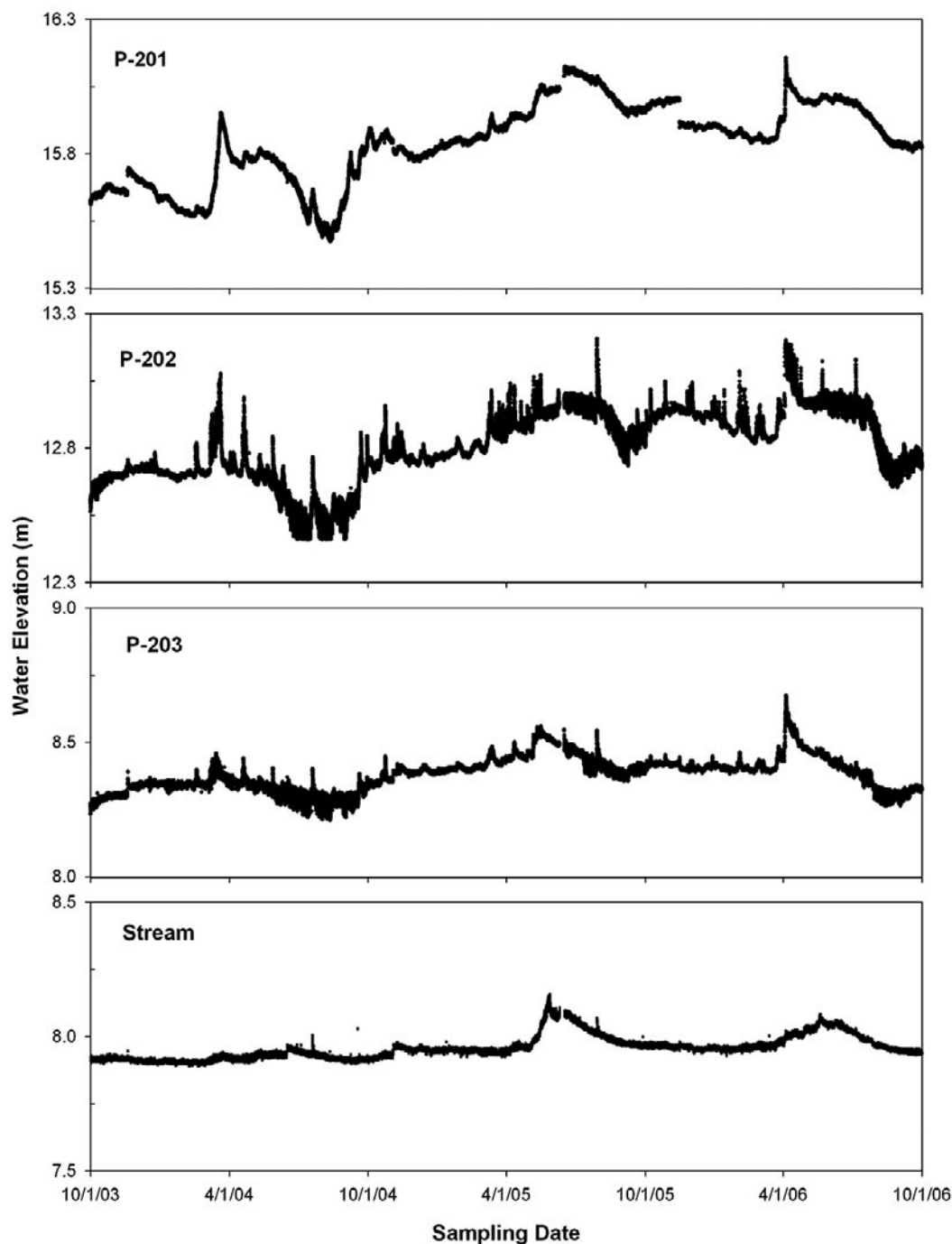


Figure 4.16. Three-year hydrographs for piezometers instrumented with dataloggers in Big Creek meadow.

zones when sunlight was on the wet meadow. Diurnal fluctuations were not observed in the other hydrographs.

The temporal changes in hydrologic processes and patterns at the Big Creek site illustrate the role of multiple variables on meadow conditions. There are predictable seasonal cycles of fluctuations in water table depths that correspond with timing of plant growth cycles, snowmelt runoff, and precipitation. Water level data from four groundwater wells and the creek at Kingston 3 meadow (figs. 4.2 and 4.3) illustrate this pattern. Figure 4.18 shows water level data for the 2005 calendar year that were normalized to percent of maximum water level. That is, all water level data

were recalculated for each well to percent of maximum water level for 2005. For three well locations (101S, 87D, and 33D) and the stream, water levels patterns showed two distinct patterns: rising water levels that were most pronounced from May through June, and falling water levels. While the recession began immediately after maximum water levels for most sites, the water table at the site of well 33D remained high from mid-May to August before declining. The rising stage occurred over a shorter time period than the falling stage. This pattern was especially pronounced at well 33D, where more than 50 percent of the annual rise occurred over a two-week period—a similar pattern to Kingston 3 meadow,

