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TASK ORDER
TASK 2: Monitoring and evaluation of 200 acres of restored riparian habitat
CalFed Contract 97-NO3

Scope of Work for
Subtask 3: Measure key connections between the river and floodplain

Final Project Report

Prepared for The Nature Conservancy, Sacramento River Project

by

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Project Summary

In this study, several biological and physical ecosystem processes were monitored to investigate interactions between the Sacramento River and its bordering riparian zone/floodplain. The purposes of this monitoring were to: (1) evaluate the extent to which riparian forest restoration success can be measured in terms of functional ecosystem processes; (2) identify specific measures of ecosystem function that can effectively document the ecosystem changes that occur when a site is converted from an agricultural crop to a native forest; and (3) evaluate practical water quality improvement benefits that coincide with restoration progress. Monitoring was performed at the River Vista VII Restoration Site (Site VII) planted in 1999, River Vista II Restoration Site (Site II) planted in 1993-94, and at the adjacent Wildlife Conservation Board (WCB) property which contains a mature (approximately 40 year-old) riparian forest. Efforts to quantify changes in selected nutrient cycling processes during early ecosystem restoration focused changes in nitrogen (N) mineralization. The results of monthly N-mineralization sampling showed no site differences between the three sites. Other, simpler ecosystem metrics such as soil carbon or soil bulk density appear to be more informative as far as ecosystem indicators of riparian forest restoration success. Development of soil profiles during riparian forest succession and/or restoration is another ecosystem process that occurs over a time span of decades or more. Soils descriptions from this study documented the current early stage of soil pedogenesis at Site VII. Plant litterfall provides the major input of carbon in nutrient cycling processes. Plant litterfall was greatest at the WCB site, intermediate at Site II, and lowest at Site VII, the "youngest" site. Soil carbon in shallow soil layers showed a similar trend, and showed seasonal variation as well with maximum carbon concentrations occurring in the spring and lower concentrations during the other three seasons. The effect of early ecosystem restoration on shallow groundwater quality was monitored through a series of monitoring well transects extending away from the river. Unfortunately, the last agricultural activity that would have added nutrients to shallow groundwater via fertilization ended in 1986. Thus, it is not feasible to quantify the direct improvement in groundwater quality conditions as a result of restoration compared with the prior land use. Overall, nitrate concentrations were the highest of the nitrogen and phosphorus constituents measured (NO3, N02, TKN, Total P and ortho-P), but were generally less than 10 mg/L in Sites VII and II. Nutrient concentrations in the WCB forest were usually much lower, at or below approximately 0.5 mg/L.

Project Overview

The final report for this project covers three specific tasks guided by the Project Objectives described below. We have chosen to combine individual task deliverables into a common report so as to facilitate the synthesis of whole ecosystem function. We believe that this approach better relates the individual tasks to each other.

Rationale

Interactions between the river and the bordering riparian zone/floodplain are both continuous and episodic. The primary continuous connection between the river channel and the floodplain is through alluvial groundwater. The alluvial aquifer is a direct connection between the floodplain and the river channel for the exchange of dissolved nutrients and toxic compounds. The primary episodic connection is through flooding and flood inputs. Floodplain inputs of coarse particulate matter and nutrients improve instream primary productivity. The monitoring activities described below will investigate the evolution of soil nutrient (nitrogen and carbon) cycles within the riparian zone. Fully functioning riparian ecosystems have been repeatedly shown to be capable of improving groundwater and stream quality by removing undesirable constituents such as nutrients and pesticides. Ongoing and future groundwater monitoring will provide useful insights on the timing of groundwater quality improvement relative to nutrient cycling evolution and ecosystem recovery.

In this project we studied a few selected ecosystem measures in an analysis of temporal change in riparian forest ecosystem function. Our approach was that of a chronosequence, taking "snapshots" in time from sites of different successional ages and projecting these changes onto a temporal sequence. In time, repeated measurements of the same sites will afford a more precise characterization of functional change. The ecosystem measures studied here were chosen for reasons of practicality, functionality, and presumed relevance to riparian ecosystems. Ecosystem function is studied primarily from two complementary approaches: carbon flux (usually through biomass measurements) and water/nutrient flux. This study uses elements of both approaches. We studied soils and soil carbon because of their central role in nutrient and water retention, which directly affects site productivity (Aber and Melillo 2001). Groundwater represents the direct connection between the river and the floodplain. Nitrogen is usually the most limiting nutrient in terrestrial ecosystems, and the rate at which complex organic forms (e.g. in dead biomass such as leaves) are broken down by microorganisms into simple forms such as ammonium and nitrate available to plants (i.e. the N-mineralization rate) is often regarded as the critical step in the nitrogen cycle. For this reason we studied N-mineralization rates.

Our overall questions were: (1) can the success of riparian forest restoration be measured in terms of functional ecosystem processes? (2) are there measures of ecosystem function that can document effectively the ecosystem changes that occur when a site is converted from an agricultural crop to a native forest? and (3) are there practical water quality improvement benefits that coincide with restoration progress?

Project Objectives

1. Quantify changes in selected nutrient cycling processes during early ecosystem restoration.
2. Sample riparian soils to document soil profile development during ecosystem restoration.
3. Install a monitoring well network to detect changes in groundwater quality.

Site Background

The River Vista VII Restoration Site (Site VII) consists of approximately 200 acres within the larger River Vista Unit of the Sacramento River National Wildlife Refuge (SRNWR) as shown on Figure 1. The irregularly shaped Site VII has a narrow border on the eastern bank of the Sacramento River at approximately river mile 215 and just south of Woodson Bridge State Park. Prior to recent restoration efforts, Site VII was farmed as an almond orchard from the mid-1960s until 1986 (TNC, 1993). Following acquisition by The Nature Conservancy in 1986, Site VII was left fallow with stumps left in place.

Restoration of the Site VII was completed in 1999. Three units were planted: a large 175 acre unit of mixed riparian forest, a 15 acre patch of willow shrubs and a 10 acre elderberry savannah. The 175-acre site of mixed riparian forest is studied here. This site was planted at a density of 260 plants/acre and consisted of: 22% valley oak, 20% western sycamore, 16% cottonwood, 10% each of arroyo willow, narrow-leaved willow and Goodding’s willow, 5% coyote bush, 3% blue elderberry, and 4% box elder (TNC, 1999).

The River Vista II Restoration Site (Site II) consists of approximately 100 acres within the larger River Vista Unit of the Sacramento River National Wildlife Refuge (SRNWR) as shown on Figure 1. As with Site VII described above, Site II was left in fallow condition from

1986 until restoration was initiated in 1993. Restoration of Site II was completed in 1994. Inter-cropping was performed, mixing the restoration plantings with an existing alfalfa rotation (TNC, 1993). Site II was planted at a density of approximately 260 plants per acre, including: valley oak, cottonwood, arroyo willow, California sycamore, box elder, elderberry, and California rose.

The Wildlife Conservation Board (WCB) property is located immediately to the south of River Vista Sites I and II. We estimated the age of this forest at approximately 40 years. It is mapped by the Geographical Information Center at California State University, Chico, as mixed forest with extensive areas of gravel bars and herbland. We used the mixed forest portion of this remnant natural vegetation site as our reference site or "target" site. The overstory of this remnant forest is composed mainly of western sycamore, Fremont cottonwood, California black walnut and some valley oak. The limited understory consists of box elder, pipevine, wild grape, blue elderberry, narrow-leaved willow and some coyote brush. Although a naturally occurring forest, the presence of black walnut in the overstory makes this site somewhat problematic as a reference site. The Nature Conservancy does not plant this species in restoration sites because it is not considered to be naturally occurring in this area.

Study sites for this project at the River Vista Unit of the Sacramento River National Wildlife Refuge complex were selected based on proximity to one another and their relative ages: young restoration (2 years old, planted in 1999 – Site VII), old restoration (8 years old, planted in 1994 – Site II), and remnant riparian (>35 years old – Site WCB).

Subtask 3.1a Nutrient Cycling: Soil Nitrogen Mineralization Rates

Objective 1 of this project was to: Quantify changes in selected nutrient cycling processes during early ecosystem restoration. Nitrogen is nearly always the most limiting nutrient in terrestrial ecosystems (Aber and Mellilo 2001), thus the rate at which elemental nitrogen is recycled (mineralized) in the soil is of fundamental importance.

Background

A soil's capacity to transform organic nitrogen in soil organic matter to inorganic nitrogen—its nitrogen mineralization potential—is often used as an index of the nitrogen available to plants in terrestrial ecosystems (Robertson et al. 1999). Essentially, N-mineralization is the rate at which nitrogen is replenished in the soil nutrient pool. It is perhaps the most common and best means available to assess nitrogen fertility (Robertson et al. 1999). N-mineralization is influenced by many factors such as type of material being decomposed, climate, microbial activity, soil, etc. Moisture and temperature conditions strongly affect decomposition and mineralization rates (Waring and Running 1998). The goal of this phase of the project is to examine nitrogen mineralization rates within the riparian corridor of the Sacramento River and to examine potential differences in these rates through time resulting from habitat restoration efforts. This corresponds with the first project objective, which was to: Quantify changes in selected nutrient cycling processes during early ecosystem restoration.

Methods

Two methods were used to determine rates of N-mineralization in riparian soils, following the methods described in Robertson et al. 1999 (this reference to be consulted for all methodology described below except where noted). The first method used field incubations of soil cores; the second used laboratory incubations of soil samples at constant temperature and moisture. Data were collected monthly at five locations within each site (Figure 2) beginning in December 2000 and continuing until December 2001. At each site a central sample point was established and four additional sample points were paced off 75 m to the north, south, east, and west of the central point.

Black plastic cylinders 24 cm long and 5 cm inner diameter schedule-40 ABS) were used to collect soil cores. Each month, at each sample point, pairs of cores were hammered into the ground to a depth of 23 cm. One core was then removed, placed into a zip-loc bag and stored on ice in a cooler and taken to the laboratory for analysis of instantaneous mineralized nitrogen (“initial”). The second core was left in the ground to incubate for approximately 30 days. At the end of the incubation period, the second core was removed for determination of “final” mineralized nitrogen. The rate of mineralization was then calculated as the difference between final and instantaneous mineralized nitrogen.

To measure initial nitrogen in the lab, the volume of each soil core was first estimated (these were usually about the same for all samples). Each core was then passed through a 40mm mesh soil sieve and homogenized (i.e. briefly mixed in a soil pan). A 50g subsample was then set aside for determination of gravimetric water content (initial weight minus oven-dry weight).

Three 10g subsamples were then added to three extraction cups containing 100mL 2M KCl. Cups were shaken and left to sit for 12-24 hours. A Lachat autoanalyzer (Zellweger Analytics) was used to measure nitrogen content from nitrite/nitrate and ammonia concentrations in soil extractions, expressed as mg N/kg soil.

For lab incubations, the moisture content of a 100g subsample of the field-collected soil was first adjusted to approximately 60% water-filled pore space (in order to maximize microbial activity) and then homogenized. Three 10g subsamples were added to 125 mL Erlenmeyer flasks and covered with polyethylene film. Flasks were stored in a dark, humidified, 25 degree C constant-temperature room for 30 days. After this period, soil extractions were run through the Lachat autoanalyzer as described above. The calculation for net N-mineralization is then Final (nitrite/nitrate + ammonium) – Initial (nitrite/nitrate + ammonium).

In addition to nitrogen analyses, data on soil bulk density and gravimetric water content were also collected. Bulk density = (soil dry mass /volume), and gravimetric water content is percent moisture loss upon drying ((initial mass minus ovendry mass)/initial mass).

Results

Soil bulk density over the one-year sampling period is given in Table 1. A repeated measures ANOVA was used to test for differences among sites, with time as the repeated measure. A significant difference among sites was found ($p<0.01$). A Tukey multiple comparisons test revealed that the WCB site differed significantly from both Site II and Site VII, although the latter two sites were not different from each other. Thus, the remnant riparian forest had significantly lower bulk density than did the two restoration sites. A seasonal trend is also apparent at all three sites ($p<0.01$). Bulk density is highest in the winter months (September through April) and lowest in midsummer (July and August).

Percent soil moisture over the one-year sampling period is given in Table 2. A repeated measures ANOVA was again used to test for differences among sites. No difference was found among sites ($p>0.7$). Thus, soil moisture is consistent across remnant riparian forest at WCB and the two restoration sites. Curiously, the highest soil moisture values at all three sites (18%) occurred in July and August, a period of very hot temperatures in the Sacramento Valley. Possibly this is due to elevated levels of the Sacramento River at this time for agricultural water use, creating a higher capillary fringe extending into the study sites

Mean daily mineralization rates are plotted in Figure 3. A repeated measures ANOVA was used to test for differences among sites and through time (the repeated factor). No significant difference was found among sites ($p>0.4$) but a significant difference was found for Time ($p<0.01$), the latter effect due mostly to the large negative spike in the September sample. Confidence intervals in Fig. 3 are not shown for clarity, but for each point a 95% CI includes the other two points at that month. Thus, our initial null hypothesis of no difference in net N-mineralization among sites is accepted. A trend from young restoration to old restoration to remnant riparian is not apparent from these data.

