Yosemite Valley:

Hydrologic Regime, Soils, Pre-Settlement Vegetation, Disturbance, and Concepts for Restoration

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Introduction

Restoration of ecosystems that have been altered by human activity has emerged as a fundamental challenge for contemporary ecologists and land managers. Successful restoration requires understanding the characteristics and functioning of ecosystems that occurred prior to disturbance, the physical drivers that supported them, and the range and intensity of impacts that may have disturbed the site. It is also critical to understand the feedbacks that may potentially inhibit the restoration of desired conditions (Suding et al. 2004).

Anthropogenic alteration of hydrologic processes is one of the most common impacts to wetland and riparian ecosystems, and includes the damming of rivers (Collier et al. 1999), water diversions (Chimner and Cooper 2003), ground water pumping (Cooper et al. 2002; Cooper and Wolf 2006), ditching to lower water tables (Cooper et al. 1998, Patterson and Cooper 2007), and irrigation to artificially wet dry areas. These impacts could be purposeful, such as ditching a meadow to dry it out for hay production or forestry, or inadvertent, such as the installation of a sewer line or road fill that blocks or diverts surface or ground water flow from hydrologically connected ecosystems (Patterson and Cooper 2007). These hydrologic effects can cascade down gradient lowering ground water levels, reducing the duration of soil saturation and anoxic conditions, and altering soil forming processes and vegetation composition (Merritt and Cooper 2000). Indirect feedbacks also may change land uses that influence human use of floodplains and stream bank stability. Consequently, the restoration of degraded ecosystems may require mitigating indirect as well as direct effects of the initial impacts.

Restoration Concepts

Restoration includes the set of actions that bring an ecosystem back to its former condition (van der Valk 2006). This can be accomplished only if a complete understanding of the pre-existing ecosystems can be developed, impacts to these ecosystems can be removed, and the climate and environmental conditions will still support those ecosystems (Williams and Jackson 2007). Setting restoration goals in a national park must begins with the mission of the land management agency. The National Park Service mission is to restore natural processes. The earliest time for which natural processes are documented for Yosemite National Park is the middle to late 1800s. This period is well-documented because the area has a rich history of mapping and photography since the time of settlement.

Research is necessary to determine the characteristics of pre-settlement ecosystems and the cumulative impacts created by settlement in Yosemite Valley. The bulk of this report details our analyses of hydrologic processes, soils, and vegetation that provide indicators of the pre-settlement conditions and the ecosystems they likely supported. From the maps and photographs, perspectives of presettlement hydrologic regimes and vegetation can be developed and formulated into a valley wide concept for restoration. As is commonly the case in the restoration of degraded systems recovery may require mitigating secondary effects as well as reversing the direct effects of the original stressor.

Study Sites

The restoration area includes parts of Upper and Lower River, and Upper and North Pines Campgrounds. The study area extended north and south of the campground area to allow hydrologic, soils and vegetation analyses that extended from valley wall to valley wall in the region of these campgrounds. Meadows not included in the campground restoration were uses as reference sites, including Ahwahnee, Stoneman, Sentinel, Bridalveil, Cooks and El Capitan (Figures 1, 2). A number of oak and pine forest reference sites, and riparian reference sites were also analyzed. These reference sites were selected in areas that, to the best of park staff knowledge, have been minimally impacted by human activities. In the case of forested reference areas, efforts were to locate stands that are little disturbed since European American settlement.

Methods

Historical Analysis

The earliest records of Yosemite Valley are written reports from Clark (1855, cited by Gibbens and Heady 1964). Several maps of valley landforms and vegetation along with ownership plats were created in the 1860s (Kind and Gardner 1865, Hoffmann 1867, Whitney 1868) (Figures 3, 4, 5). Photographs of the valley date from the 1850s and were sold as tourist souvenirs. Relatively few early photos show the landscape well enough to make conclusive decisions about the vegetation, stream channel width, or hydrologic processes, but several excellent photos are available (Figures 7, 8).

Hydrology

A total of 127 ground water monitoring wells were installed in transects across the study area and in reference meadows (Figure 12). The location of wells in the campground area is shown in Figure 13a. Additional wells were installed in other meadows that were used as reference areas, ie. Liedig and Sentinel (Figure 13b), El Capitan (Figure 13c), and Bridalveil (Figure 13d). Ground water monitoring wells were installed either into a pit excavated with a backhoe (campground wells) or in hand augered holes. Wells were cased with 3.175 cm (1¼ in) inside diameter, hand slotted, schedule 40 PVC pipe. Holes were backfilled with native soil. Wells were installed deep enough to allow the water table to be measured at any season. Wells were monitored weekly using an electronic tape during the growing seasons of 2004, 2005, and 2006. During 2004 well installation and monitoring occurred late in the summer, therefore data are available for only that later part of the growing season. All wells were topographically surveyed for location and elevation to the nearest cm.

Soils

Soil morphology and organic matter content provide an important long-term perspective of site hydrologic regime. Soil stratigraphy at each monitoring well was recorded by horizon, noting soil texture, mottles, oxidized root channels, depleted matrix colors, and other indicators of a persistently high water table, and the development of a hydric soil. A soil sample collected from the upper 20 cm of each soil profile was analyzed for % organic matter present by loss on ignition (Ball 1964).

The age of four buried logs was analyzing using 14C methods. The analyses were performed by Beta Analytic, Miami, Florida. The goal of these analyses was to provide a minimum age for the deposition of valley sediments that covered the logs.

Vegetation

Modern Vegetation

The vegetation composition and canopy cover by species was recorded for one 20 m^2 plot centered on each monitoring well or soil pit. Vegetation data were analyzed using indirect ordination with Detrended Correspondence Analysis (DCA) to identify the overall structure and major vegetation gradients in the data set (Jongman et al. 1995). This analysis was used to identify stands with similar vegetation composition, and to determine whether stands with similar vegetation also had similar soils and water table depths. The DCA axes are in SD (standard deviation) units. A change of 200 - 300 SD units along a DCA axis indicates a complete change in species composition. For example, an axis with a gradient length of 600 units includes two complete changes in species composition.

Conifer Tree Age in Campgrounds

The point-quarter method was used to select 100 conifer trees in the campground area for the collection of increment cores. Points were the monitoring wells, and the nearest tree in each cardinal direction was cored. The goal of this analysis was to determine the approximate timing of tree establishment. Cores were collected from as low on the bole as possible, but represent minimum ages for each tree. There was no minimum size for trees to be included in this sample. Cores were mounted on wooden blocks, sanded and the rings counted.

Results

Historical Analysis

Maps

Maps illustrating the characteristics of upper Yosemite Valley were created by Whitney (1868), Hoffmann (1867), and King and Gardner (1865) (Figures 3, 4 and 5) and all indicate that meadow and marsh complexes dominated the valley bottom. Trees, which likely are *Quercus kelloggii*, were abundant on the valley margins. In addition, scattered trees are drawn along the Merced River corridor, and likely are *Populus trichocarpa* (black cottonwood) and/or *Salix* spp. (willows) with scattered *Quercus* and likely some *Pinus ponderosa*. The maps clearly illustrate the broad extent of herbaceous dominated vegetation, and the marsh symbols on the Whitney and King and Gardner maps indicate that wetland conditions occurred.

From these maps and additional reports the area of wet meadows in Yosemite Valley has been estimated six times between 1868 and 1982. A polynomial equation of meadow acreage over time shows a significant ($R_2 = 0.9928$) decline from approximately 800 to <350 acres (Figure 6), with most of the loss occurring between 1880 and 1930. Articles documenting "vanishing meadows" in Yosemite Valley were published as early as 1943 by Ernst (1949).

Ground Photographs

Historical ground photographs, matched in recent years, provide an excellent overview of the types and spatial extent of vegetation changes that occurred during the past 100+ years in Yosemite Valley. The photos from Columbia Point show a tremendous increase in conifer tree cover (largely *Pinus ponderosa*) from 1899 to 2006 (cover and Figure 7). Large expanses of meadow, with scattered *Quercus* and what appear to be *Populus* trees can be seen in the early photograph. However in 2006 only Cooks and Sentinel meadows are visible as remnants of the formerly large meadow area. Drainage ditches and roads are prominently seen on the 1899 photo, and conifer invasion, apparent by the numerous small trees, was occurring. However, by 1899 considerable meadow invasion by conifers have already occurred, and Galen Clark, the state's first "Yosemite Grant guardian" reported that during his first visit to the valley in 1855 the area of "clear open meadow ground" was at least four times as large as at the present time, 1894 (Gibbens and Heady 1964). Therefore, the photo record, and the data on meadow extent provides only a minimum estimate of the area of meadows that existed in the middle 1800s. The photos of Grizzly Peak and Glacier Point (Figure 8) show the loss of riparian *Populus* and *Salix* species, loss of undercut banks and a deep channel, and an increase in *Pinus* resulting in a taller canopy.

Hydrology

Merced River Flows

The Merced River is a snowmelt driven stream that is periodically influenced by rain on snow flood events. Winter snow accumulation and normal spring melting produce annual instantaneous peak flows of 5,000 ft^3/s to 12,000 ft^3/s (Figures 9 and10), which typically occur in May. Rain on snow events have produced the largest floods with flows exceeding 20,000 ft^3/s in 1937, 1950, 1955, and 1997 at the Pohono Bridge gauge, all during winter months. Late summer flows, from late July through October are very low, because the dry and hot summers produce little precipitation (Figure 11).

During the study period, 2004 had a low snowpack winter, with the lowest peak flows since 1994 (Figures 9, 10, 11). Even lower flows occurred in 2007, after this study was concluded. Very large spring snowmelt driven stream flows occurred in 2005 and 2006 (Figures 10, 11), with 2005 having one of the two largest spring flows on record at the Happy Isles gauge, and 2006 being only slightly lower.

Variation in ground water table depth and duration across the valley

The location of wells in the campground area is shown in Figures 12 and 13 (a-d). Water table elevation along a transect through the former Upper and Lower River campgrounds from well 3 to well 11 indicates that ground water at these wells is hydrologically connected to the flow and stage of the Merced River (Figure 14) as measured at river cross section 28 (X28). The nearly identical pattern and magnitude of river stage and ground water rise and fall indicates that stream water is flowing through the coarse gravels of this floodplain area. At peak stage in late May 2005, wells 1, 2 and 3 have higher water levels than the Merced River at X28, but during the rest of the year, the ground water is lower than river stage on the downstream end of the cross section. This suggests that at high river stage, water is flowing from well 3 through the bar, likely recharged by the Merced River near X20 on the upstream portion of this transect. During most of the summer, the Merced River at the downstream end of this transect has a higher elevation than ground water and the river is supplying water to the ground water system at all times.

A transect from wells 73, 70 and 69 in North Pines campground through wells 46, 55, 60, and 63 in Lower Pines campground illustrates similar hydrologic processes (Figure 15). Stream stage at cross sections X13 and X20 controls the elevation and seasonal pattern of ground water level along this transect. Ground water levels in North Pines are nearly identical to those of the Merced River at X13 throughout the year, while river levels at X20 are lower than at the wells in the lower River Campground indicating ground water flow under the campground from X13 toward X20.

Ground water elevation along a transect extending from well 34 and running north across Stoneman Meadow to the Merced River on the north edge of Lower Pines CG at cross section X16 indicates that ground water from Stoneman Meadow flows is tributary to the Merced River (Figure 16). Ground water flows from higher elevation at the southern valley edge toward the Merced River and has a longer period of high water levels than the river. Water levels in wells 34, 33, 38 and 39 are higher than the Merced River prior to and following peak and do not show any response to river stage changes, including the peak. However, ground water in wells 59, 60 and 61 maintain similar elevations as the river. This indicates that two major water sources supply Yosemite Valley, ground water flowing from the valley margins (termed “wall water”) and Merced River water flowing from its watershed. This pattern is even clearer along a transect from well 26 in upper Ahwahnee Meadow to well 34 in upper Stoneman Meadow (Figure 17). Ground water elevations along this transect indicate that ground water flows from both north to south (from well 26 toward the Merced River), and south to north (from well 34 toward the Merced River). Thus, ground water from both valley margins flows toward the River supporting wet meadows with seasonally high water tables on the valley margins as well as the valley center.

Water Table Profiles

The ground surface and water table elevation profile across the Rivers Campgrounds (Figure 18) indicates that the elevation of Merced River stage at X20 is always higher than ground water and the river is strongly losing into the ground water system. The downstream river cross section X28 also has a higher stage than adjacent ground water monitoring wells 10 and 11 at all times. Thus, this reach is also losing. We would expect that ground water flowing from X20 under the Rivers Campground would be higher than the river at X28 and flow into it. Because the Merced River is losing on both the upstream and downstream portion of this transect it suggests that drain(s) may exist in the campground area.

The water table elevation profile from well 34 through Stoneman Meadow and across Lower Pines campground to river cross section X16 shows river elevation is higher at peak stage in May 2005 and 2006 than wells 59, 60 and 61. Thus, the river is losing water to ground in the northern portion of the campground (Figure 19). However, ground water levels in upper Stoneman Meadow (wells 34 and 33) are always higher than water in other wells and ground water flows from Stoneman Meadow toward the Merced River. Wells 34, 33, 38, 39, 40 and 41 are supported by ground water flowing down Stoneman Meadow during the late summer, while wells 59, 60 and 61 appear connected to and approximately the same elevation as the Merced River.

The water elevation profile across the valley from well 26 to 34 (Figure 20) clearly shows ground water supported areas on both sides of the valley and an area connected to the Merced River in the valley center (X20, wells 7, 1, 6). Thus, both ground water supported, and stream water supported areas occur in the valley.

Water Table Maps

Water tables elevations and flow directions are more easily visualized as contour maps. The maps provide a broad view of water table gradients and overall flow directions than is possible from examining individual profiles or well hydrographs. Data presented in Figures 22-25 support the concepts developed using well hydrographs and water table profiles; that multiple flow paths occur, including those from the south and north valley walls, and these enter a third system in the valley center that is supported by and connected to the Merced River. The ground water gradient from valley edge to valley center is steep in the early summer as illustrated by the 17 May 2006 water table map (Figure 22). Ground water contours in lower Pines campground bend where ground water from Stoneman Meadow meets ground water flow system supported by the Merced River. However by mid to late summer, river stage declines more than floodplain ground water levels (Figure 25), and the gradient from meadows toward the Merced River increases. The importance of ground water flow from the valley walls increases as the summer progresses, supporting meadow water tables throughout the valley.

Soils

Several soil features were used to identify the long-term hydrologic regime and vegetation of the study area. Long-term saturation and anoxic condition are indicated by the presence of mottles, low chroma colors, depleted soil matrices, and the formation of oxidized root channels in mineral soils (US Army Corps of Engineers 2008) (Figures 26, 27). These features were identified in the upper parts of many soils, and the depth to mottling at each monitoring well was used to produce a map (Figure 28). Many study area soils had been heavily disturbed by plowing, drainage, and other activities in the past and some hydric soil features may have been obscured or destroyed. A second character of seasonally or perennially wet soils is the preservation of soil organic matter or soil carbon (Figure 26a). It takes a very long time to accumulate organic matter in soils, for example, peat soils in montane wetlands occurs at a mean rate of ~20 cm/1000 years (Chimner and Cooper 2003). High organic content wet meadow soils also indicates great antiquity, as do mottles and gleying. In temperate climates soils do not form or change rapidly, thus the presence of hydric features in the upper soil profiles indicates that the study area soils were saturated regularly and for long duration for many centuries.

Most of Ahwahnee and Stoneman Meadows have hydric soil features in the upper parts of their soils. Only the area near Curry Village, the Ahwahnee Hotel, and areas along the Merced River lack hydric soil features. This suggests that historically soils in most of the study area were saturated for long duration during the growing season.

Percent soil organic matter is another excellent indicator of past hydrologic regimes. Saturated soil conditions inhibit decomposition of organic matter, which results in high soil organic matter content. Frequent, low intensity fires, like those set by Native Americans within the valley, typically burn off dry above-ground plant matter and are not hot enough to burn off soil carbon or belowground biomass. Because organic matter deposited on the ground surface is exposed to air (thus decomposing rapidly) and fire, the primary process by which organic matter reaches high levels in soils is through belowground biomass additions (root growth) (Chimner and Cooper 2002). Grasses, sedges, and meadow plants produce high belowground biomass and increase soil carbon by introducing this organic matter directly into wet soil conditions where it remains largely undecomposed. Most farm soils have 3 to 4 % organic matter, and tall grass prairie on the American Great Plains has 3 to 7 % (Weaver

1954). Conifer forest soils in summer dry climate zones like the Sierra Nevada, and riparian forests on newly formed soils have low organic matter content. Fens, have >24 % organic matter content (USDA 2005).

Reference meadows in Yosemite Valley (including wet and dry meadows) averaged 12.5 % organic matter, oak forests 7.0 %, mixed conifer forest 2.9 %, and riparian areas 1.8 % (Figure 29). The Upper River, Lower River, Lower Pines and North Pines campgrounds had mean organic contents of 8.4, 6.1, 4.6, and 7.0 %, respectively. Of the 36 campground sites, 9 have soil OM similar to meadows, 18 similar to oak forest and meadow margins, and 9 pine forest or riparian soils.

Much of Ahwahnee and Stoneman Meadows have organic content > 6 to 8 % (Figure 30) reflecting values that would be anticipated in oak forests and meadows. In addition, large areas of Upper and Lower River CGs and part of North Pines CG also have high organic content. The high organic content indicates that these areas historically were meadows and oak savannahs. Much of Lower Pines CG has lower organic content (mean of 4.6 %). This area is repeatedly disturbed by floods, and has thick recent fluvial deposits of sand and gravel.

Age of Buried Wood

One sample buried 220 cm below the surface was found at well 22, in the southwestern corner of Ahwahnee Meadow (Figure 31). This site is close to the Merced River. The sample was 520 ±40 years BP (Beta 205422). A second buried sample collected from 250 cm depth had a radiocarbon age of 650 ±40 years BP (205423). One sample collected from 240 cm depth at well 66 in the lower portion of Lower River Campground had a radiocarbon age of 5000 ±40 years BP (205424). This site is also close to the Merced River.

The last sample, collected from well 86 at 140 cm depth had a radiocarbon age of 1980 ±40 years BP 205425). The three samples that range from 500-650 years BP indicate a period of floodplain building occurred at that time. These sites (well 22 and 66) are both close to the Merced River, and likely were point bars at the time of deposition since the wood was deposited in a large gravel matrix, and more than two meters below the current landscape surface.

The sample from well 86 was found on the northeastern side of Stoneman Meadow in a layer of coarse sand and gravel with cobbles. The gravel and cobbles in this site extend to within 60 cm of the soil surface. Above that the soils are a dark brown sandy loam. This sample indicates that the lower soils in this part of Stoneman Meadow are much older, nearly two thousand years, and has allowed sufficient time for the development of an organic rich meadow soil above it.

Vegetation

Conifer Tree Establishment

Most conifer trees in our sample established in the period from the late 1860's through the early 1930's (Figure 32). By 1900 conifers were abundant in the campground area and growing large enough to have an impact on site visual characters, litter quality, sunlight reaching the ground and understory vegetation. The timing of conifer invasion matches the comparative photos, particularly the photo from Columbia point from 1899 (Figure 6) that shows conifer trees on the Merced River floodplain.

Location of *Quercus kelloggii* trees in the campgrounds

In Yosemite Valley the current habitat of *Quercus kelloggii* includes meadow edges and talus fields on valley margins. The distribution of older trees (greater than ~125 years old) in the study area can indicate the location of historic meadow margins (Figure 33). Most *Q. kelloggii* mapped are large, likely >125 years old, and occur below taller *Pinus ponderosa* and *Calocedrus decumbens* trees. Individual *Q. kelloggii* are scattered throughout the campgrounds, suggesting that these areas historically were not conifer forests, and likely were riparian areas, wet meadow margins, or *Quercus* savannahs.

Vegetation of Yosemite Valley

DCA analysis of vegetation stand floristic composition data indicates that a wide range of vegetation types occur in the study area (Figure 34). The DCA axes have a gradient length of 600 SD units along both axes 1 and 2 indicating high species turnover within the ordination space. The left side of the ordination space is occupied by conifer forest stands dominated by *Pinus ponderosa* and *Calocedrus decurrens* with varying understory composition, but dominated by *Bromus tectorum* and *Conyza canadensis*. The top portion of the ordination space is occupied by riparian stands dominated by *Alnus rhombifolia*, *Populus trichocarpa* and *Salix* spp. as well as monocultures of *Carex vesicaria,* a sedge species that occupies deeply flooded ox bow ponds and other basins. The bottom left portion of the ordination space is occupied by stands of *Quercus kelloggii* that occur on wet meadow margins. The central portion of the ordination space is occupied by wet meadows with floristic composition varying from sites with deep summer water tables and supporting *Poa* *pratensis*, *Agrostis stolonifera*, and *Leymus triticoides* to sites with seasonally saturated soils dominated by *Carex lanuginosa*. The bottom right portion of the ordination space is occupied by stands dominated by the wettest meadow stands, particularly those dominated by *Carex senta* and which occur in Bridalveil and Cooks Meadows.

DCA Axis 1 stand axis scores are negatively correlated with August water table depth and soil mottle depth, indicating that sites with seasonally high water tables occur on the right side of the ordination space, and those with deeper water tables on the left. These correlations are not strong, suggesting that the vegetation does not reflect the current hydrologic conditions of the valley. Thus, conifer forests may occupy sites that are hydrologically similar to *Quercus* dominated savannahs and some meadows. The current vegetation patterns are due to the lack of fire over the past 150 years, and a somewhat lower water table under the forest stands. The main vegetation types are illustrated in Figure 35 (a-d). In addition, there is no correlation of DCA Axis 1 with stand % soil organic matter indicating that highly organic soils can occur under both wet meadows and conifer forest stands.

Percent soil organic matter for each stand plotted using DCA axis 1 and 2 scores indicates that highly organic soils occur in many vegetation types, including wet meadows and conifer forests (Figure 36). Riparian areas generally have low soil organic matter content. The presence of high organic content in conifer forests indicates that these forests formed in former meadows.

Depth of soil mottles plotted using stand DCA axis 1 and 2 scores indicates that meadows all have mottles near the soil surface (Figure 37). Conifer forest stands have both deep and high mottles, suggesting that stands with high mottles have formed in former meadows.

Discussion, Synthesis and Restoration Options:

Water sources, hydrologic regimes and potential natural vegetation of the campground area

Two main water sources supply the eastern portion of Yosemite Valley, ground water flowing from the north and south valley walls toward the Merced River, and Merced River water that supplies the floodplain ground water flow system. Based upon the 2005 Merced River water year, we have identified portions of the study area that are (a) largely ground water fed during large water years, such as 2005 and 2006, and (b) areas that are hydrologically connected to the Merced River (Figures 38, 39). Ground water driven areas with seasonally or perennially high water tables are wet meadows, and have high soil organic matter content. Using hydrologic patterns and processes observed during the study period we have divided the study area into a riparian zone, supported by periodic Merced River over bank floods and ground water recharged and controlled by the River, and meadow zones supported primarily by ground water from hillslope sources.

The potential vegetation of the riparian zone includes woody plant species present in historic photographs and that are still present in small populations in the study area. These include species that establish on bare and wet mineral soil, such as black cottonwood (*Populus trichocarpa*), alder (*Alnus rhombifolia*), and willow (*Salix exigua*) (Figure 34D). Stands of *Quercus kelloggii* also were abundant historically, and still occur on meadow and valley margins. Many individual *Q. kelloggii* trees are present beneath the *Pinus* and *Calocedrus* dominated canopy in the Upper and Lower River and Lower and North Pines campgrounds (Figure 34B) and areas with high density of large *Quercus* trees likely supported wet meadow and *Quercus* dominated stands in a mosaic with other community types.

Several wet meadow community types occur in the study area, dominated by *Carex senta, C. lanuginosa, Agrostis stolonifera* and *Poa pratensis* (Figure 34A). Areas suitable for each community type are determined by the long-term summer maximum water table depth and its duration. A typical hydrograph for five major wet meadow and *Quercus* communities is shown in Figure 40, illustrating important differences in early and late summer water table depth.

Hydrographs for reference community types can be used to set hydrologic restoration goals for portions of the study area that contain organic rich soils but have deep summer water tables today and/or support conifer vegetation. A key aspect of hydrologic restoration is the systematic removal of alternations to natural surface and ground water flow processes in the study area. Stoneman Meadow (Figure 41) south of the road has a longer duration high water table than areas north of the road, indicating that the road or any below ground utilities may blocks or capture water flow. A hiking trail and channel on the south side also interfere with natural flows. Buried drains may be present in and around Curry Village, particularly near buildings, roads, and the parking lot that surrounds the apple orchard.

