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12 October 2010

TO: Bob Joyce Esq.
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RE: Antelope Valley vadose zone analyses – **FINAL** summary report

Introduction

Seepage of excess irrigation "deep percolation" from the rootzone to groundwater at depths in excess of ~100 feet is an unsaturated (vadose zone) flow process controlled by the soil-water hydraulic or water retention characteristics of the subsurface materials. In the Antelope Valley of southern California, there is an interest in estimating the "travel" or "lag" time required for surface generated recharge or deep percolation associated with alfalfa hay irrigation to reach possible groundwater at depths of 200-250 feet bgs. Information about subsurface geologic materials was limited to available driller logs from across the Valley. Excess irrigation recharge depends on the irrigation schedule developed for the crop grown and prevailing climatic (evapotranspiration, ET) conditions. Antelope Valley is a dry region with fairly high ET as compared to similar regions due to persistent wind conditions. The Valley has historically been recognized for continuous cropping of alfalfa hay; a year-round crop often grown in 4-5 year cycles in southern California desert regions. More recently, production of vegetable crops including carrots, potatoes and onions grown in rotations with winter wheat or barley have become more common across the Valley. This analysis considers the likely irrigation schedules for surface or sprinkler irrigated alfalfa hay production, and carrot/green chop/wheat or potato/green chop/wheat rotations in the Antelope Valley based on rootzone water balances for average ET conditions determined from recent CIMIS data. From the water balance calculations, rootzone seepage "lag" times required to reach hypothetical groundwater at a depth of 225 (or 245 in one case) feet bgs for a range of subsurface geological conditions found in the Valley are determined.

Irrigation Deep Percolation Estimation

Alfalfa hay water use efficiency (WUE) in the Antelope Valley during the past two decades is consistent with that of neighboring desert regions of southern California based on 100% of net ET_o and county hay production records (see Figure 1 and Grismer, 2001). This similar WUE suggests that a similar irrigation schedule as that used in these other regions is reasonable for modeling daily rates of rootzone deep percolation (DP) losses to deep groundwater in the Valley. Here, daily DP, or recharge below the alfalfa rootzone (5 foot thick soil profile), was determined from daily water balance calculations presuming full stand establishment. A similar set of calculations were developed for irrigation of carrot/chop/wheat and potato/chop/wheat rotations in which the active rootzone depth increases from a minimum of 2 inches to a maximum of 24 inches as the crop matures.

Rootzone water balance calculations rely on net ET (daily ET less effective rain fraction), changes in soil-water storage and the management assumption that irrigation is required when soil-water storage falls to <30% of capacity. Net ET was determined from historical CIMIS data available for the Valley and neighboring regions. Soil-water holding capacity was taken from NRCS soils information and assumed to apply across the entire 5 ft soil profile in the case of alfalfa hay production and across a 2-24 inch thick profile for the vegetable/grain production rotations. While the daily water balance indicates a single recharge event on the day of irrigation, such instantaneous recharge is unlikely. Both field and theoretical subsurface drainage studies indicate that rootzone seepage rates decrease exponentially following surface irrigation events. While such variable DP rates are briefly considered here for comparison purposes, the focus here is on the more conservative (in terms of greater lag-times required for DP water reach groundwater at depth) constant DP rates between irrigation events. Thus, daily rootzone DP was assumed to occur at an average rate of the irrigation day DP event divided by the number of days between irrigations across all days between events.

While the actual event DP depth varies little from one irrigation to the next for alfalfa hay production (at the same application efficiency), average DP rates progressively increase and peak mid-summer declining into the winter. DP rates were developed for three different irrigation application efficiencies (AE = Net ET/applied water) of 70, 80 and 90% and two net ET$_o$ values of 90% and 100%. While often in desert hay production there is a small mid-winter pre-irrigation or leaching irrigation that is applied to restore stand vigor and possibly leach accumulated rootzone salinity, in only the greatest annual application schedule (100% net ET$_o$ case) was one small (2.3 in) January leaching irrigation presumed in determining the daily DP rates.

For the vegetable crop rotations, DP rates are somewhat more variable and smaller as compared to that for alfalfa hay production. Initial planting irrigations result in individual recharge events that are much greater than the DP rate averages during the remainder of the growing season. In addition, one complete rotation cycle of approximately 14 months duration rather than 12 is considered though lag times are computed with respect to the one-year period for comparison purposes. Application efficiencies for the vegetable crop rotations are fairly high, roughly 85% for the entire rotation and 81-84% for the carrot or potato crops individually. Table 1 summarizes the annual irrigation, AE's and resulting DP values considered in the vadose zone modeling.

Figure 1. Desert alfalfa hay water use efficiency for the Antelope Valley as compared to neighboring regions (adapted from Grismer, 2001).

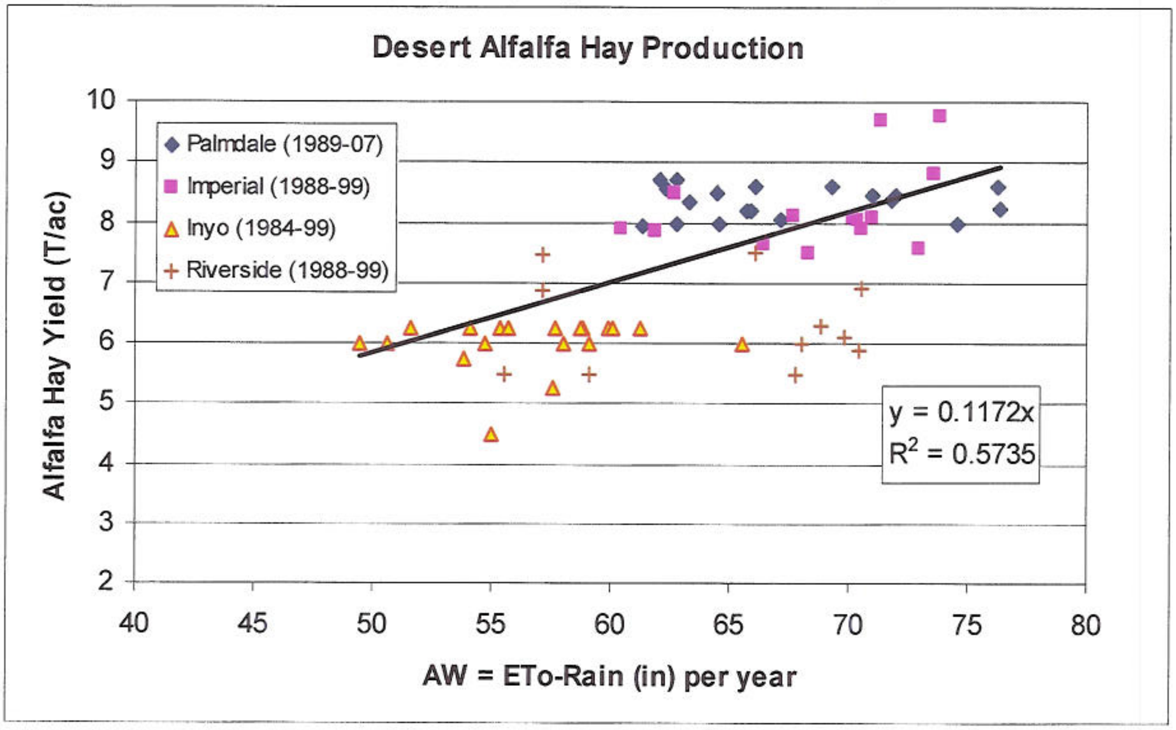


Table 1. Summary of average annual alfalfa hay and vegetable crop rotation irrigation scheduling information used in vadose zone modeling.

Water Use	AE (%)	Annual AE (%)	Irrigation depth (in)	Annual Irrig. (in)	Annual DP (in)
100% net ET_o + pre-irrigation	70	69.0	6.0	96.0	29.8
90% net ET_o, no pre-irrigation	70	71.0	6.0	84.0	24.4
80% net ET_o, no pre-irrigation	80	78.9	5.4	75.6	16.0
70% net ET_o, no pre-irrigation	90	88.7	4.8	67.2	7.6
100% net ET_o + planting-irrig.	84	Carrots*	0.3-2.4	41.5*	6.7*
100% net ET_o + planting-irrig.	81	Potatoes*	0.3-2.4	44.2*	8.3*

* Values for growing season only of 140 days after planting on March 1st.