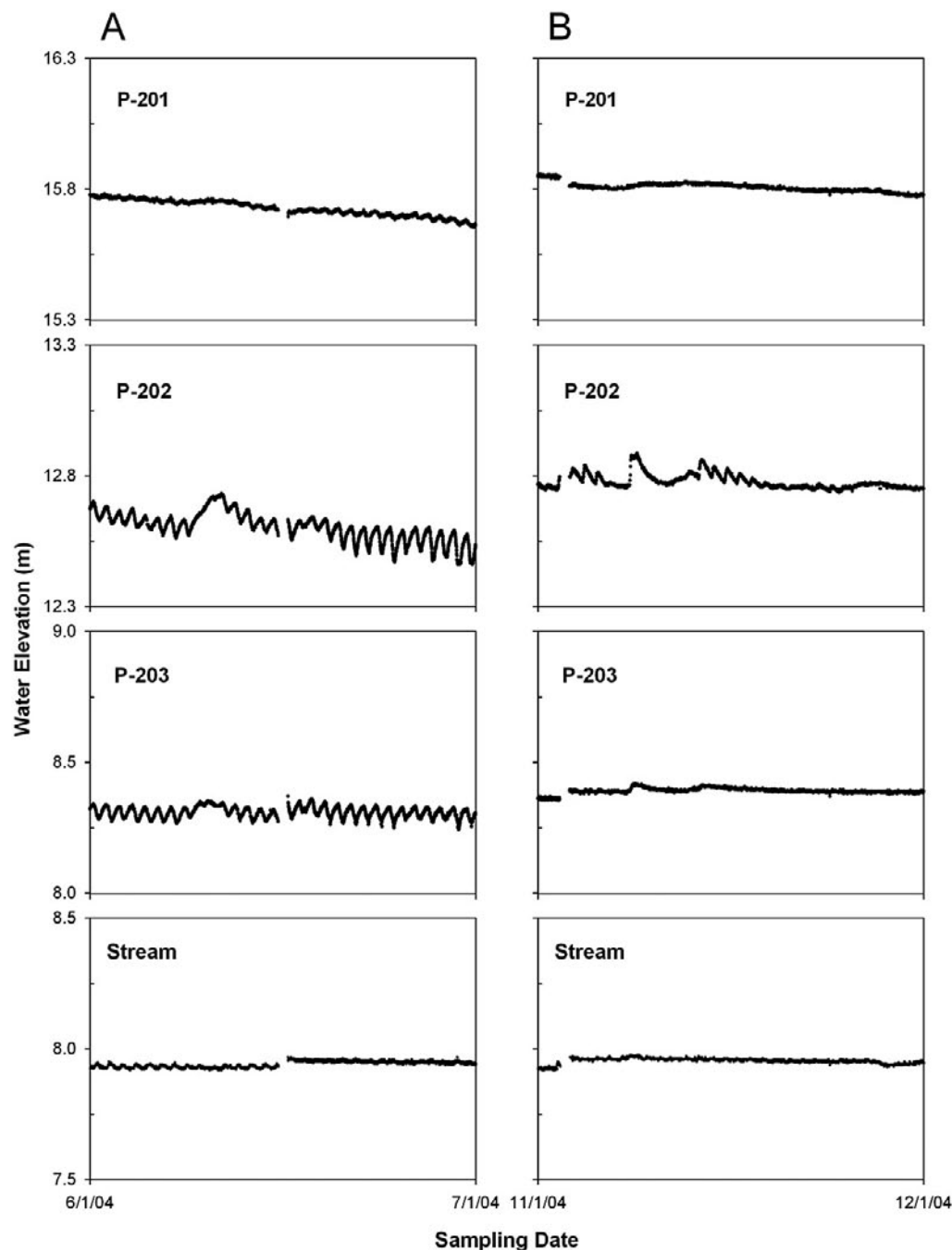


Figure 4.17. Sections of hydrographs in fig. 4.16, illustrating water level fluctuations recorded during (a) a growing season (June 2004) and (b) a non-growing season (November 2004) in Big Creek meadow.

adjacent to the stream. Differences in responses between sites were most likely due to differences in the timing and location of groundwater recharge for different groundwater sources. The short timeframe for the rising portion of the hydrographs suggests that the meadow may be very sensitive to changes that occur in the amount or timing of recharge in the source regions. These general patterns are consistent with studies of groundwater recharge in arid and semi-arid regions, where groundwater recharge through losing streams (that is, stream-focused recharge) is an important process (Constantz and others 2007; Prudic and others 2007). From a management perspective, this suggests that source areas for groundwater recharge need to be considered when evaluating meadows for management activities (Chapter 5).