Discussion

The initial null hypothesis of this phase of the project was (1) that there would be no difference in rate of N-mineralization among the sites sampled (e.g. young restoration, old restoration and remnant riparian), and (2) that there would be no seasonal trend. The first null hypothesis cannot be rejected but the second null hypothesis is tentatively rejected.

There is no difference in N-mineralization rate among the three study sites. All three sites have similar, high-quality soils under a common temperature and precipitation regime. Apparently orchard agriculture had little impact on the intrinsic mineralization capacity of these soils. Values of N-mineralization reported here are within the typical range reported for eastern deciduous forest (Waring and Running 1998, Aber and Mellilo 2001), the closest ecological analog that could be found in the literature to Sacramento River riparian forest ecosystems. Robertson et al. (1999) also point out that mineralization values are notoriously high in variability, with order of magnitude differences sometimes occurring even within a single study site as a result of patchiness (e.g. animal burrowing, defecation sites, microtopographic influences, etc.). Thus it is not surprising (in retrospect) that N-mineralization differences did not appear among our study sites. Most studies in the literature that find differences in N-mineralization among sites are analyzing widely disparate sites along large scale gradients of temperature and/or moisture (Aber and Mellilo 2001). .

The seasonal trend in N-mineralization offers some interesting glimpses into this process in California riparian zones. First, most values are small positives, indicating small gains in mineralized nitrogen over the 30 day incubation period (the negative values indicate losses, due mostly to microbial immobilization). The most notable pattern is the small positive spike in

August followed by the large negative spike in September 2001 at all three sites. The following is a hypothesis to explain this pattern. As seen in Table 2, soil moisture increased during August due to unknown reasons (possibly due to higher flows of the Sacramento River as a result of releases from Shasta Dam for agricultural use). This higher soil moisture, coupled with such factors as the characteristically high temperatures of that month, and typical leaf senescence pattern of dominant species such as Fremont cottonwood (resulting in less nitrogen demand from soils), the August increase in mineralization may be due to increased microbial activity as microbes were released from root competition for nitrogen. Then, as microbial populations built up, the large negative spike in September may be explained by microbial immobilization of nutrients released during the previous month. However, it must also be noted that the September anomaly is problematic due to the lab analyses becoming interrupted for 24-36 hours due to the shutdown of the university following the September 11th attack on the World Trade Center. Thus it is unknown whether this downward spike is a real or artificial result. However, we can think of no biological or chemical reason that would explain why a small delay in laboratory processing (i.e. a slightly longer incubation period; fresh samples were contained on ice during the entire time) should result in such a large effect. If funds permit, sampling will be repeated during this same time frame during 2002 to potentially resolve this question.

Perhaps the most noteworthy effect across our study sites is in soil bulk density. Here, the effects of previous agriculture on soil compaction can be clearly seen. Soils are significantly less dense (i.e. looser) in the remnant riparian forest, and most dense in the young restoration site (VII). This effect was demonstrated early on in the study, while pounding in PVC soil cores. At WCB just a few mallet strokes accomplished this task, whereas at Site VII it took many powerful smashes to insert the core. Low bulk density in soils of similar origin and texture is a result of biological activity—earthworms, beetles, small mammals, etc.—aerating the soil (Robertson et al. 1999). Thus it can be hypothesized that older aged riparian forests are more biologically productive, which may in turn promote higher species diversity.

Conclusion

Measuring N-mineralization is both costly and time-consuming. Laboratory analyses are long and involved, and there is a substantial learning curve for the Lachat. Sacramento River riparian forest restoration sites are generally on former agricultural land, with high quality soils.

N-mineralization measurements thus should only be undertaken where there is a clear need or purpose for the data. To our knowledge, no prior data on N-mineralization existed for riparian areas in California, much less for the Sacramento River corridor or for restoration sites. For this reason, our data in this pilot study are valuable. Although no site differences were found, the seasonal peaks in our data are in need of further study. Still, in our opinion the data do not justify further research effort on N-mineralization unless more specific hypotheses about ecosystem function are constructed and related to other ecosystem parameters such as microbial respiration, litter decomposition, plant nitrogen demand, etc. Other, simpler ecosystem metrics such as soil carbon or soil bulk density appear to be more informative as far as ecosystem indicators of riparian forest restoration success.

Subtask 3.1b Soil Development

Objective 2 of this project was to: Sample riparian soils to document soil profile development during ecosystem restoration. One potentially complicating factor in studying early soil development following restoration at River Vista is the time lag between the fallowing of the orchards in 1986 and the onset of sampling in 2000. The issues raised by this sequence of events are addressed below.

The development of soil profiles from riparian/floodplain sediments can significantly affect and potentially reflect riparian restoration progress. Biological activity and soil organic matter (SOM) accumulation alter the structure of soils, which in turn affects drainage characteristics and the soil water storage capacity. Soil horizon development can be a slow process measured on the time scale of decades or more. However, since mature riparian forests can develop on the time-scale of 30 years, it seemed possible that some soil development processes could be detectable over the time scale of this monitoring program. Based on searches in several electronic databases, the journal literature does not appear to contain any studies of soil development corresponding to riparian restoration efforts. The few references that do exist focus on natural pedogenic processes (Brock, 1985) or upland meadow riparian systems (Blank et al., 1995).

Beyond the time frame of pedogenisis (decades to millennia), one of the challenges in monitoring soil development is selection of appropriate metrics. Clay weathering and accumulation, development of cemented layers, and development of structural peds may be useful, albeit on a time-scale beyond the current study. Color change may be useful on young soils such as the Entisols present at Site VII. In the fluvial deposition environment along the Sacramento River, changes (increases) in soil organic matter can contribute to color changes as soil development proceeds. Soil organic carbon was selected as a metric for monitoring soil profile development since it is more reliably quantified through instrumental analysis and for its importance in ecosystem function.

Soil Conditions

Background

Soils at the River Vista sites are variants of the Columbia Series (Gowans, 1967) and are described as coarse-loamy, mixed, superactive, nonacid, thermic Oxyaquic Xerofluvents. As Entisols, they are young soils derived from deposition of fluvial sediment parent material by the Sacramento River. The Columbia series consists of nearly level to gently sloping, brown, well-drained, neutral soils that are medium textured to moderately coarse textured. They are on recent flood plains along the Sacramento River. The soils mapped beneath Site VII consist of: the Columbia complex (Cu), channeled, variable texture and slope; and the Columbia silt loam (Ct), moderately deep, 0 to 3% slopes.

Methods

Soils were described using standard Natural Resource Conservation Service soil survey methods. Three soil pits were examined and described. Soil moisture characteristic curves were developed for each different soil series encountered. Soil cores were collected at three locations (Figure 4) at the 25-cm depth with a minimum of disturbance. Brass rings with a length of 3 cm and a diameter of 5.7 cm were carefully pounded into the ground. After returning to the lab, the soil samples were placed in Tempe Cells and water retention curves were estimated following the methods described by Klute (1986). Analysis of soil carbon is described in a later section.

Results

Soil pits were excavated at three locations: Site II and Site VII restoration units and the adjoining natural riparian forest (WCB) to the south. A summary of the soil horizons is given on Table 3. Pit depths were 2.02 m, 1.74 m, and 1.62 m, respectively. At a depth 2.62 m in the

WCB site, a buried soil surface was encountered with identifiable organic matter still visible. Soils in Site VII were more compacted and fewer discrete soil horizons were visible.

Conclusion

Soil conditions at all three sites are dominated by the common depositional origin in terms of parent material and soil forming processes. While not directly assessed, spatial variability of fluvial processes has created a mosaic of soil profile differences, most notably depth to highly drained gravel bars. Changes in profiles with soil development need to be monitored at longer time frames, possibly at three to five year intervals.

Plant Litterfall

Background

The first of the chain of events in nutrient cycling comes in the form of leaf fall from plants. Leaves fall to the ground, are colonized or fed upon by a series of organisms (bacteria, fungi, slime molds, insects, etc.), and are gradually decomposed to form humus (Waring and Running 1998). Humus is a potential source of nutrients for plants and other organisms (through mineralization) but can also become incorporated into the soil profile as organic matter (Aber and Mellilo 2001). Thus, quantifying litterfall is an essential first step in the analysis of nutrient cycling as an ecosystem parameter. Decomposition rates are also important but are not addressed in this study.

Methods

Following the methods of Hughes and Fahey (1994), nine litter traps at each site were placed in a 3 x 3 grid spaced 75 m apart, for a total of 27 traps (Figure 2). Litter traps were placed in the same general location as the N-mineralization samples (within 10 m, but placed so as not to interfere with soil cores). A piece of flexible PVC was formed into a 0.25 m^2 circle from which mesh netting was suspended. The entire trap was placed on a tripod to sit 1 m off the ground. This arrangement was optimized to catch woody plant litter fall (e.g. shrubs and trees). Herbaceous litter was generally not captured in this study, but this was not our intent. Traps were emptied monthly, their contents sorted by species, then dried and weighed.

Results

Figure 5 shows litterfall mass at all three sites over time. Not surprisingly, peak litter fall occurred during the fall and winter months, beginning in September and continuing into December. This reflects the mainly winter deciduous character of the vegetation. Of greater interest is that the WCB site (remnant riparian) consistently had the greatest litter mass, followed by Site II (old restoration) and then Site VII (young restoration). All three sites differ significantly as revealed by a repeated measures ANOVA ($p<0.01$) and a Tukey multiple comparison test. It is interesting that Site II, the old restoration site, is closer to the WCB site than to Site VII. The WCB data target the more-or-less natural level that the restoration sites should eventually achieve.

Table 4 gives the species composition of woody plant litterfall at the three sites. Fremont cottonwood is a major contributor to the leaf litter at all three sites, but aside from that species clear differences exist among the sites (chi-square test $p < 0.001$), reflecting mostly the proportion of particular species planted. The WCB remnant riparian forest has a high proportion of walnut leaf litter as well as mugwort and wild grape, whereas the younger restoration Site VII has a high proportion of sycamore (40.2%) and the older restoration Site II has a high proportion of arroyo willow (42.6). Sycamore and arroyo willow are currently dominant components, respectively, of Sites II and VII.

Discussion

Both the amount and species composition of plant litter differ significantly among the sites. The remnant riparian forest (WCB) stands clearly apart from the restoration sites, most especially in terms of litter mass, although Site II is rapidly approaching it. We now have a point estimate of a "target mass" for the restoration sites to achieve as one measure of their success. However, the fact that the WCB site has a high component of black walnut is problematic. Black walnut is not considered native to this area by most authorities (including TNC, who does not include it in their planting mix). Thus the WCB site cannot be considered a true target site for restoration at least in terms of species composition. Other remnant forests should be sampled as well to better define target endpoints of restoration succession.

The litterfall data can also be viewed as baseline data to feed into the nutrient cycling framework, which was begun with the N-mineralization study. Due to the higher input of leaf litter as compared to the restoration sites, the WCB remnant forest, our closest approximation locally to a natural forest stand, has the potential for higher rates of nutrient recycling and a concomitant greater biodiversity of decomposer food chain species. We still lack data on relative rates of leaf decomposition, which directly affect nutrient cycling rates. Based on the literature we hypothesize, for example, that oak and walnut leaves will be slower to decompose than cottonwood and willow leaves. This aspect of riparian forest ecosystem dynamics, that of differential rates of leaf decomposition among both sites and species, will be addressed in a Masters Thesis by a graduate student of Wood's, Brianna Borders. Data on the species composition and abundance of certain taxa within the decomposer food chain are currently being collected for another Masters Thesis by another graduate student of Wood's, John Hunt (John is collecting specific taxonomic information for beetles, but he will address diversity of other macroarthropod taxa at the Family and Orders levels).

Conclusion

The data presented above are not surprising but are nonetheless informative. Little baseline data exists for Sacramento River riparian systems, which makes any quantified process a valuable contribution. Plant litter fall data, especially when coupled with decomposition rates by species and site (e.g. restoration age, different remnant riparian sites, etc.), has value in two ways: one, by highlighting differences between restoration sites and remnant forests; and two, by providing important baseline data for future studies of ecosystem function. Litter fall data are relatively easy to obtain, and we believe there is merit in extending this study to other restoration sites and remnant forests.