As irrigation technology and ET management (e.g. availability of CIMIS data) improved in the past several decades, it is likely that AE's also improved and that the 100% net ET_o case no longer applies in the Valley, however, it sets an upper limit of likely DP rates that may have occurred historically. Alfalfa hay production results in regular cuttings several times each year that lower actual crop water use or ET, such that the 90% ET_o on an annual basis has been shown to apply (Grismer, 2001). Crop coefficients for the vegetable crop rotations vary with crop growth stage and methods described in FAO-56 were used here to determine crop water demands. From the averaged CIMIS data, the annual ET_o applied here was 68.2 in and the annual net ET_o allowing for 50% effective rainfall was 66.2 in. At full hay production, 100% net ET_o and the 69% annual AE efficiency, DP from irrigated hay production is 2.48 ft/yr. In contrast, at 90% net ET_o, no leaching irrigation, two fewer seasonal irrigations and an annual AE of 71%, the DP from irrigated hay production is 24.4 in/yr, or 2.03 ft/yr. Similarly, at AE's of 80 and 90% that may be associated with pressurized irrigation, DP rates of 1.33 and 0.63 ft/yr, respectively, can be expected, though the latter is unlikely.

Figure 2 illustrates the DP hydrographs from alfalfa hay production for the irrigation scheduling conditions summarized in Table 1, while Figure 3 compares the average and exponentially decreasing DP rates for the 90% ET/70% AE case. Finally, Figure 4 illustrates the variation in daily DP rates for the carrot and potato crop rotations analogous to those for alfalfa hay production in Figure 2.

Figure 2. Daily DP rates associated with the different irrigation schedules for alfalfa hay production summarized in Table 1.

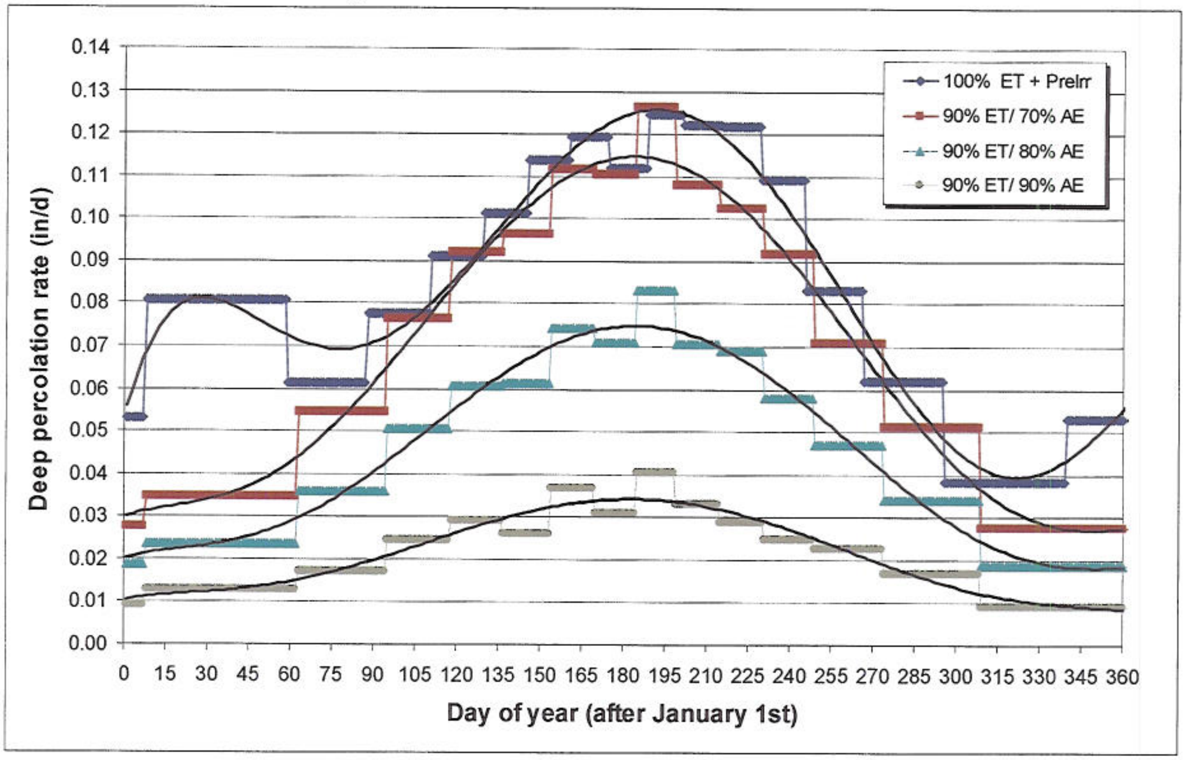


Figure 3. Averaged and exponentially decreasing daily DP rates for the 90% ET/70% AE alfalfa hay irrigation schedule (note that annual DP is the same, though maximum daily DP rates are much greater in the variable DP case).

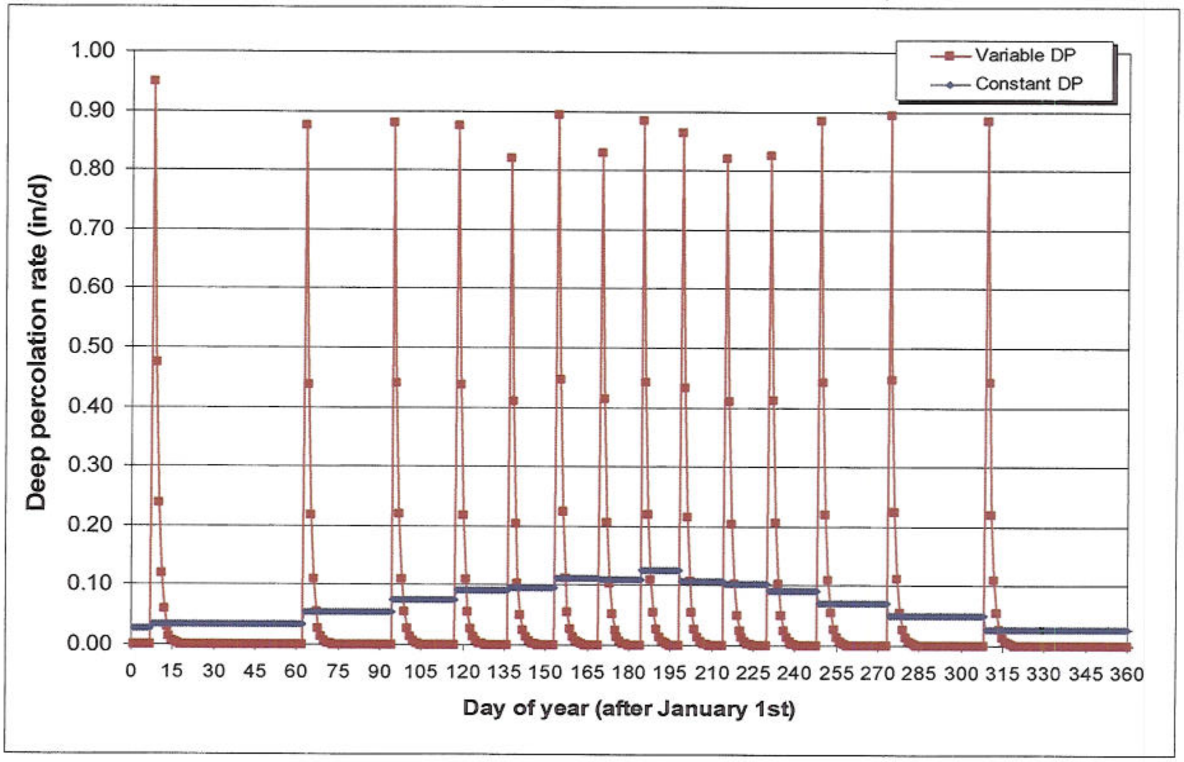
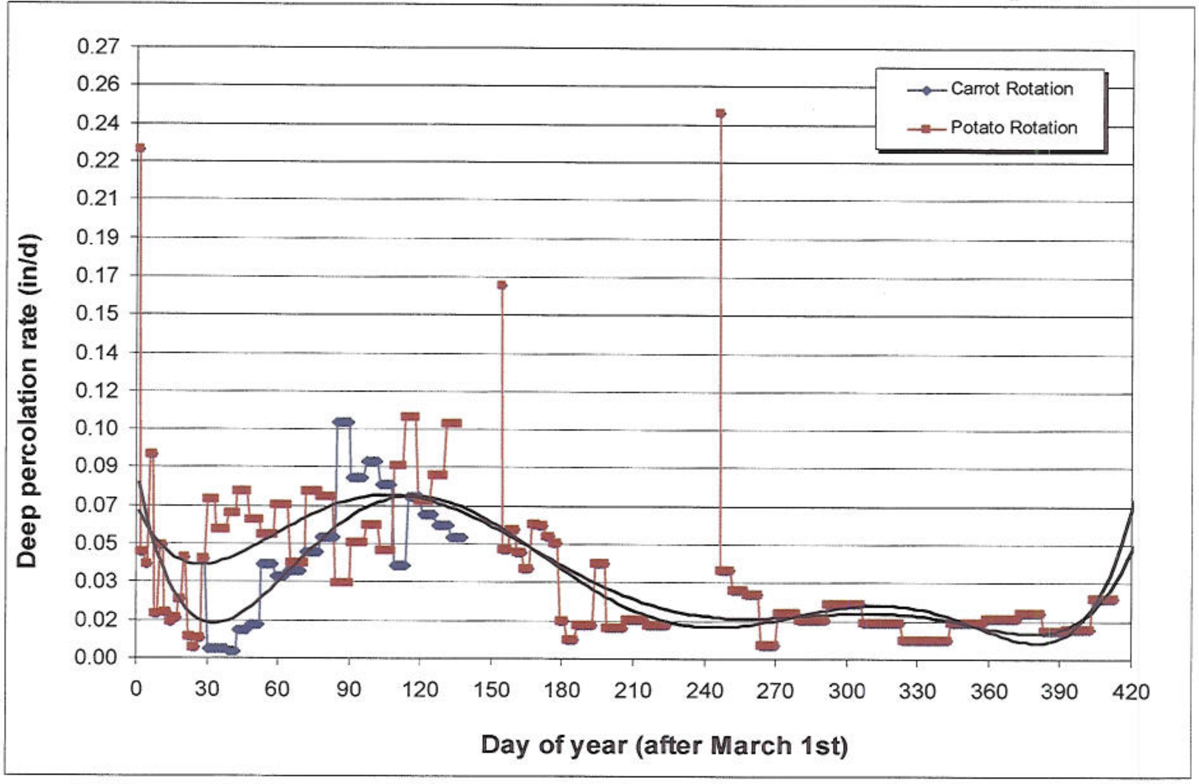