General Hydrologic Traits of the Study Meadows

In general, the riparian meadow complexes in the mountains of the central Great Basin are groundwater discharge zones with shallow water table depths that commonly have springs, artesian conditions, and perched water tables. However, the specific traits of each meadow may vary widely. These variations result in large part from the stratigraphic and geomorphic conditions that have developed over hundreds to thousands of years along the hillslopes and valley bottoms, but particularly within and immediately adjacent to meadow boundaries. Individual meadow characteristics

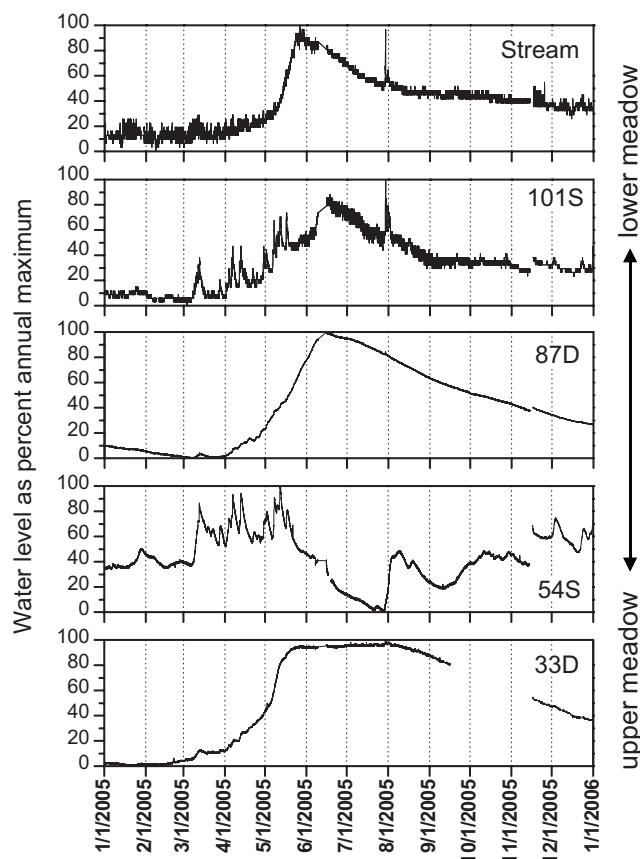


Figure 4.18. Groundwater and stream water level plots showing annual water level patterns as a percent of annual maximum water level in the Kingston 3 meadow. Annual hydrographs for all sites, except well 54S, show a relatively short period of rising levels and a much longer period of declining levels. At the stream and well sites 33 and 87, about three-quarters of the annual rise occurs within one month.

result from the cumulative interplay of vegetation, watershed and stream physical processes, climate, and anthropogenic activities. Despite the variation in meadow conditions and processes, general hydrologic traits are apparent based on observations at the 56 meadows studied.

In about half of the meadows studied, the shallowest water table is located in the center of the valley rather than adjacent to or nearby a stream. This observation is supported by the mapped spring locations and groundwater-dependent wet meadow vegetation. In other meadows, the shallowest water table occurs at the edge of the valley floor against the valley hillslopes and is typically fed by springs or occurs next to shallow streams. Stream channels are present in all meadow complexes, but they vary greatly in size, flow characteristics, bank materials, and the degree to which they affect meadow hydrology.

In many meadow complexes, springs create perennial channels and support shallow groundwater tables. Springs emerge at sharp breaks in slope or where there are heterogeneities in the underlying geology, such as faults (Chapter 2). Springs are present in 75 percent of the meadows, and

20 percent of the meadows have more than 10 mapped springs. They vary in shape, size, and flow rate and range from discrete, bubbling springs at the head of channels (fig. 4.19a), to diffuse seep zones on the valley floor or along channel banks (fig. 4.19b), to piped flow out of exposed banks (fig. 4.19e). Springs often are associated with shallow water tables and wet meadow vegetation unless they have well-developed or incised drainage channels. Springs are important to many wetlands in the Great Basin and in other arid and semi-arid regions (Tooth and McCarthy 2007; Patten and others 2008). Perennial springs in these regions are commonly sustained in part by deep outflow from regional groundwater systems (Anderson and others 2006).

Artesian conditions, where groundwater is under enough pressure to rise above the land surface, have been observed in piezometers of most instrumented meadows (fig. 4.19c). A natural expression of artesian conditions is a bubbling spring on a horizontal ground surface. At the Kingston 3 meadow, three artesian “pipes” have been identified (fig. 4.19f). These pipes are naturally formed vertical shafts that range in diameter from about 15 to 50 cm and that connect the land surface to a confined aquifer (up to 1.5 m deep). The pipes probably formed by erosion of unconsolidated sediments by high-pressure groundwater from an underlying confined aquifer as it worked its way to the surface. Another expression of artesian conditions is a blister or spring mound (Ashley and others 2002; Tooth and McCarthy 2007). Artesian blisters represent areas where very low-permeability soil has blocked and been elevated by an accumulation of upward moving groundwater. Walking on one of these blisters is very much like walking on a waterbed. In the central Great Basin, blisters reach up to 0.5 m in height, are several square meters in area, and have been observed in six meadows.