A large area of fill is present in the southwestern corner of Ahwahnee Meadow. In addition a sewer line bisects the meadow, a ditch runs the meadow length, and drains or pipes occur in the northeastern corner of the meadow (Figures 42, 43). Surface water draining toward Ahwahnee Meadow from the northwest is captured in ditches and drained west before it reaches the meadow. The effects of these hydrologic impacts could be prioritized and addressed in restoration planning (Patterson and Cooper 2007).

The campground areas have experienced extensive Merced River bank trampling, bridge construction which altered surface water flow, and paving and utility placement over campground area soils. Our backhoe pit excavations, as well as borings by Jones and Stokes (2002) indicate that very little fill has been placed into the campground areas. Ground water profiles indicate that the Merced River loses groundwater to the Upper and Lower River Campgrounds. This may be due to the presence of a sewer line or other below ground structures that divert groundwater. Tree invasion likely has occurred due to hydrologic alterations, as little conifer invasion occurs in the natural portions of Stoneman, Ahwahnee, Cooks, Sentinel, Bridal Veil and other meadows in the study area.

An important factor to research in the future is how the Merced River channel width has changed during the past 150 years (Madej et al. 1994). A wider river channel would produce lower river stage for any flow, and reduce ground water levels under the campgrounds and overbank flood frequency. These factors could have dried the campground soils sufficiently to allow conifer invasion. Reports of the removal of boulders from a El Capitan terminal moraine downstream from El Capitan Meadow have documented a potential river stage reduction extending several miles upstream from the moraine, but not reaching the area of the campgrounds (Milestone 1978).

Summary and Synthesis

Two water sources produce different ecosystem types on the floor of Yosemite Valley. Ground water from valley walls, including water from bedrock and talus slopes recharged by rain and snowmelt and small streams that flow from above the valley rim and lose their water into valley margin alluvial fans, flow toward the valley center supporting seasonally high and stable water tables. This hydrologic regime supports wet meadows which have formed highly organic soils, and in one case a fen (Happy Isles). The second water source is the Merced River, fed by its large watershed, and daily discharges that over the year vary by several hundred-fold. Merced River overbank floods occur periodically from winter rain-on-snow events, such as occurred in 1997 (Figure 11), and large spring snowmelt driven flows as occurred in 2005 and 2006. Overbank floods may deposit sediment onto the floodplain, erode banks, and rework point bars.

Understanding, characterizing and distinguishing portions of the valley supported by these two types of these flow systems is a critical component of identifying the restoration potential for any portion of Yosemite Valley. Some portions of the valley are riparian ecosystems that are hydrologically and geomorphically connected to and influenced by the Merced River. However, a larger portion of the valley is supported by ground water flowing toward the Merced River, and historically supported wet meadow ecosystems (Figures 4, 5, 6, 10). Areas with predominantly riparian or wet meadow hydrologic regimes, based upon measured hydrologic regimes, soils and vegetation, are identified in Figure 37. The restoration goals for these two areas should be distinctly different, as described below.

The hydrologic restoration goal for wet meadows should be a water table near the soil surface from April through mid July of most years (see Figure 40), with the water table depth slowly declining during the summer. The water table goal for any area should be decided based upon the soil organic matter content, landscape position, and current hydrologic regime compared with suitable reference areas. The interannual frequency and duration of soil saturation and inundation driven by the water table as well as the late summer water table depth influence the floristic composition of meadow communities (Allen-Diaz 1991). In Yosemite Valley a gradient of wet meadow communities occurs, as shown in Figure 34. The wettest meadows are saturated to the surface for most of the summer and are dominated by the tussock forming *Carex senta*. Meadows that are saturated to the surface on many years, but have deeper water tables by mid summer are dominated by *Carex lanuginosa*. Meadows that are saturated to the surface only in wet years and regularly have deeper water tables during the summer are dominated by exotic grasses *Agrostis stolonifera* and *Poa pratensis* with many herbaceous species present. The restoration of wet meadows is critical in Yosemite Valley because the drying of soils is leading to the loss of soil carbon and the soil seed bank, which will make restoration in the future increasingly difficult.

The existing portions of Stoneman and Ahwahnee Meadows represent less than 50% of the meadow area that existed in the upper Yosemite Valley in the middle to late 1800's. The remaining area is now influenced by resort development or supports conifer forest. Conifer forests support relatively low herbaceous species cover, yet much of the herbaceous cover and biodiversity in Yosemite Valley has been and continues to be in the wet meadows. Conifer trees likely colonized former meadows due to several reasons: (1) hydrologic changes such as drains and water diversions lowered the summer water table making the sites suitable for trees, or widening of the Merced River, (2) the cessation of burning by Native Americans allowed fire sensitive species to persist (Anderson et al. 1991), (3) disturbance of the meadows by plowing and planting of hay crops and the development of apple orchards allowed conifer to invade the bare soils after the rhizomatous meadow species were destroyed, and (4) fill placed to raise the ground elevation allowed upland species to invade.

Meadow restoration should begin with removal of all known impacts to surface and ground water flow. Over the past 100+ years Yosemite Valley has experienced numerous alterations of water flow. Restoration should be a step by step process, with one project to fill a ditch or eroded channel, remove fill, with follow up monitoring to determine the effects of each action. Our work, as well as that by Jones and Stokes (2002) evaluating soils in the Rivers and Pines campground complex showed that few areas have been filled, and fill is only a few cm thick where it has been placed. Thus, filling is not a major cause of landscape change, other than in the southwestern corner of Ahwahnee Meadow. The role of fire in killing conifers invading meadows cannot be replicated through resources management activities, however periodic removal of invading conifers might be desirable in some circumstances. Conifer removal will be necessary in areas where water tables are effectively raised because the high water table could destabilize the tree root systems. This will also prepare areas for the planting of *Carex* and other meadow species once natural water table dynamics are restored.

Riparian areas have periodic been flooded by the Merced River, creating largely sand and gravel soils and a water table controlled by river stage. These areas naturally support a relatively broad (see Figure 7, historic photo), and diverse woody community dominated by species of *Populus, Alnus* and *Salix* mixed with *Quercus kelloggii* and a few conifer trees. These native riparian species require full sun for seedlings to establish from wind and water dispersed seed. However, there are too few *Populus* present to promote seedling establishment, and too much trampling of potential seed beds on river point bars, intermittent channels, and islands by summer visitors to allow seedlings to survive. Riparian areas could be restored through direct plantings of dormant stems, rooted stems, and nursery grown material. However, these restoration areas would require limited public access for several years to eliminate trampling induced mortality. The area that could accommodate riparian restoration is outlined in Figures 37 and 38. Many campground areas with deep water tables may easily be restored to *Quercus kelloggii* forests which were part of the riparian zone stand types in the 1800's.

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Figure 1. Aerial image of the Yosemite Valley study area. Reference meadows are identified, as well as the flooded campground restoration area.

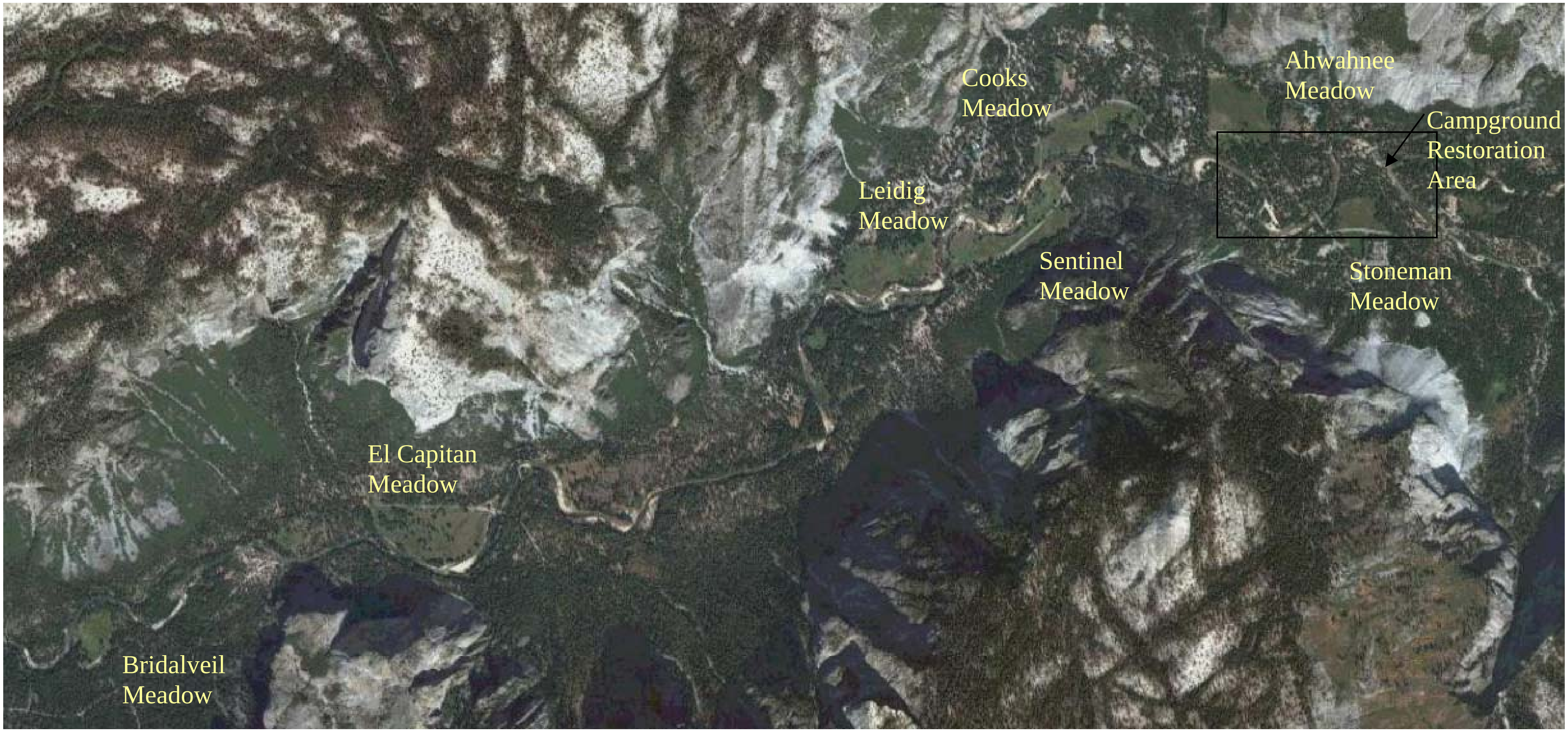

Figure 2. Aerial image of the campground study area. Shown are Ahwahnee Meadow (top center) and Stoneman Meadow (bottom right) and the Merced River.

Figure 3. Map of Yosemite Valley by J. C. Whitney, 1868. This map shows the valley to be covered primarily by wet meadows and scattered *Quercus kelloggii* woodland on the valley margins.

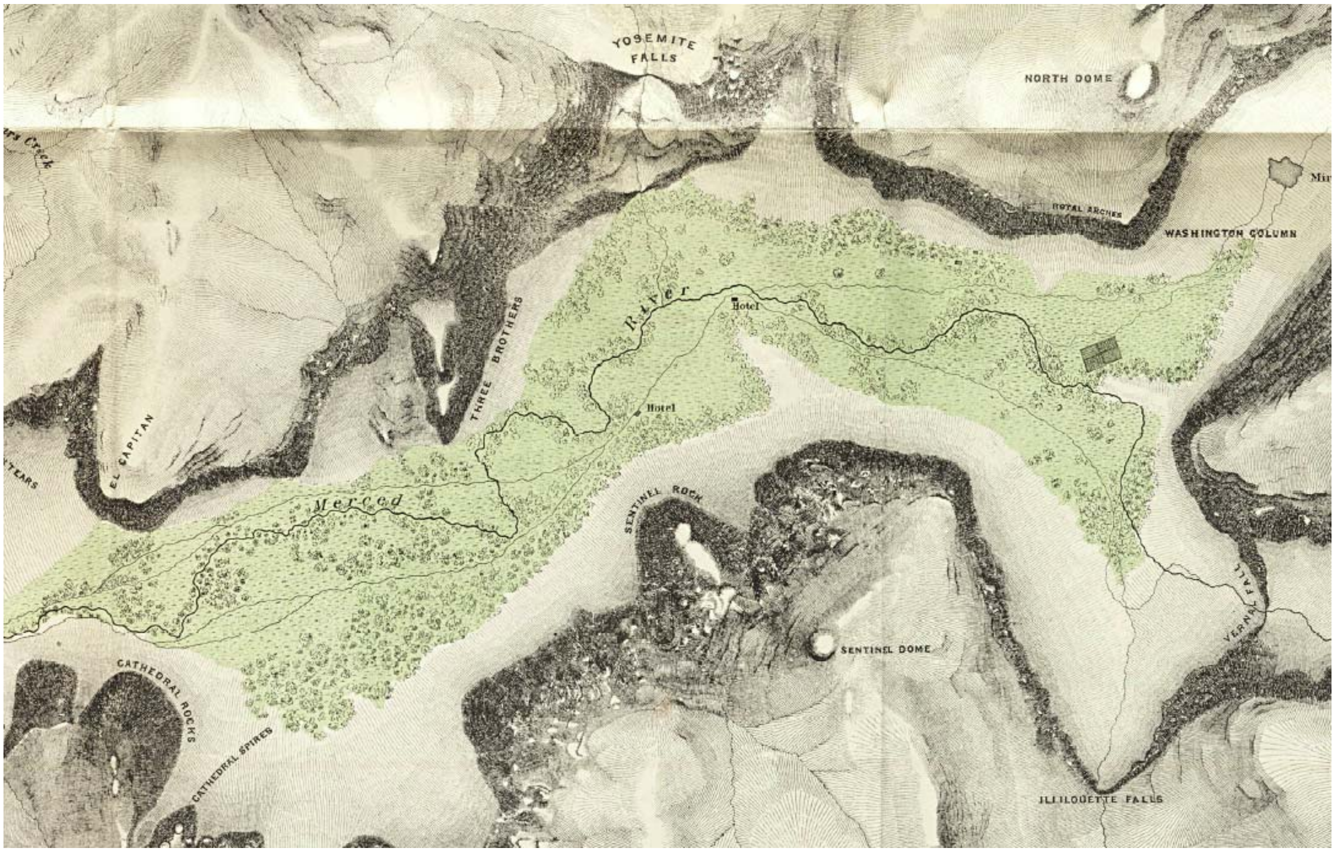

Figure 4. Plat of Yosemite Valley by C. Hoffmann, 1867. This map shows the valley to be largely wet meadows, with orchards shown in the area of Curry Village (A) and upper Pines (B).

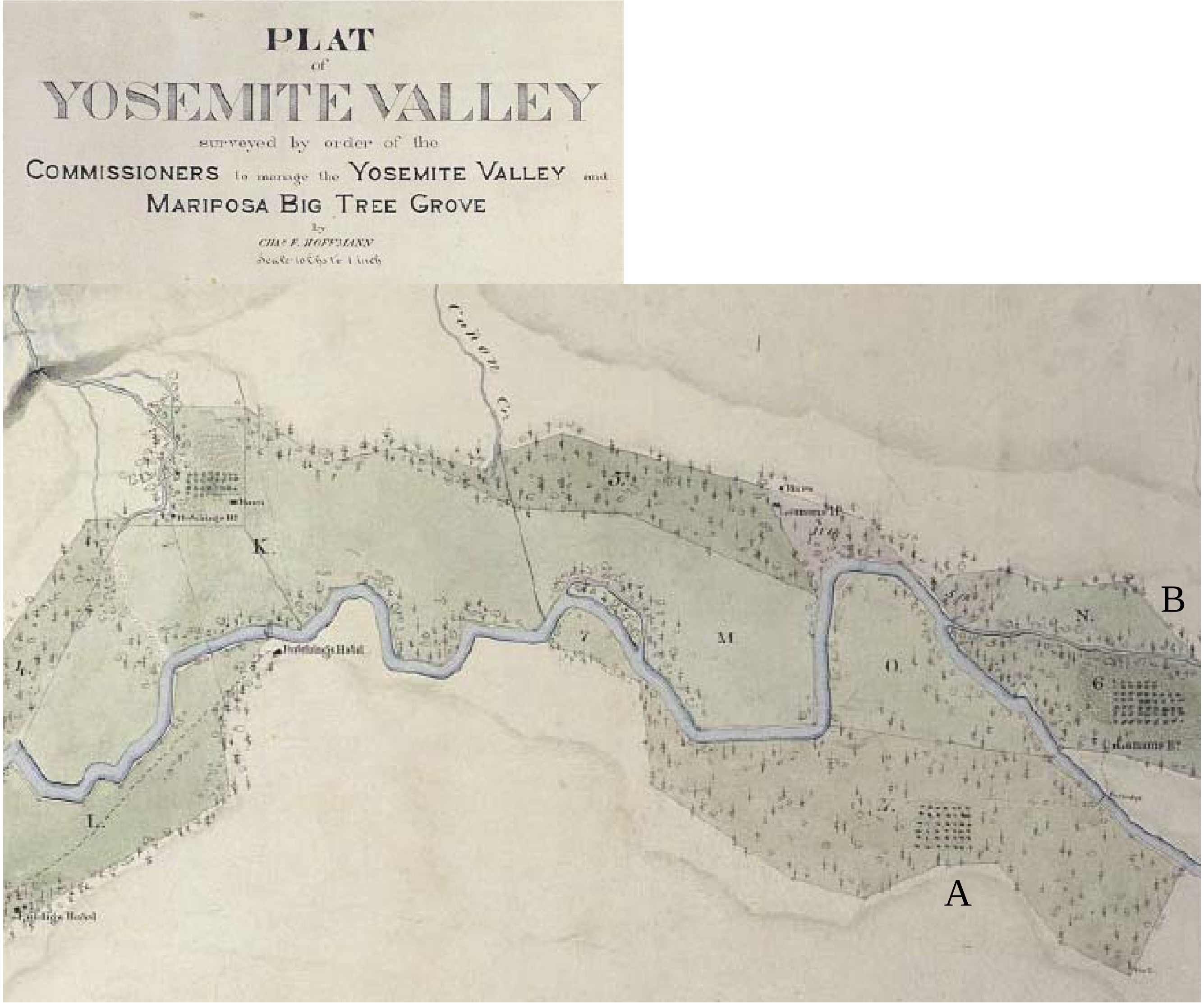

Figure 5. Map of Yosemite Valley by King and Gardner, 1865. Scattered trees are shown, along with the same orchards illustrated in Figure 4.

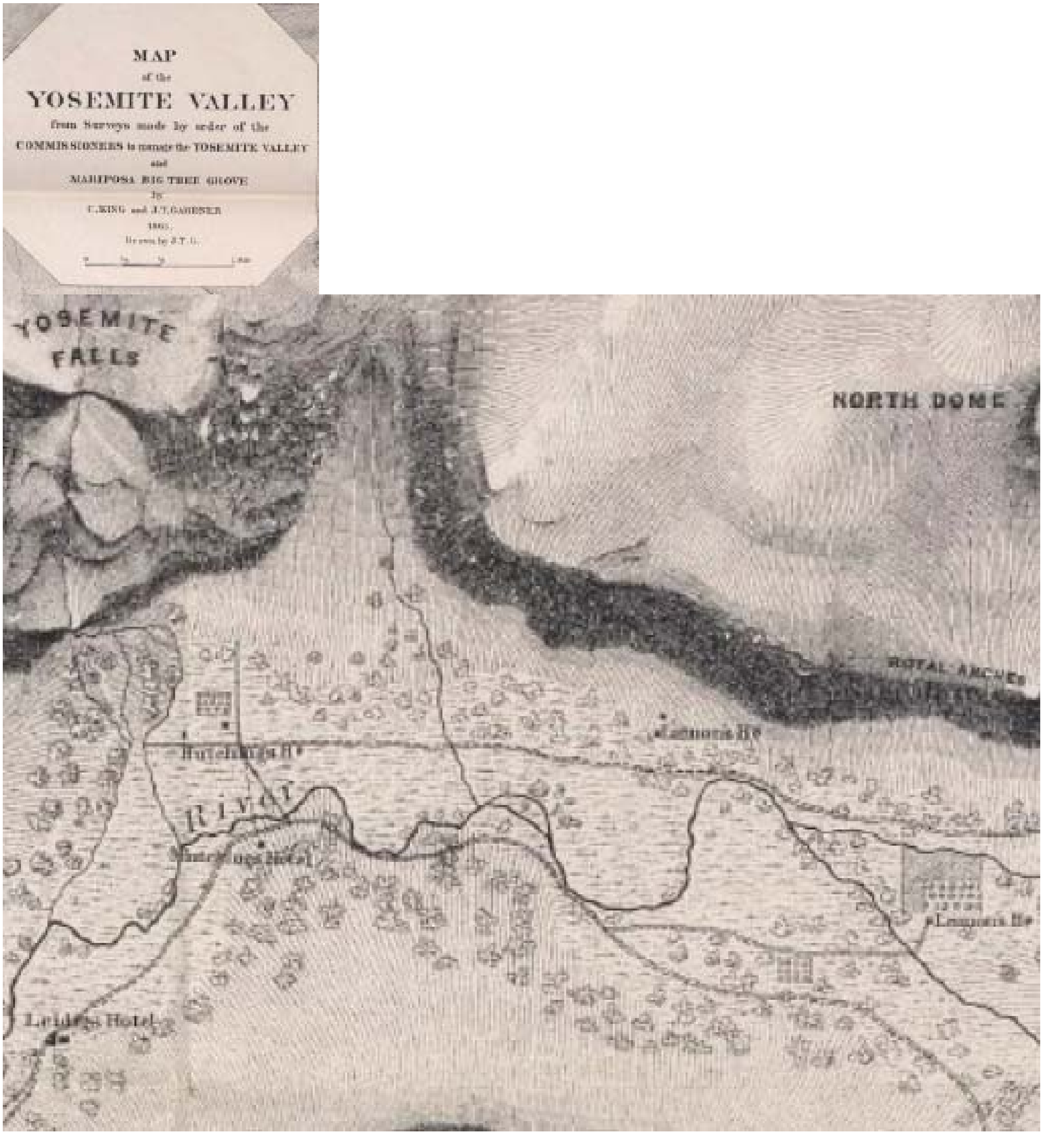

Figure 6. Acres of meadow in Yosemite Valley from the 1860's through 1980's. Data from 1878 Wheeler, 1922 Russell, 1937 from Ernst published in 1949, 1960 from Gibbens&Heady published in 1964, amd NPS 1982.

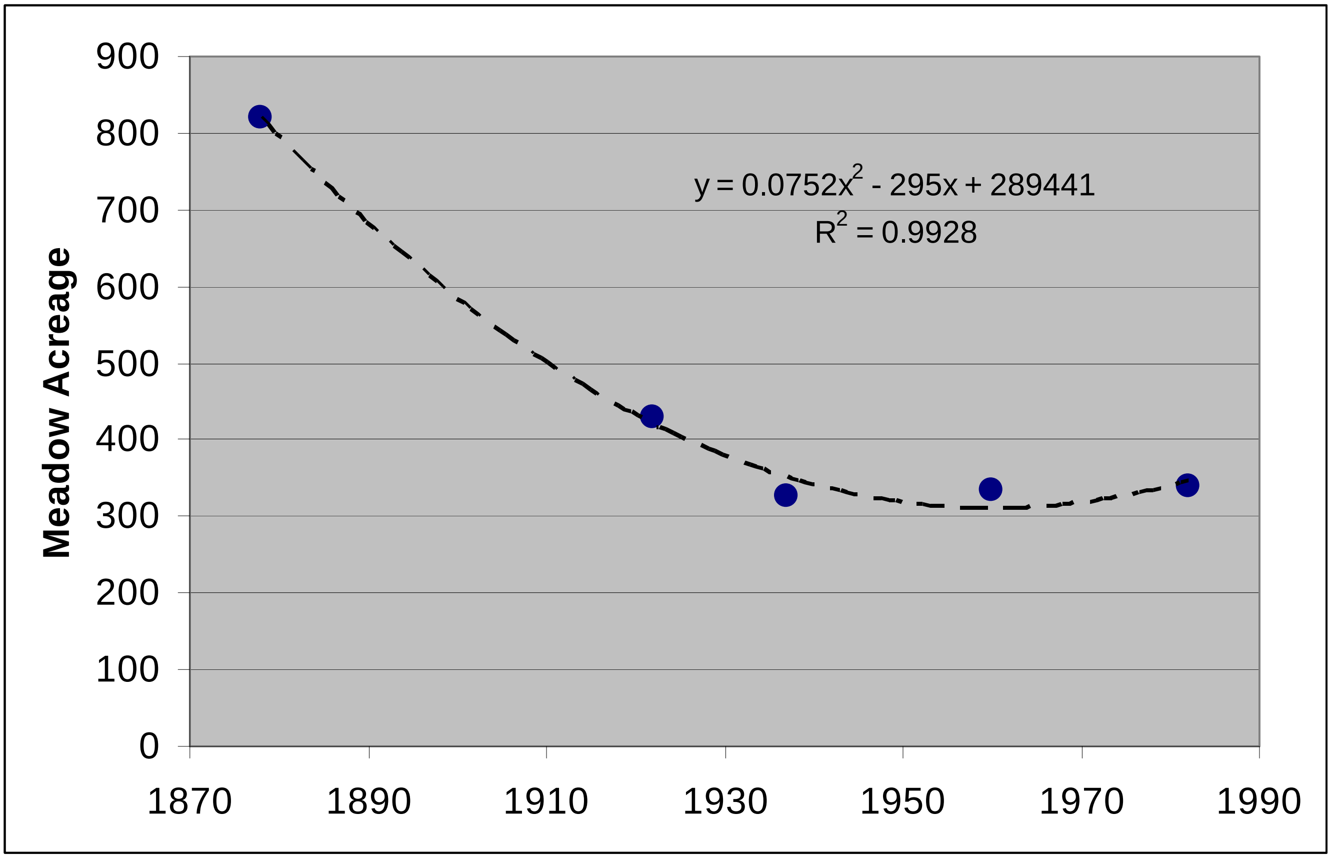

Figure 7. Photo looking east toward Half Dome from Columbia Point, 1899 and 2006. An increase in conifers and a decrease in *Quercus* and meadows are apparent. Also see report cover.