Figure 4. Daily DP rates associated with irrigation schedules for vegetable crop rotations.



Vadose Zone Seepage Modeling

The lag time required for irrigation water to reach a specified depth depends on the application frequency, subsequent rootzone DP rates and subsurface soil-water hydraulic characteristics (related to soil textures and bulk densities) and depth of interest. Here, the Richards equation for one-dimensional vertical soil-water transport is used assuming Green-Ampt or "square-wave" water content profiles with time and depth following the approach of McWhorter & Nelson (1979). This equation is solved using a variable time-step and assuming successive quasi-steady-state conditions, possible due to the very small soil-water (Darcy) fluxes associated with rootaone DP rates on a daily and annual basis. Flow below the rootzone is assumed to be at capillary pressure heads (i.e., matric suctions) greater than the substrata displacement pressure heads, h_d, typically small values for sandy materials. When solving the Richards equation for the lag times to depth, the resulting equations can be simplified such that the parameter requirements for this model are few; a major advantage of this approach considering the lack of soil-water hydraulic parameter availability for the Valley substrata. The key parameters required in the unsaturated flow model are summarized and described in Table 2.

Table 2. Summary of unsaturated flow equation parameters used in vadose zone modeling (see Grismer, 1986).

Parameter Description	**Symbol**	**Normal Range**	**Modeled Values**	**Comments**
Initial volumetric water content	θ_i	0-0.4	θ_r	Substrata assumed near dry or gravity drained
Residual vol. water content	θ_r	0.05-0.2	NA	Gravity-drained value
Maximum vol. water content	θ_m	0.3-0.45	NA	90-95% of porosity
Specific yield (%)	S_y	3-25	$(\theta_m-\theta_r)*100$	Estimated from driller logged soil textures
Displacement pressure head (in)	h_d	2-35	NA	Measure of largest inter-connected pore size. Vadose flow assumed at $h_c>h_d$
Saturated hydraulic conductivity (in/hr)	K_s	orders of magnitude	0.1-20	Depends on h_d; here determined from S_y
Pore-size distribution index	λ	1-5	1-3	1=broad pore-size range to 5= near singular pore-size

The required unsaturated flow model information about the shallow aquifer hydraulic characteristics was estimated from the driller log information and the S_y values assigned to each log classification (e.g. sands, clays, etc). Using the S_y values assigned for each aquifer material by layer, the K_s of that layer was determined from the USBR Drainage Manual relationship between S_y and K_s (USBR, 1993). Relative to the parameters outlined in Table 2, uniform-grained sands generally have large K_s, S_y and λ values with small θ_r and h_d values. In contrast, clay-loam like materials are characterized by small K_s, S_y and λ values with larger θ_r and h_d values. The unsaturated flow hydraulics are controlled in part by the porous media λ values for which a value of two has often been adopted for most agricultural loam soils and has an otherwise theoretical basis from pore-channel hydraulics considerations. All λ values at three or larger are effectively equivalent and are associated with sandy materials having a very narrow pore-size-distribution and potentially large S_y. Flow in unsaturated soils is somewhat counter-intuitive in that fluxes are more limited, or rates can be much smaller in sands as compared to say clay loams at equivalent capillary pressure heads greater than h_d of the sand.

Vadose Zone Seepage Processes and Lag-times to Depth

Six different subsurface porous media textures that more-or-less comprise the range of shallow aquifer conditions found in the Valley based on the driller-log information reviewed are considered in the vadose zone modeling for seepage from alfalfa hay production. Two different subsurface textural profiles were used for the vegetable crop rotations; a uniform sand and a composite profile developed from the driller logs for the Kotchian ranch area. First, the seepage and associated lag times for alfalfa hay production are considered followed by that for the vegetable crop rotations.

Accumulated alfalfa hay production DP seepage though a progressively coarsening substrata is considered to illustrate the key processes associated with the DP advance to depths bgs of 245 ft. Next, irrigation recharge questions associated with net ET_o fraction, AE and variable DP rates (i.e. Figure 3) and their effects on lag times for the simplest, most conservative sand-only case are considered. This is followed by a discussion of the lag-times associated with substrata profiles that are representative of the Valley. Finally, model parameter sensitivity is considered so as to envelope the likely range of DP lag-times to a depth of 225 bgs that might be expected in the Valley.

Figure 5 illustrates the irrigation (90% ET/70% AE) recharge wetting front (cumulative seepage) through a mid-range textured aquifer material (loamy soils) that progressively coarsens with depth in 40 ft increments (S_y increases from 10-14% and λ from 2.0 to 2.4). The greater average daily DP rates occurring mid-summer, or more than 100 days after the first irrigation, and the earlier starting, but slower DP waters combine with later faster DP waters resulting in greater accumulations relatively earlier than that suggested by the 5ft bgs cumulative DP. As a result, the center of mass (~12.2 in cumulative DP) travels much faster than the entire mass due to “tailing” of very slow moving waters. This “tailing” is accentuated with increasing depth. The staggered, or “stepping” of the cumulative recharge is a result in part from the step-like structure of the DP rate hydrograph as illustrated in Figure 2. Figure 6 shows the lag times between surface application and appearance at depth of the DP center of mass and the total DP mass as taken from the data used in Figure 5. Lag times for the center and total DP masses to reach more than 200 ft deep are 1.7 and 6 years, respectively. The long “tailing” of the cumulative seepage at long times suggests that the center of DP mass timing is probably a better indicator of when the wetting front reaches a particular depth of interest as compared to the time for the total DP mass to reach depth. However, an advantage of plotting the cumulative DP mass with time is that any fraction of the DP mass considered relevant can be selected to assess the particular lag-time of interest.