Perched groundwater conditions are very common in the meadows. Perched conditions occur where shallow groundwater is underlain by a low-permeability layer that is separated by unsaturated materials from the deeper, regional groundwater table. Some meadow complexes (e.g., Johnson and Corcoran; fig. 4.2) are largely supported by perched water tables. Groundwater wells can be used to determine if conditions are perched (fig. 4.20b); however, the presence of a small, shallow stream immediately adjacent to sagebrush often indicates perched conditions in the field (fig. 4.19d). Another indicator of low-permeability layers is how wet and mesic plant communities are distributed in relation to small-scale topography. The Corcoran meadows are blanketed by a fine-grained, low-permeability unit (a paleosol) that maintains the high water table conditions to support wet and mesic communities even on gentle slopes (fig. 4.20a). Low-permeability, buried soils also were shown to play an important role in supporting near-surface water and associated wetland ecosystems in California’s central valley (Rains and others 2006).

Stream channels are present in all meadow systems but vary in the degree to which they directly influence meadow water tables and vegetation. In some cases, the effects are negligible, but in others, they are highly significant. Reasons for this variation are differences in the path of the



Figure 4.19. Hydrologic features common to meadows. (a) springs; (b) groundwater seeps along channel sides; (c) artesian conditions (picture of flowing well); (d) perched water table, commonly characterized (as in this photo) by a wet meadow stream immediately adjacent to sage brush; (e) groundwater piping in fine sediments (see flow at arrow); and (f) artesian pipes: photo shows arm down muddy water flowing to surface from confined aquifer.

channel with respect to the meadow, the size of the channel, the nature of the subsurface materials, the interaction with groundwater, and the water source (groundwater, runoff, or both) (Chapter 5). Stream channels produced the deposits in the geologic past that created the hydrologic conditions necessary to support these meadows but do not necessarily control the current hydrologic state of the meadows. The location of meadows is explained by groundwater conditions, but that does not mean that streams are unimportant to the present or, especially, future status of meadows.

An important trait of the relationship of stream channels to meadow hydrology is whether the stream reach is being fed by groundwater (gaining) or is recharging groundwater (losing). In a gaining stream reach, the depth of the water table increases with distance from the stream, whereas the water table depth decreases with distance from a losing stream (figs. 4.10a and b). Riparian vegetation patterns can be used to infer if a stream reach is gaining or losing because groundwater-dependent plant communities can serve as a proxy for average depth to the groundwater table. At the Kingston 3 meadow, the plant communities became drier closer to the stream (fig. 4.21), indicating a gaining stream (an inference supported by groundwater well data). At the Corcoran meadow (fig. 4.20c), the plant communities became drier toward the margins of the valley indicating a losing system.

The significance of stream connection, or control, on the groundwater table can be assessed by comparing vegetation on either side of a stream. In Cottonwood Canyon, the creek has dry vegetation (sage brush) on one side and mesic vegetation (baltic rush) on the other side; this suggests that the groundwater flow direction is from the wetter to the drier side and, importantly, that stream incision has intercepted and lowered the groundwater table (fig. 4.20d). In this case, the stream may have contributed to some loss in the area of wet meadow complexes. Alternatively, some streams do not alter the groundwater flow patterns or table in the meadow, as reflected in the similar plant communities on both sides of the stream (Birch 1; fig. 4.20e). Although these streams have not yet lowered the groundwater table enough to cause shifts in plant community types, future stream incision may affect the groundwater table and plant communities.

Some channels are completely disconnected from the groundwater under most conditions as they do not support perennial streams. These channels, such as in lower Indian Valley, are typically larger than perennial spring channels (fig. 4.20e) and have developed to convey seasonal discharge typically associated with snowmelt runoff (fig. 4.20f). Most of the time, these channels have little affect on groundwater because the channel bed is well above the water table. When they do transmit runoff, they are sites of stream-focused groundwater recharge (Constantz and others 2007).