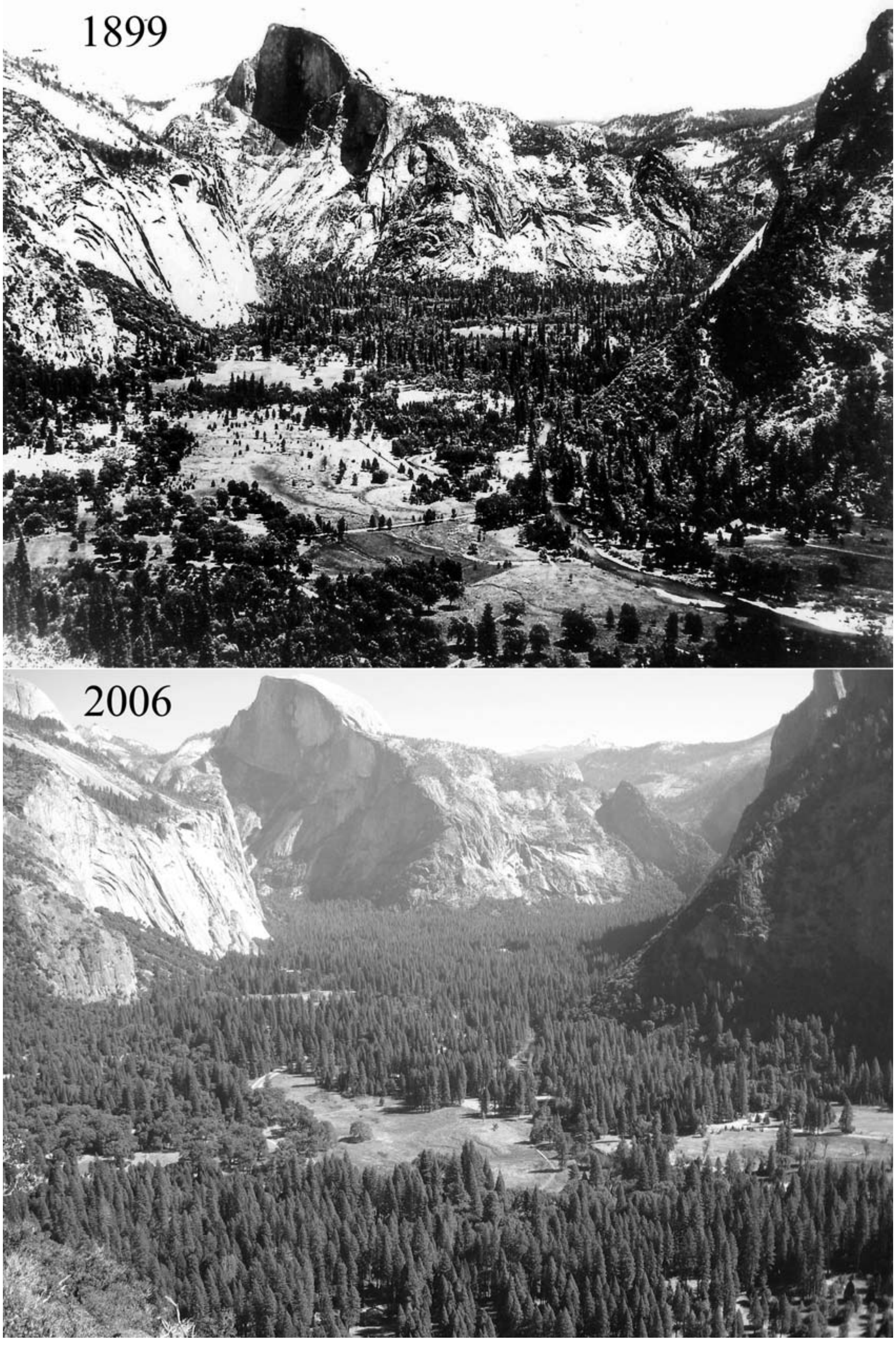

Figure 8. Grizzly Peak and Glacier Point, 1868 and 2006. The channel is considerably wider in 2006 than in 1868 and riparian vegetation of *Populus, Salix and Alnus* is nearly lacking in the later photograph.

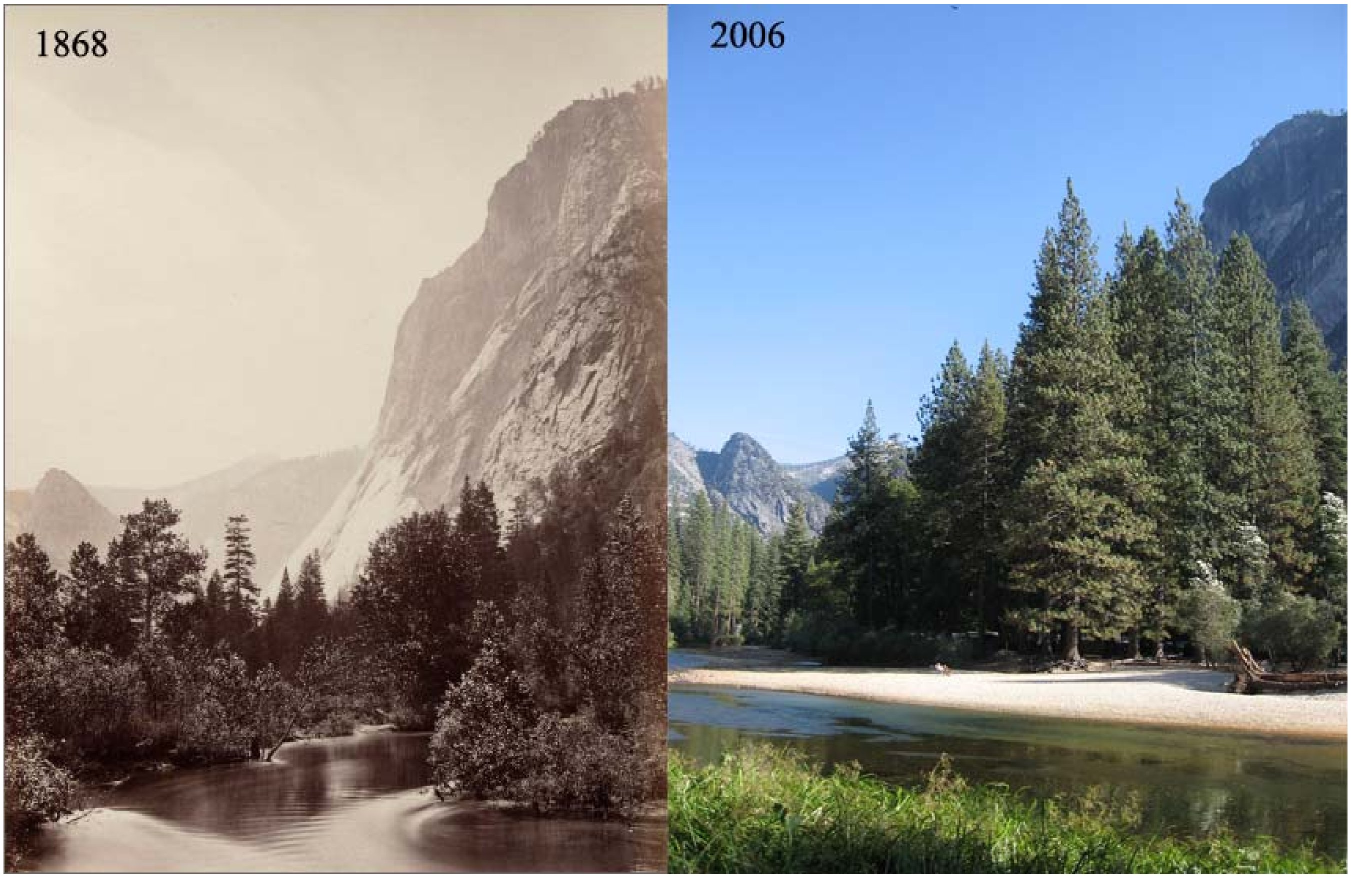

Figure 9. Annual instantaneous peak stream flow for the Pohono Bridge and Happy Isles Bridge gauges along the Merced River.

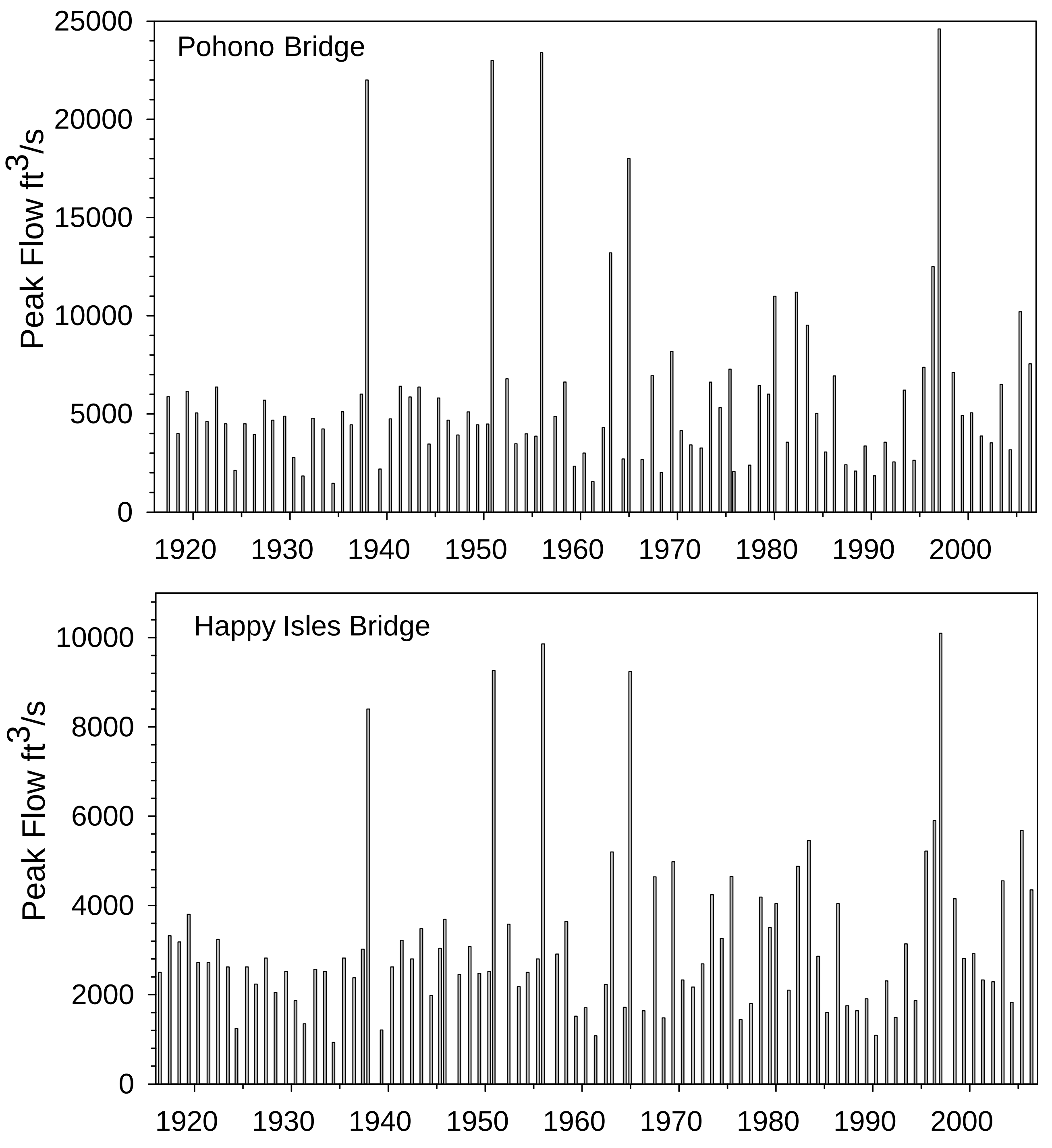

Figure 10. Mean daily flow at the Pohono Bridge and Happy Isles Bridge gauges, Merced River.

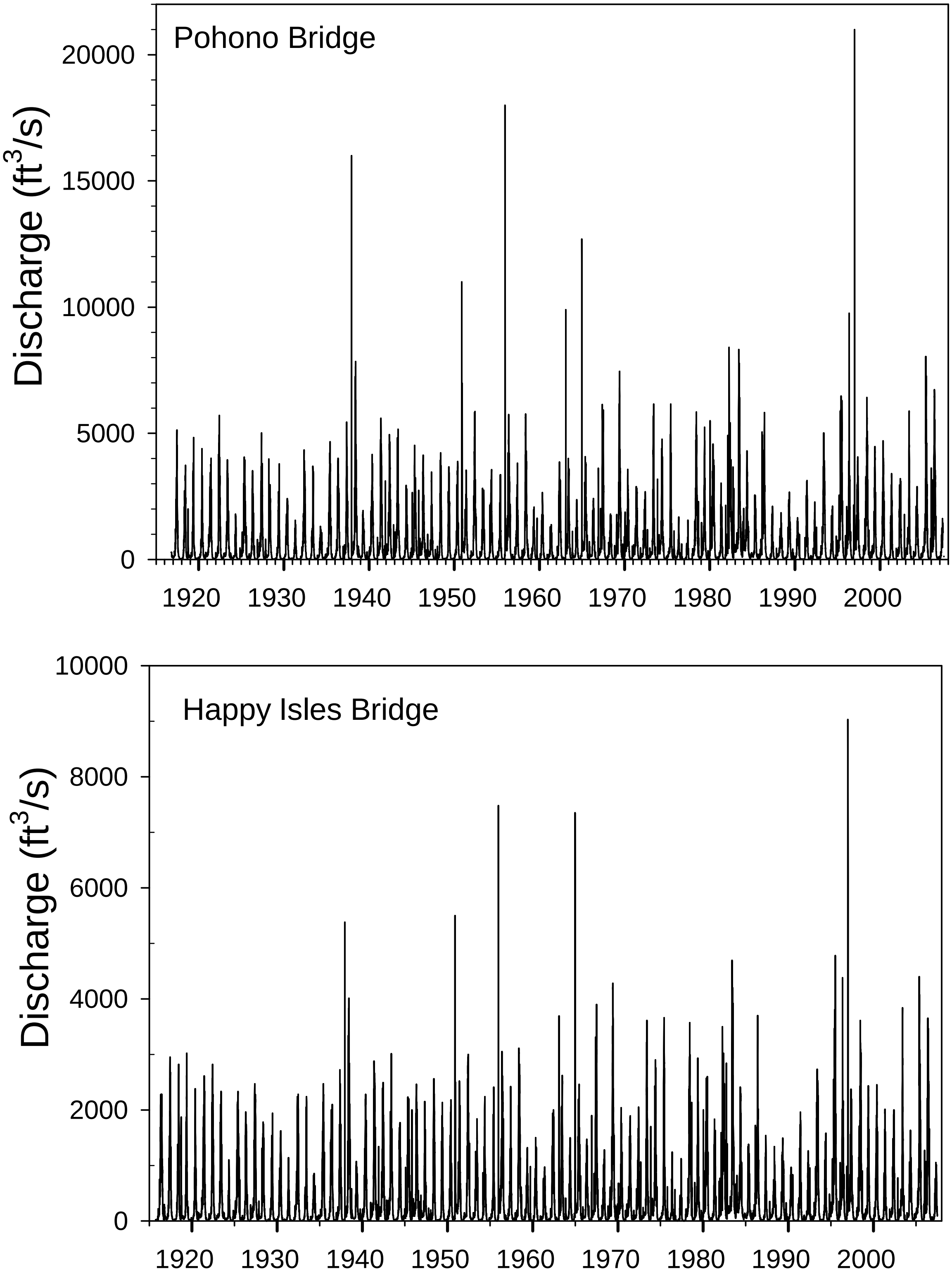

Figure 11. Mean daily flow at the Pohono gauge during 2004, 2005 and 2006.

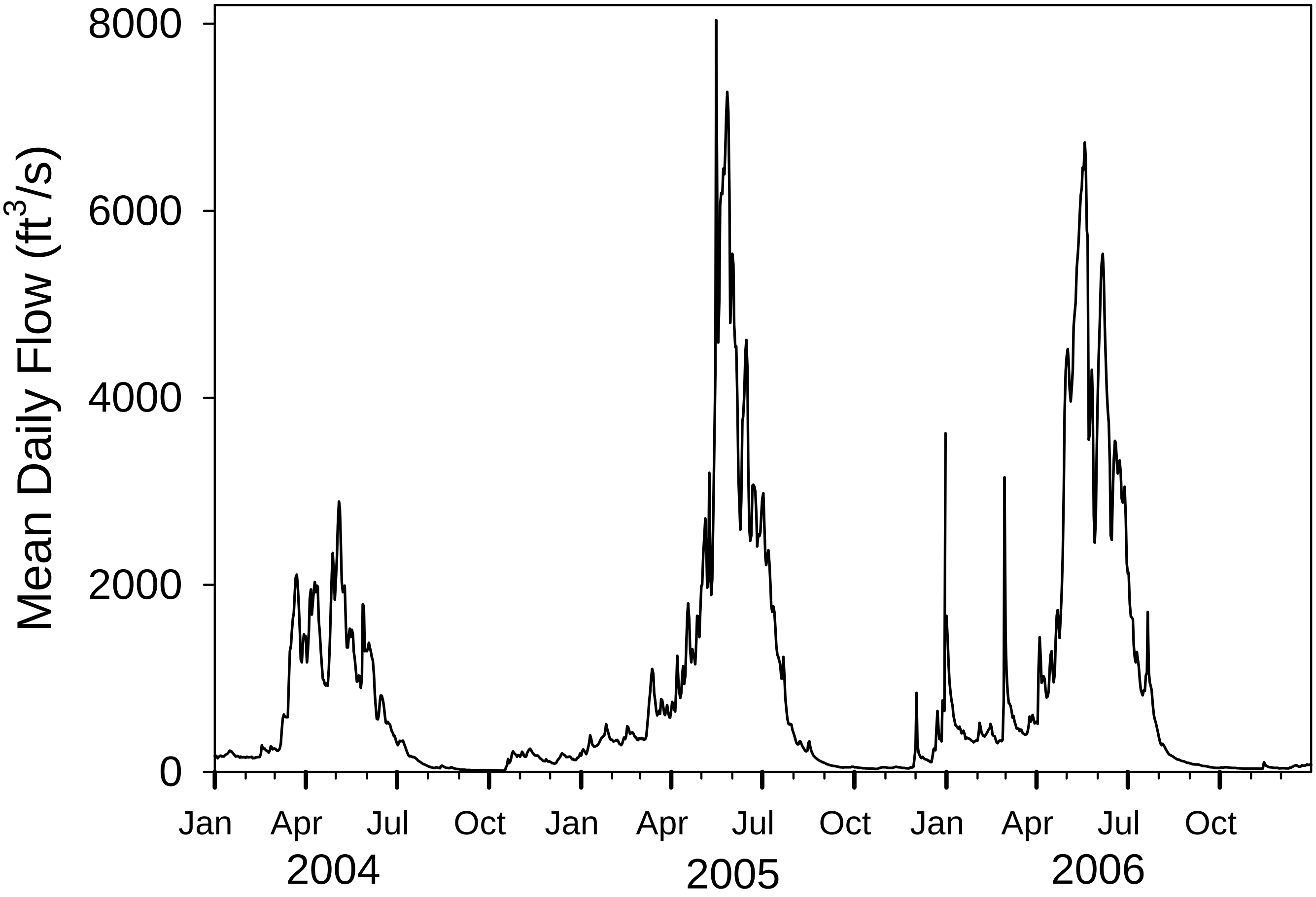

Figure 12. Location of all monitoring wells in the study area, shown as red dots, reference sites in green, and USGS river gauges in blue.

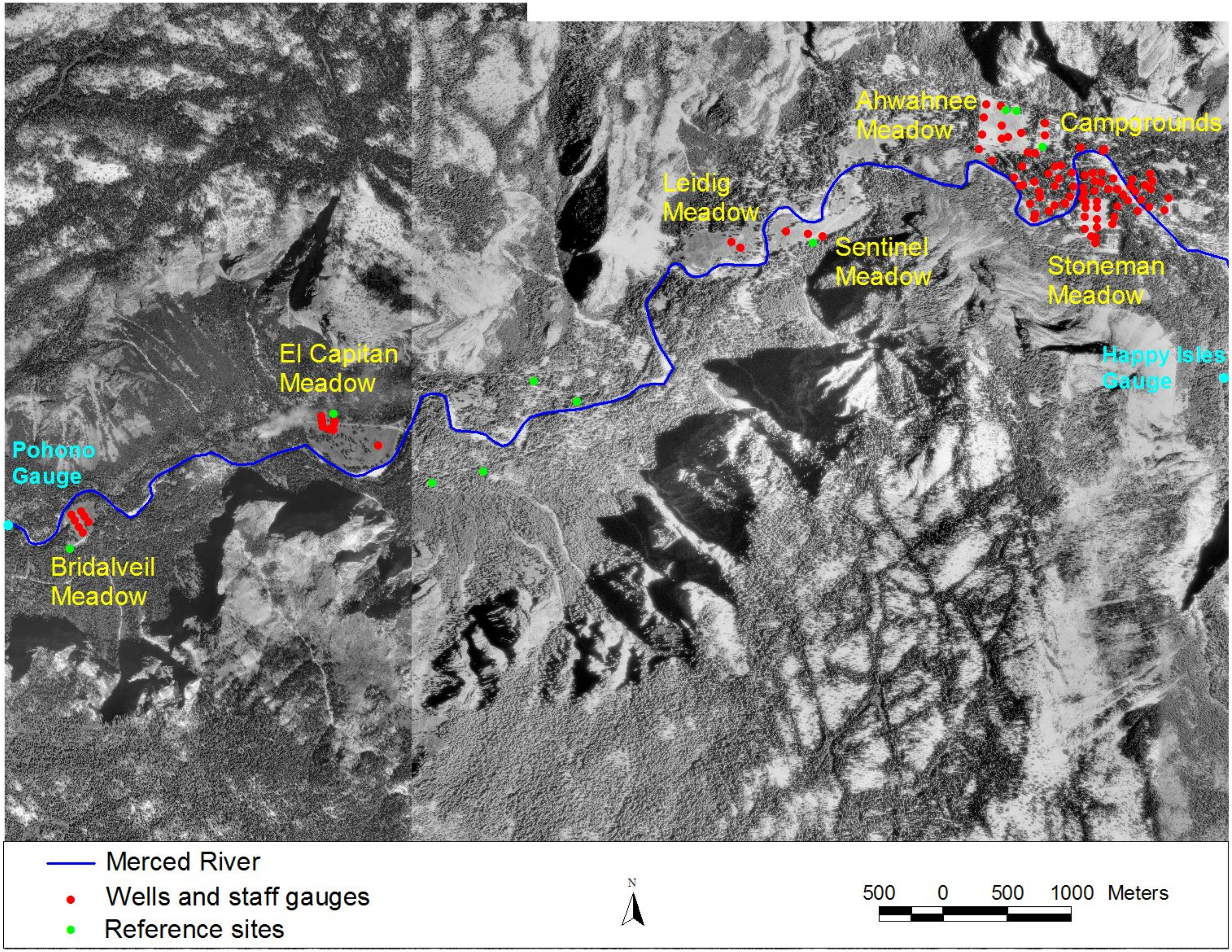

Figure 13a. Location of monitoring wells, staff gauges (x), and profile lines (yellow, orange, and purple with figure references) in the campground study area.