Soil Carbon

Background

Soil organic matter and its contribution to carbon and nutrient cycling are of fundamental importance to biological systems. SOM pools and dynamics have more recently been recognized as being a critical component of the global carbon cycle. Plant residues comprise the largest source of organic carbon entering soils (Paul and Clark, 1989). The dense vegetation of mature riparian forests provides a constant source of plant litter that will decompose to become humic substances that comprise SOM. In contrast, there is wide variation in the quantity and characteristics of plants litter inputs to riparian soils prior to restoration due to the many agricultural practices that form the initial condition of riparian ecosystem sites along the Sacramento River. For example, almond orchards are "swept" nearly free of any litter while some prune orchards have grass planted between the trees for weed control. Thus, previous studies of succession from row-crop agricultural fields and pastures may not be directly relevant to the recovery of riparian forests. However, there are so few comparable studies (Boggs and Weaver 1994) on this topic that our studies will be largely exploratory. Afforestation is generally thought to increase soil carbon and by correlation SOM, but more study is needed (Bashkin and Binkley 1998). Since restoration sites are mainly on old orchard land, and orchard tree root systems were left intact, substantial soil carbon pools may exist at the time of planting.

Methods

Triplicate subsamples of approximately 50 g from each soil horizon observed in the soil pits at Site VII and WCB sites were used in the analysis (Figure 4). Additional soil sampling for carbon content was performed on a quarterly basis at the locations where nitrogen mineralization and plant litter samples were collected Figure 2). As shown on Figure 4, nine samples were collected in a 3x3 grid with sample locations 75 m apart (corresponding to litter sampling described above). Soil samples were analyzed using the same methods as described for samples from the soil pits.

Analysis for soil carbon was performed using Shimadzu 5050A Total Organic Carbon (TOC) analytical equipment. Visible large rocks or debris were removed from the subsamples prior to drying the samples in an oven for 24 hours. Subsamples were then pulverized and homogenized before being placed in the instrument.

Results

Soil samples from the horizons in the pits for Site VII and WCB were analyzed for total carbon. In the WCB soil pit, mean total carbon ranged from 0.25% - 2.28 % (Table 5). After declining in concentration with depth, the buried soil surface encountered contained the upper end of this range. The results from the restoration unit soils revealed a much narrower range of mean carbon contents, ranging from 0.31% – 0.79% (Table 5). As with the Site VII results, the surface horizon at the WCB site showed the high carbon content. Samples collected from the soil pits show that the natural riparian forest contains three times as much soil carbon in surface soil horizons than for Site VII. Both locations show a sharp decline in carbon concentration with depth to more comparable concentrations (Figures 7 and 8).

Soil carbon concentration results are presented at depths of 2 cm, 10 cm, and 24 cm on Figures 9, 10, and 11, respectively. Each seasonal carbon concentration represents a mean of the nine samples collected for each location. There appears to be a seasonal trend at all three depths with maximum carbon concentrations occurring in the spring and lower concentrations during the other three seasons. The natural riparian forest site (WCB) and the older restoration unit (Site II) had generally higher soil carbon content than did the youngest restoration site (Site VII), which is the focus of this monitoring project (Figures 9-11).

Discussion

Soil carbon accumulates as a result of the decomposition process of organic material, the main input being from plant material. In winter deciduous forests such as those studied here, there is a yearly pulse of litterfall in the fall (September through December (Figure 5). Given the greater amount of standing biomass and subsequent leaf litterfall in the WCB site, it is not surprising that this site should contain a greater amount of soil carbon than the restoration sites. Still, the restoration sites are not deficient in soil carbon and indeed exhibit an increasing trend from the youngest site to the oldest site. Our data show the seasonal pulse expected in these forests—plant litter accumulates on the forest floor during the fall, decomposes with the onset of the fall rains in November/December, soil organic matter (SOM; humus) is formed, and these humic materials are leached down into the soil profile where they exhibit a peak during spring. Following this flush of SOM, fungi and other soil microbes take up this carbon for their own growth and thus soil carbon levels decline once again. A final caveat to these data must be mentioned, and it concerns the preexisting conditions in the restoration sites. In our study sites we do not have a direct conversion of orchard agricultural land into restoration. Rather, there was an extended period (14 years) during which the restoration sites contained resprouted tree stumps and a high amount of weed biomass. We have no soil carbon data for either the agricultural period or for the stumpy/weedy period. The amount of plant biomass contributed yearly to the soil profile is unknown during this fallow period, however it is almost certainly less than for mature forests and probably less than immature (i.e. older restoration) forests. Thus we are tentatively confident that our data represent a significant trend in increasing soil carbon as a function of restoration, but this hypothesis needs confirmation.

Conclusion

In spite of the limited time period and time gaps in our sampling regime due to the fallow pre-restoration period, soil carbon nonetheless appears to be a sensitive indicator of riparian forest ecosystem development. Our data do exhibit a trend of increasing soil carbon with increasing forest development and do exhibit the expected seasonal pulse during the spring months. Data collection and analysis, although time-consuming, is much easier than for N-mineralization. When combined with data on litterfall (e.g. this project) or standing biomass, and leaf decomposition timing and rate (upcoming Masters thesis), additional soil carbon analyses will be valuable in documenting positive changes in ecosystem function during the maturation of restoration sites.

Subtask 3.2 Groundwater Quality

Objective 3 of this project was to: Install a monitoring well network to detect changes in groundwater quality. A major limitation of this study is the lack of groundwater quality data at the end of cultivation (1986) and over the 14-year period until monitoring began in 2000. Thus, groundwater quality conditions beneath the Site VII must be viewed as current conditions rather than a definitive post-restoration trend.

Background

Given their position within a watershed, riparian zones can act as a sink for solutes passing from upland soils through shallow groundwater to surface water. In this role, riparian zones have been shown to be effective in controlling nonpoint source pollutant releases from agricultural lands (Lowrance et al., 1985; Gilliam, 1994; and Perry et al., 1999). Thus far, chemical transport through riparian zones has mainly been quantified in regard to mediating nutrient releases from agricultural fields (Lowrance et al., 1983; 1984; Emmett et al., 1994, and Perry et al., 1999). Riparian soils may also act as an important sink for the adsorption of organic constituents (Fiebig et al., 1990). For example, flow through riparian zones draining agricultural runoff may attenuate agricultural pesticides and herbicides. Entry et al. (1994) found that riparian forest soils can degrade triazine-based herbicides such as atrazine, although this study was limited to the upper 10 cm of riparian soils.

Nutrient nonpoint source pollution resulting from fertilization in agricultural fields is a potential water quality concern in California, both in terms of groundwater and surface water. Given the demonstrated value of riparian zones in reducing nutrient releases to streams, it is important to study the subsurface transport processes that occur in these zones. Traditional approaches used in studying the fate and transport of contaminants in groundwater often includes tracer studies, but this technique has rarely been applied to riparian zones (Altman et al., 1993).

Virtually all of the studies cited above have focused on smaller rivers or streams where overland flow is an important runoff generation process. Larger rivers, particularly those with managed flow regimes such as the Sacramento River, may have a significant subsurface flow component contributing to local river flow. However, after a review of three comprehensive electronic databases (Agricola, Applied Science and Technology Index, and GeoRef), no recent citations (1992-date) were found that specifically address the function of riparian systems in affecting water quality on larger or managed rivers. Likewise, the buffering function of riparian systems undergoing various stages of restoration does not appear to have been studied to date. Overall, there exists a need to systematically study the attributes of riparian zones that control solute transport through groundwater to streams.

Methods

The final groundwater-monitoring well network consisted of eight shallow wells installed at depths ranging from 15 ft to 24 ft (Figure 12). The requirement by the SRNWR that the wells be removed upon the end of the project meant that insufficient budget was available to construct the wells with an auger drill rig as originally planned. Instead hand augers were used for the initial well installations. Two shallow stratigraphic conditions were encountered that limited the installation depths using hand methods. First, gravel bars, or strata with high gravel content were encountered. Second, saturated sands created flowing sand conditions that made it impossible to maintain an open borehole. These conditions caused the preliminary wells to remain dry during the water year 2000-2001, which was one of the driest years on record. One well, RV7-1 was installed by hand auger to a depth sufficient to sustain monitoring over two years. Monitoring agricultural wells at the River Vista Units was discontinued after a review of the driller's reports for these wells. The construction of the agricultural wells is such that they span multiple discreet aquifer zones. Thus, it is not possible to correlate changes in their water levels with those from the shallow wells installed during this study.

Use of drive-point wells proved successful in overcoming the gravels and saturated sand conditions described above. Perforated ¾-inch stainless-steel drive points were attached to standard galvanized pipe and were hand-driven to a minimum of 5 feet below the water table during the fall 2001 when water levels were at their maximum depth. Polyethylene tubing attached to a stainless steel barb within the drive point provided clean sampling conditions for water quality analysis as well as access for water level measurements.

Two transects of three wells each were installed in the restoration unit, and a two-well transect was installed in the adjoining natural riparian forest (Figure 12). Well transects will begin at the top of the bank immediately adjacent to the river or at the western edge of Site VII and extend away from the river. A limited number of wells were surveyed with a total station to estimate general groundwater flow directions from water table contour maps.
Once the well network was completed, groundwater quality was monitored by sampling all wells on a quarterly basis. Wells were sampled using a portable peristaltic pump after three well casing volumes were purged.

Field sampling and laboratory protocols followed standard methods specified by the U.S. Environmental Protection Agency and the State Regional Water Quality Control Board. Basic Laboratories, Inc. in Redding, which is a State-certified laboratory, performed the analyses of groundwater samples. During each quarterly sampling event, field measurements were made of, pH, temperature, and electrical conductivity. Laboratory analytical parameters included: nitrate/nitrite, total Kjeldahl nitrogen (organic nitrogen and ammonia), and total phosphate. Given the long duration since active orchard cultivation and budget limitations, no pesticide analysis was performed. The small sample volumes obtained using the drive point wells made it infeasible to obtain reliable measurements of dissolved oxygen (D.O.) and thus these data were not collected.

Results

Depth to groundwater data is summarized on Table 6. The well with the longest monitoring record was RV7-1, and depth to groundwater (below ground surface) ranged from a minimum of 1.51 meters to a maximum of 3.92 meters. Water table depths tend to decrease with distance away from the Sacramento River (Table 6). Groundwater contour maps are shown on Figures 13, 14, and 15 for fall, winter, and spring conditions, respectively.

Water quality results show that nitrogen and phosphorus nutrients are generally present at very low concentrations at the WCB site (Table 7). In well RV7-1, total nitrogen (includes organic nitrogen compounds and ammonia), nitrate, and total phosphorus show a limited trend of declining in concentration through 2000-2001. Nitrate and total phosphorus concentrations showed a slight increase in February 2002 and then increased in the final sample. Over Site VII, nitrate concentrations have remained high at interior wells RV7-2, RV7-3, RV7-5, and RV7-6. Wells RV7-1 and RV7-4 near the upgradient eastern boundary (Figure 12) show relatively low nitrate concentrations compared to well downgradient along their respective transects. Field groundwater chemistry measurements are shown on Table 8.

Discussion

In the fall and during the winter, following the end of groundwater pumping on adjacent orchard property, the gradient is generally toward the Sacramento River (Figures 13 and 14, respectively). This is consistent with unpublished groundwater data gathered by the California Department of Water Resources (DWR). The general interpretation by Northern District DWR staff is that the Sacramento River is in a gaining condition (i.e., net groundwater inflow) above Princeton (G. Pearson, DWR, personal communication). During the spring, agricultural pumping (D. Zaleke, TNC, personal communication) is initiated on adjoining orchards and appears to have created a localized groundwater depression along the eastern edge of Site VII by mid-April 2002 (Figure 15).

One of the primary questions is to what extent the restored riparian forest ecosystem contributes to improved water quality. Answers to this question involve an understanding of the source of nutrients. Based on the analytical results shown on Table 7, nitrate is the only major nutrient of interest. Two major sources of nitrate in shallow groundwater could be residual nitrogen released from Site VII soils and groundwater nitrate loads flowing in from adjoining agricultural operations. Since the orchard operation ended in 1986, it is assumed that no further fertilizer amendments were added. N-mineralization does not seem to be a significant source of nitrogen replenishment based the work reported in section 3.1a. Given the high solubility and mobility of nitrate, it seems likely that leaching and/or biological uptake would reduce residual nitrate over the time. However, a lack of soil solid or liquid phase nitrate data between fallowing and the onset of this study precludes a definitive interpretation of on-site nitrogen sources.

Knowledge of nitrate loading from upgradient agricultural sources is also unknown. Walnut orchards immediately to the east of Site VII would subject to one or more fertilizer applications depending on the growing conditions in a given year (D. Zaleke, TNC, personal communication). With the moderately or well-drained soils, there is the potential for leaching of nitrogen fertilizers, especially in nitrate form to reach groundwater. A recent U.S. Geological Survey study by Domagalski et al. (2000) found detectable nitrate in shallow groundwater in over 75% of the samples collected from agricultural lands in the Sacramento Valley. The ranges of nutrient concentrations obtained in this study (Table 7) fall within the middle 50% of Sacramento Valley samples for total Kjeldahl nitrogen. The wider range of nitrate concentrations spans both the lower 25% and middle 50% of levels found in regional samples. Total phosphorus results are not reported for shallow groundwater in the U.S. Geological Survey study. Overall, the nutrient concentrations beneath Sites VII (and II) appear fairly typical for shallow groundwater in agricultural areas of the Sacramento Valley.