Figure 5. Cumulative recharge as a function of depth and time for midrange aquifer characteristics (90% net ET/ 70% AE).

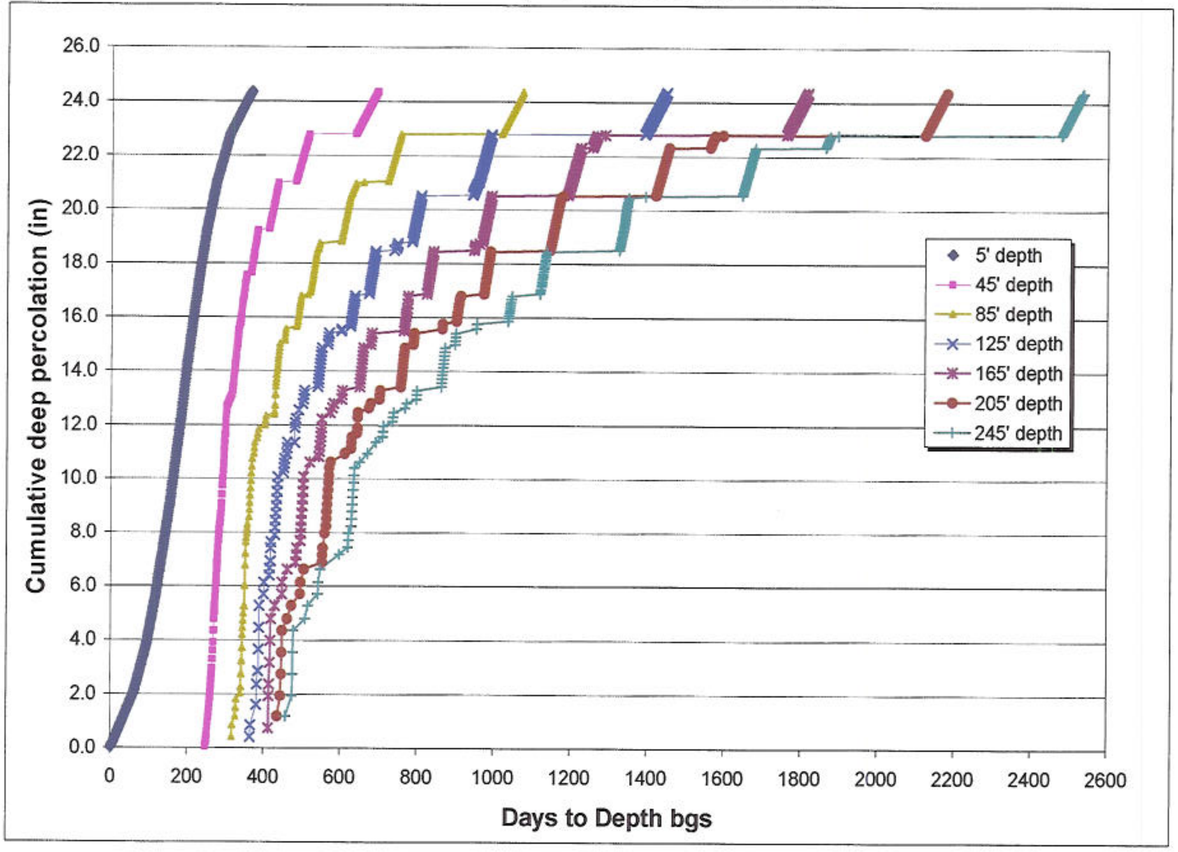
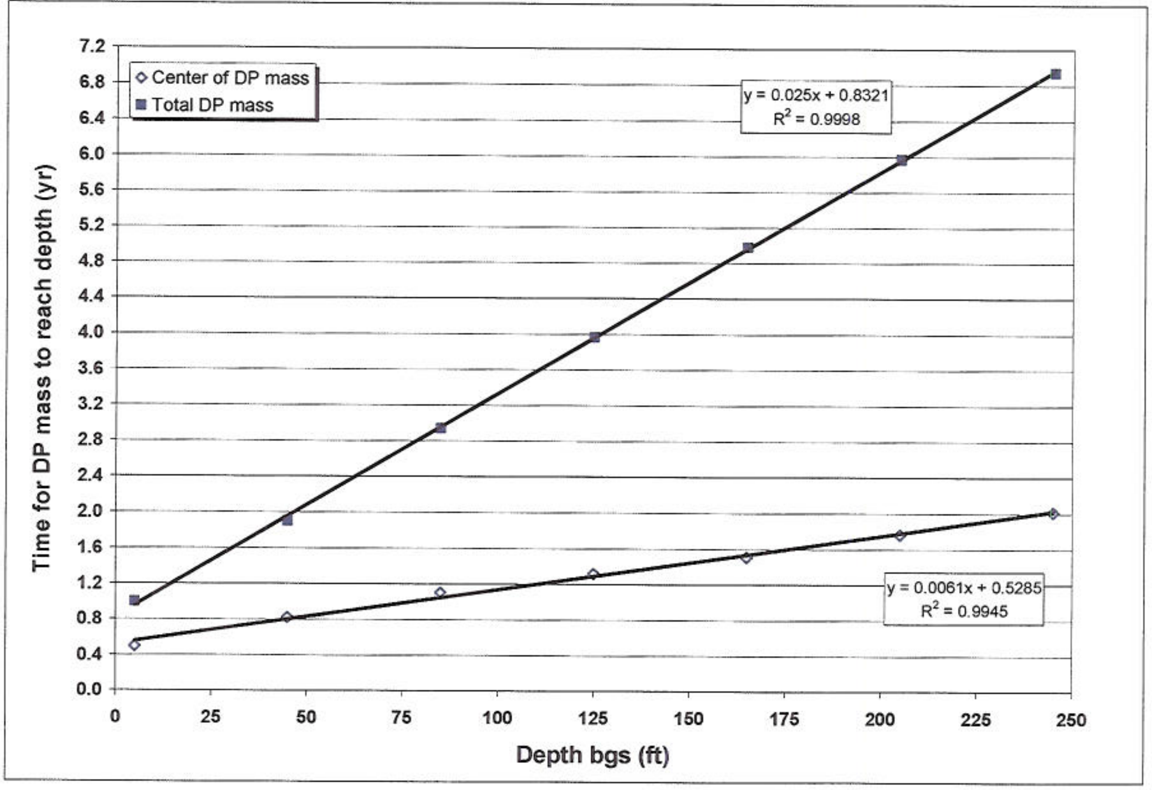


Figure 6. Lag times for midrange aquifer characteristics (90% net ET/70% AE).