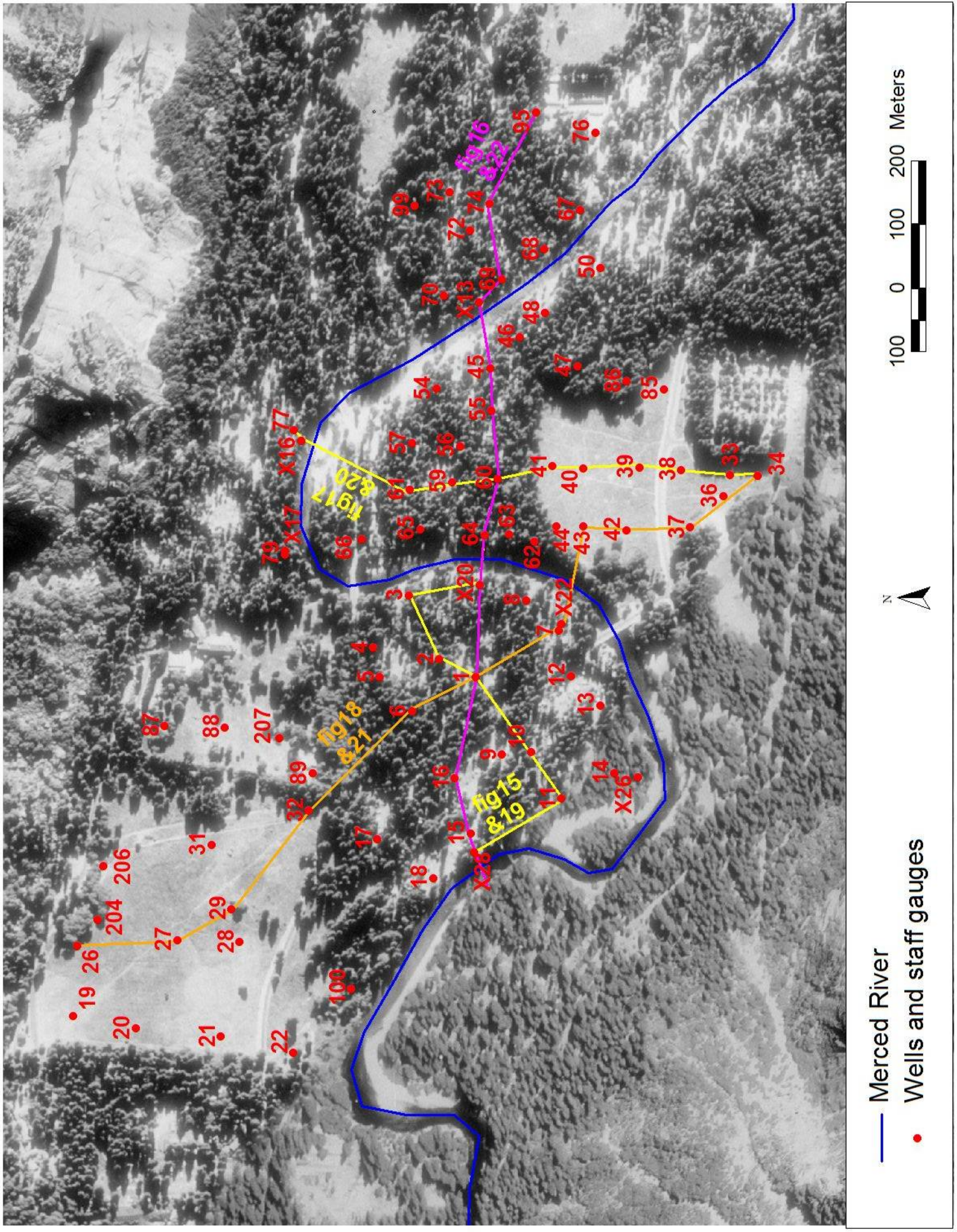

Figure 13b. Location of monitoring wells in the Liedig and Sentinel Meadows study areas.

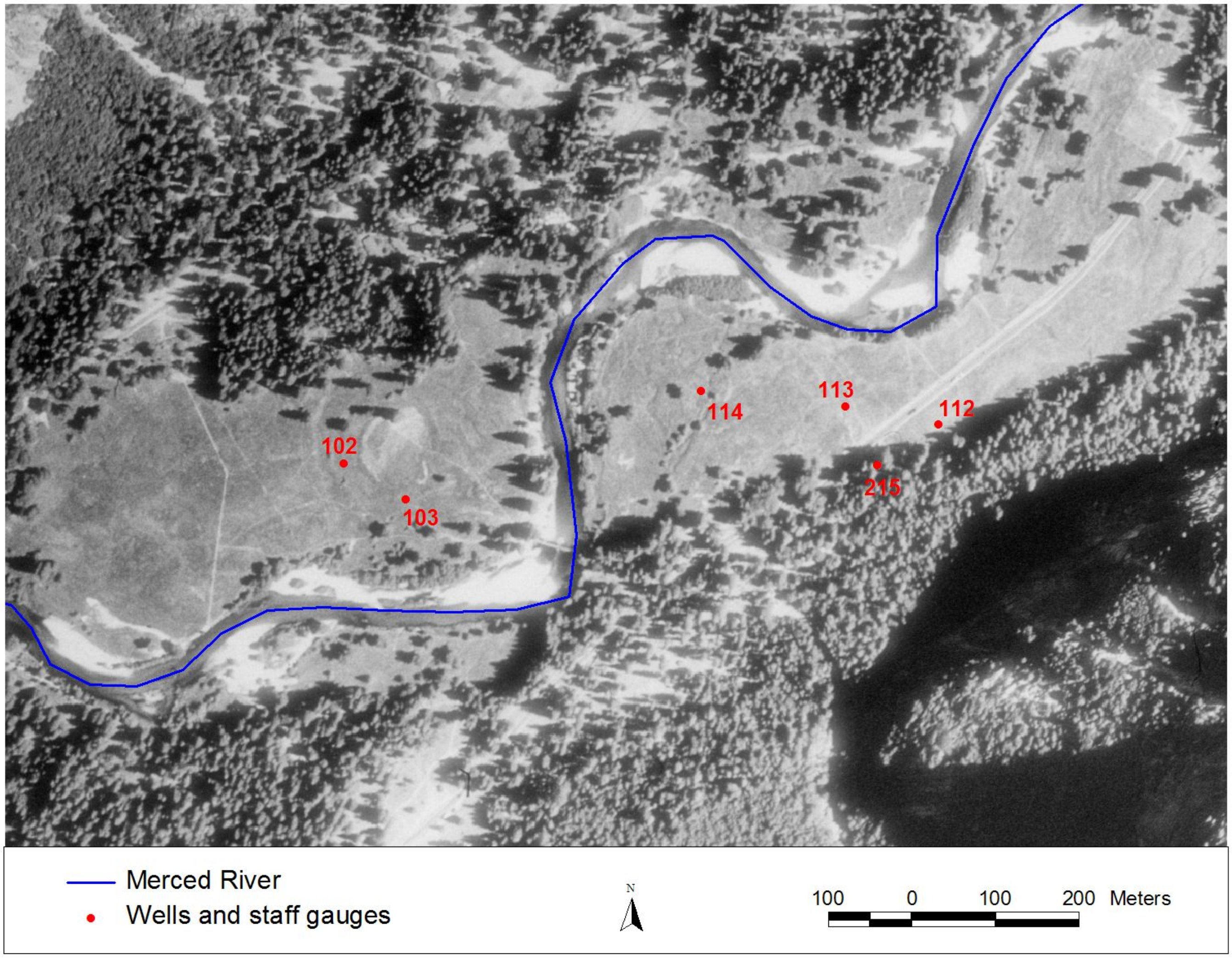

Figure 13c. Location of monitoring wells in the El Capitan Meadow study area.

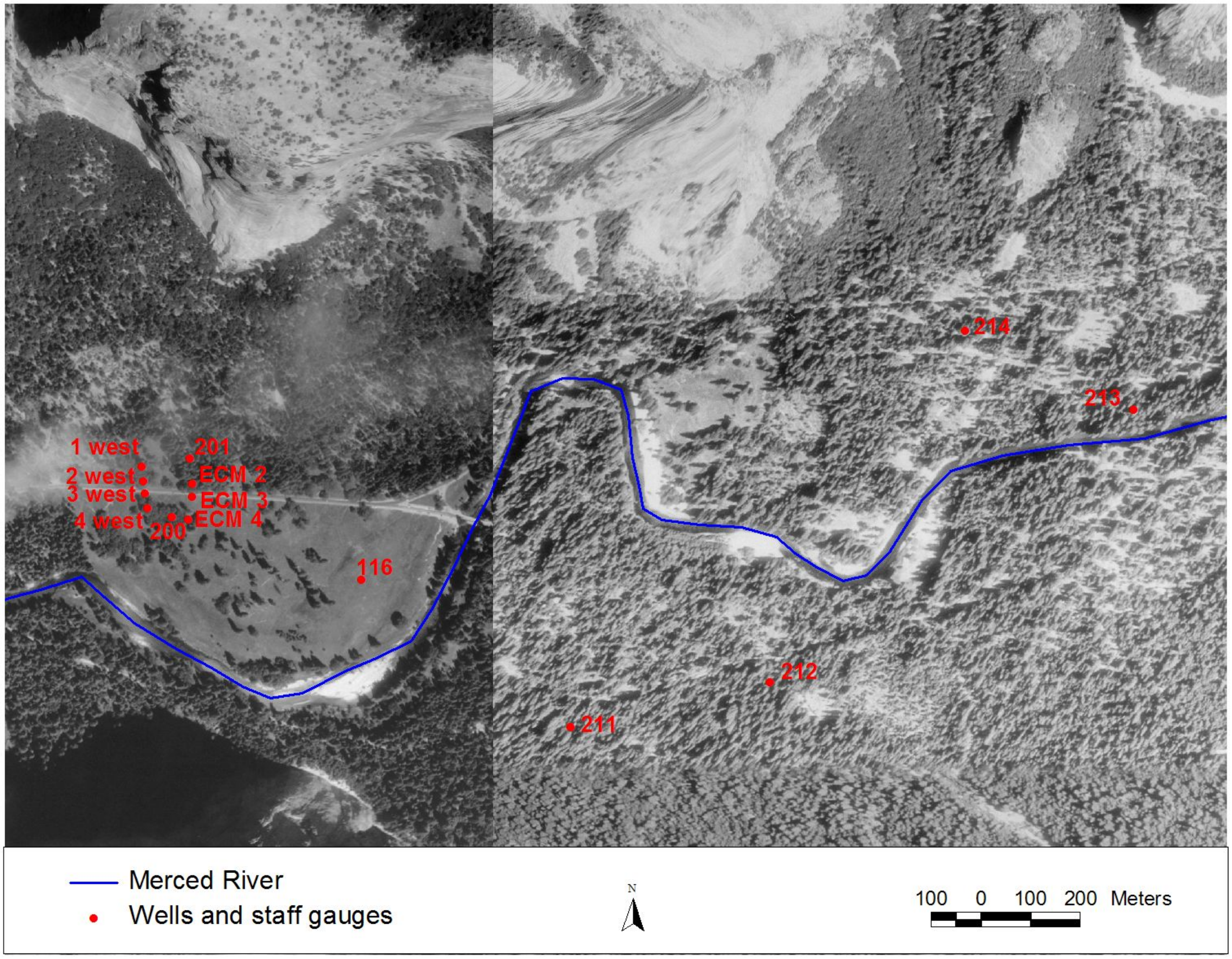

Figure 13d. Location of monitoring wells in the Bridalveil Meadow study area.

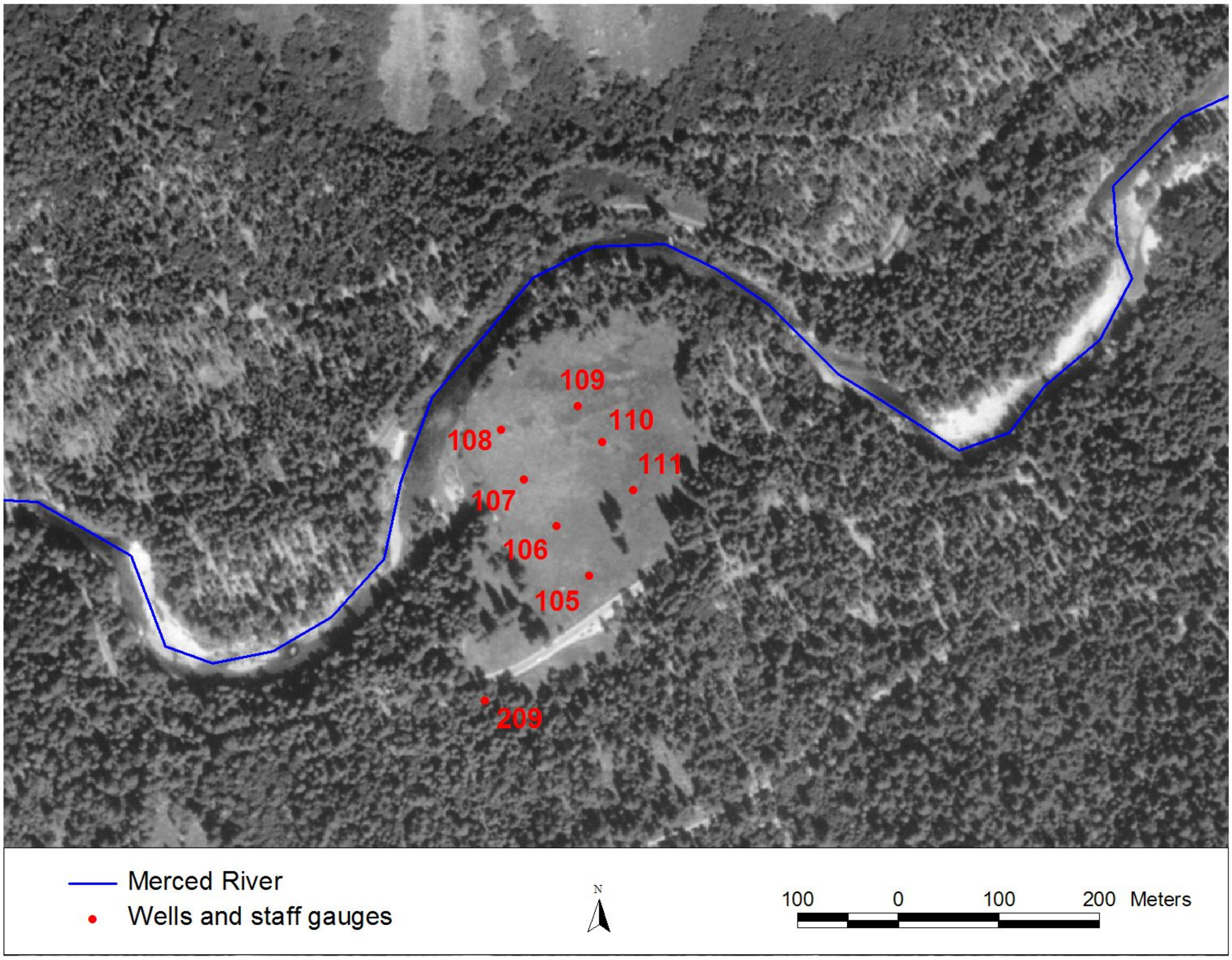

Figure 14. Ground water elevation in wells 1, 2, 3, 9, 10, 11 in Upper and Lower River Campgrounds and surface water elevation at cross sections 20 and 28.

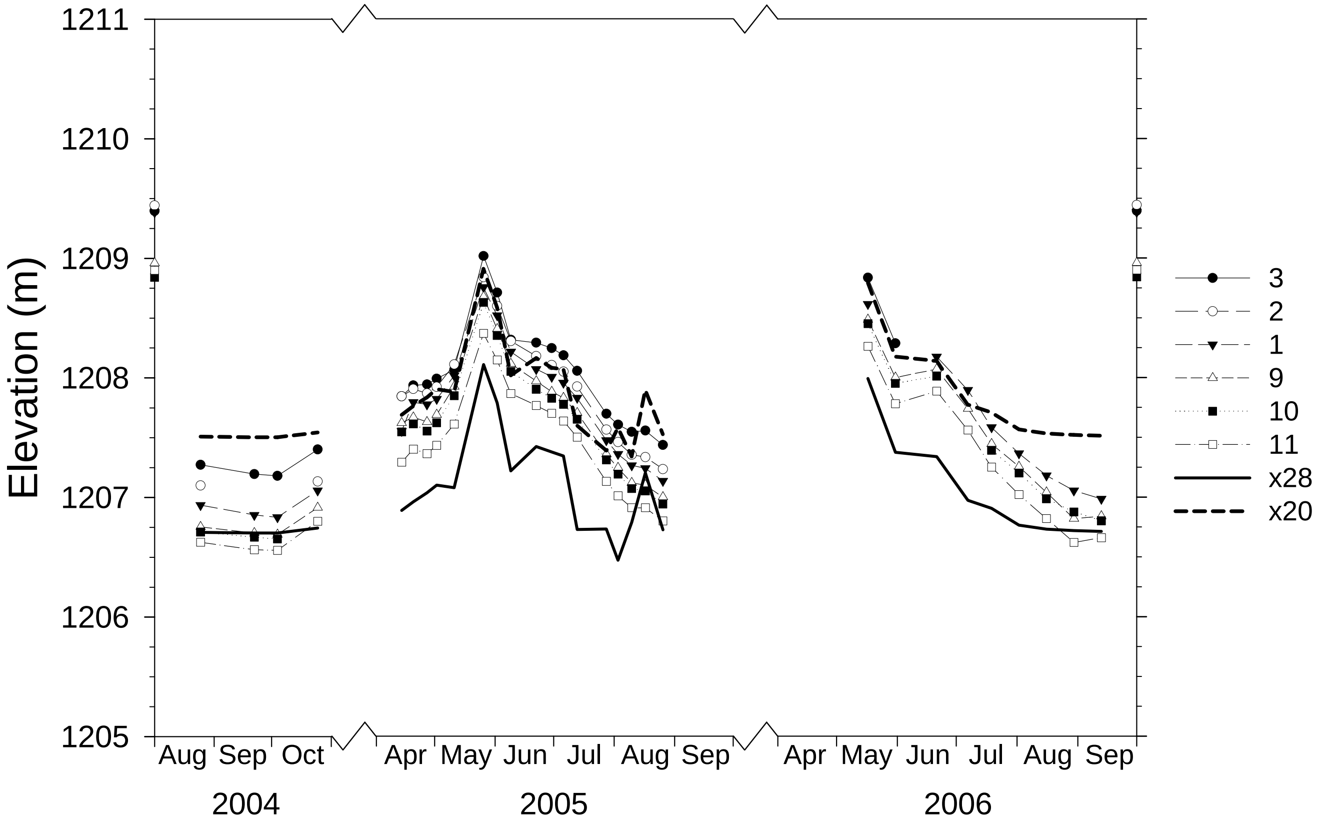

Figure 15. Ground water elevation in wells 46, 55, 60, 63, 69, 72 and 73 in Upper and Lower Pines Campgrounds and surface water elevation at cross sections 13 and 20.

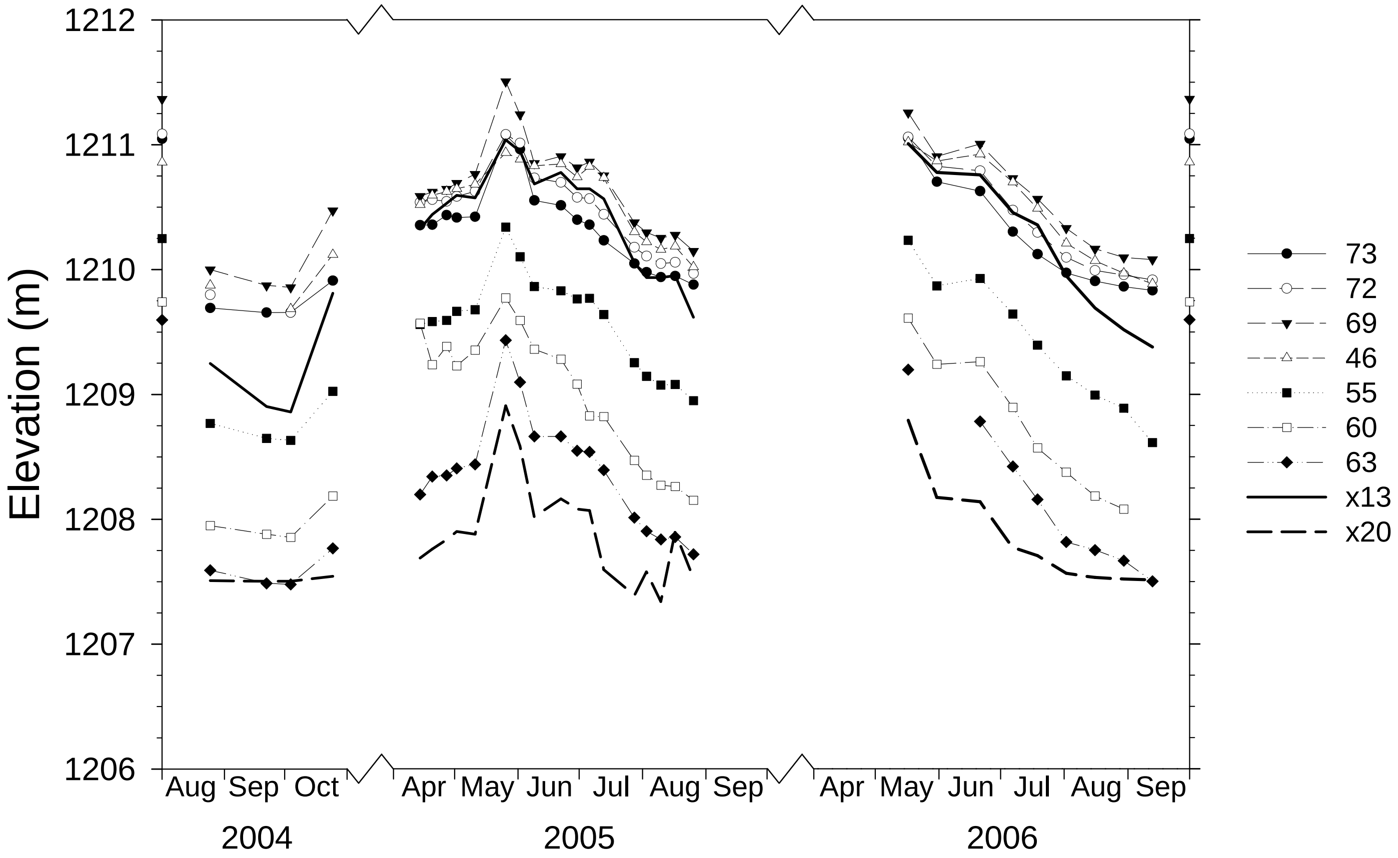

Figure 16. Ground water elevation in wells 33, 34, 38, 39, 40, 41, 59, 60, 61 and 77 in Stoneman Meadow and Lower Pines Campground and surface water elevation at cross section 16.

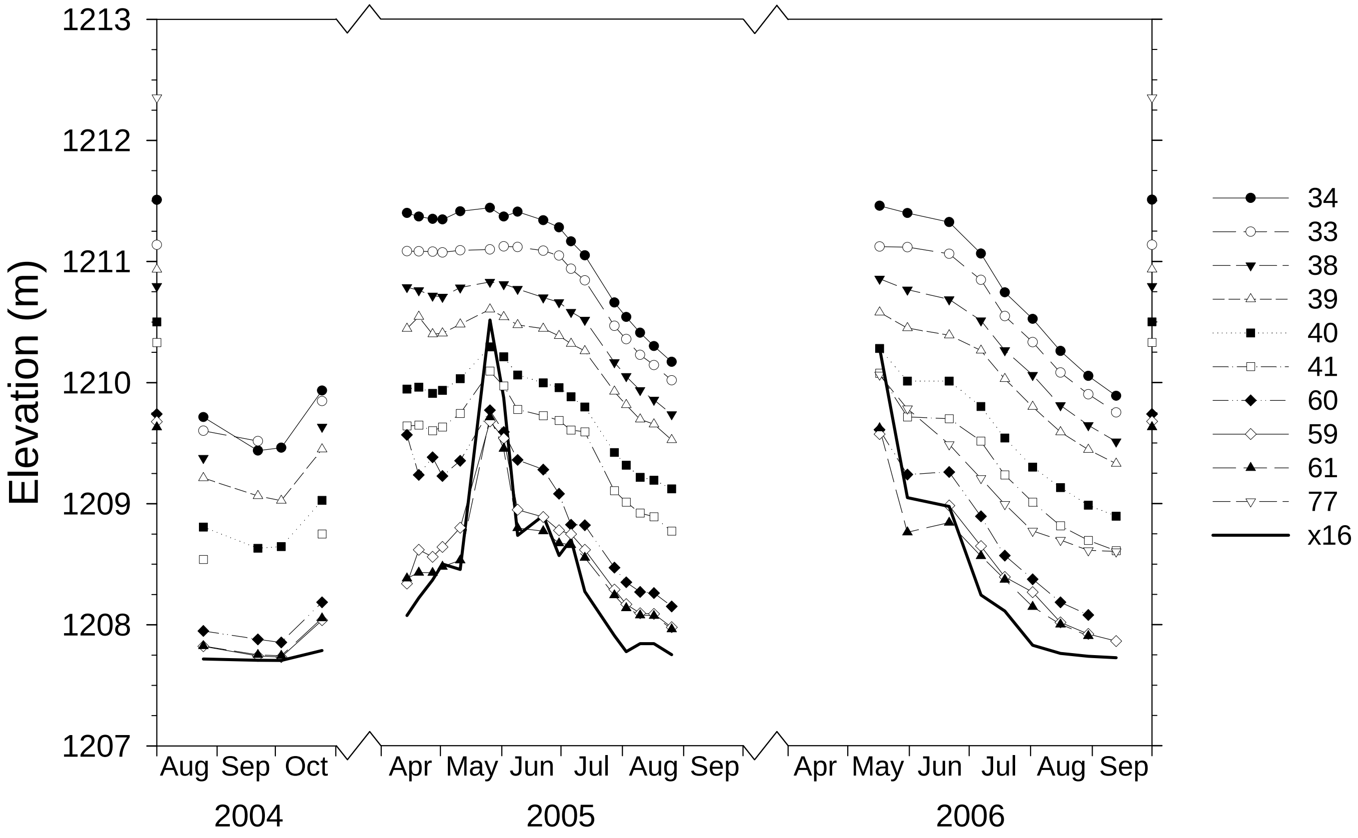

Figure 17. Ground water elevation in wells 1, 6, 7, 26, 27, 29, 32, 34, 37, 42, and 43 in Ahwahnee Meadow, Upper Rivers Campground, and Stoneman Meadow and surface water elevation at cross section 20.