As the root system of a restored riparian forest develops in Site VII, nitrogen uptake from groundwater may increase over time. However, well RV7-6 is within Site II and does not show significant reductions in nitrate concentrations compared with well RV7-5. Thus, if the low nitrate concentrations in the WCB wells indicate increased nutrient uptake ability for mature riparian forests, water quality benefits from riparian restoration might lag beyond the eight years since Site II was planted. Additional monitoring and wells are needed to resolve this question.

Conclusion

Groundwater flow beneath the River Vista Units and WCB site follows the expected trend of net influx to the Sacramento River. Agricultural pumping appears to exert a seasonal localized influence on shallow gradients. Further monitoring with additional wells would facilitate a more detailed understanding of the significance of these effects. The source of nitrate is not definitively known, but it appears likely to be from upgradient agricultural sources rather than residual on-site release from past agricultural activity. Continued monitoring will also facilitate estimation of the potential rate of attenuation of nitrate and other nutrients as riparian vegetation matures.

Recommended Future Work

- N-mineralization should not be emphasized in future studies.

- Other soil variables such as bulk density, percent soil moisture, and soil carbon should be investigated at a wider variety of sites and time scales to confirm the trends in the data from the present study. Spatial variability of these variables should also be characterized.

- Groundwater monitoring should be continued on a quarterly basis. Additional wells should be installed to verify upgradient nutrient sources from adjacent agricultural operations. *

- Soil development monitoring should be continued albeit on a 3- to 5-year interval, emphasizing soil carbon and color changes.

- Soil water conditions, flux and chemistry should be characterized to examine linkages between the forest vegetation and shallow groundwater quality. *

- Conduct litter decomposition studies to link plant litterfall rates with soil carbon dynamics. *

* Work in progress or planned as follow-up beyond this study.

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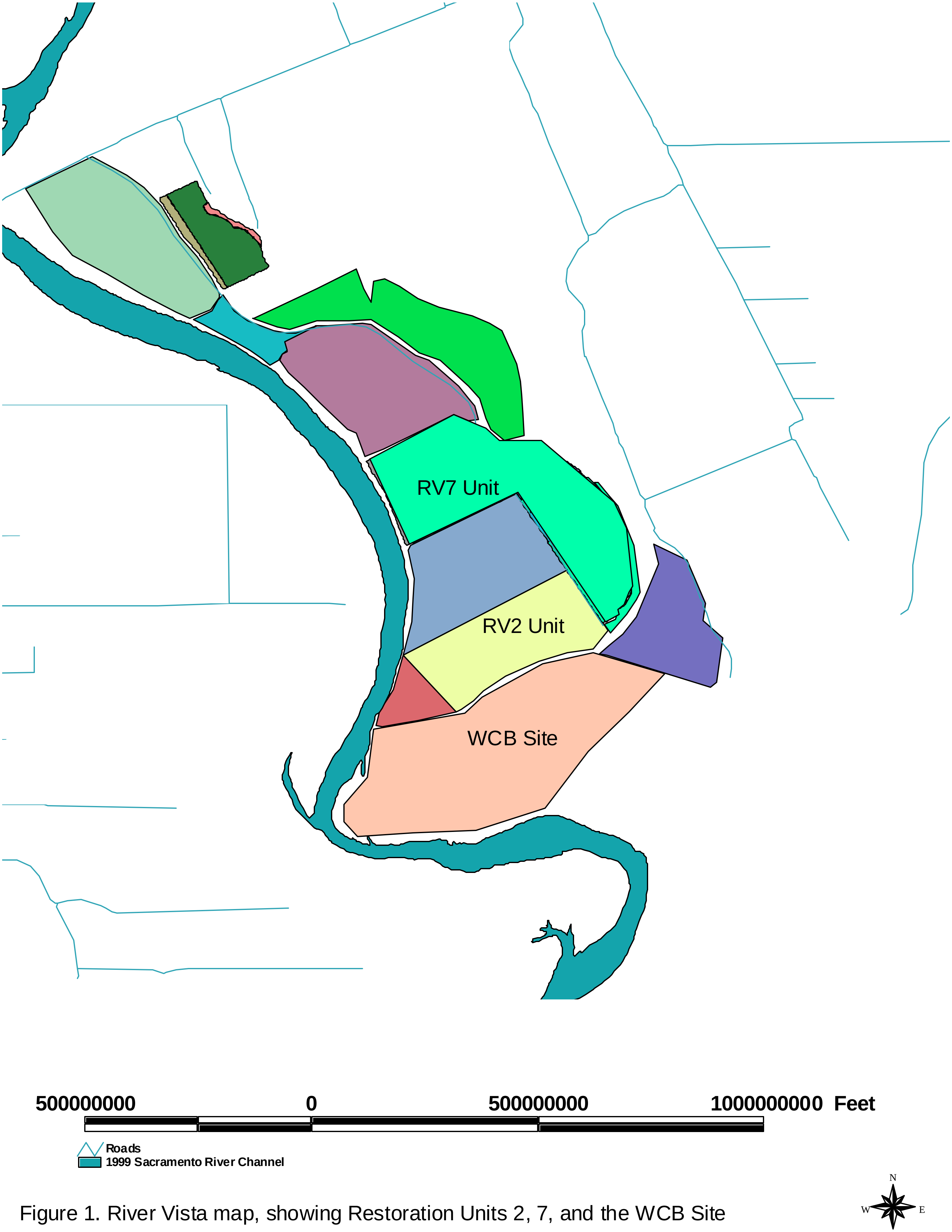


Figure 1. River Vista map, showing Restoration Units 2, 7, and the WCB Site

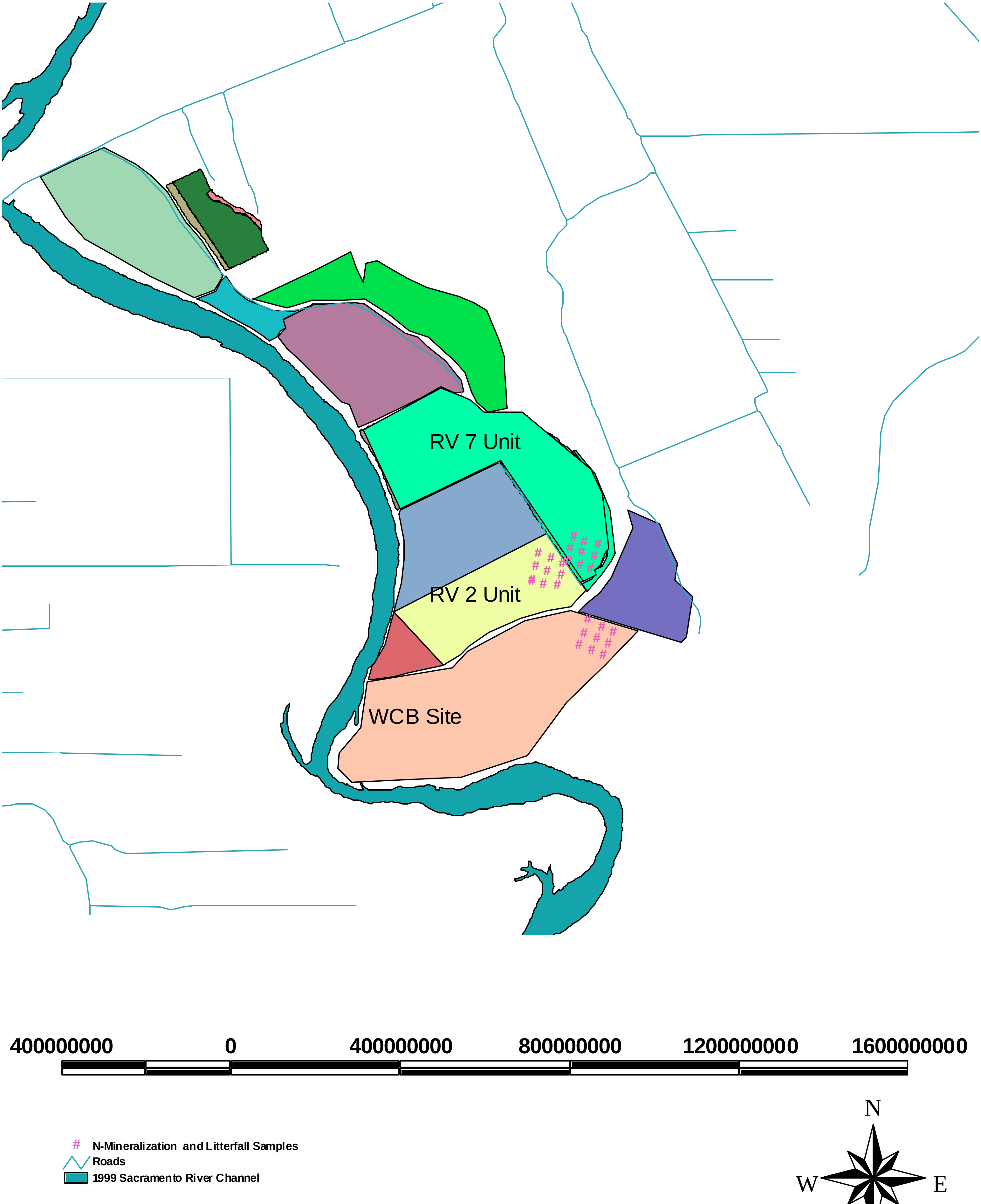


Figure 2. Nitrogen-mineralization sampling locations (also Litterfall trap locations)