Alfalfa Hay DP Recharge Lag-times to Depth for Valley Subsurface Conditions

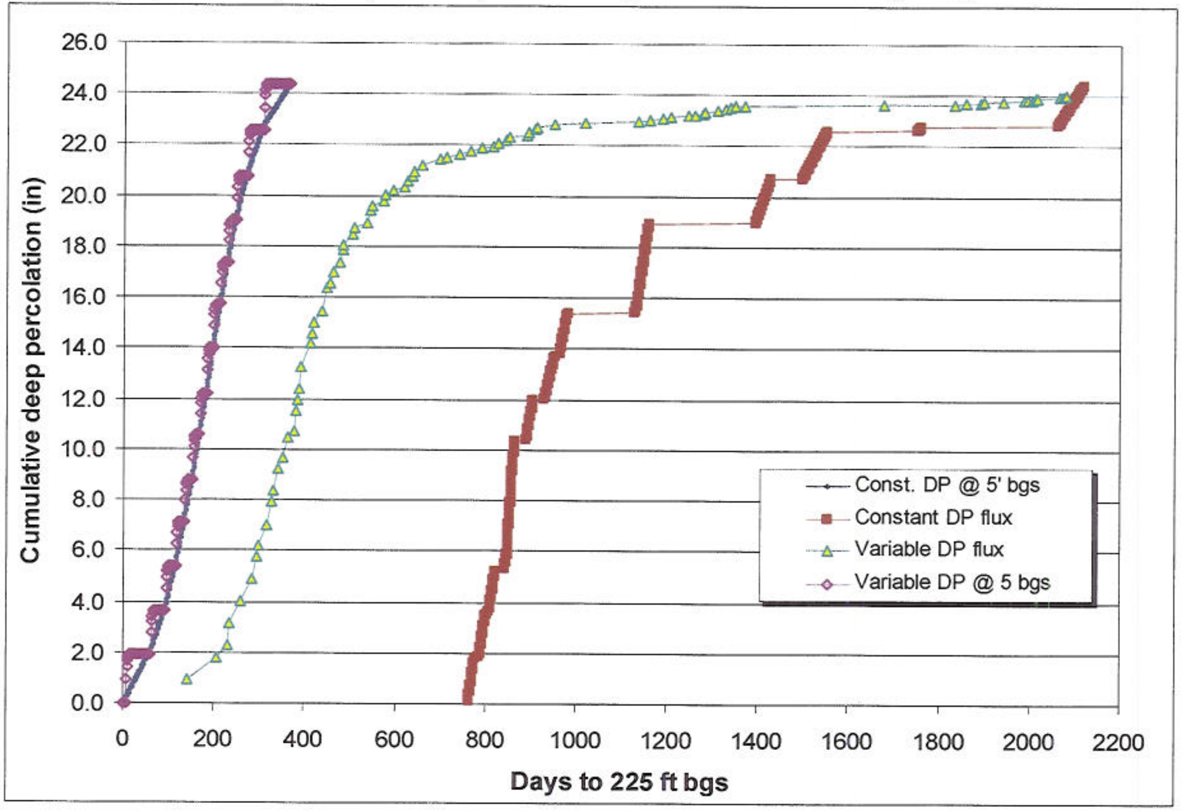
Based on the driller log information reviewed, typical unsaturated aquifer layers that may represent the range of subsurface conditions across the Valley and for Kotchian Ranch were assembled and these profile characteristics are summarized in Table 3. With the exception of the alternating layer and coarsening loam profiles having depths of 245 ft, all depths modeled were 225 ft bgs.

First, the effect of exponentially decreasing DP rates immediately following alfalfa hay irrigation events is considered in order to estimate the impact of the "pulsed" recharge as compared to "stepped" average recharge on possible lag-times to 225 bgs. Figure 7 illustrates the cumulative DP curves for the simplest subsurface case of sand only porous media under conditions of averaged and variable daily DP associated with 90% ET/70% AE irrigation conditions. The initially much greater DP rates (see Figure 3) from the "pulsed" as compared to the average recharge rates enable DP to reach depths of 225 ft bgs much more rapidly; however, the exponentially decreasing much slower DP rates that follow the initial "pulse" increase the cumulative DP mass "tailing". As a result of both effects, the pulsed recharge DP center of mass reaches 225 ft bgs nearly 1.5 years earlier than predicted for the average DP rate, but the time required for 99% of the pulsed DP recharge to reach 225 ft bgs is 3 years greater than that for the average DP rate. In both cases, however, 98.5% of the DP recharge reaches the 225 ft depth in 4.75 years after irrigation application. As the average DP recharge rates are more consistent with the quasi-steady flow modeling assumption and they result in more conservatively (greater) estimated lag-times, the remaining analyses employ the average DP rates as shown in Figures 2 or 4 only depending on the crop.

Table 3. Representative subsurface texture and hydraulic property profiles used in vadose zone modeling of seepage.

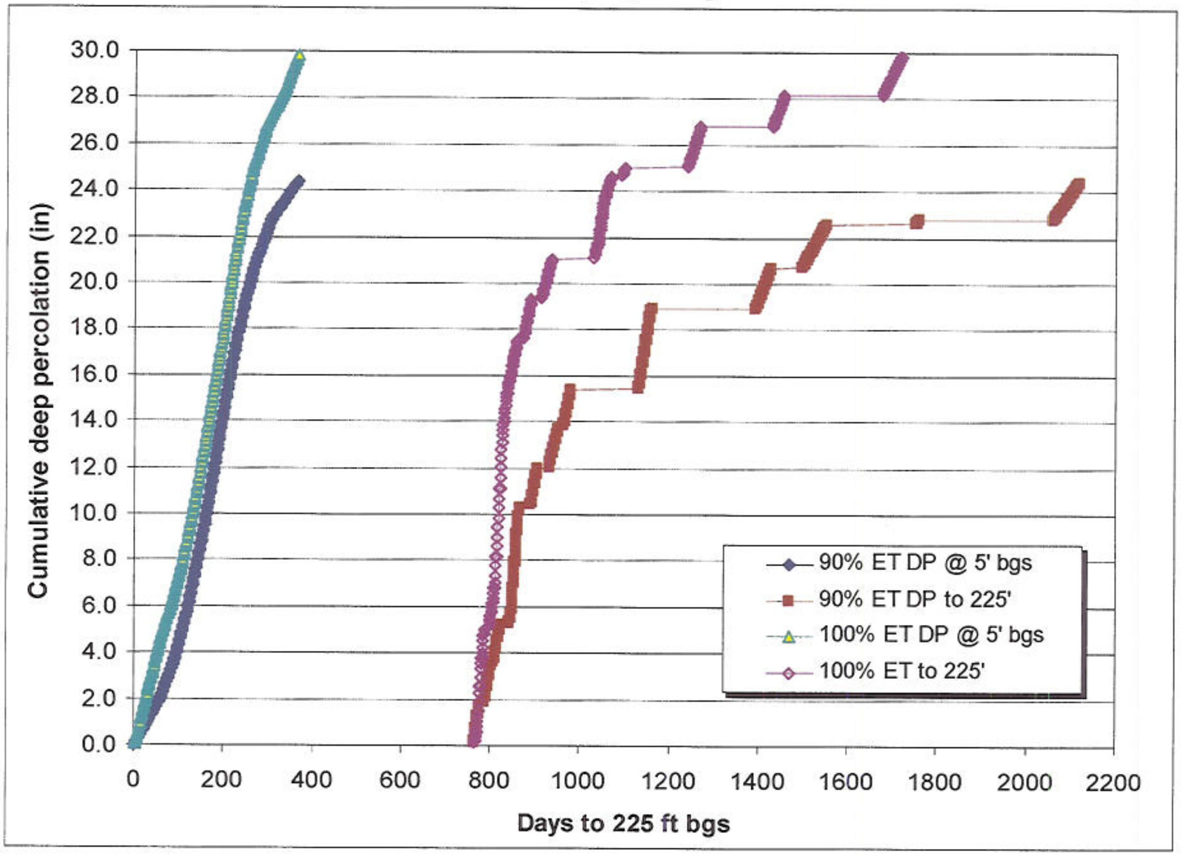
Crop	**Profile**	**Aquifer materials & layer thickness**	**S_y/λ Values**
alfalfa	Sand only	5' soil/220' sand	20/3.0
alfalfa	Clay/sand	5' soil/120' clay/ 100' sand	3/1.1 & 20/3.0
alfalfa	Sand/clay	5' soil/120' sand/ 100' clay	20/3.0 & 3/1.1
alfalfa	Sand/clay/sand	5' soil/20' sand/100' clay/ 100' sand	25/3.0, 3/1.1 & 25/3.0
alfalfa	Alternating loam/clay/sand/cl/snd	5' soil/80' loam/20' clay/20' sand/40' clay/80' sand	10/2.0, 3/1.1 & 25/3.0
alfalfa	Progressive coarsening loams	5' soil/40' loam/coarsening by 40' intervals to s. loam	10/2.0, 11/2.1, 12/2.2, 13/2.3 & 14/2.4
rotation	Sand only	2' soil/223' sand	20/3.0
rotation	Soil/clay loam/sand	20' soil/80' c. loam/125' sand	15/2.0, 10/1.2 & 20/3.0

Figure 7. Cumulative alfalfa hay recharge as a function of time for a sand-only aquifer subjected to pulsed (variable) and averaged DP rates from hay irrigation.