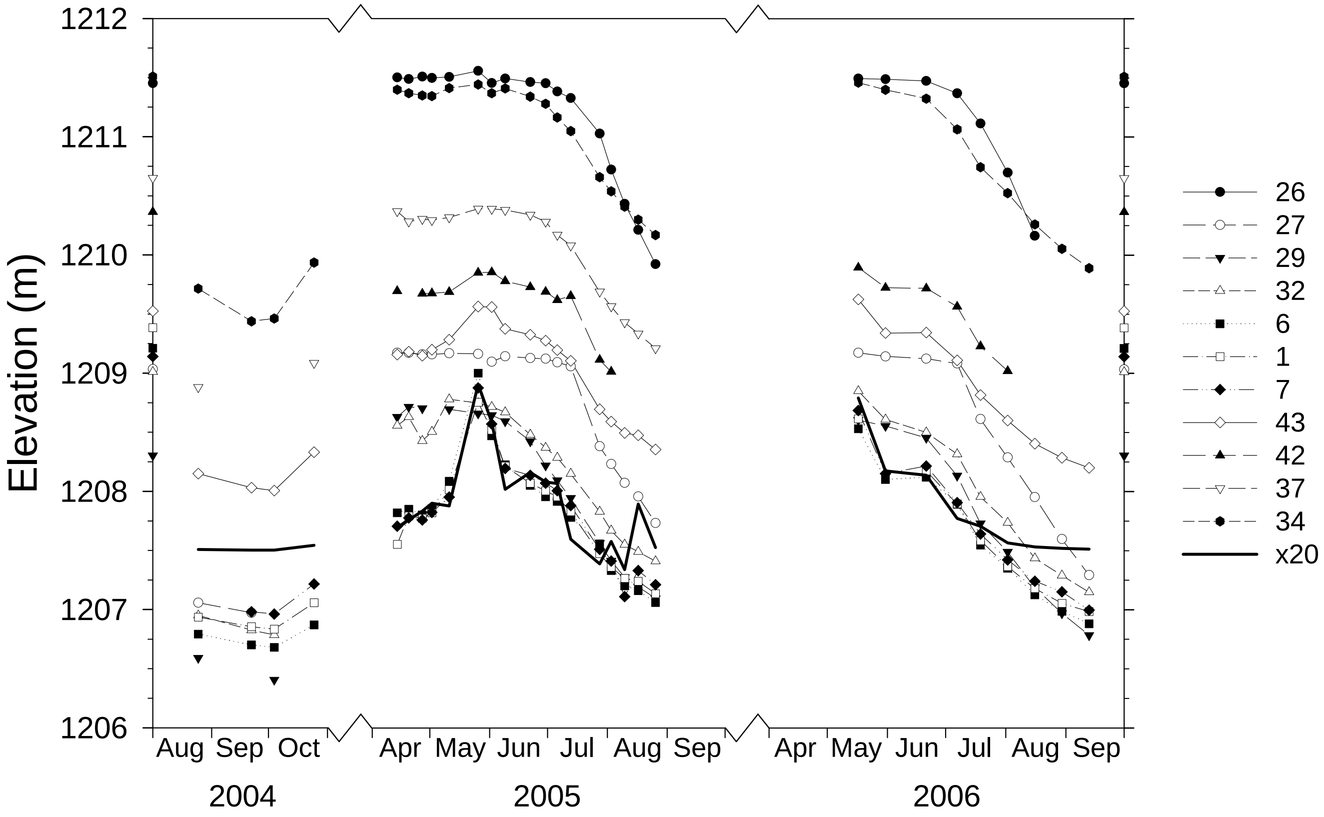

Figure 18. Ground surface, ground water and land surface elevation at wells 1, 2, 3, 10, 11 and surface water elevation at cross sections 20 and 28 for typical dates in May and August in 2004, 2005 and 2006.

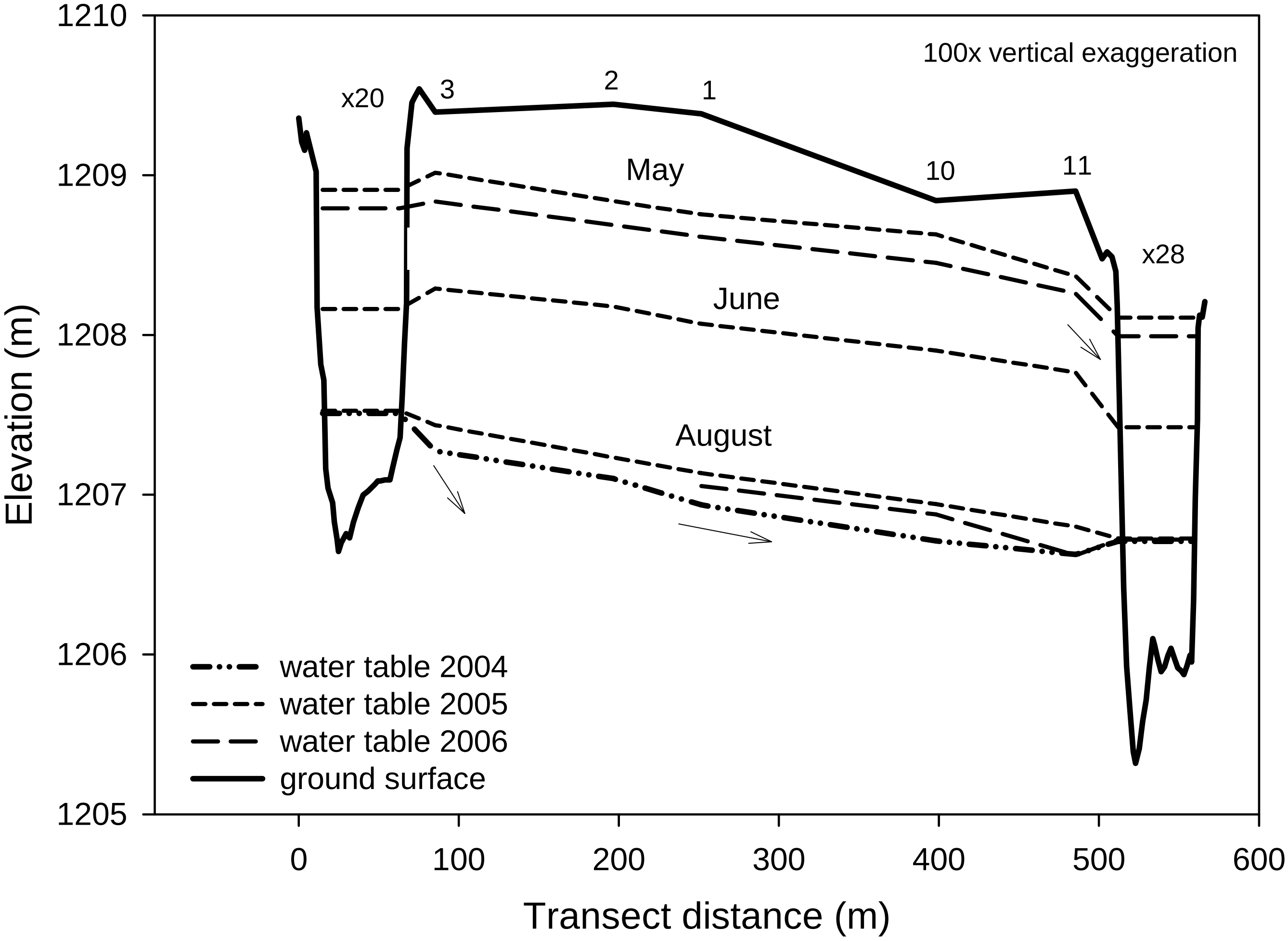

Figure 19. Ground surface, ground water and land surface elevation at wells 34, 33, 38, 39, 40, 41, 60, 59, 61, and 77 and surface water elevation at cross section 16 for typical dates in May and August in 2004, 2005 and 2006.

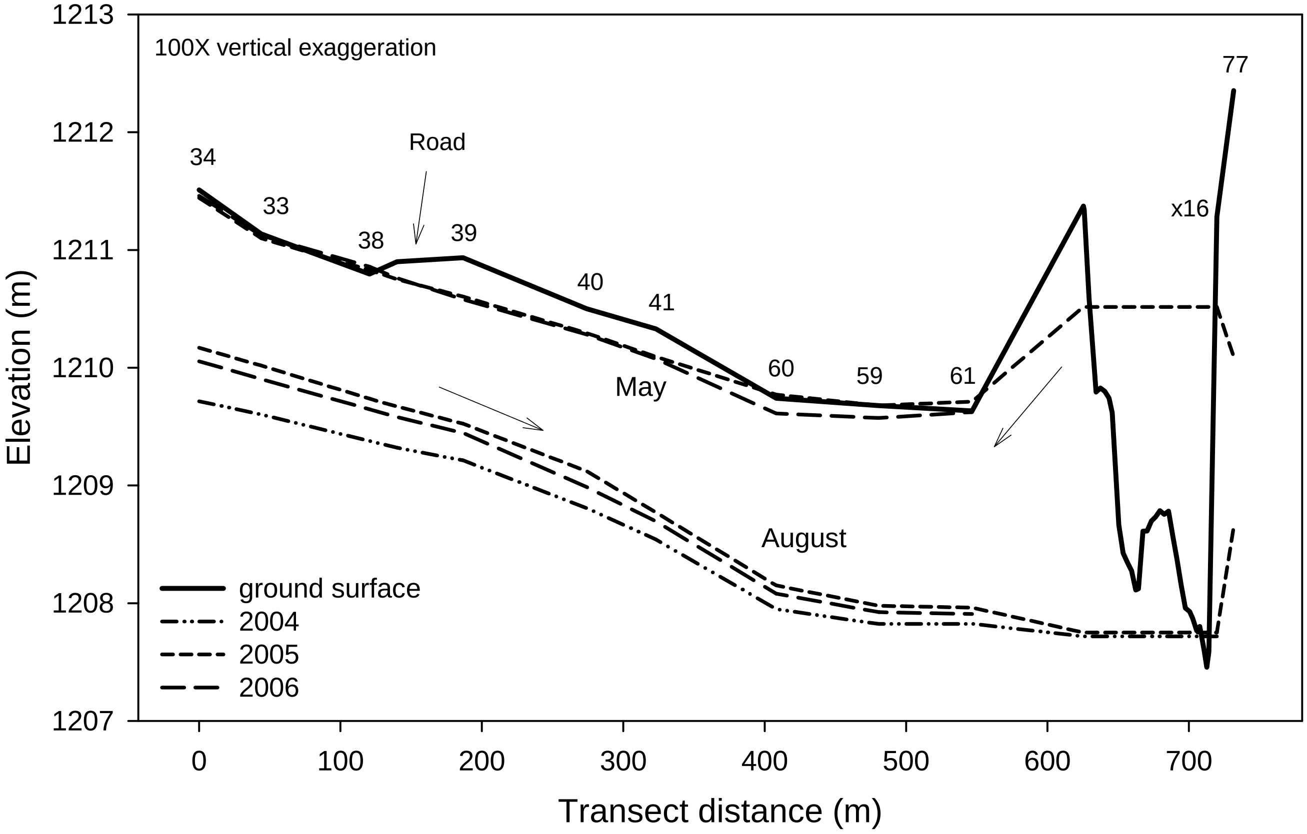

Figure 20. Ground surface, ground water and land surface elevation at wells 26, 27, 29, 32, 6, 1, 7, 43, 42, 37 and 34 and surface water elevation at cross section 20 for typical dates in May and August in 2004, 2005 and 2006.

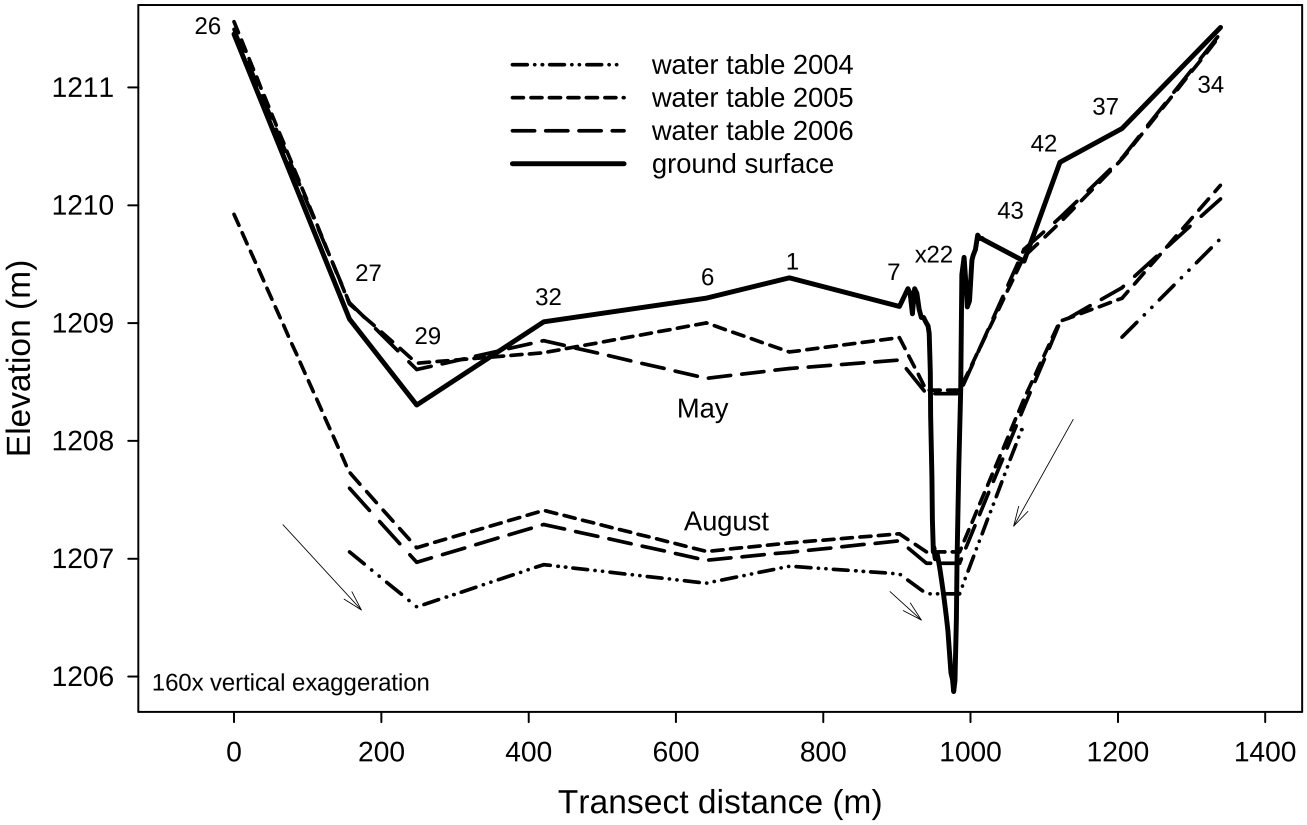

Figure 21. Ground surface, ground water and land surface elevation at wells 95, 74, 69, 45, 55, 60, 64, 1, 16, and 15 and surface water elevation at cross sections 13, 20, and 28 for typical dates in May and August in 2004, 2005 and 2006.

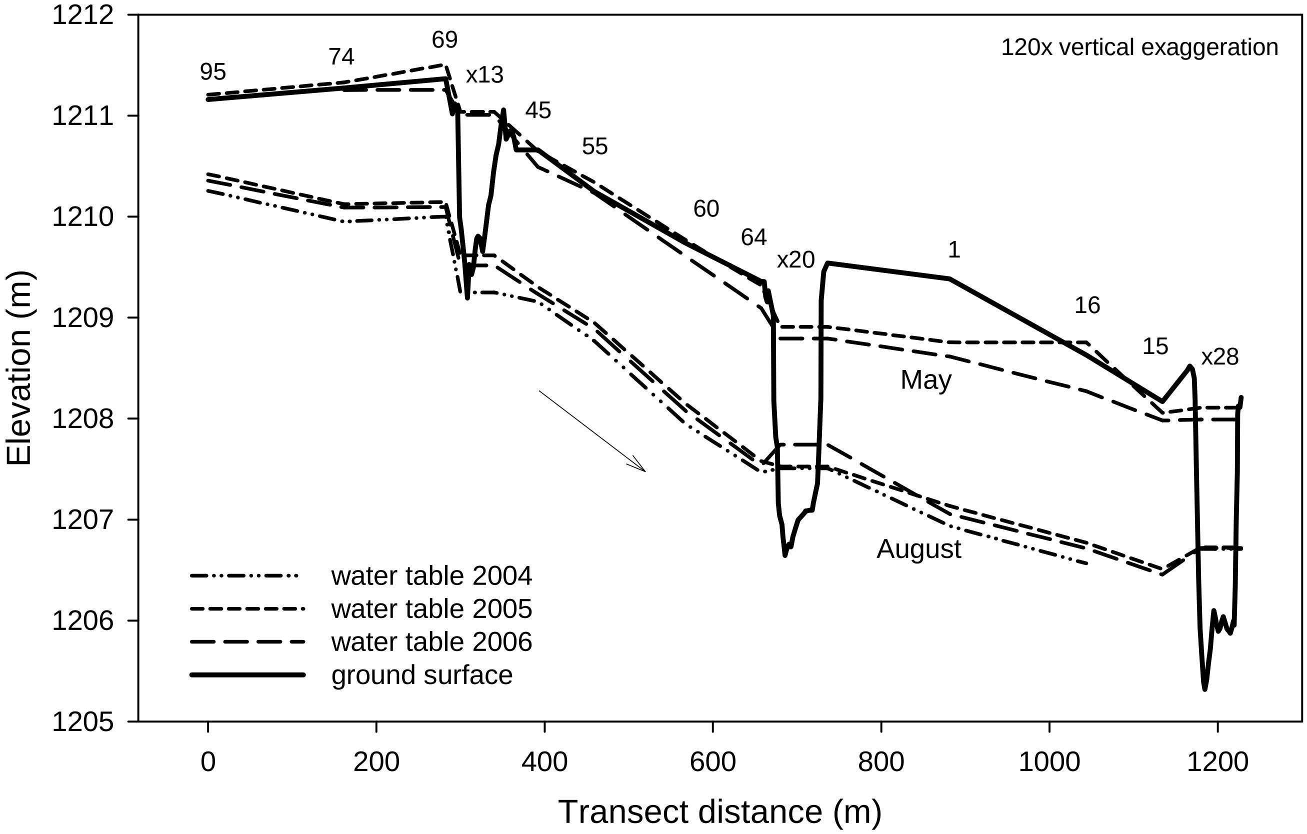

Figure 22. Water table elevation contour map for 17 May 2006. Contour interval is 0.5 m.

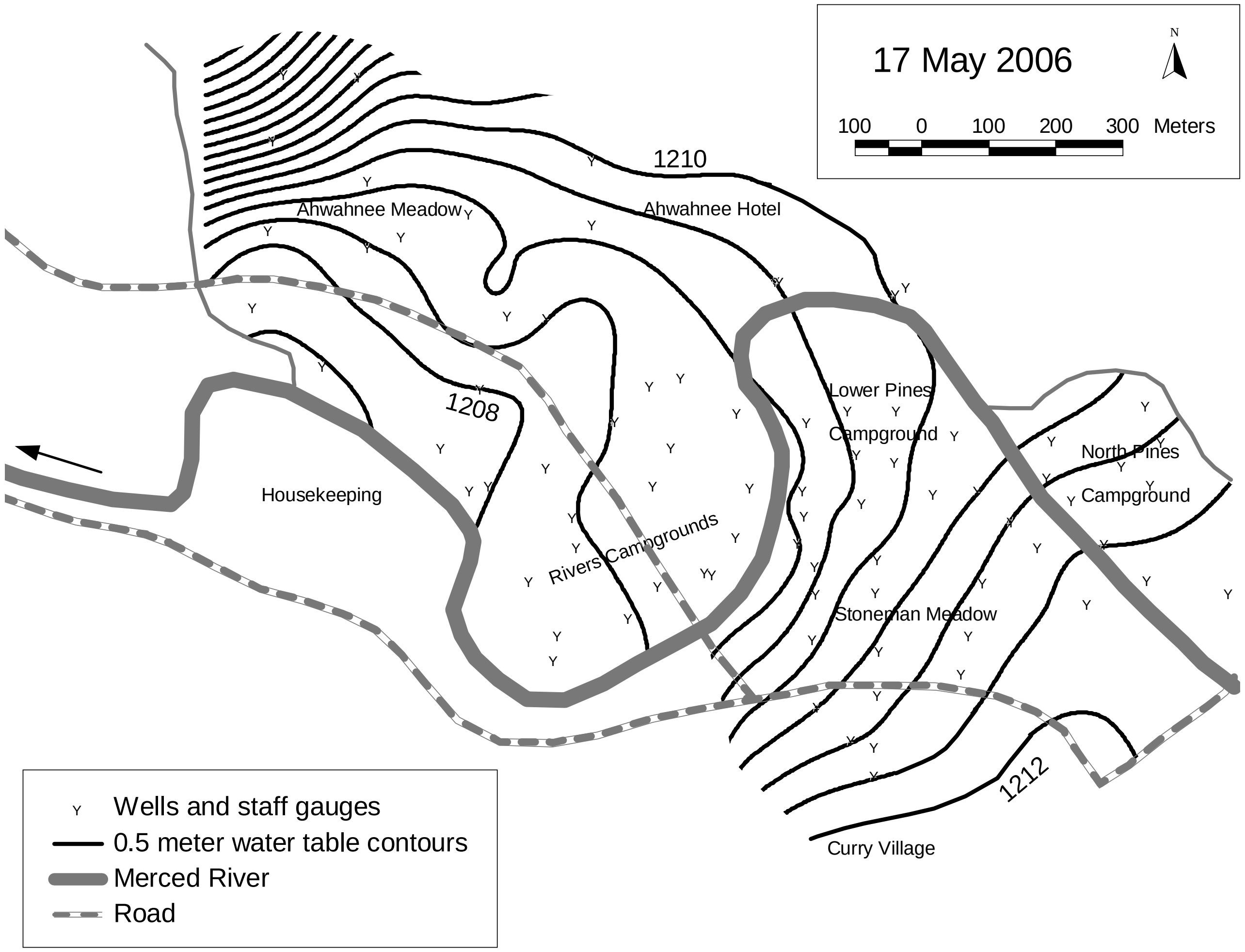

Figure 23. Water table elevation contour map for 22 June 2005. Contour interval is 0.5 m.