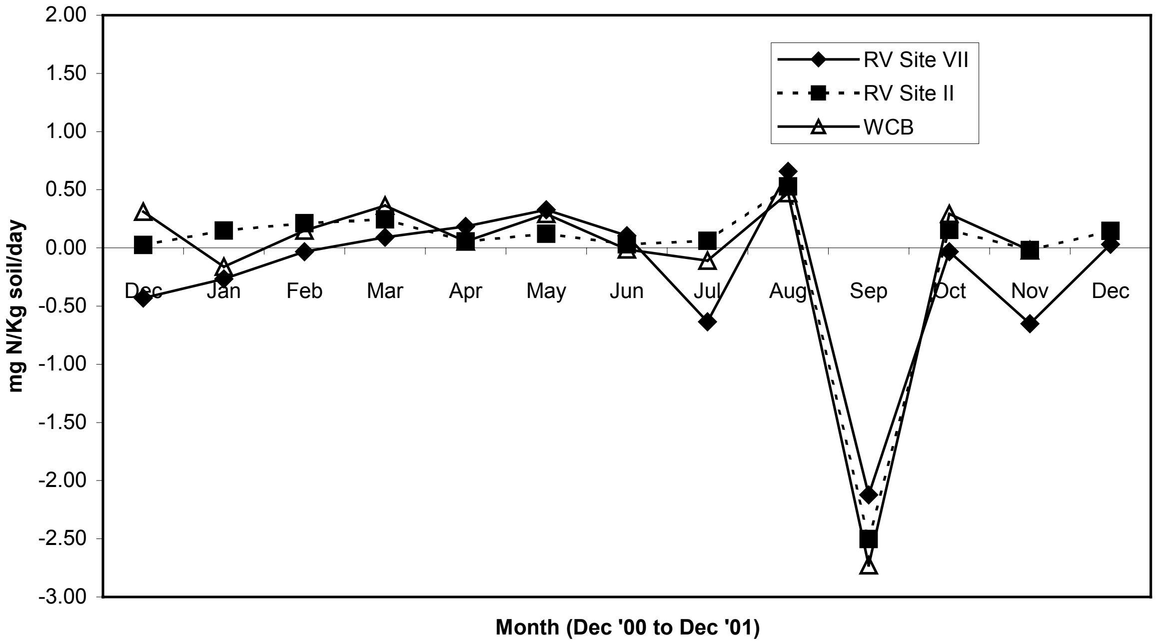


Figure 3. Nitrogen mineralization rates

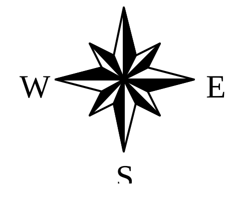


Figure 4. Soil core/soil pit sites

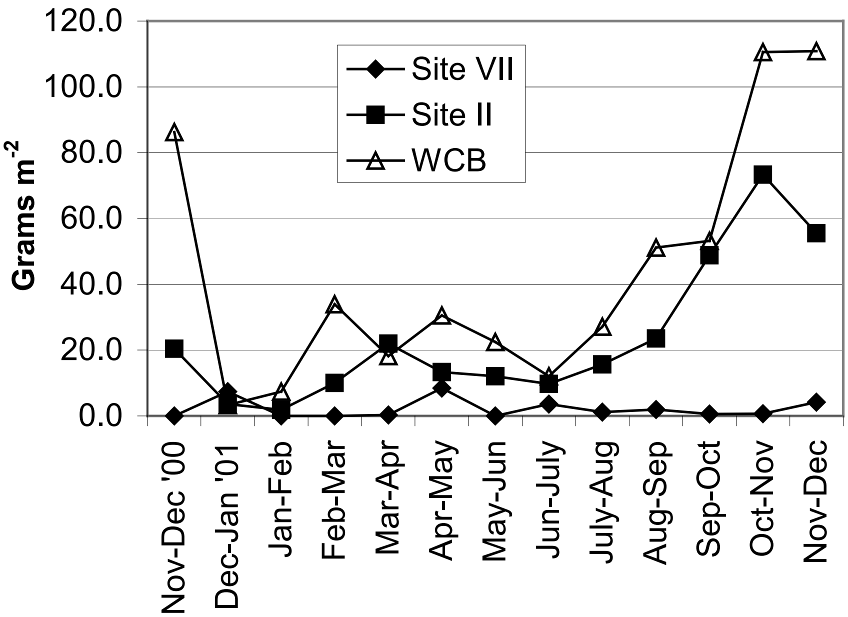


Figure 5. Leaf litterfall over time

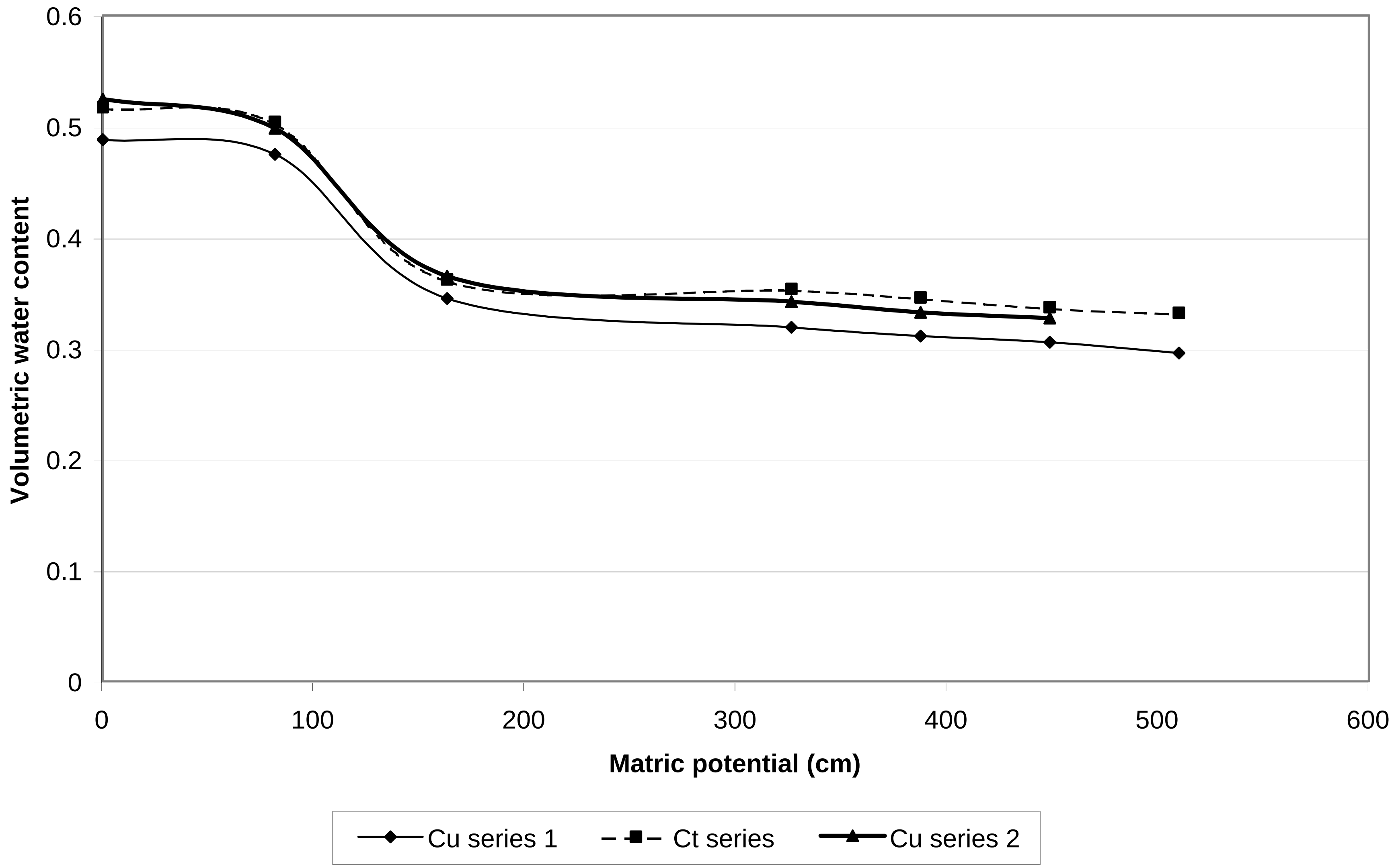


Figure 6. Soil water retention curves

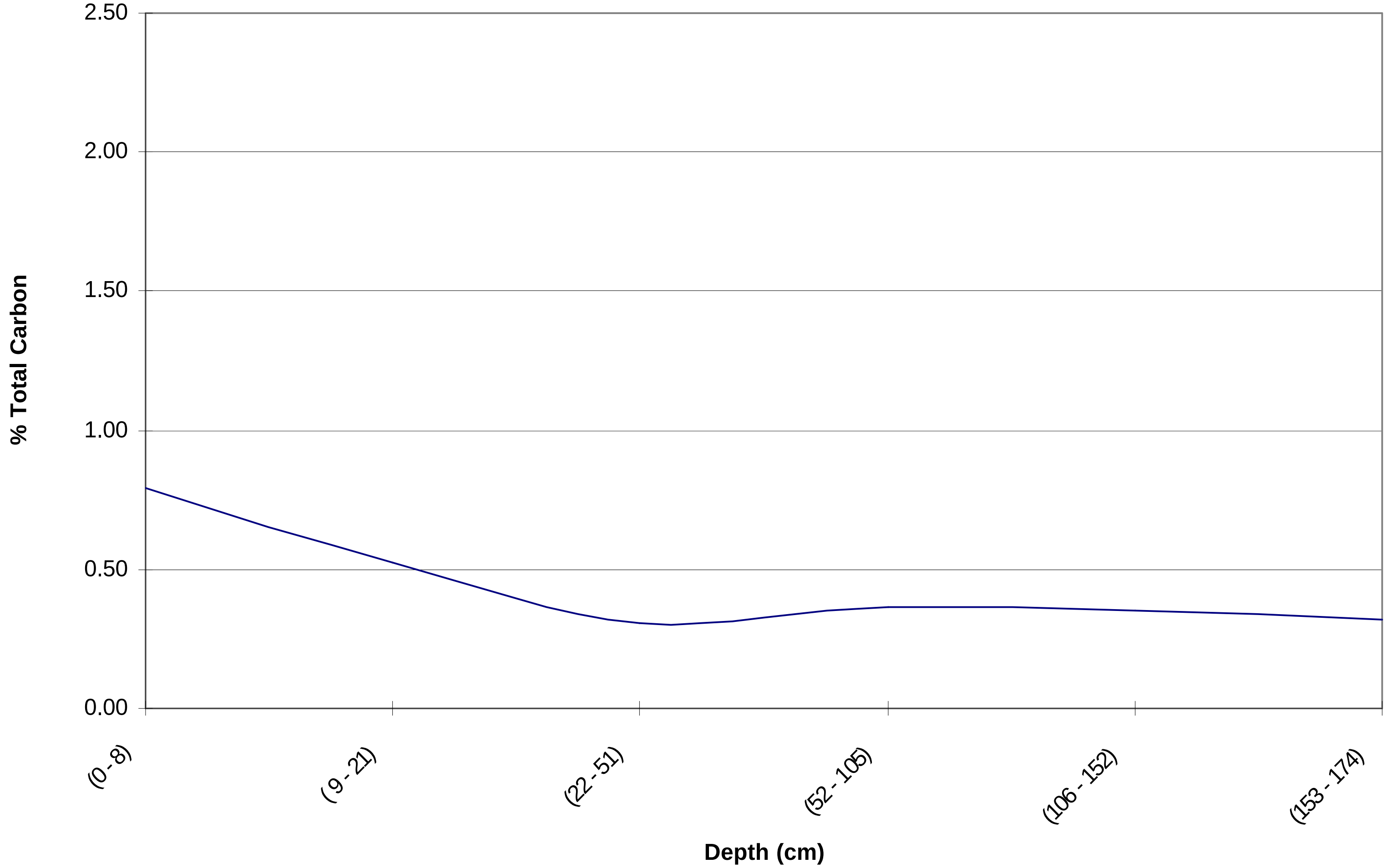


Figure 7. RV7 Soil carbon by depth