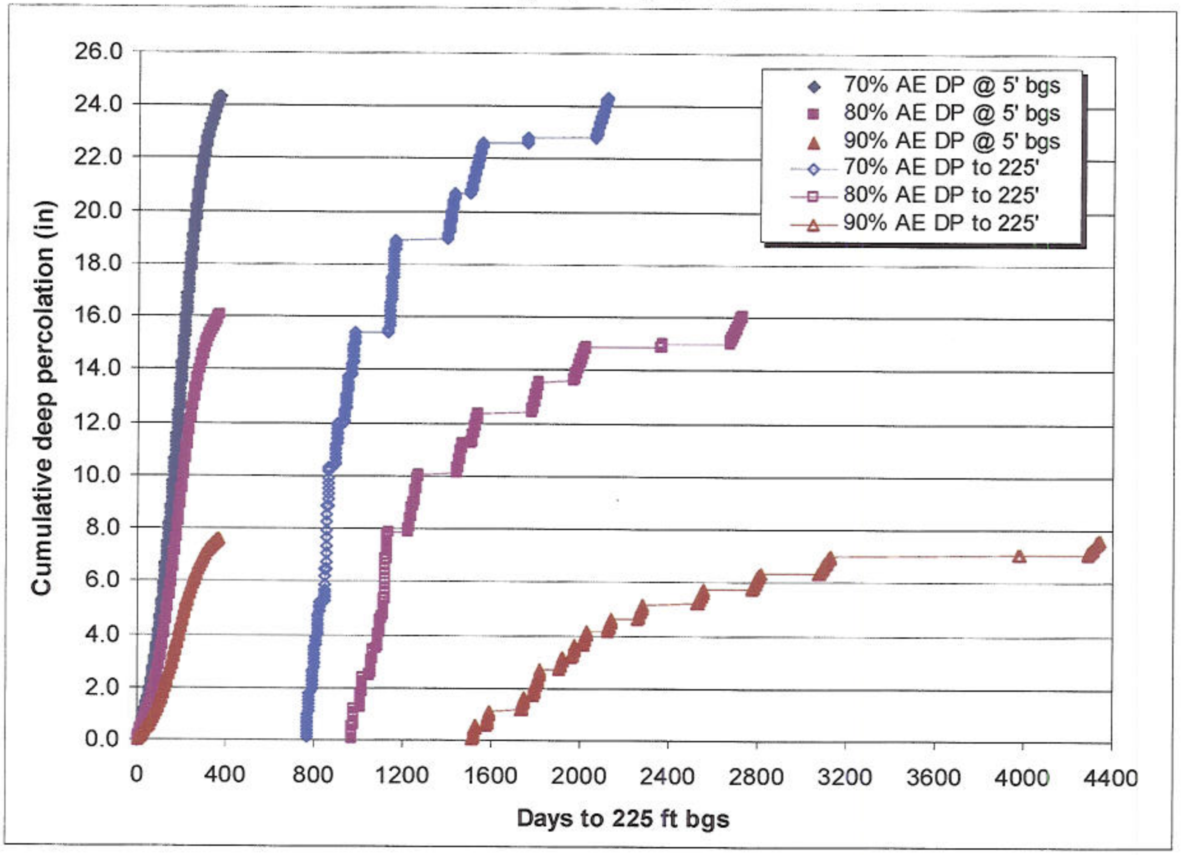
The second issue related to irrigation DP recharge is the effects of net ET_o fraction and AE on DP lag times to depth. Examining the net ET_o fraction question first and again using a sand only subsurface profile, Figure 8 illustrates cumulative DP as functions of time for the combinations of 100% ET_o/70% AE and 90% ET_o/ 70% AE. Not surprisingly, the greater DP rates and overall DP from the 100% net ET_o condition results in smaller lag times overall with the centroid and total DP masses for the 100% net ET_o case arriving at 225 ft bgs approximately 3 and 13 months, respectively, prior to that for the 90% net ET_o case. Interestingly, both net ET_o conditions result in the same initial time to contact the 225 ft bgs depth as a result of similar maximum DP rates from the rootzone. As noted above, irrigation at 100% net ET_o with a pre-irrigation may have been more common in decades past, but is not expected to occur presently, thus, subsequent analyses largely focus on the 90% net ET_o case.

Figure 8. Cumulative alfalfa hay DP recharge as it depends on net ET_o fraction at 70% AE for a sand-only aquifer profile.



Irrigation AE has the effect of reducing the net rootzone DP through smaller applications designed to more closely match crop water needs. Again, using the sand-only subsurface profile, Figure 9 illustrates the effect of AE on cumulative DP lag times to 225 ft bgs. Decreasing recharge rates by increasing AE from 70% to 80% and 90% results not only in smaller net annual DP, but increases centroid DP mass arrival times at 225 ft bgs by almost 10 and 36 months, respectively. However, irrigation application efficiencies on a seasonal basis of near 90% are not likely in practice and potentially unsustainable in terms of salt leaching so this analysis retains focus on 70% AE case in the discussion below.

Figure 9. Cumulative alfalfa hay DP recharge as it depends on AE for 90% net ET_o in a sand-only aquifer profile.



As different substrata have differing soil-water hydraulic properties, lag times to depth depend in part on the layering complexity of the subsurface; from sand only to sand/clay and alternating sand/clay combinations. Starting with the simplest case of a sand only profile, Figure 10 illustrates the cumulative DP or wetting front advance to depth for sand-only, clay/sand and sand-clay subsurface profiles. As noted above and seemingly counter-intuitive, lag-times for DP cumulative masses to reach depth are greatest for the sand-only, followed by the sand/clay and then clay/sand profiles. The thickness of each layer and its relative location in the depth sequence is important toward estimation of lag-times as thicker clay layers enable greater DP rates to then enter sand layers below. Figures 11 and 12 illustrate this effect in part through display of the cumulative DP for the sand-clay-sand and loam-clay-sand-clay-sand profiles, respectively. Overall, relative to the sand-only profile, clay layering results in smaller DP mass lag-times.

Figure 10. Cumulative alfalfa hay DP recharge as a function of depth and time for sand-only and clay/sand aquifer profiles.

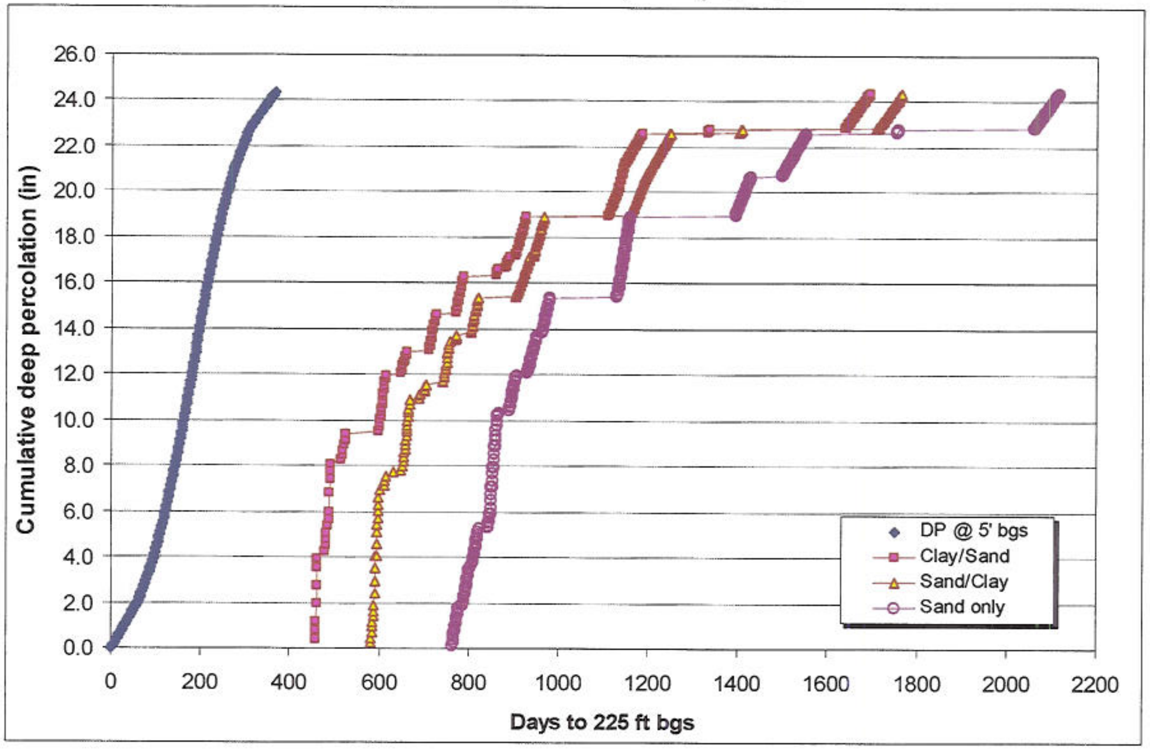


Figure 11. Cumulative alfalfa hay DP recharge as a function of depth and time for sand/clay/sand aquifer profile (90% net ET$_o$).