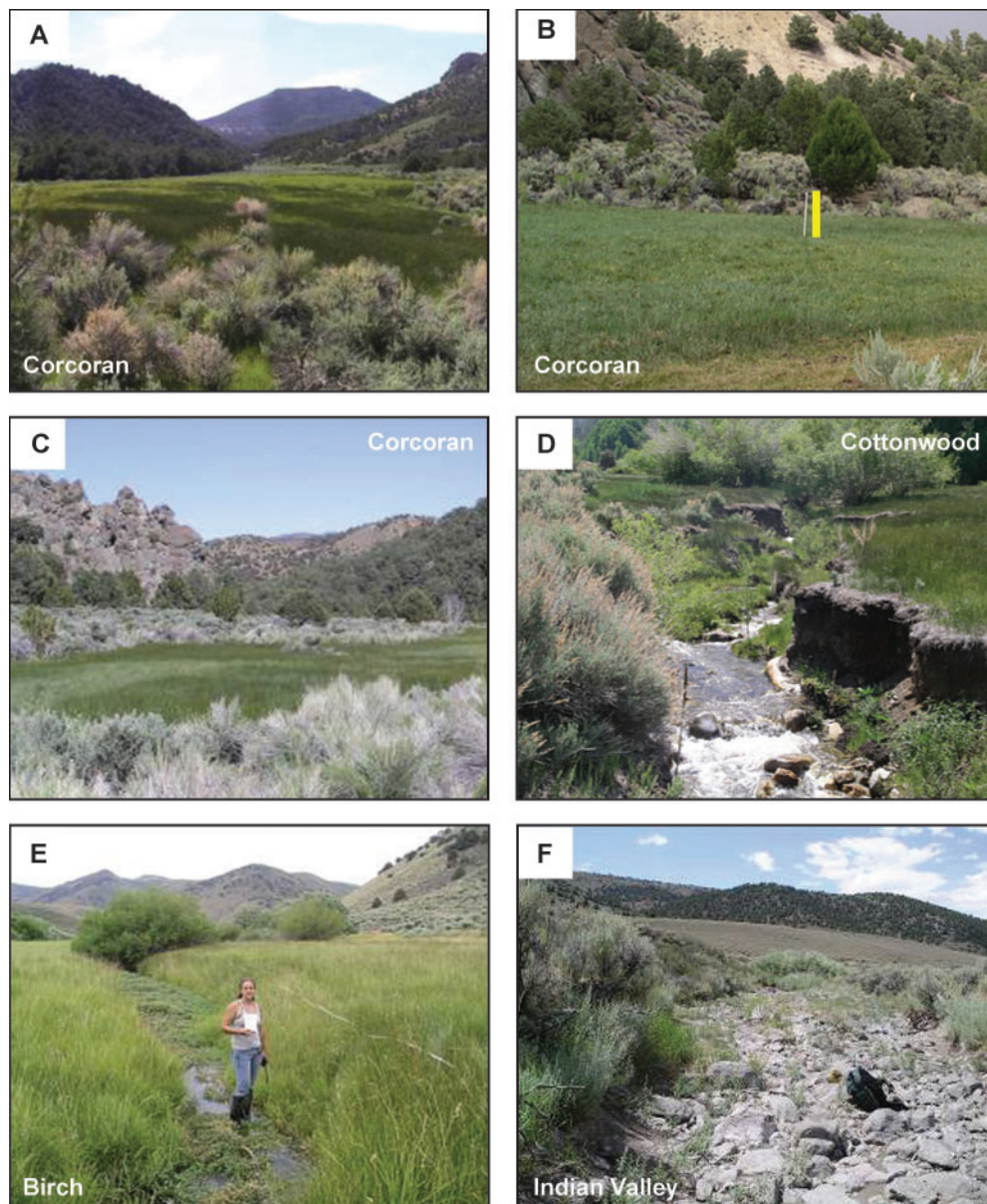


Figure 4.20. Photographs display meadow traits that reflect hydrologic characteristics and interrelationships between vegetation, hydrogeologic setting, and stream channel. (a) Wet meadow vegetation occurrence over slopes reflects a continuous blanket of near-surface, fine-grained sediments. This is common in meadows with perched water tables. (b) Perched water table supporting wet meadow complex; yellow line marks a dry, groundwater well that is set in saturated meadow soils. (c) A losing stream is indicated by wet meadow species centered in the meadow with successively drier vegetation types away from the meadow axis. (d) Channel incision has caused a drop in the water table on left bank, as indicated by sage; because groundwater flow is from right to left, the water table on the right bank has been less affected. (e) Minor channel incision has had no significant effect on groundwater, as indicated by wet meadow vegetation on both banks. (f) Dry, bouldery channel is a seasonal runoff channel, mostly from snow melt, that has little relationship to the groundwater hydrology that supports the adjacent meadow.

Creation of new channels or enlargement of existing channels can partly or completely degrade the hydrologic framework necessary to support a meadow. Stream incision and subsequent channel adjustments can occur over a few years to decades, with subsequent effects on both water table depths and vegetation. Thus, an important consideration in evaluating the effects of streams on meadows is to determine whether the present-day stream is connected to the meadow and, if the stream is actively incising, how groundwater hydrology may change.

Springs, artesian conditions, and perched water tables in meadows of the central Great Basin indicate the presence of heterogeneous geologic materials that cause complex groundwater conditions. The typical meadow has a geologic setting with complex stratigraphy characterized by strongly contrasting hydraulic conductivities and high hydraulic gradients. Consequently, any changes in the meadow systems, whether by streams, people, or climate, are likely to result in

a complex response that may vary from meadow to meadow or even within one meadow.