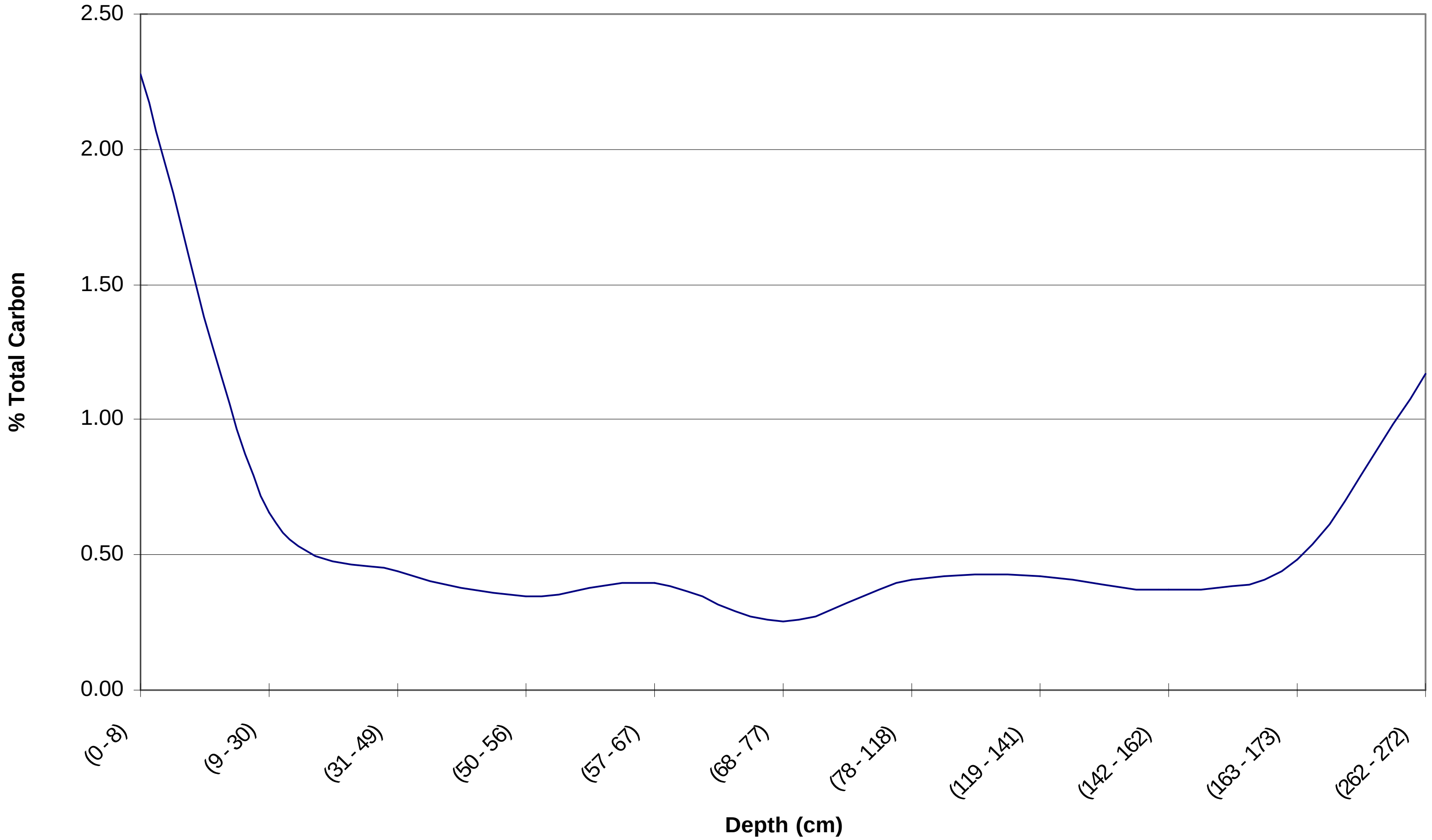


Figure 8. WCB Soil carbon by depth

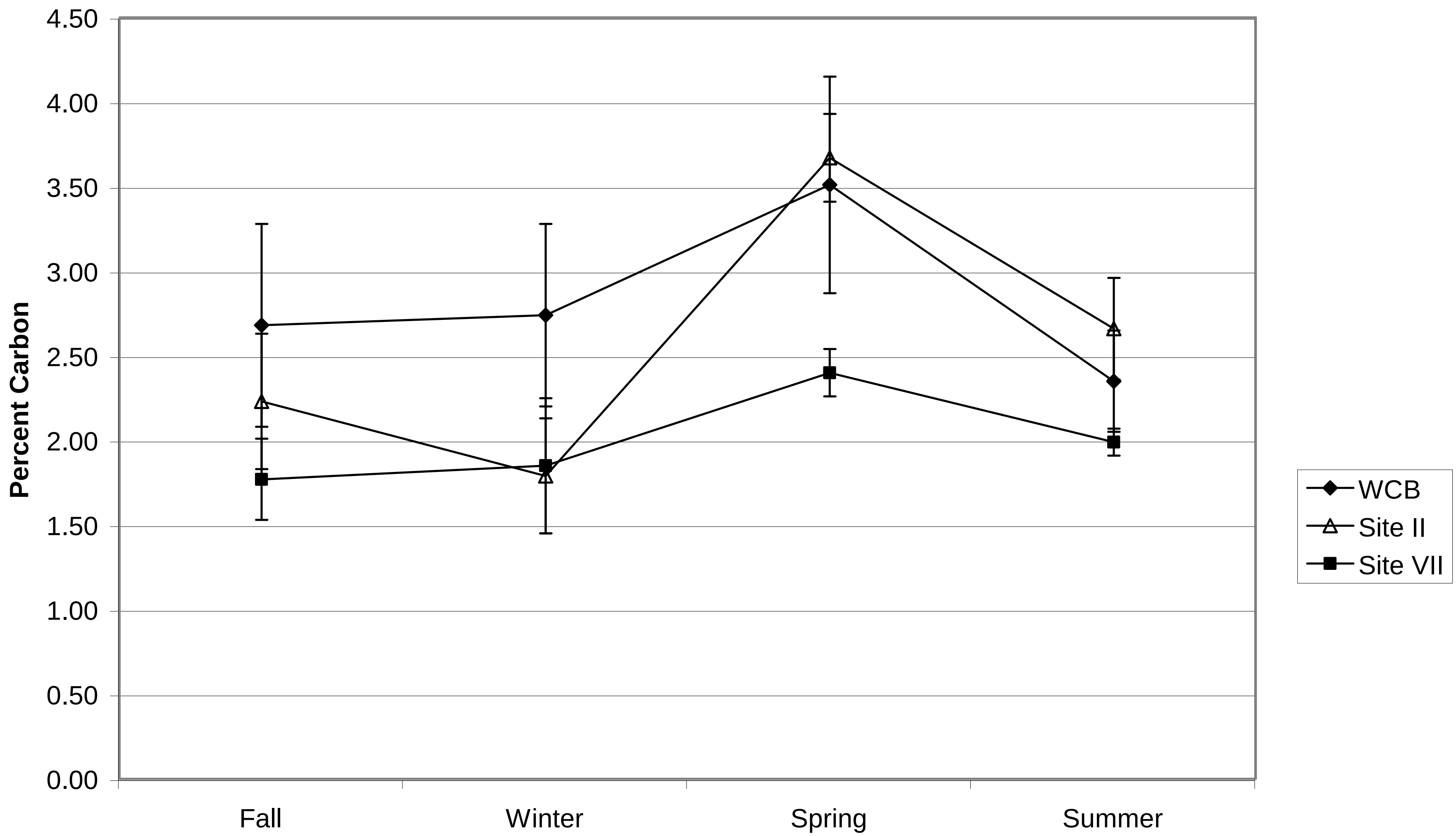


Figure 9. Soil carbon at 2-cm depth. Values are means +/- 95% confidence intervals.

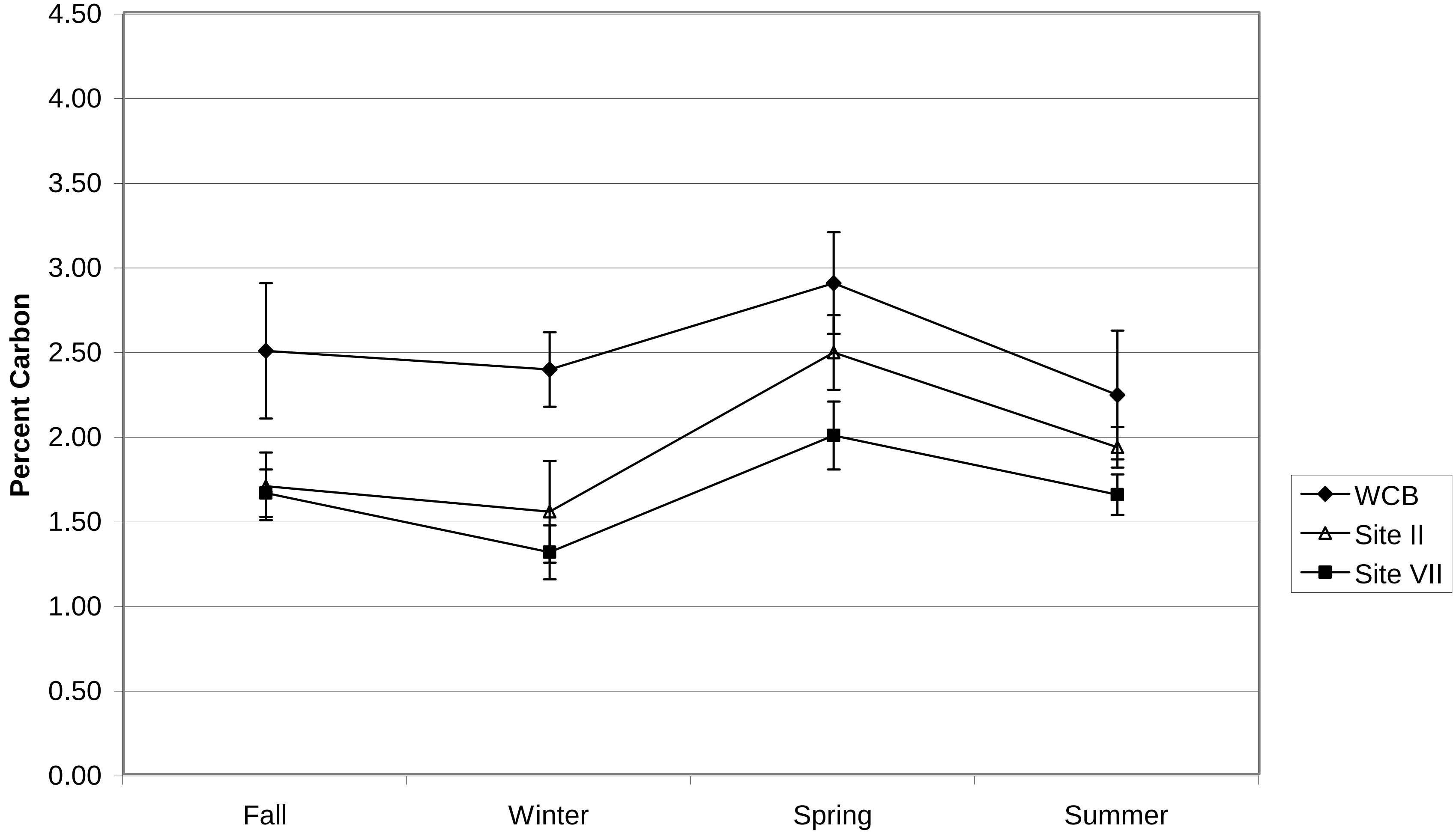


Figure 10. Soil carbon at 10-cm depth. Values are means +/- 95% confidence intervals.

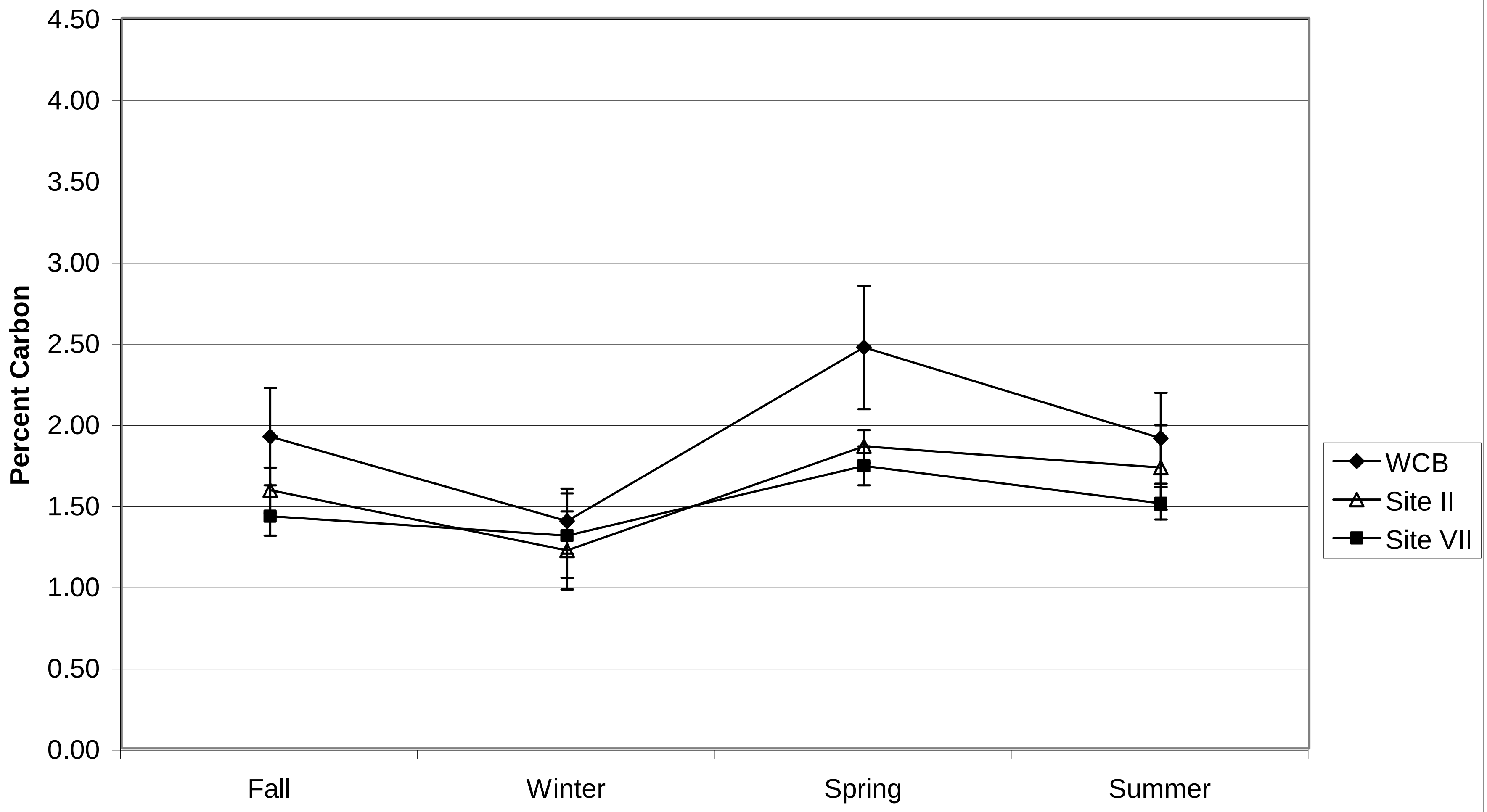
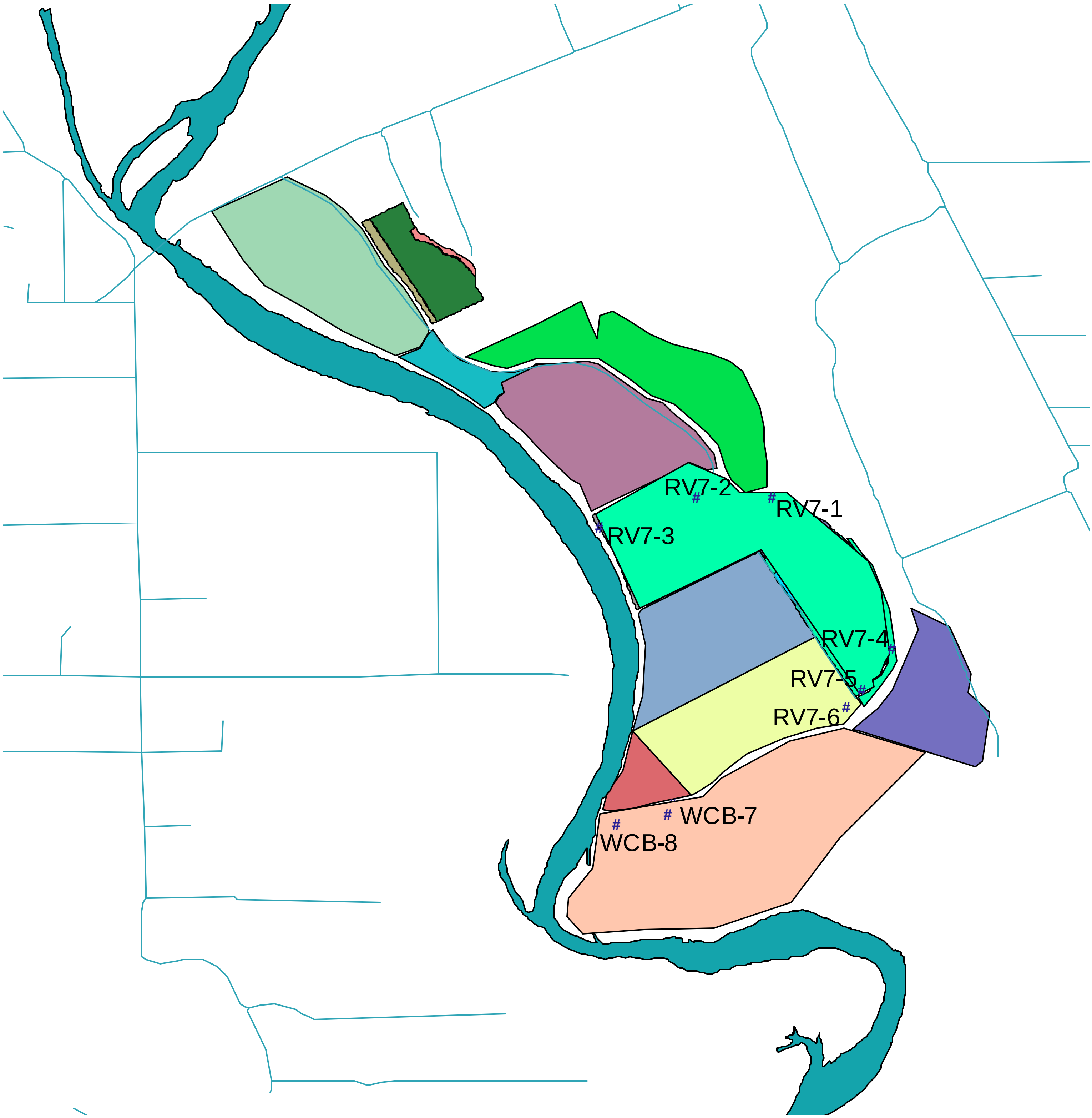