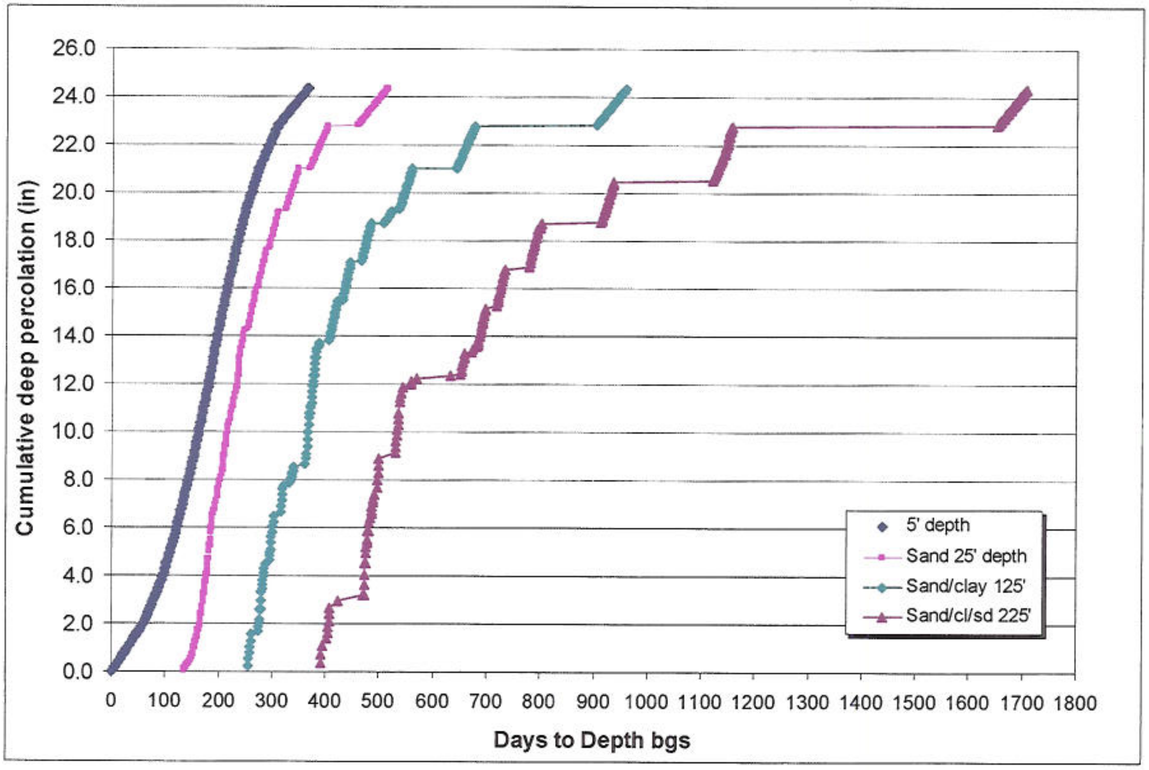
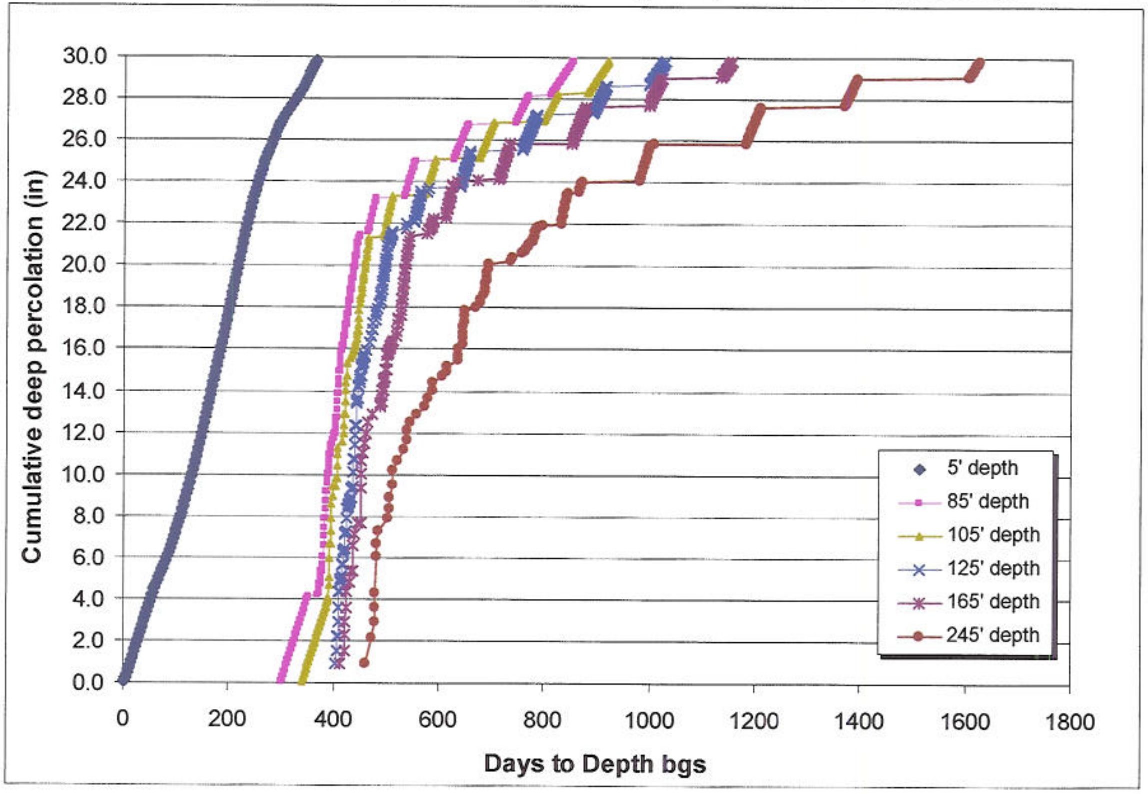


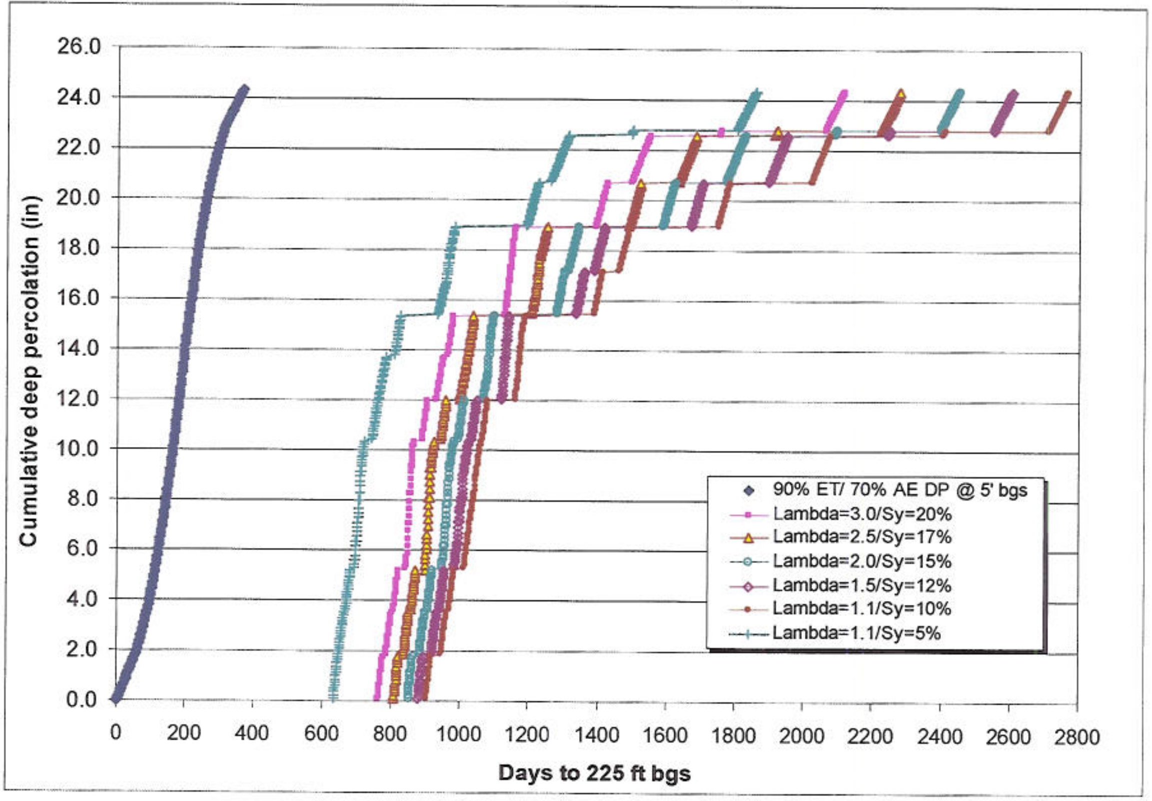
Figure 12. Cumulative alfalfa hayDP recharge as a function of depth and time for alternating loam/clay/sand/clay/sand aquifer profile (100% net ET_o).