Approach for Assessing the Hydrologic Status of Meadows

A general assessment of the current status of meadows can be made based on the hydrogeologic setting, groundwater sources, the occurrence and effects of stream incision, and stream-subsurface water interactions. Table 3.2 illustrates the use of field indicators to characterize six meadow complexes that were evaluated in this study. Part of this assessment was based on using meadow vegetation patterns to interpret hydrologic characteristics. This approach was justified by the strong relationship between plant community type and depth to groundwater table (figs. 4.1a and b and 4.21; Allen-Diaz 1991; Chambers and others 2004; Jewett and others 2004). In

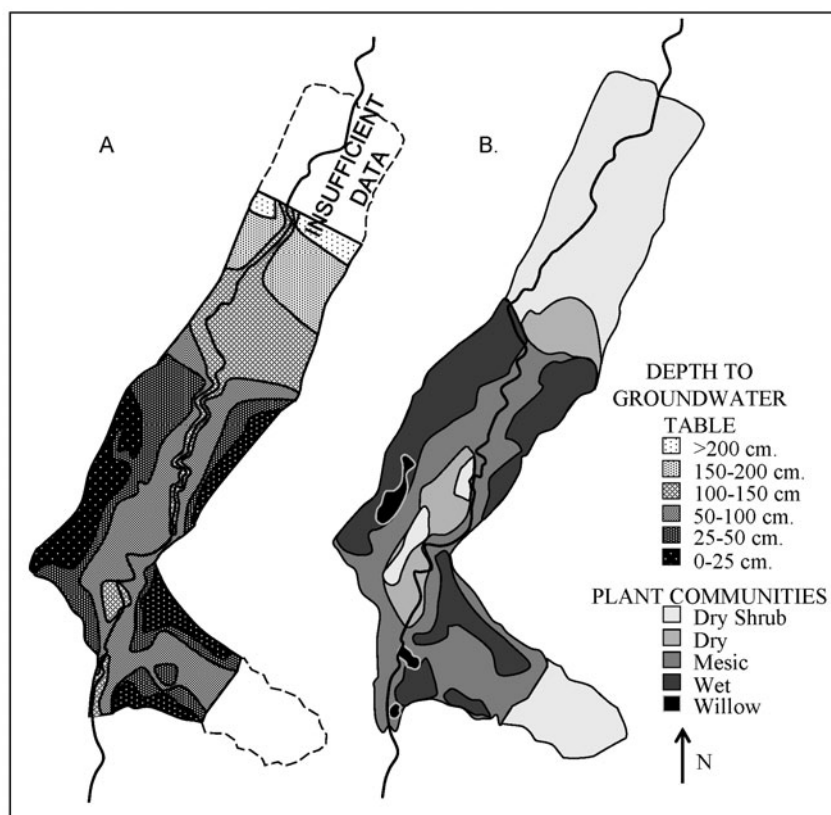


Figure 4.21. Maps of the Kingston 3 meadow; downstream is south. (a) Depth of groundwater table below ground. (b) Plant communities. The depth to groundwater is shallowest at the valley sides and is deepest upvalley and adjacent to the stream. In general, the vegetation and depth to water table patterns are very similar, especially where the water table is most shallow.

some cases, interpretation of the relationship can be complicated by the lag in time for certain vegetation types to adjust to new hydrologic conditions. For this and other reasons, these assessment examples are not intended to substitute for field work with detailed observations. However, the examples demonstrate that important inferences regarding meadow processes can be made based on relatively simple field observations of vegetation patterns, stream characteristics, and the locations and types of springs.

Kingston 3 (table 4.2, trait E) is an example of a meadow system with complex stratigraphy and an incised stream, which have caused some meadow degradation. This meadow complex is located upstream of an alluvial fan and has a complex geologic setting and discontinuous stratigraphy with highly variable permeability. Stream incision has resulted in a drop in the water table adjacent to the stream and, as previously noted, the stream is gaining through much of the meadow. An increase in the depth to the water table adjacent to the stream has resulted in conversion from wet to mesic or dry meadow vegetation and, in some locations, encroachment of sagebrush (fig. 4.21). Wet meadow communities are associated with springs at the edges of the valley floor or side-valley alluvial fans, and artesian conditions are common. Although meadow vegetation in Kingston 3 appears largely adjusted to the current hydrologic regime, a lag in the response of long-lived riparian species like *Juncus balticus* and *Iris missouriensis* often occurs after stream incision (Chambers and others 2004). Also, because stream incision and subsequent channel adjustments can continue over years to decades (or longer), interpreting the relationships between

water table depths and meadow vegetation requires accounting for the degree and activity of incision and determining the traits of the stream connection to the meadow hydrology.

In contrast to Kingston 3, Birch 1 (table 4.2, trait B) is a meadow system with simple stratigraphy that has been minimally degraded by stream incision. This meadow complex is located upvalley of a bedrock constriction and has largely continuous geologic units. The groundwater sources are from the upstream axial valley fill and side-valley areas that include numerous springs in the northeast portion of the meadow. The water table is largely perched in the down-valley portion of the meadow, which is capped by a low-permeability sediment/soil layer. The side-valley tributary is incised through much of the upper portion of the meadow and has caused a shift to drier meadow vegetation in that area. In contrast, despite over 1 m of incision in the main channel, there has been little effect on water table and vegetation, probably because of the perched water table.

Summary of Meadow Hydrologic Processes and Properties

The meadow complexes of the central Great Basin are groundwater-dependent ecosystems that, in some cases, are threatened by stream incision. In general, the headwater zones of watersheds that support meadow ecosystems are groundwater recharge areas, and groundwater recharge often occurs along the bed of losing streams primarily during seasonal snow melt. The meadows down-valley are

Table 4.2. Types of meadow complexes in the central Great Basin. The left column describes key hydrologic characteristics and the current relationship of the stream to meadow hydrology and vegetation patterns. The middle and right columns show a map of the plant communities in the meadow and an aerial photograph of the meadow, respectively.