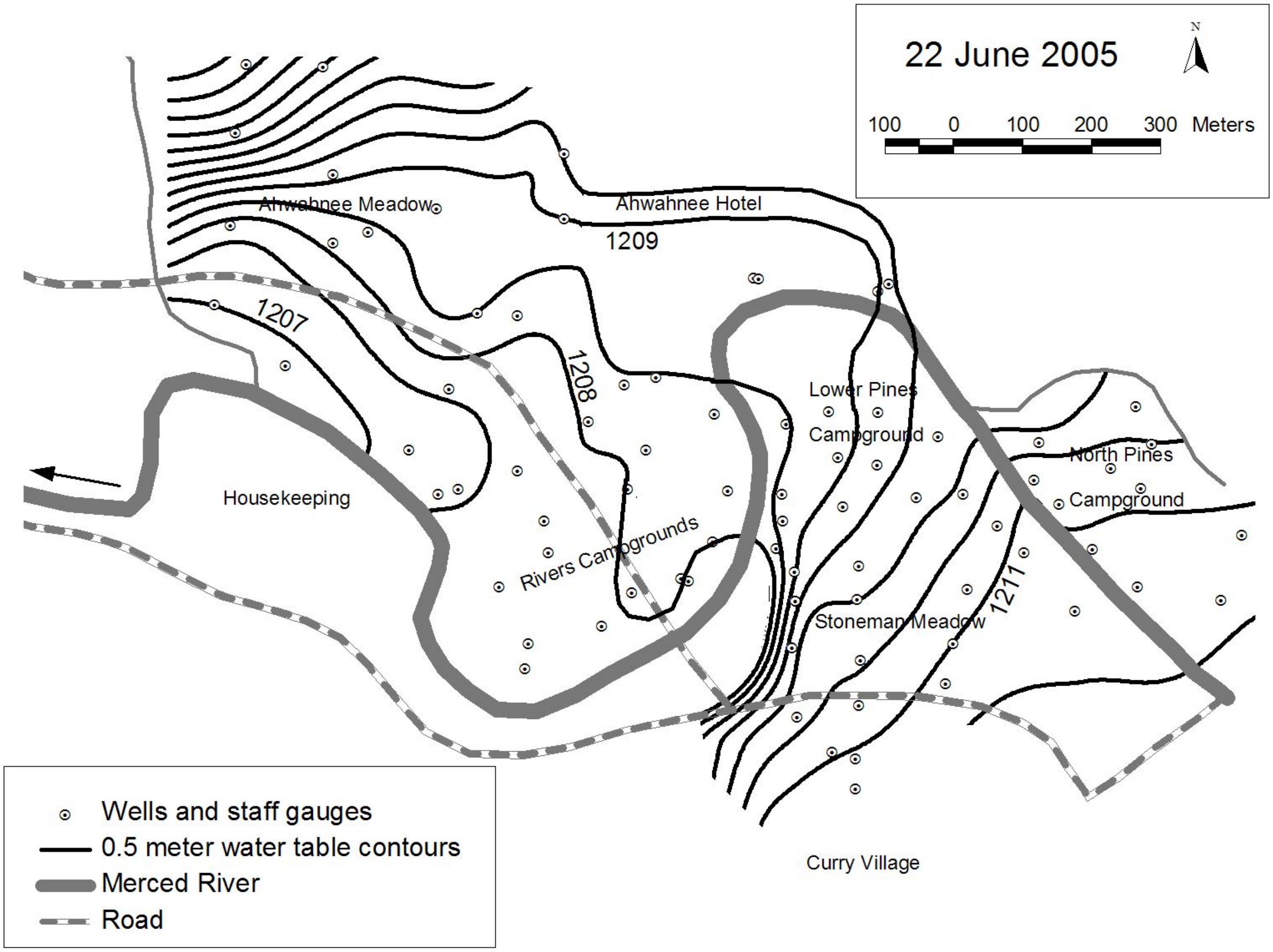

Figure 24. Water table elevation contour map for 19 July 2006. Contour interval is 0.5 m.

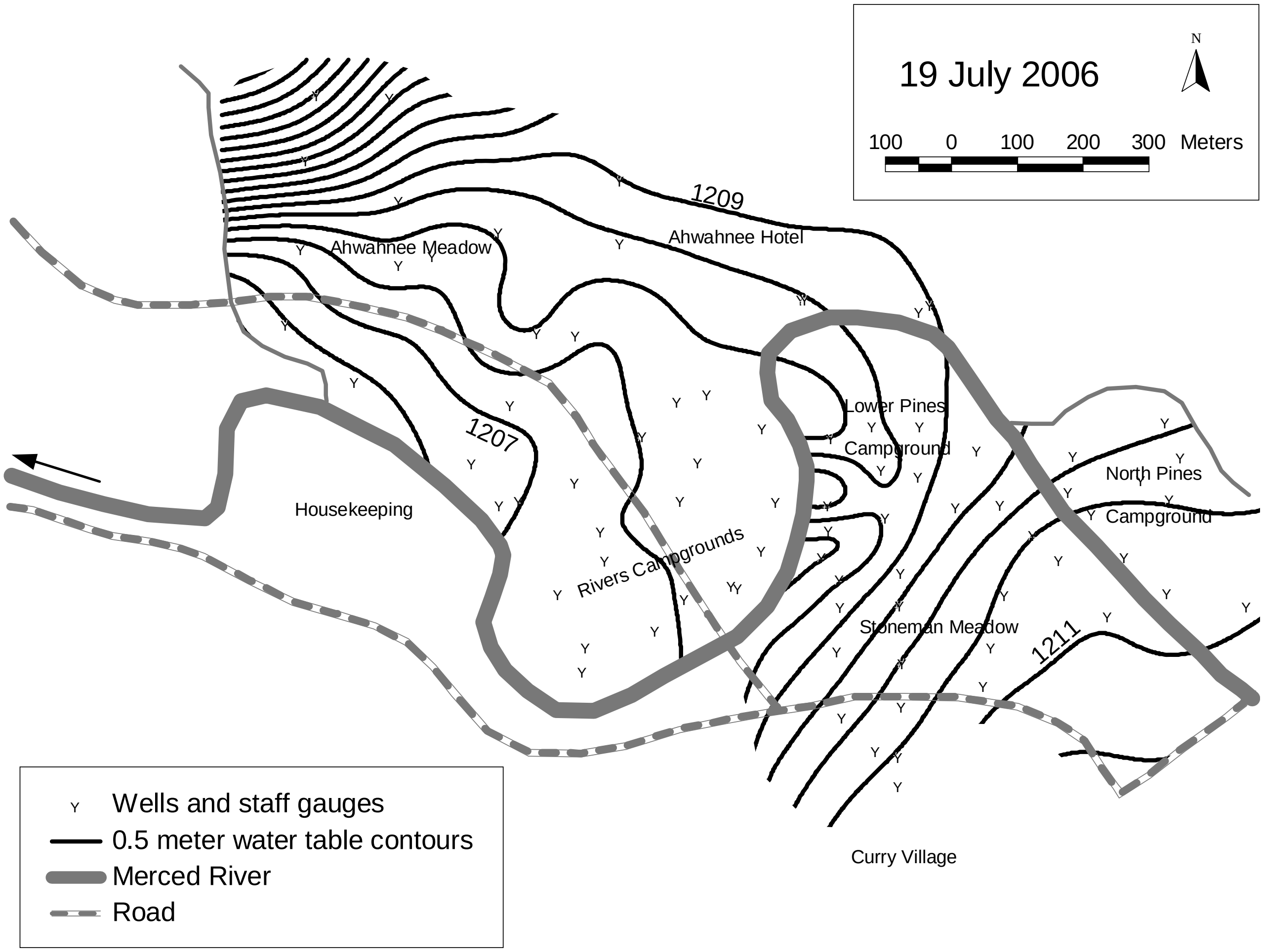

Figure 25. Water table elevation contour map for 16 August 2006. Contour interval is 0.5 m.

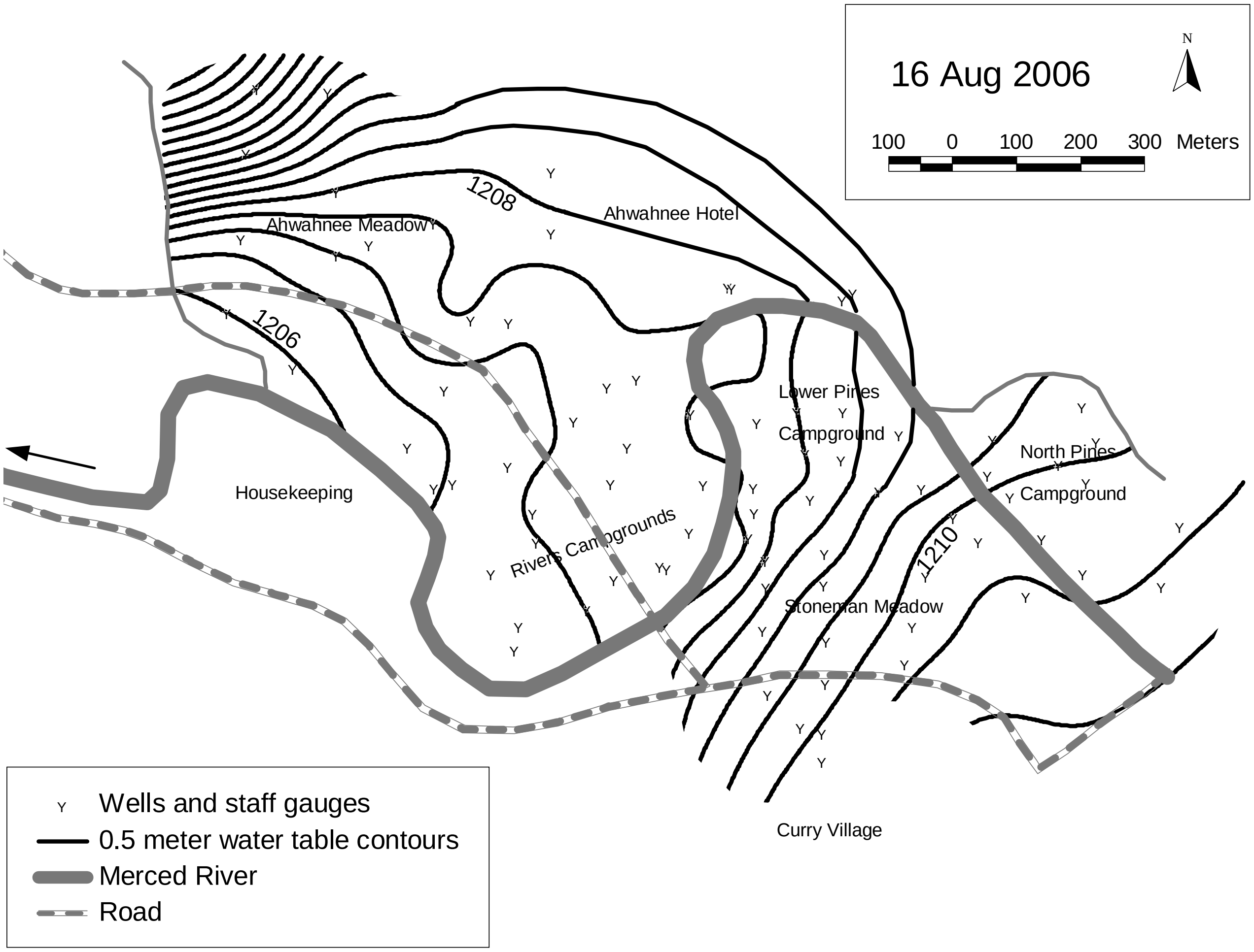

Figure 26. Three soil profiles in backhoe pits. A shows a very dark, organic rich soil (below dashed line) with some sandy layers above. B shows a dark surface horizon, a sandy buried soil, and a dark buried soil below the sand. C shows a cobble soil.

Figure 27. Examples of bright (A) and faint mottles (B) in study area soils.

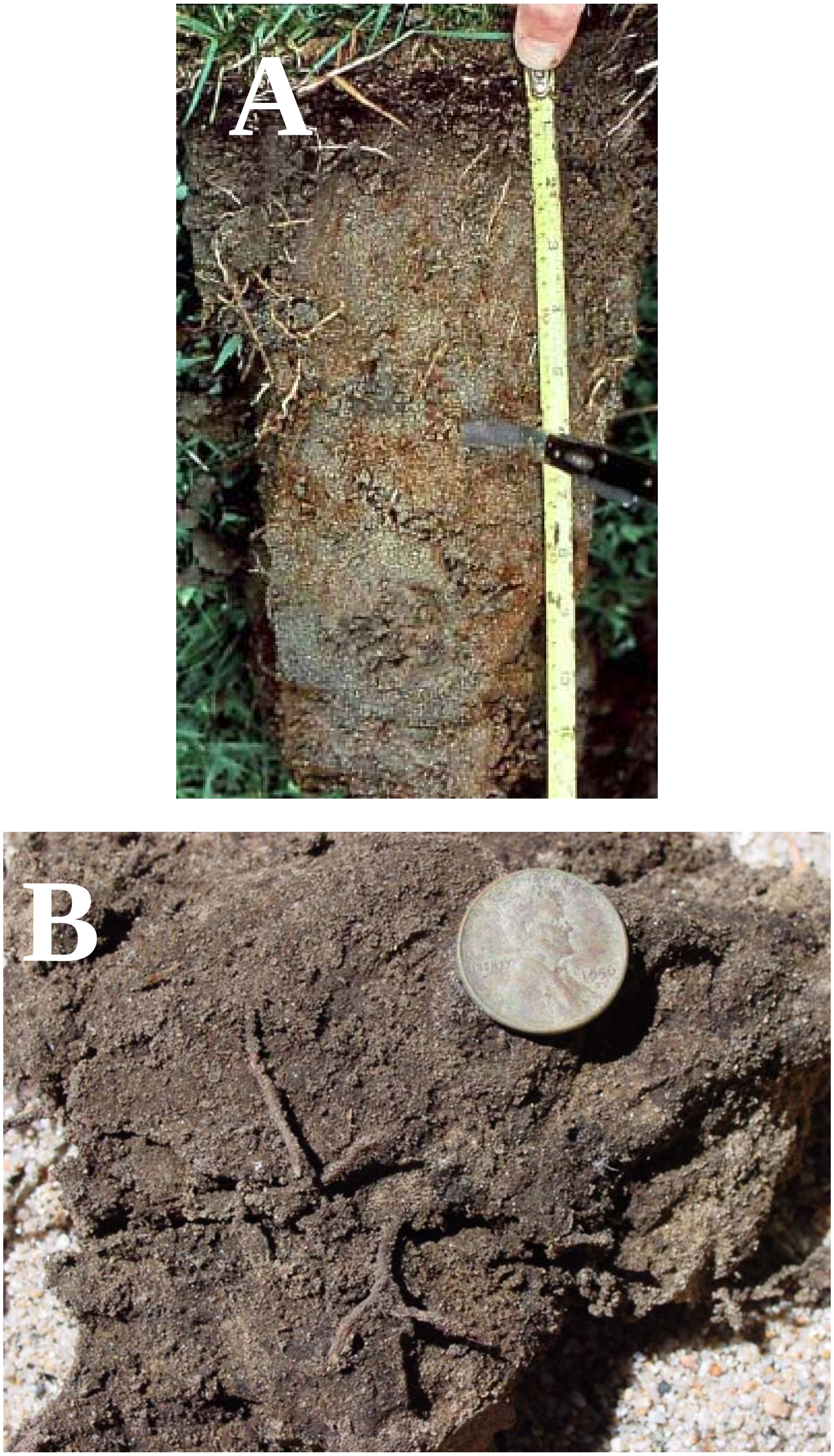

Figure 28. Depth to mottling and other hydric features in soils in the campground study area.

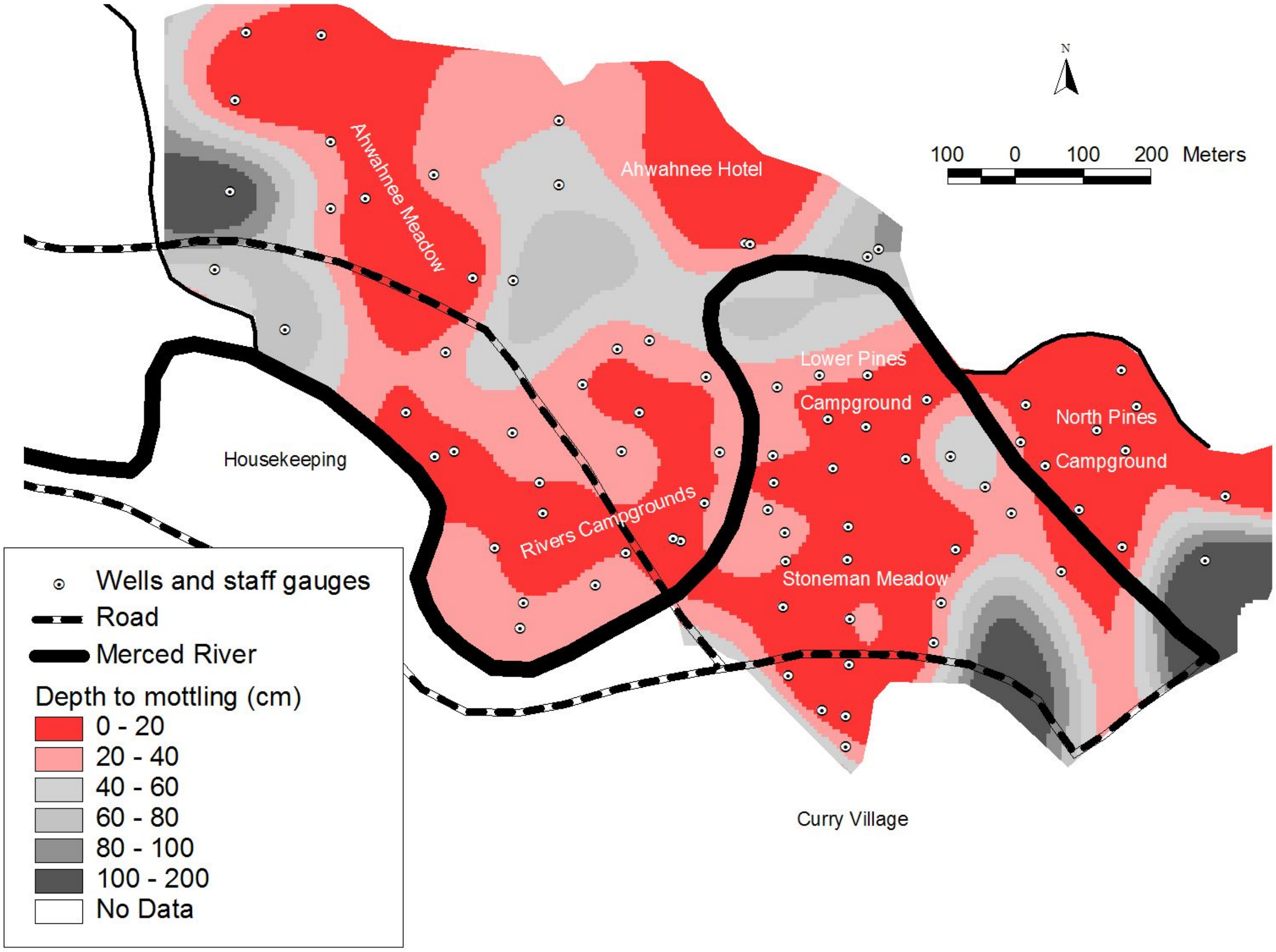

Figure 29. Percent organic matter in soils. A. Box plots showing mean ± 1se, plus extremes for reference areas and campgrounds. B. % OM for campground wells. Boundaries for %OM indicate the range of meadow, oak forest/meadow margins, pine and riparian areas. Sites with different lower case letters are statistically significantly different.

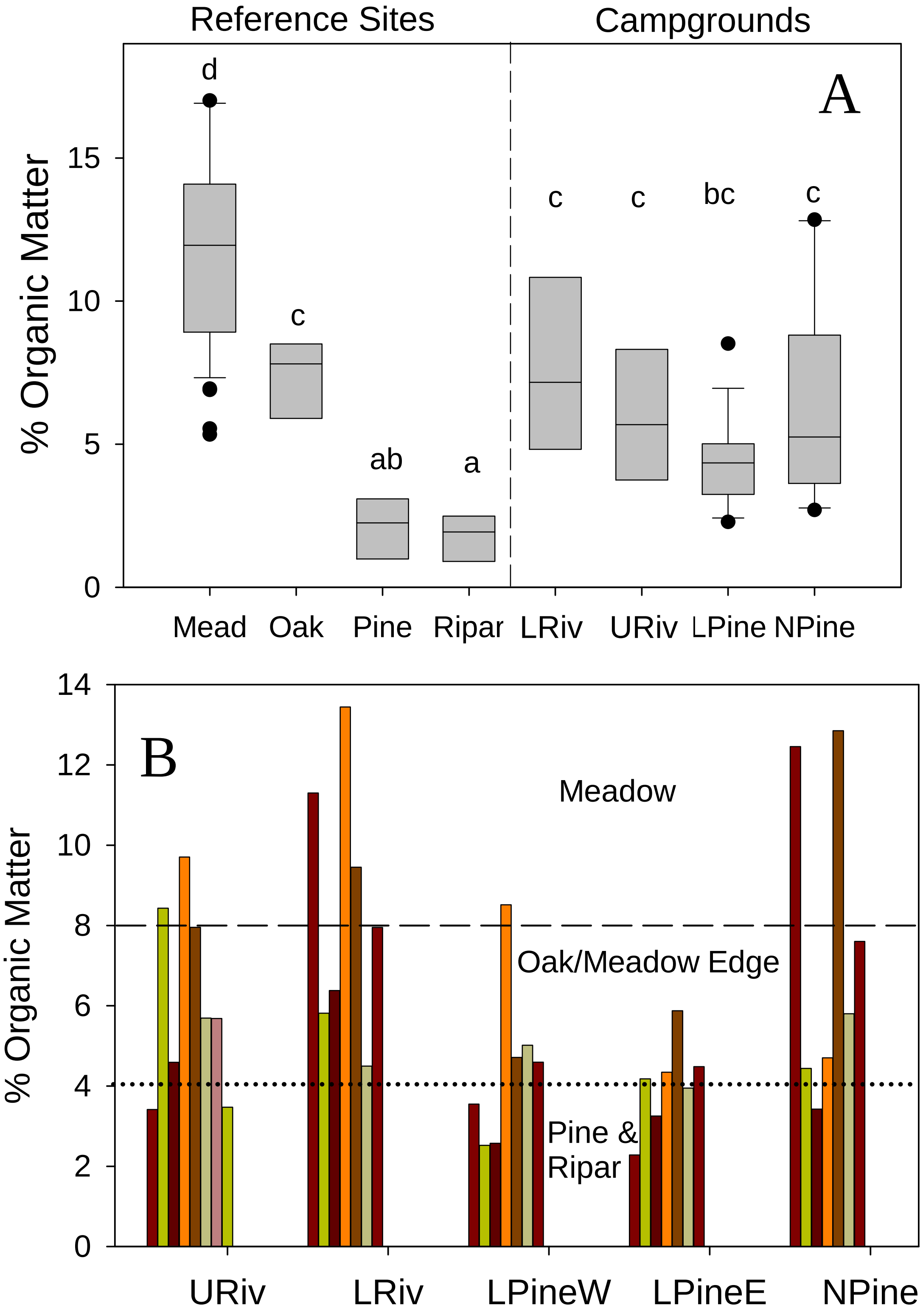

Figure 30. Percent organic matter in soils in the campground study area.

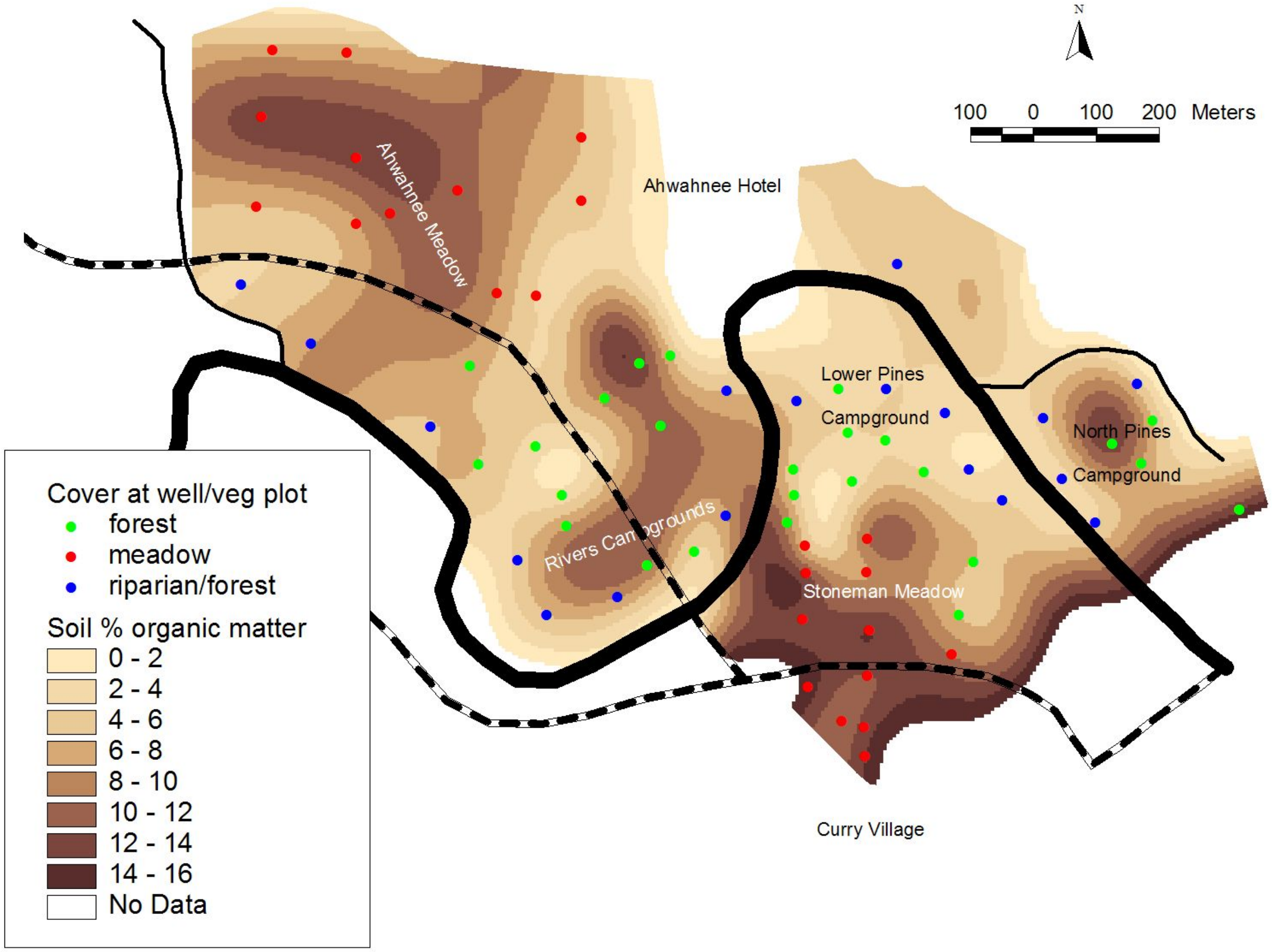

Figure 31. Locations for buried conifer logs aged using ^{14}C analysis.