Figure 11. Soil carbon at 24-cm depth. Values are means +/- 95% confidence intervals.



1:3254619125

Groundwater Wells
Roads
1999 Sacramento River Channel

N
W
E
S

Figure 12. Shallow groundwater well locations

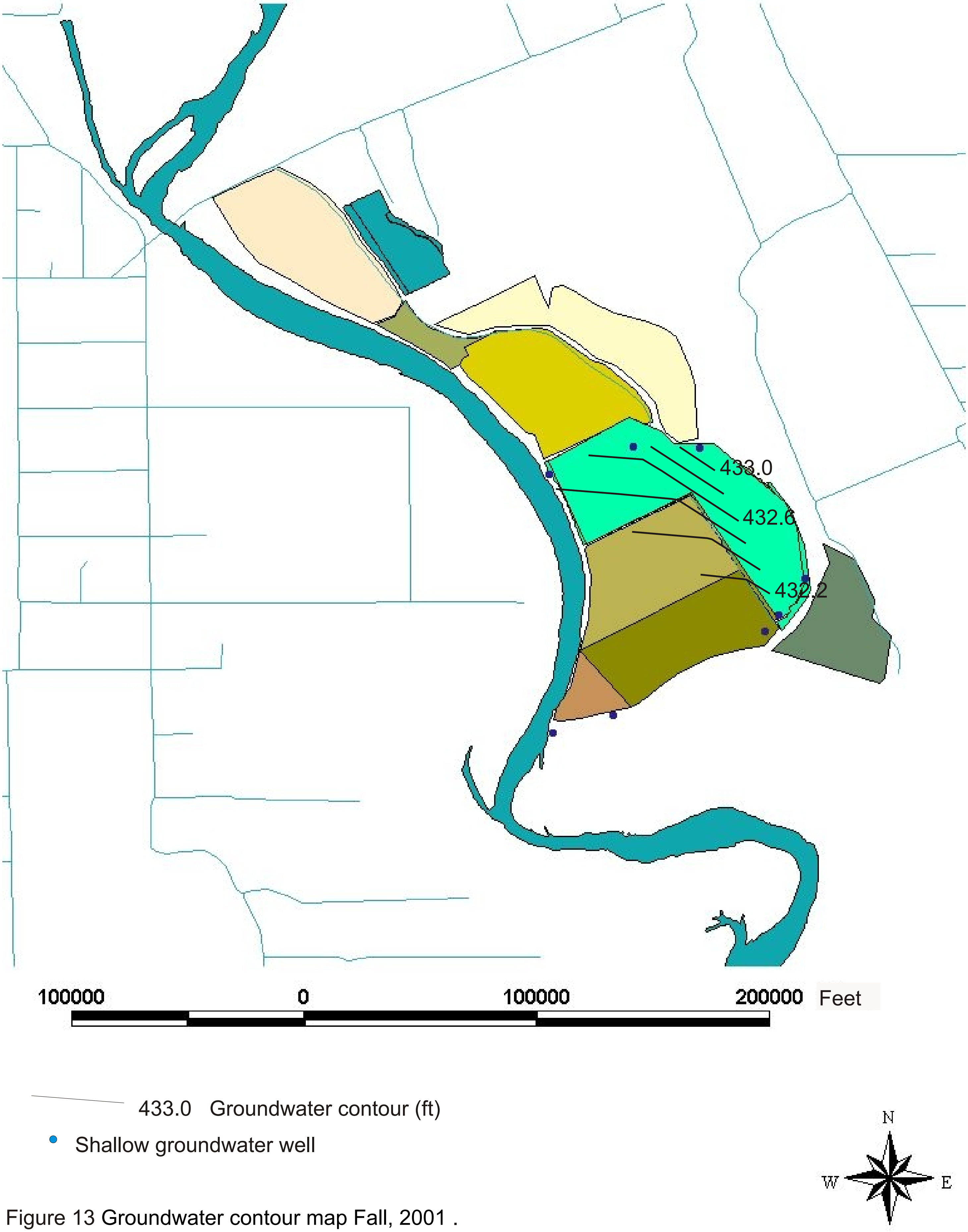


Figure 13 Groundwater contour map Fall, 2001 .

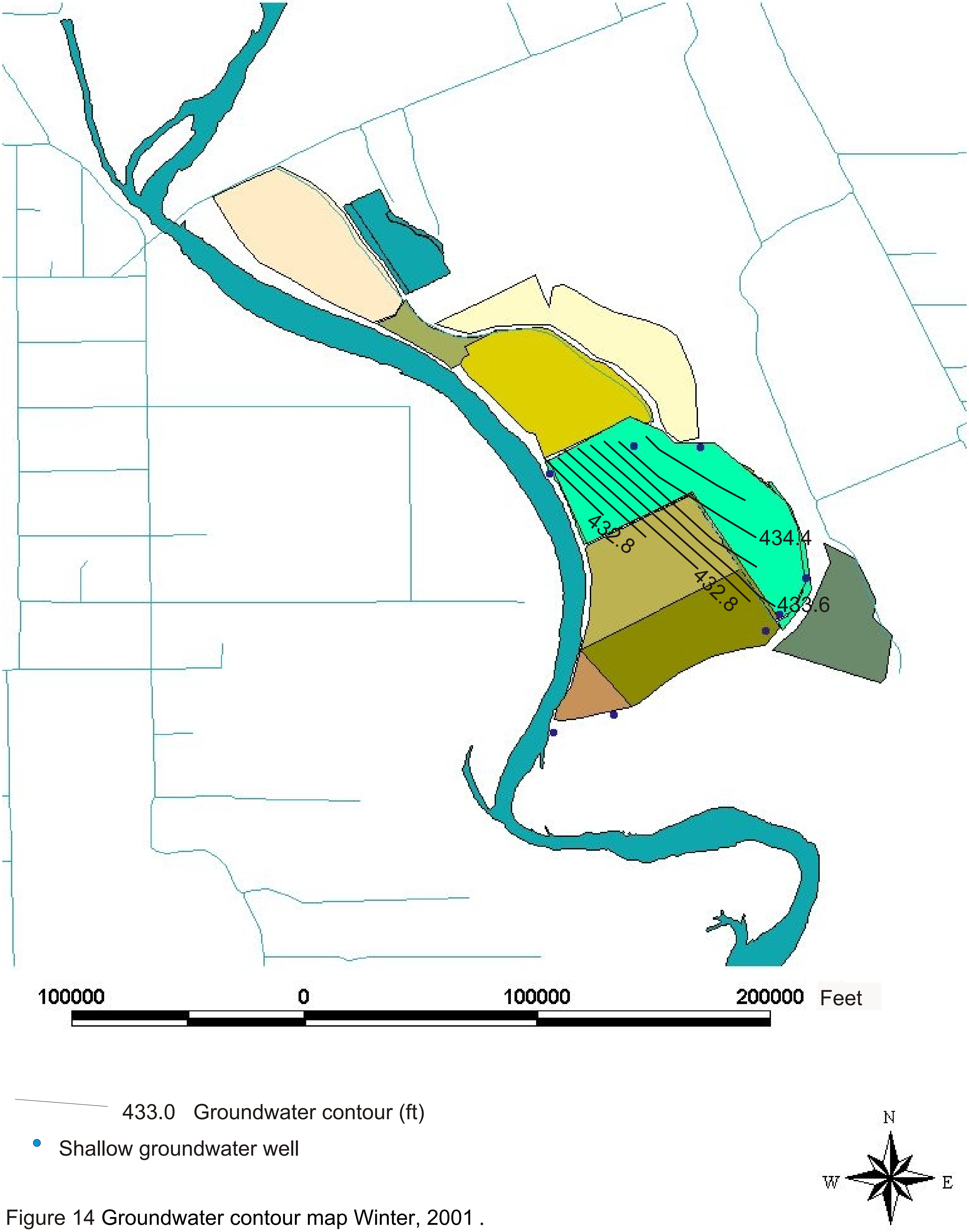


Figure 14 Groundwater contour map Winter, 2001 .

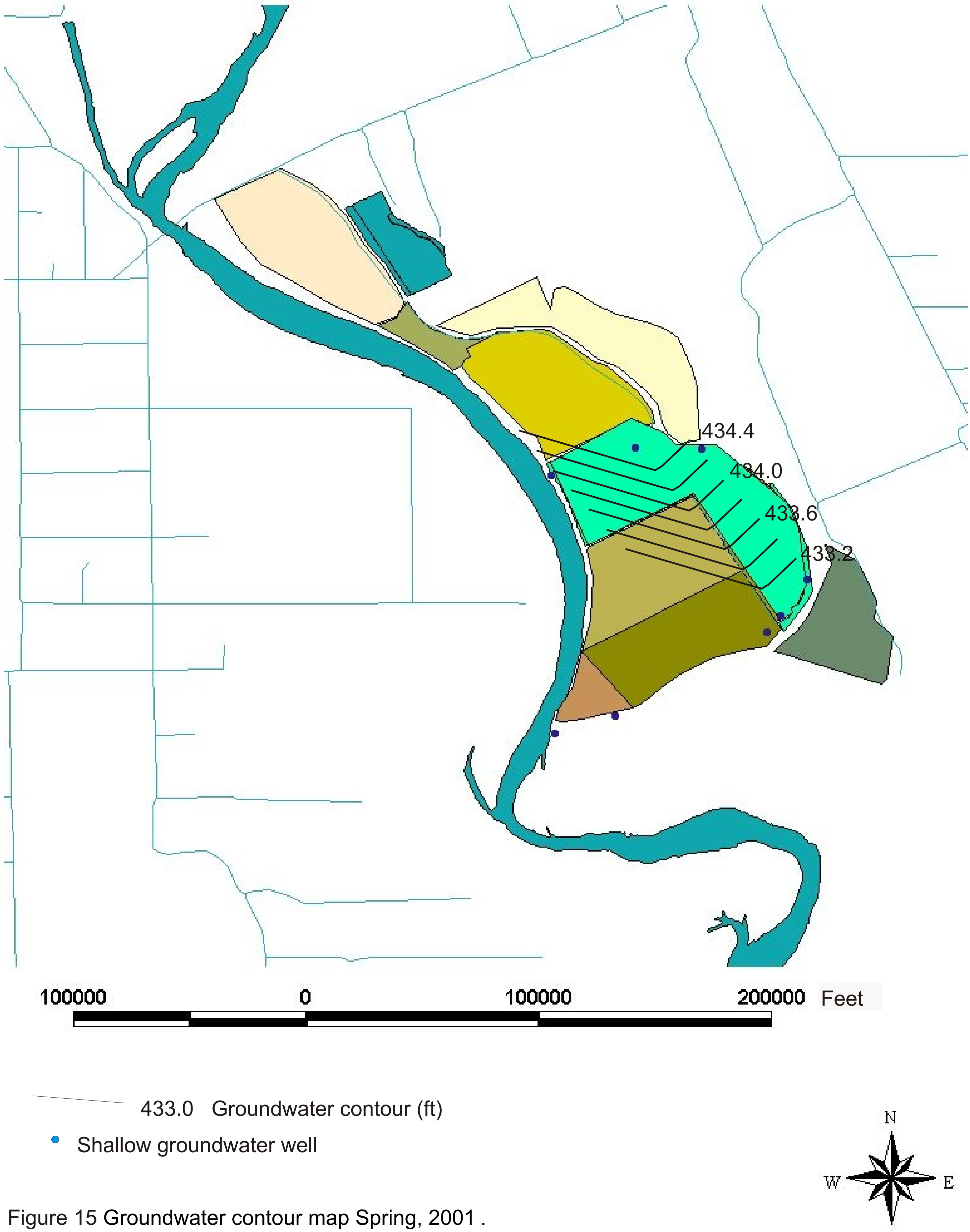


Figure 15 Groundwater contour map Spring, 2001 .