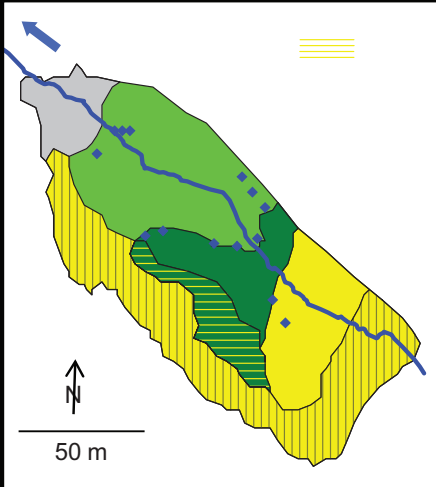
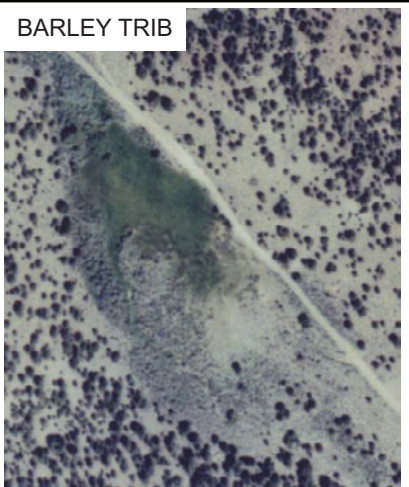
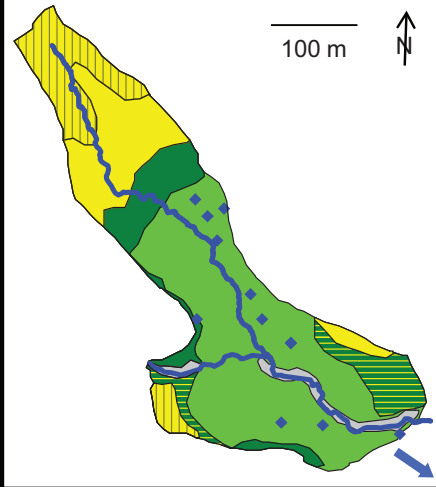
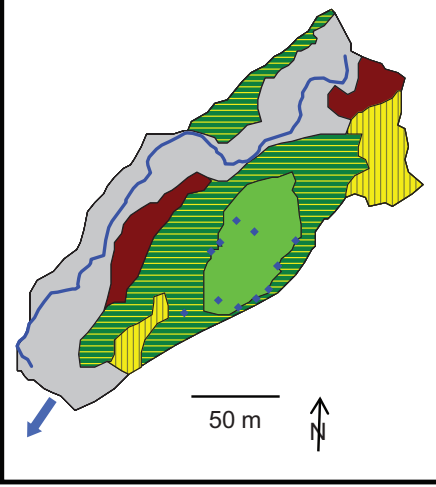
Meadow Traits	Meadow Plant Map	Meadow Aerial Photograph
A. Simple, Not Degraded by Stream <u>Hydrogeologic Setting</u> • bedrock constriction • continuous geologic units <u>Hydrology</u> • GW source is down valley • springs common in low permeability sediment layer <u>Stream Connections</u> • gaining • incision has little effect on GW & vegetation patterns		BARLEY TRIB 
B. Simple, Minimally Degraded by Stream <u>Hydrogeologic Setting</u> • bedrock constriction • continuous geologic units <u>Hydrology</u> • GW source is down & side valley • springs common in low permeability sediment layer • perched GW table downmeadow <u>Stream Connections</u> • gaining some; perched some • >1 m of incision has little effect on GW & vegetation patterns		BIRCH 1 
C. Simple, Stream Degraded <u>Hydrogeologic Setting</u> • downstream valley constriction & alluvial fan <u>Hydrology</u> • GW source is center and down valley • artesian conditions and springs common <u>Stream Connections</u> • gaining • incision has likely breached confined aquifer and has effected riparian GW & vegetation patterns		BARLEY 1 

Table 4.2 continued.

D. Complex; Minimally Degraded by Stream

Hydrogeologic Setting

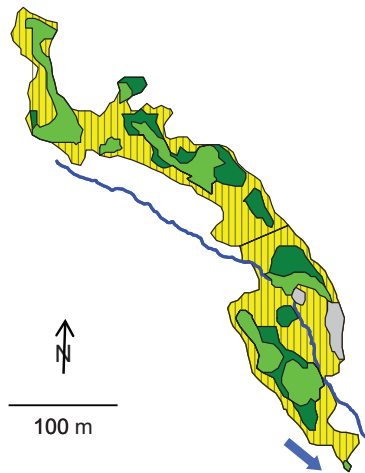
- Draped, old alluvial fans
- dominantly fine-grained geologic units