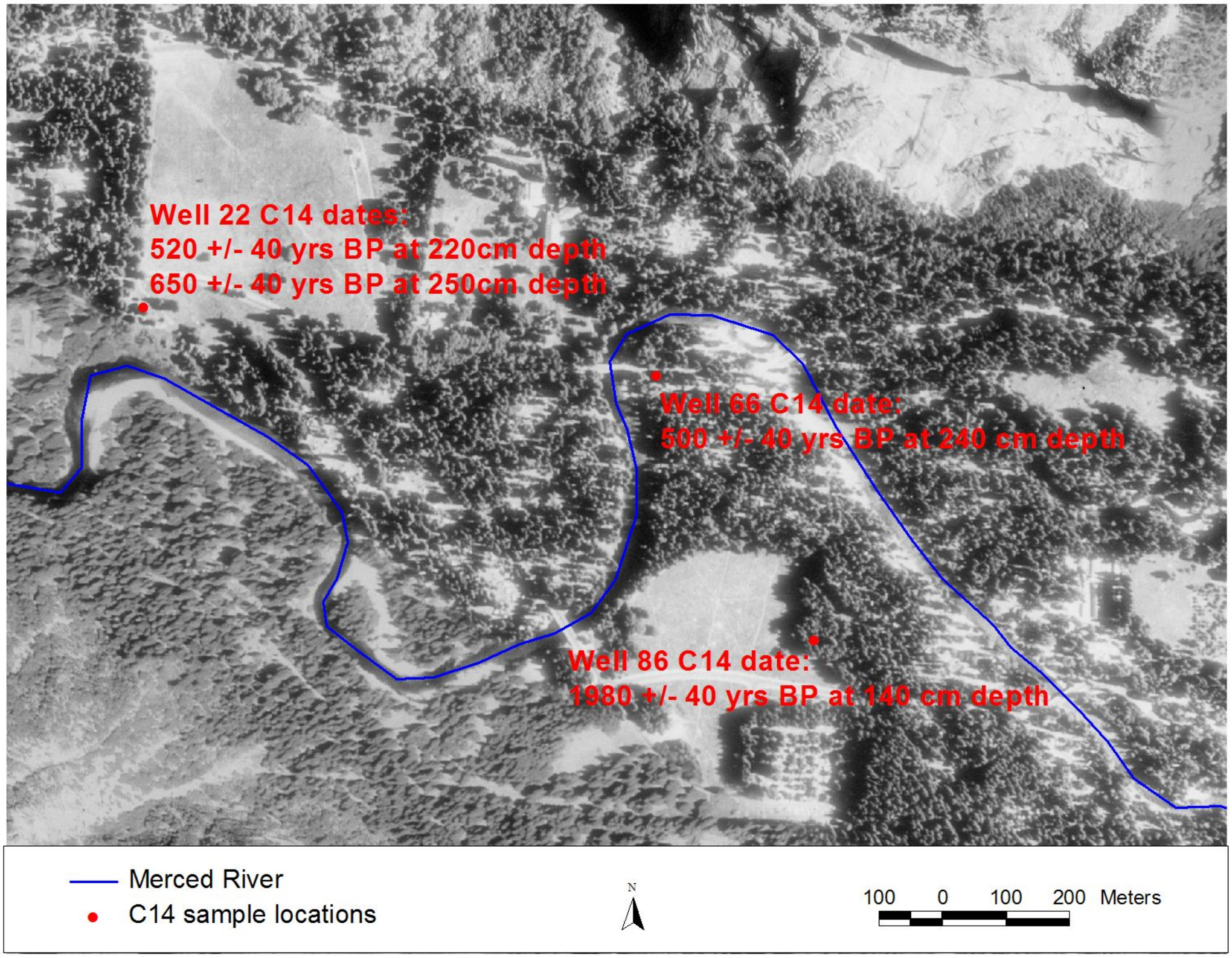

Figure 32. Number of conifer trees in 10 year age classes in the campground study area.

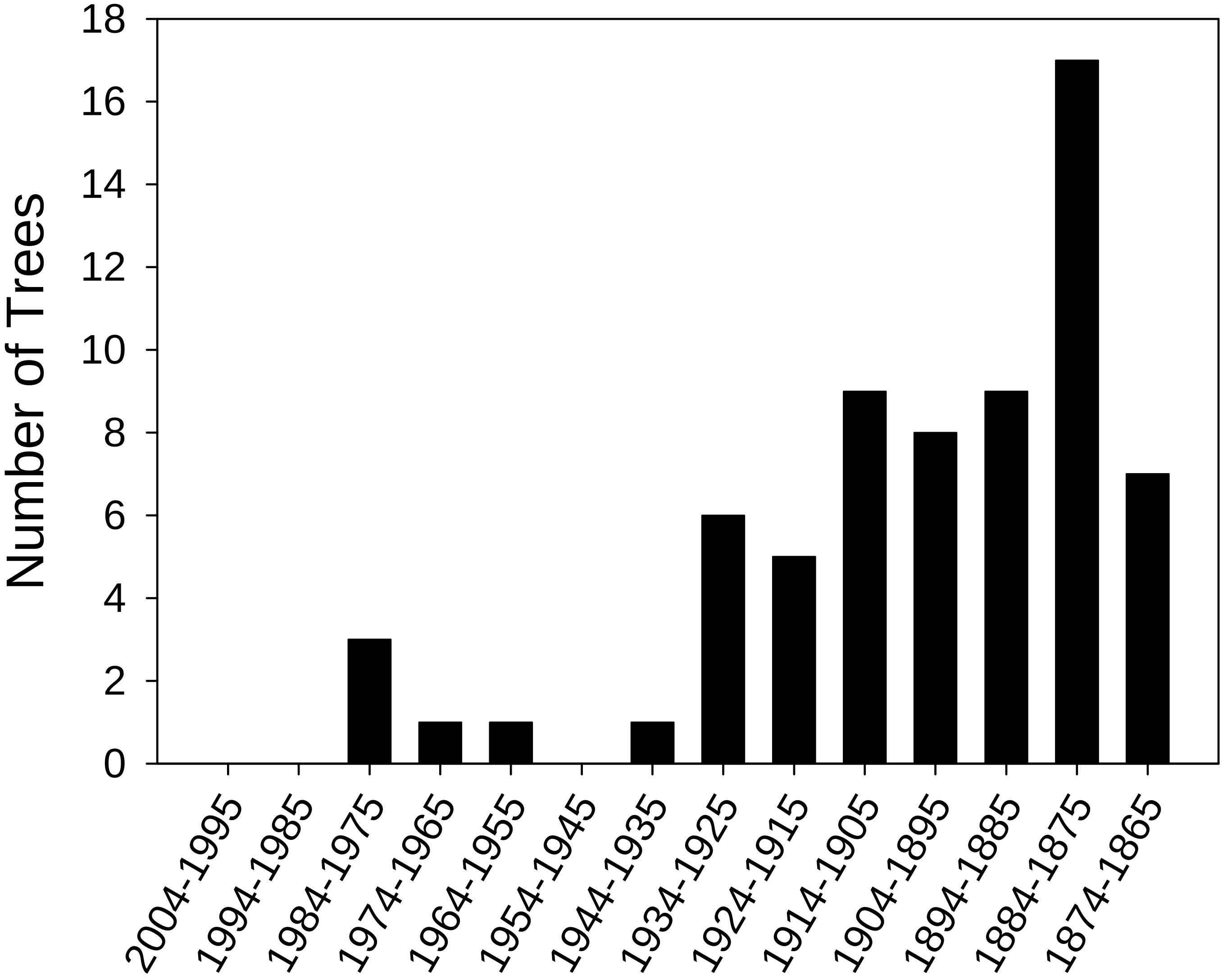

Figure 33. Distribution of *Quercus kelloggii* trees in River and Lower Pines Campgrounds.

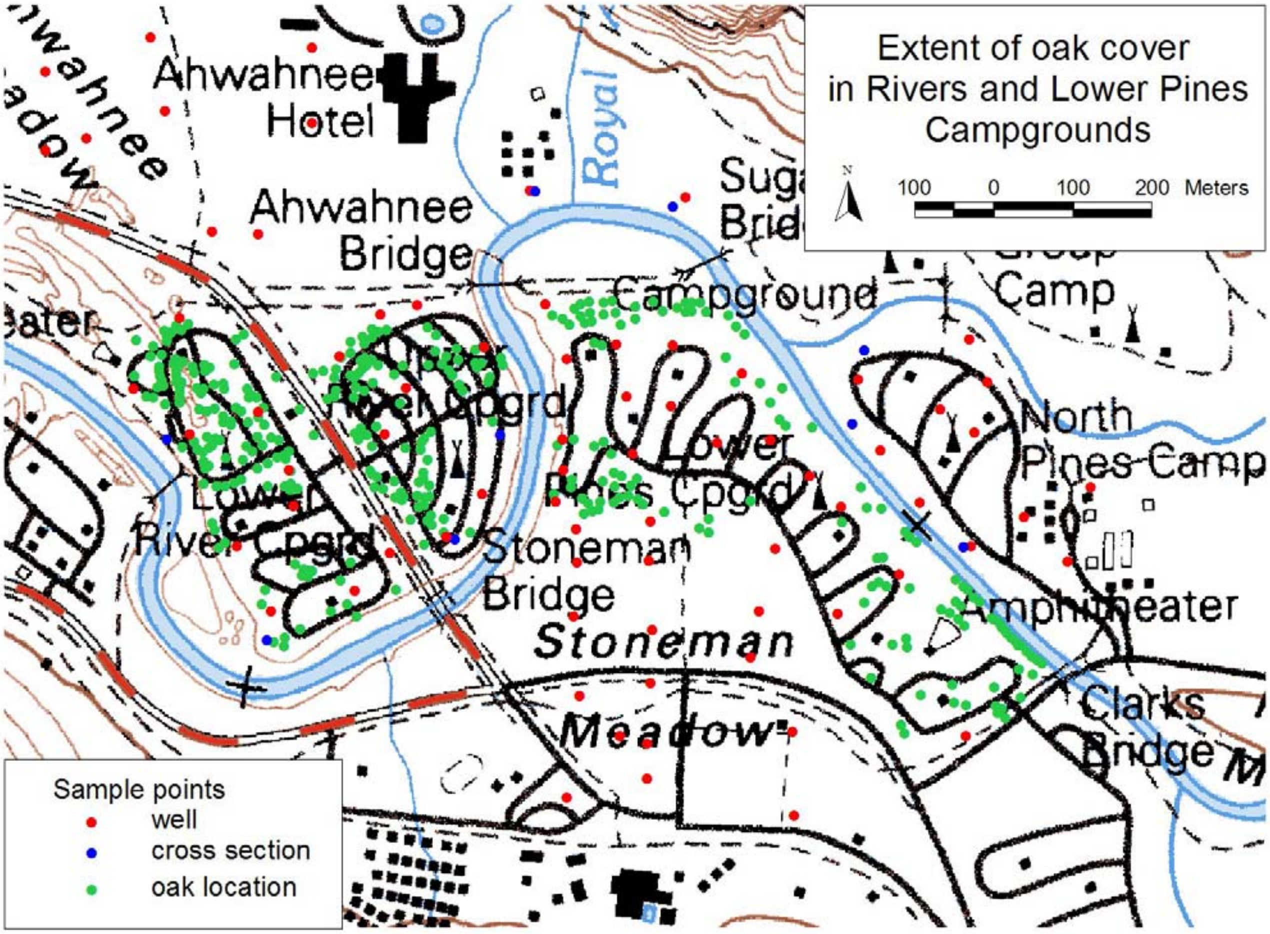

Figure 34. Indirect ordination, using detrended correspondence analysis (DCA) on all vegetation data in the study area. Axes are in standard deviation units (see text). Correlations of site scores with selected environmental variables are shown at top of figure. Ovals identify plots with similar vegetation composition and are grouped into conifer forests, riparian/wetland, oak forests, wet meadows, and very wet meadows.

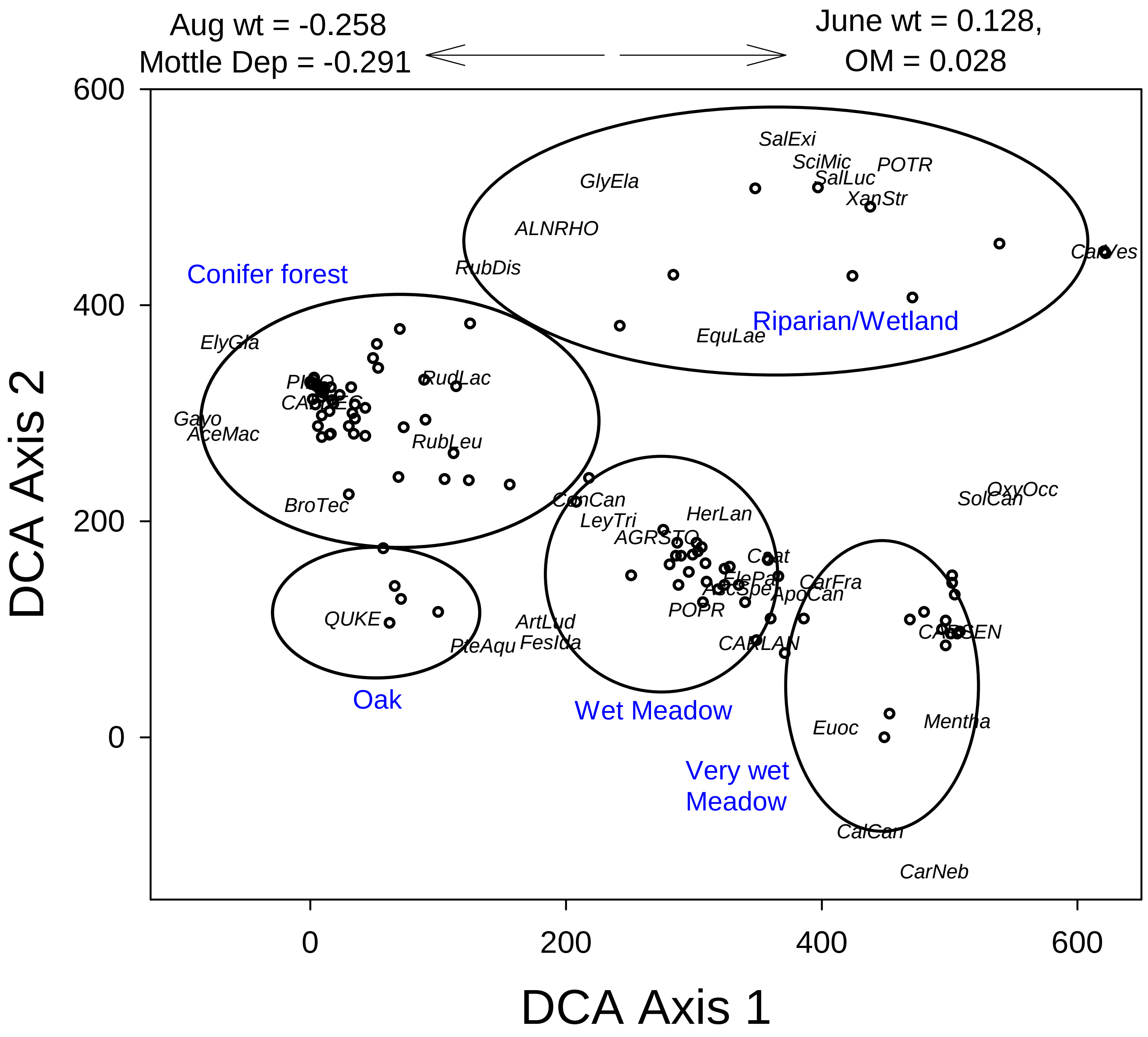

Figure 35. Typical wet meadow (A) (Ahwahnee), *Quercus kelloggii* forest (B), upland conifer forest (C), and riparian zone (D).

Figure 34 (cont.)

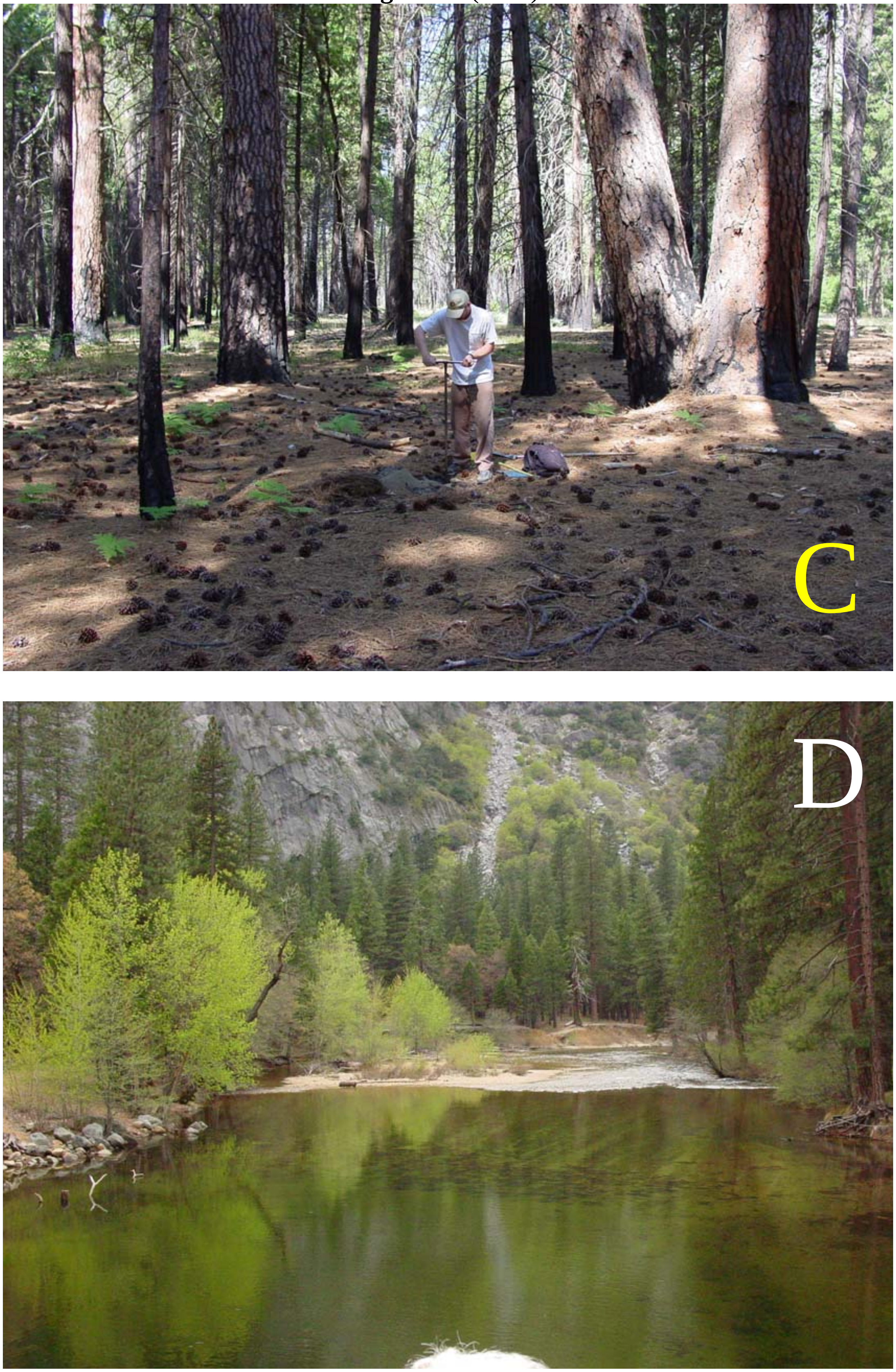

Figure 36. DCA output showing the soil organic matter (SOM) content for each plot. High is >8% SOM indicating soils that formed under wet meadow conditions, M is 4-8% organic matter, indicating soils that formed under oak forest and wet meadow margins, and D are soils with 0-4 % organic matter, and having formed in upland mixed conifer forest, riparian zone with new soils, or highly disturbed conditions. Ovals indicate the same communities illustrated in Figure 33.

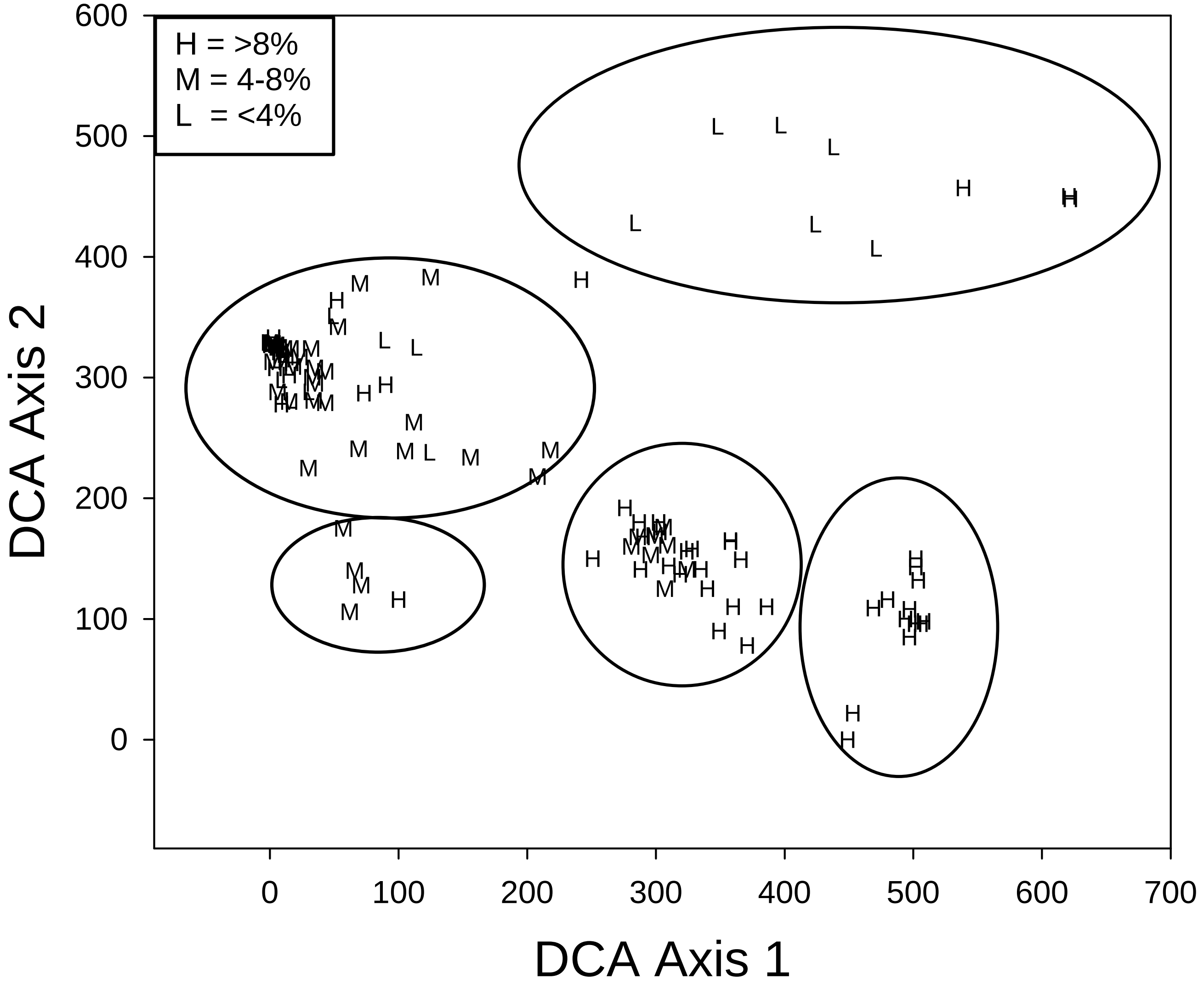

Figure 37. DCA output showing the soil depth at which hydric soil characteristics are evident for each plot. High is within the upper 20 cm of soil, M is 20-40 cm depth, and D is > 40 cm depth. These depths reflect sites that have had or still have a predominantly wetland hydrologic regime with water tables near the soil surface for extended periods during the summer of many years. Ovals indicate the same communities illustrated in Figure 33.