Table 1. Means and standard errors (SE) of soil bulk density at River Vista and the adjacent Wildlife Conservation Board remnant forest. Values are means of five replicates at each date.

Bulk Density (g soil/cm^3)

	WCB		Site II		Site VII	
	Mean	SE	Mean	SE	Mean	SE
Dec '00	1.06	0.03	1.37	0.04	1.29	0.03
Jan '01	1.04	0.03	1.31	0.04	1.28	0.05
Feb	1.09	0.04	1.16	0.06	1.36	0.04
Mar	1.05	0.04	1.25	0.07	1.32	0.07
Apr	1.18	0.04	1.18	0.04	1.27	0.02
May	0.99	0.04	1.14	0.07	1.18	0.05
June	0.94	0.07	1.12	0.03	1.02	0.05
July	0.85	0.07	0.96	0.07	0.85	0.08
Aug	0.77	0.03	0.91	0.05	0.89	0.06
Sept	1.06	0.05	1.24	0.04	1.34	0.03
Oct	1.08	0.02	1.28	0.02	1.37	0.03
Nov	0.92	0.03	1.09	0.07	1.24	0.03

Table 2. Means and standard errors (SE) of percent soil moisture at River Vista and the adjacent Wildlife Conservation Board remnant forest. Values are means of five replicates at each date.

Percent Soil Moisture (% by mass)

	WCB		Site II		Site VII	
	Mean	SE	Mean	SE	Mean	SE
Dec '00	11	0.1	11	0.1	11	0.1
Jan '01	11	0.1	11	1.4	10	0.1
Feb	12	0.2	12	0.1	11	0.1
Mar	13	0.1	12	0.2	14	0.3
Apr	11	0.2	11	0.2	11	0.2
May	13	0.3	11	0.2	10	0.2
June	13	0.6	15	2.1	13	1.7
July	18	0.1	18	0.5	18	0.5
Aug	19	0.4	18	0.6	18	2.1
Sept	9	0.1	9	0.1	9	0.1
Oct	9	0.1	9	0.1	9	0.1
Nov	22	0.6	21	0.1	21	0.3

Table 3. Descriptions of soil pits

Site/Field depth (cm)	Texture	Color	Horizon	Comments
Site II (0-20)	Loamy sand	Brown	A	
Site II (21-70)	Loamy sand	Dark brown	Bw	
Site II (71-160)	Sandy loam	Dark brown	Bw	
Site II (161-200)	Loamy sand	Brown	C	
Site II (201)	Gravel	Brown	C	Refusal at gravel bar
Site VII (0 - 8)	Sandy loam	Dark brown	A	High biological activity
Site VII (9 - 21)	Sandy loam	Brown	Bw	
Site VII (22 - 51)	Sandy loam	Brown	Bw	
Site VII (52 - 105)	Sandy loam	Brown	Bw	
Site VII (106 - 152)	Sandy loam	Brown	Bw	
Site VII (153 - 174)	Sandy loam	Brown	Bw	
Site VII (174 - 190)	Sandy loam	Brown	Bw	Apparent lower limit of biological activity
Site VII (190 - 372)	Sand	Grayish brown	C	
Site VII (372)	Gravel	Grayish brown		Refusal at gravel bar
WCB (0 - 8)	Loamy sand	Dark brown	A	
WCB (9 - 30)	Loamy sand	Brown	Bw	Cambric horizon, weak development
WCB (31 - 49)	Loamy sand	Brown	Bw	Apparent increased bulk density
WCB (50 - 56)	Sandy loam	Brown	Bw	
WCB (57 - 67)	Sandy loam	Brown	C	
WCB (68 - 77)	Sand	Brown	C	Mostly fine - medium sands
WCB (78 - 118)	Sandy loam	Brown	C	Trace evidence of root fibers; slight rust mottling
WCB (119 - 141)	Sandy loam	Brown	C	
WCB (142 - 162)	Sandy loam	Brown	C	
WCB (163 - 252)	Silty loam	Dark brown	C	
WCB (253 - 263)	Silty loam	Gray		
WCB (264 - 312)	Silty sand	Dark brown	C	Buried organic horizon, evidence of intact vegetation fragments
WCB (313 - 343)	Silty sand	Dark brown	C	Buried organic matter ends
WCB (344 - 403)	Silty sand	Dark brown	C	

Table 4. Percent species composition (by dry mass) of annual litterfall by site. p = species present but <.1% of the total.

	Site II	Site VII	WCB
Acer negundo	1.6	4.6	8.6
Alnus rhombifolia	0	0	0.8
Artemisia douglasii	0	0	p
Baccharus pilularis	p	0	0
Juglans californica	0	0	33.8
Platanus racemosa	0.3	40.2	0
Populus fremontii	43.8	31.8	48.1
Quercus lobata	1.0	0	0
Salix lasiolepis	42.6	3.1	0
Sambucus mexicana	2.5	0	0
Vitis californica	0	0	0.3
Other	8.2	20.4	7.7

Table 5. Soil carbon by site

Site/Field depth (cm)	% T.C. per sample	Average % T. C. per horizon	Comments
WCB (0 - 8)	2.174		
"	1.804	2.28	
"	2.852		
WCB (9 - 30)	0.628		
"	0.669	0.65	
"	0.667		
WCB (31 - 49)	0.667		Apparent increased bulk density
"	0.645	0.44	
"	0.013		
WCB (50 - 56)	0.391		
"	0.315	0.34	
"	0.328		
WCB (57 - 67)	0.417		
"	0.373	0.4	
"	0.397		
WCB (68 - 77)	0.263		Mostly fine - medium sands
"	0.227	0.25	
"	0.267		
WCB (78 - 118)	0.357		Trace evidence of root fibers
"	0.447	0.41	
"	0.430		
WCB (119 - 141)	0.375		
"	0.393	0.42	
"	0.489		
WCB (142 - 162)	0.373		
"	0.333	0.37	
"	0.416		
WCB (163 - 173)	0.471		
"	0.453	0.48	
"	0.529		
WCB (262 - 272)	1.373		Buried organic horizon, evidence of
"	1.148	1.17	intact vegetation fragments
"	0.985		
Site VII (0 - 8)	0.769		
"	0.813	0.79	
"	0.792		
Site VII (9 - 21)	0.540		
"	0.491	0.52	
"	0.534		
Site VII (22 - 51)	0.310		
"	0.321	0.31	
"	0.293		
Site VII (52 - 105)	0.372		
"	0.377	0.36	
"	0.338		
Site VII (106 - 152)	0.352		
"	0.318	0.35	
"	0.380		
Site VII (153 - 174)	0.334		
"	0.329	0.32	
"	0.302		

Table 6: Depth to Groundwater

	Monitoring Well Water Levels (meters below ground surface)							
Date	RV7-1	RV7-2	RV7-3	RV7-4*	RV7-5	RV7-6*	WCB-7*	WCB-8*
1/20/2000	3.81							
2/19/2000	2.35							
3/4/2000	1.51							
3/18/2000	1.57							
3/23/2000	2.05							
4/2/2000	2.66							
4/15/2000	2.97							
5/26/2000	3.19							
5/30/2000	3.19							
6/3/2000	3.33							
6/16/2000	3.21							
10/7/2000	3.81							
12/22/2000	3.92							
3/2/2001	3.33							
4/8/2001	3.52							
6/20/2001	3.63	4.58	5.78					
8/21/2001					3.58			
8/24/2001								3.40
11/5/2001	3.03				3.24	1.86		
11/7/2001	3.17	4.62	6.07	0.45	3.25	2.42	3.80	4.51
2/7/2002	3.52	4.47	6.64	2.72	3.24	3.60	4.12	5.53
4/15/2002	3.79	4.53	6.13	2.95	3.38	3.49	4.14	4.68

NOTES: *- Monitoring wells have not been surveyed to a datum.

Table 7: Groundwater nutrient analytical results

Total Kjeldahl Nitrogen (mg/l)

Date	RV7-1	RV7-2	RV7-3	RV7-4	RV7-5	RV7-6	WCB-7	WCB-8
11/5/2001	1.90	0.60	0.04	1.20	0.50	0.60	0.50	0.50
2/7/2002	0.50	0.40	0.60	0.60	0.60	0.40	0.50	0.50
4/15/2002	0.40	0.70	0.70	0.40	0.50	0.40	0.30	0.40
Minimum detection limit (MDL)			**0.2**					

Nitrate (mg/l)

Date	RV7-1	RV7-2	RV7-3	RV7-4	RV7-5	RV7-6	WCB-7	WCB-8
11/5/2001	0.11	8.50	6.97	0.39	7.71	8.30	0.20	0.05
2/7/2002	1.00	7.99	5.94	0.08	6.74	6.13	0.24	0.05
4/15/2002	0.93	9.26	7.52	ND	6.02	6.65	0.54	ND
Minimum detection limit (MDL)			**0.05**					

Nitrite (mg/l)

Date	RV7-1	RV7-2	RV7-3	RV7-4	RV7-5	RV7-6	WCB-7	WCB-8
11/5/2001	ND	ND	0.01	0.01	0.01	0.03	0.01	0.01
2/7/2002	ND	ND	0.01	ND	ND	0.01	ND	ND
4/15/2002	0.01	ND	0.28	ND	0.02	0.02	ND	0.01
Minimum detection limit (MDL)			**0.01**					

Total Phosphorus (mg/l)

Date	RV7-1	RV7-2	RV7-3	RV7-4	RV7-5	RV7-6	WCB-7	WCB-8
11/5/2001	0.79	2.70	0.46	4.92	0.64	0.74	0.99	0.41
2/7/2002	1.02	0.29	0.49	0.53	0.43	0.24	0.15	0.29
4/15/2002	0.87	0.43	0.57	0.66	0.66	0.71	0.08	1.6
Minimum detection limit (MDL)			**0.02**					

Well RV7-1 Results

Date	**Total K. Nitrogen (mg/l)**	**Nitrate (mg/l)**	**Nitrite (mg/l)**	**Total Phosphorus (mg/l)**
3/18/2000	3.80	17.10	0.01	3.87
6/16/2000	3.10	1.99	0.01	6.53
10/7/2000	1.60	0.10	ND	1.31
3/2/2001	1.30	0.14	0.01	0.75
11/5/2001	1.90	0.11	ND	0.79
2/7/2002	0.50	1.00	ND	1.02
4/15/2002	0.40	0.93	0.01	0.87

Table 8: Groundwater field chemistry measurements

Temperature (°C)

Date	RV7-1	RV7-2	RV7-3	RV7-4	RV7-5	RV7-6	WCB-7	WCB-8
11/5/2001	m	m	m	m	m	m	m	m
2/7/2002	16.44	16.56	15.61	15.33	16.50	17.17	14.89	15.11
4/15/2002	14.44	13.89	12.78	11.67	11.11	11.11	10.00	m

Electrical Conductivity (EC)

Date	RV7-1	RV7-2	RV7-3	RV7-4	RV7-5	RV7-6	WCB-7	WCB-8
11/5/2001	280	380	460	210	370	310	90	150
2/7/2002	280	560	540	220	430	460	120	200
4/15/2002	300	480	510	200	360	400	110	350

pH

Date	RV7-1	RV7-2	RV7-3	RV7-4	RV7-5	RV7-6	WCB-7	WCB-8
11/5/2001	6.90	8.51	8.38	7.22	8.22	7.63	7.56	7.10
2/7/2002	6.62	7.11	6.93	6.41	7.08	7.04	7.19	7.15
4/15/2002	6.5	6.79	6.7	6.37	6.68	6.8	6.89	6.32

Well RV7-1 Results

Date	pH	EC	Temp (°C)
3/18/2000	8.65	420	m
6/16/2000	6.96	260	m
10/7/2000	7.93	350	m
3/2/2001	8.24	310	m
11/5/2001	6.90	280	m
2/7/2002	6.62	280	16.44
4/15/2002	6.50	300	14.44

m - missing data