Hydrology

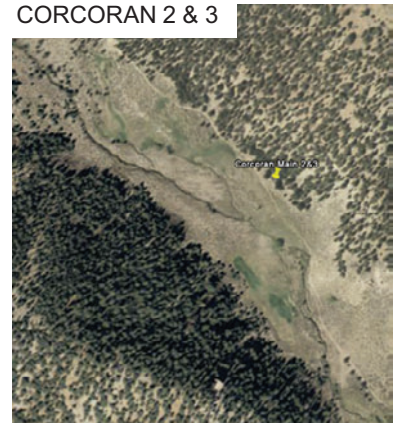
- GW source is down valley & center valley upwelling
- perched water tables

Stream Connections

- losing, perched
- incision has had little effect on GW & vegetation patterns



CORCORAN 2 & 3



E. Complex, Stream Degraded

Hydrogeologic Setting

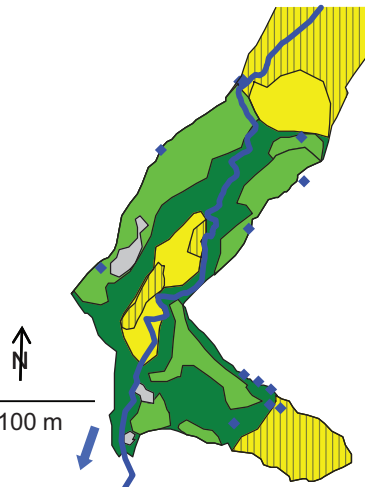
- upstream of alluvial fan
- complex geologic setting
- discontinuous hydrogeologic units with high variability in permeability

Hydrology

- GW source is valley sides and springs
- artesian conditions common

Stream Connections

- gaining overall
- incision has effected riparian GW & vegetation patterns



KINGSTON 3



F. Complex, Degraded by Stream

Hydrogeologic Setting

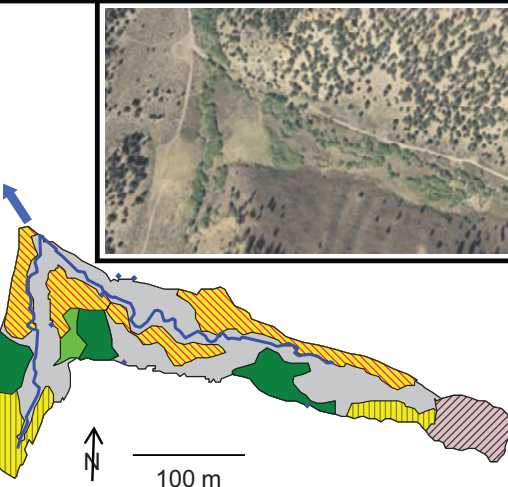
- upstream of alluvial fan
- heterogeneous geologic units

Hydrology

- GW source mostly side valley
- few springs

Stream Connections

- gaining
- incision has altered GW & vegetation patterns
- GW support for most meadows on valley floor is lost



SAN JUAN 1



Legend: Plant Communities and Water Features

	Wet		Mesic Shrub		Dry Shrub		Willow
	Mesic		Dry		Rose Shrub		Aspen
	Upland Plants		Spring		Stream		Stream Flow

discharge areas, although some stream channel reaches vary between gaining and losing over short distances or among seasons. The hydrologic regime exerts primary control on riparian meadow complexes and is strongly influenced by past and present geomorphic processes; biotic processes; and, in some cases, anthropogenic activities. There is a variety of specific geologic and geomorphic settings that create the shallow water tables necessary to support wet meadow vegetation, but a pervasive trait is the occurrence of low-permeability, fine-grained sediments in the down-valley portion of the meadow.

In most meadows, the shallowest part of the water table is at the valley margins or in the central part of the valley floor and is not adjacent to a stream channel. Springs, artesian conditions, and perched water tables are common meadow features, especially in meadows underlain by complex stratigraphy. Stream- and groundwater levels vary during the growing season at daily scales, among seasons with the highest water tables during summer, and over years with weather patterns and climatic change. Meadow plant communities occur along gradients that are controlled by the depth of the water table and, thus, are key indicators of the hydrogeologic setting of meadows.

Stream channels are present in all meadows but vary in the degree that they influence meadow water tables and vegetation. Stream incision lowers groundwater tables; causes shifts in vegetation from wetter to drier species; changes groundwater flow paths; and, in extreme cases, causes permanent loss of meadow complexes. The specific response of the water table and vegetation to stream incision varies greatly with groundwater budgets, hydraulic conductivity of sediments, stream processes, and stratigraphy. The geomorphic and hydrologic characteristics of individual meadows vary considerably, and effective management and restoration requires a basic understanding of their hydrogeomorphic settings, especially the connectedness of groundwater systems with stream channels. Research on the meadows in the central Great Basin provides the necessary information for managers to assess the key hydrologic traits of meadow ecosystems and the relationships among the hydrogeomorphic setting, the stream channel, and the vegetation communities. For example, complex vegetation patterns along a stream channel likely indicate stratigraphic complexity where stream incision has significantly lowered the water table.

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