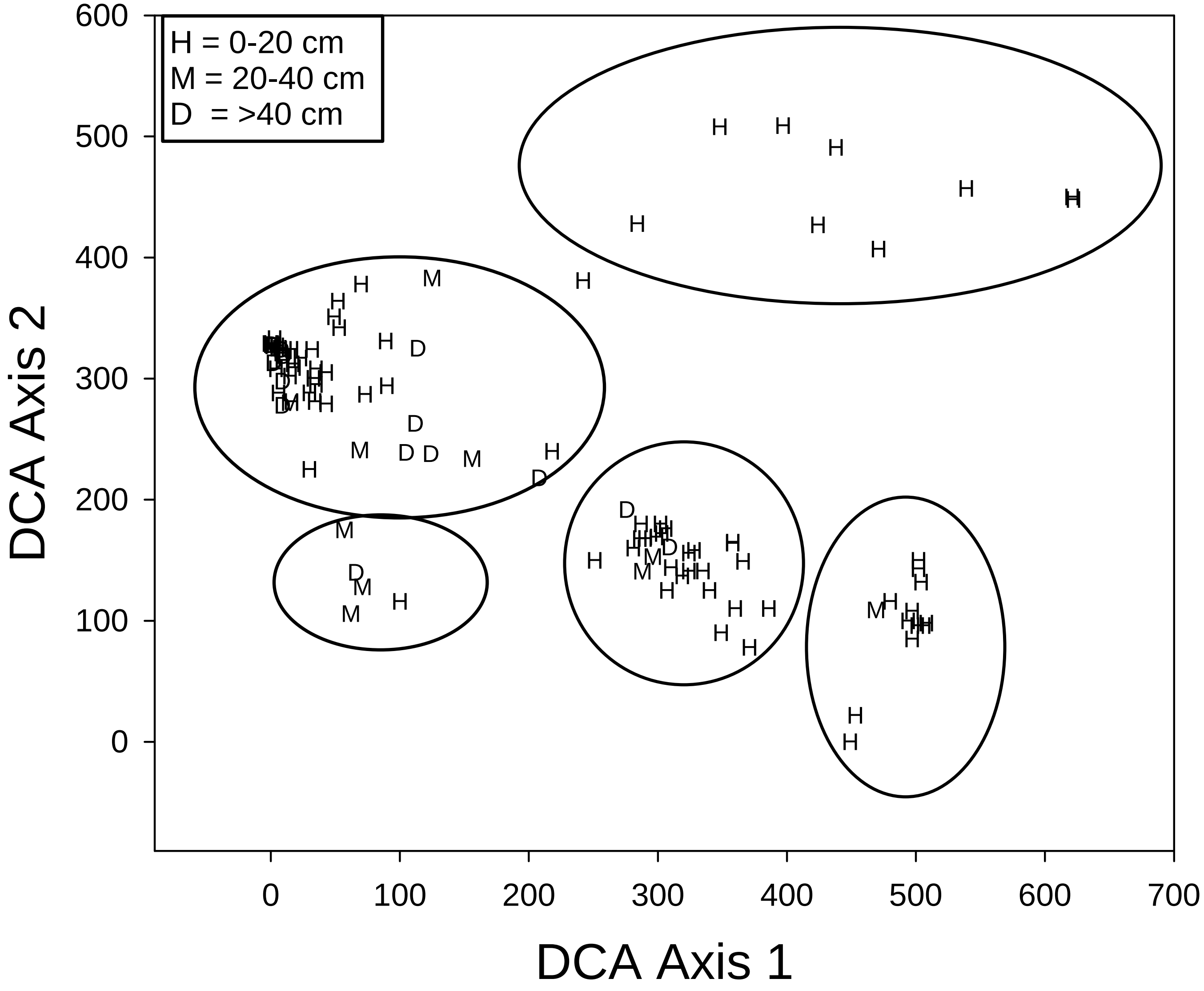

Figure 38. Portions of the study area that were connected to the Merced riparian flow system during 2005 and 2006 occur inside the dashed green lines. The area within the dotted green lines likely is supported largely by stream recharged ground water. Those supported primarily or entirely by ground water from the valley walls are north or south of the green lines. The main direction of ground water flow is shown with blue lines for the three zones.

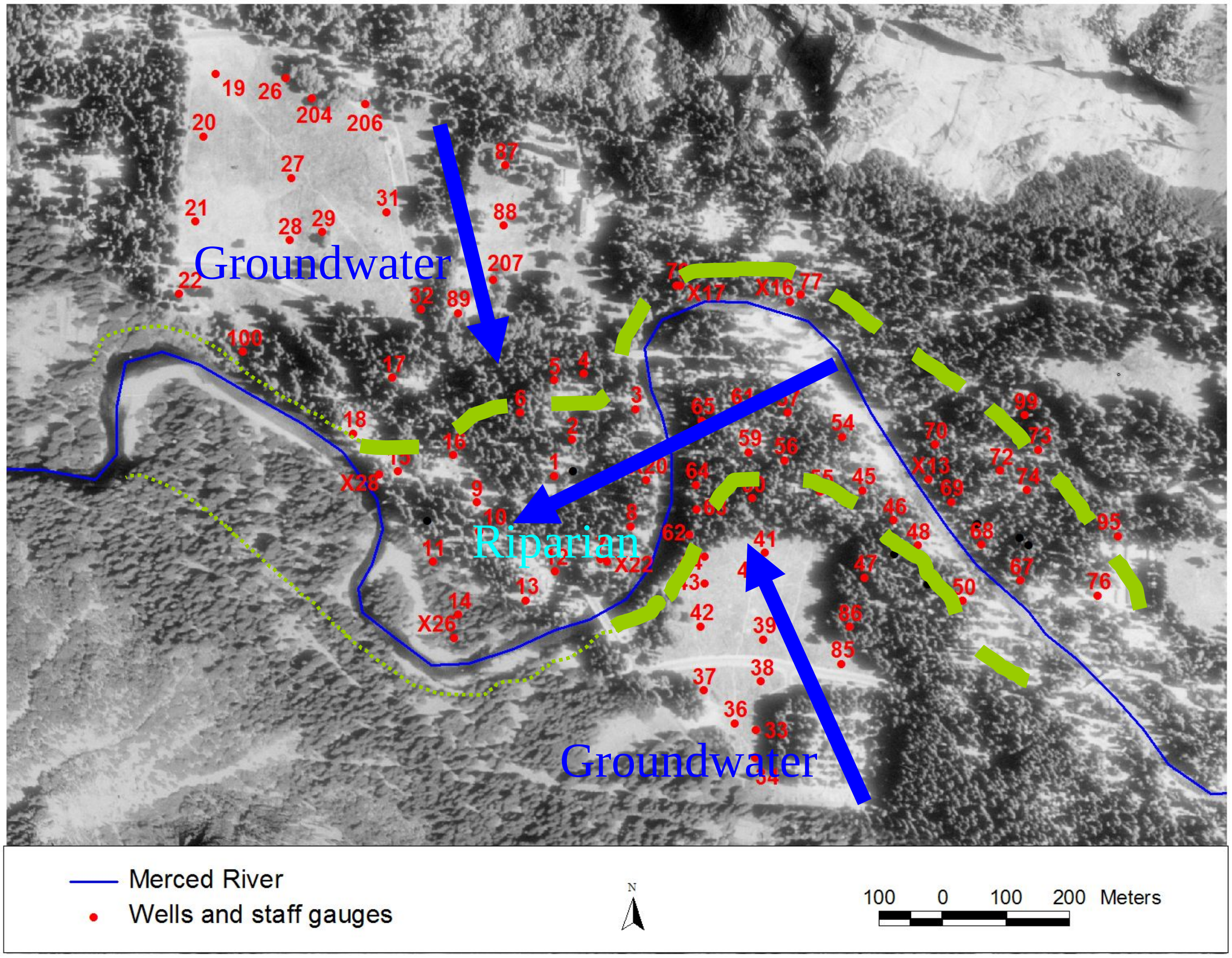

Figure 39. Potential natural vegetation of the study area. Area with diagonal lines can support a riparian/meadow complex, while the dotted areas could support a wet meadow/*Quercus Kelloggii* mosaic.

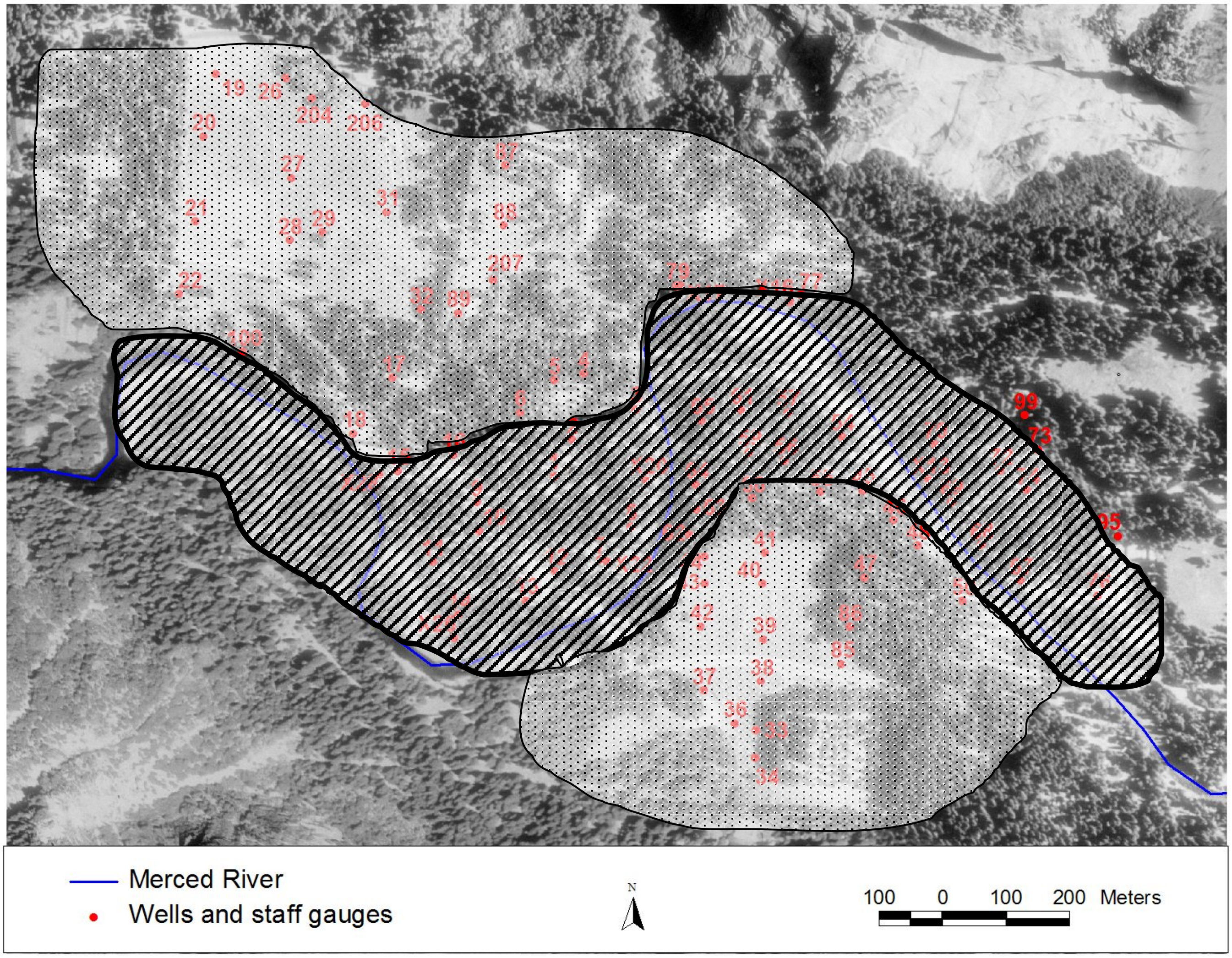

Figure 40. Typical summer water table depths during 2005 and 2006 for *Carex lanuginosa* (Car lan), *Poa pratensis* (Poa prat), *Agrostis stolonifera* (Agr stol), *Carex senta* (Car senta), and *Quercus kelloggii* (Que kel) dominated stands in the study area.

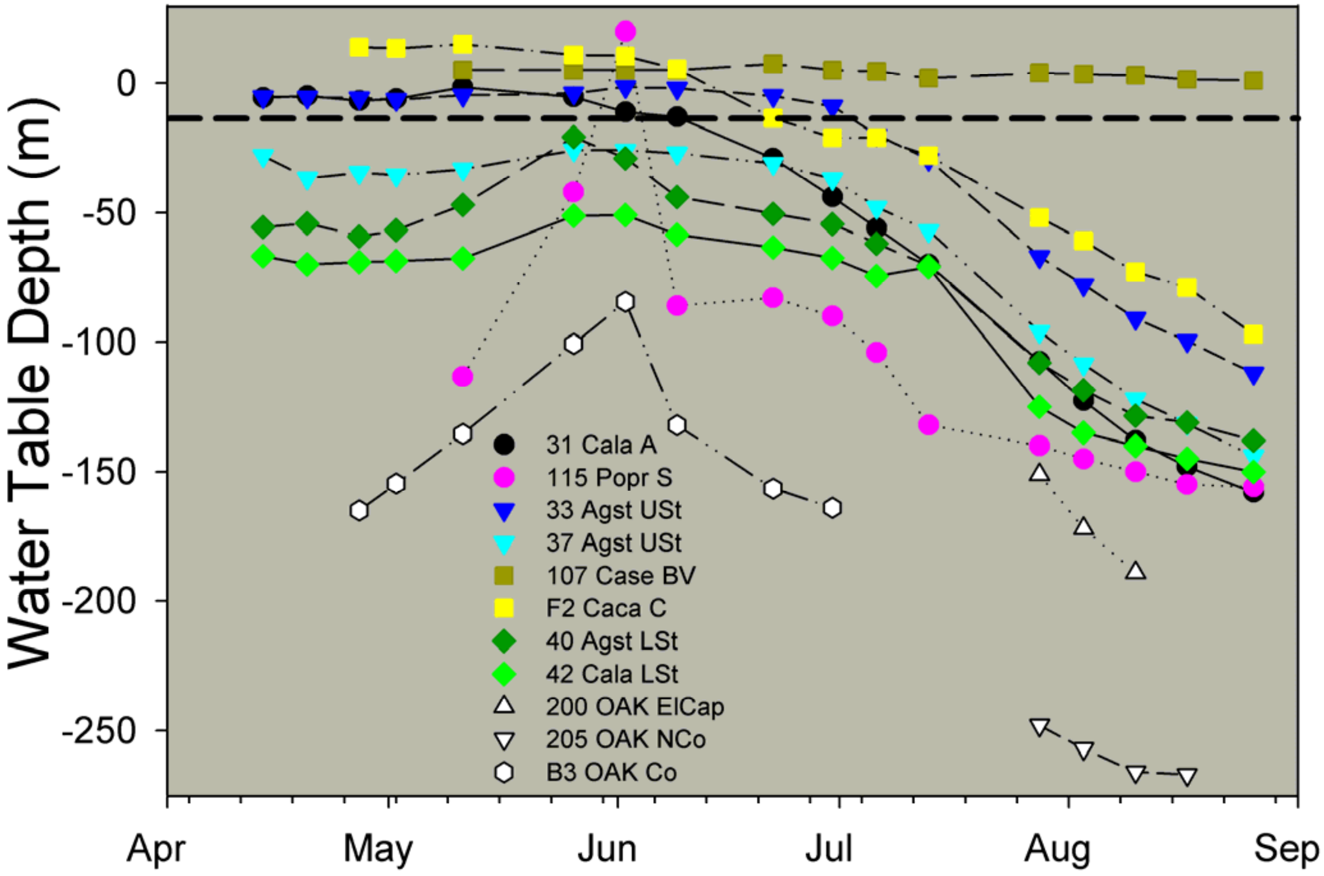

Figure 41. Photo of Stoneman Meadow from Glacier Point, with arrows identifying surface features that appear to drain ground water from the meadow.

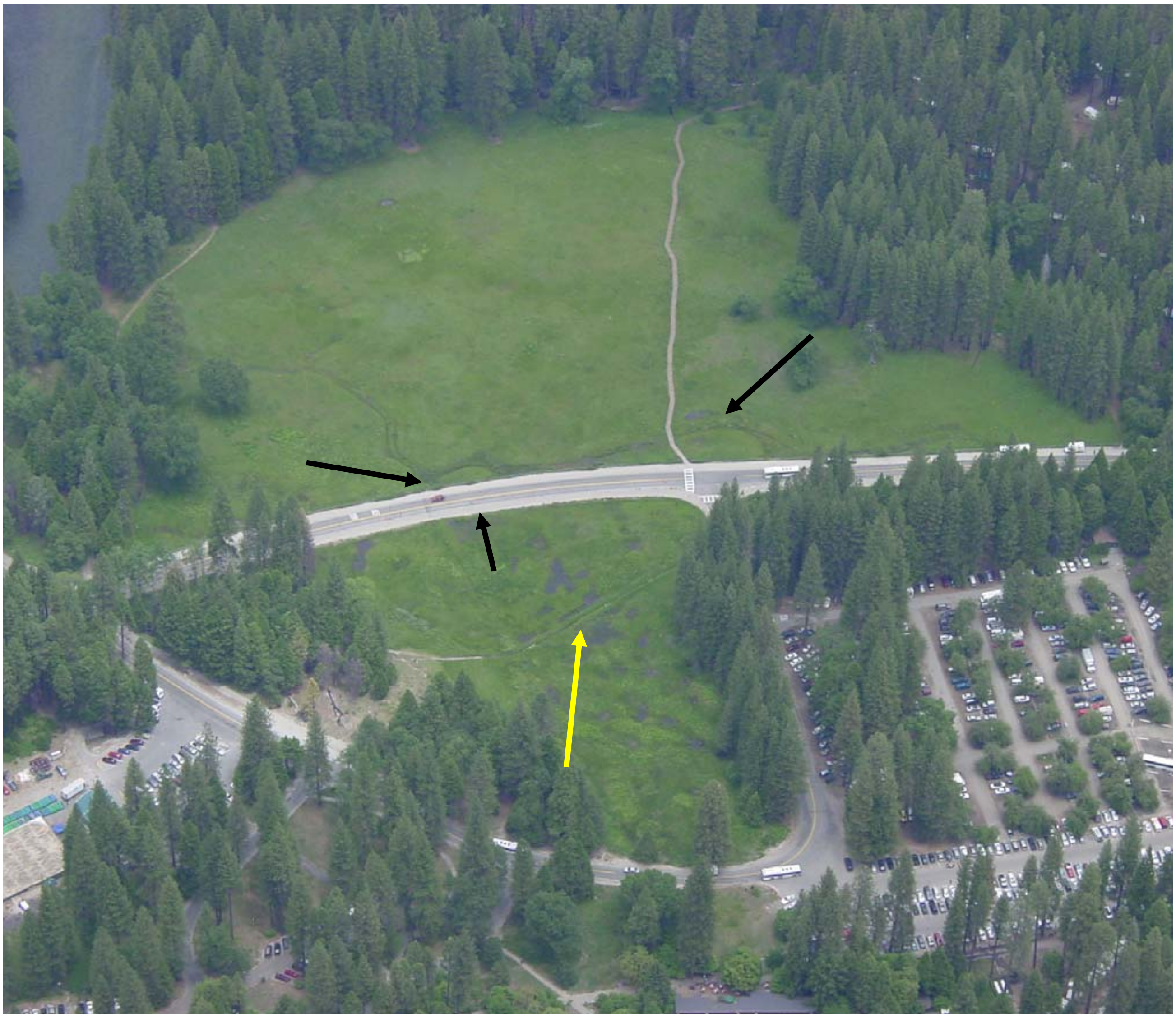

Figure 42. Photo of Ahwahnee Meadow from Glacier Point with arrows showing the location of possible drains, ditches and fill.

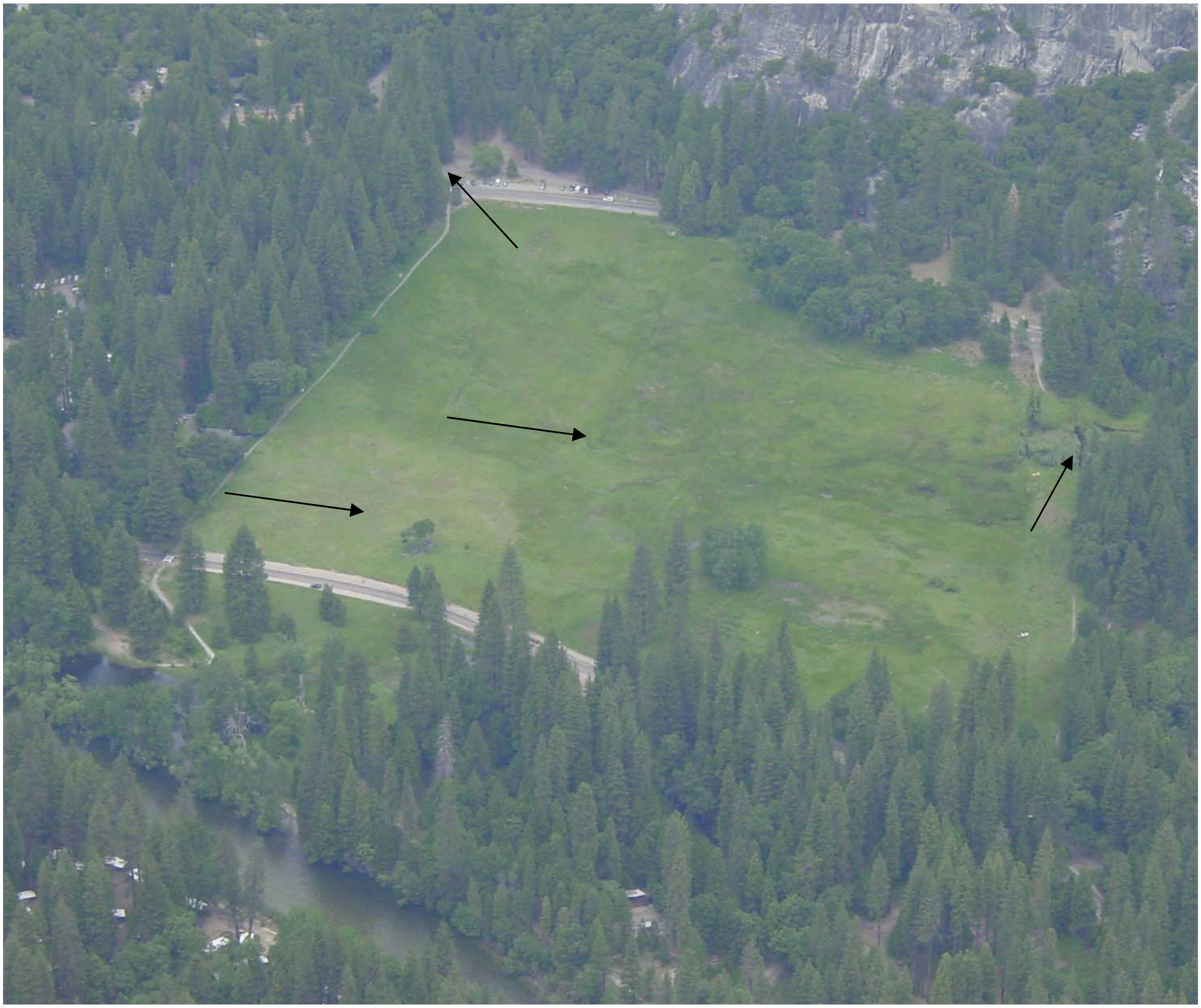

Figure 43. Air photo of Ahwahnee Meadow showing the location of ditches, fill and other impacts.