<u>Sensitivity of Hay DP Recharge Lag-times to Depth to Subsurface Soil-water Parameters</u>

Aside from the depth to groundwater assumed, S_y (thus, K_s) and λ are the two key subsurface soil-water parameters affecting determination of lag times to depth from the solution of the Richards equation. From Figures 9 and 10, it appears that when considering layers of tight clay materials with very small S_y, K_s and λ values (i.e., S_y=3%), lag times decrease relative to the sandy profiles. However, it is also possible to have soil textures with larger S_y values though small λ values, typically associated with loamy materials. Figure 13 shows the effects of changing S_y and λ values in uniform subsurface profiles on predicted lag times. Note that as subsurface material textures coarsen towards larger S_y and λ values for all S_y >10%, DP mass lag times progressively increase, however, at S_y <10%, DP mass lag times decrease substantially. This suggests that particular combinations of S_y and λ values that may be associated with similarly textured materials can result in prediction of different lag times for S_y ~10%. Nonetheless, overall DP center of mass lag times range from 1 to 3 years (see Table 4).

Figure 13. Cumulative alfalfa hay DP recharge as a they depend on subsurface hydraulic parameters (90% net ET_o).



Vegetable Rotation DP Recharge Lag-times t for Sand & Ranch Subsurface Conditions

Common vegetable crop rotations across the Antelope Valley include onions, carrots and potatoes, and for comparison purposes, the ~14-month rotations that included carrots or potatoes, green chop and winter grains were considered in the vadose zone modeling. These crops differ from an established alfalfa stand as they are sprinkler irrigated and variable and more shallow active rootzones associated with water balance calculations. After establishing the basic processes controlling lag times in the analyses above for alfalfa hay production, only two subsurface soil profiles are considered in the determination of lag times from vegetable crop rotations. Again for comparison purposes, a sand-only profile is used to set the upper limit of lag times likely from crop rotation deep percolation. The second profile is a composite from three driller logs taken at the Kotchian Ranch. Water balance determinations of irrigation schedules were similar to those used at the Kotchian Ranch in the past decade. Note that in Figure 4 the starting date is March 1st rather than January 1st and that the bulk of the overall recharge is associated with vegetable production in the first 140 days after March 1st. Following the vegetable production there is a short fallow period of no DP recharge then light irrigations associated with the green crop, a second short fallow period and then the initial irrigations to establish the winter wheat/barley crop. Calculated water use between the two rotations for averaged net ET conditions differed slightly from that measured; calculated average water use for potatoes was greater than measured while carrots was less. Nonetheless, water use records from the Ranch suggest that the irrigation schedule resulting in the DP recharge rates shown in Figure 4 are reasonable and likely slightly under-estimate actual rates encountered in the field.

Analogous to Figure 10 for alfalfa hay production, Figures 14 and 15 illustrate the cumulative DP recharge lag times associated with the carrot and potato crop rotations, respectively. As suggested by Figure 4, the bulk of DP recharge occurs early with long "tailing" of the cumulative DP as a result of fallow periods and light irrigations associated with the green and grain crops following harvest of the carrot or potato crops. Cumulative DP recharge through the Ranch as compared to the sand-only profile occurs more quickly during the vegetable growing season as a result of the thick clay loam layer, but then slows comparatively much later in the rotation. Overall, however, the effects of subsurface material layering on DP center of mass or total mass lag times are relatively minor. Based on the recharge associated with a single calendar year rather than the 14-month rotation period, the lag times of DP center of mass recharge from the vegetable crop rotations are slightly greater on avergae, though similar in range to those from alfalfa hay production. Total DP mass recharge lag times for the vegetable rotations are 1-3 years greater on average than those from alfalfa hay production due in part to the likely greater irrigation application efficiencies and the shorter growing season (140 days *vs.* 365 days) resulting in significant recharge.

Figure 14. Cumulative carrot rotation DP recharge as a function of depth and time for sand-only and Ranch composite subsurface profiles.

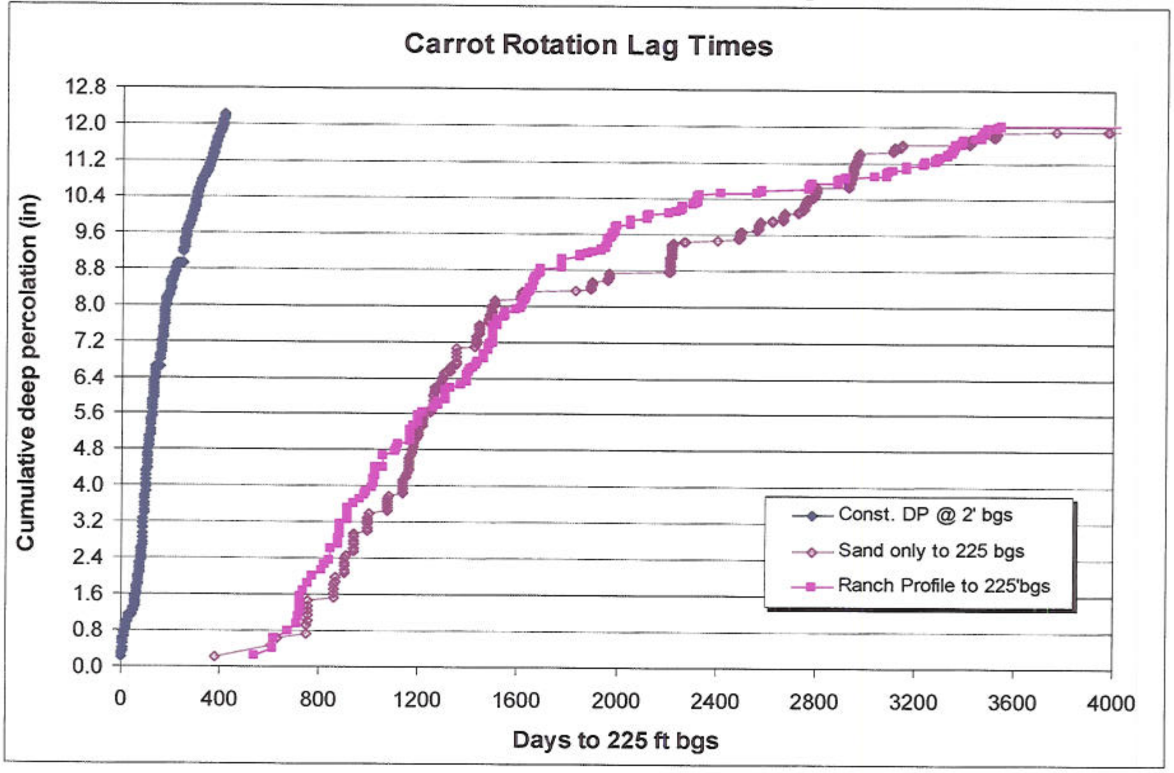
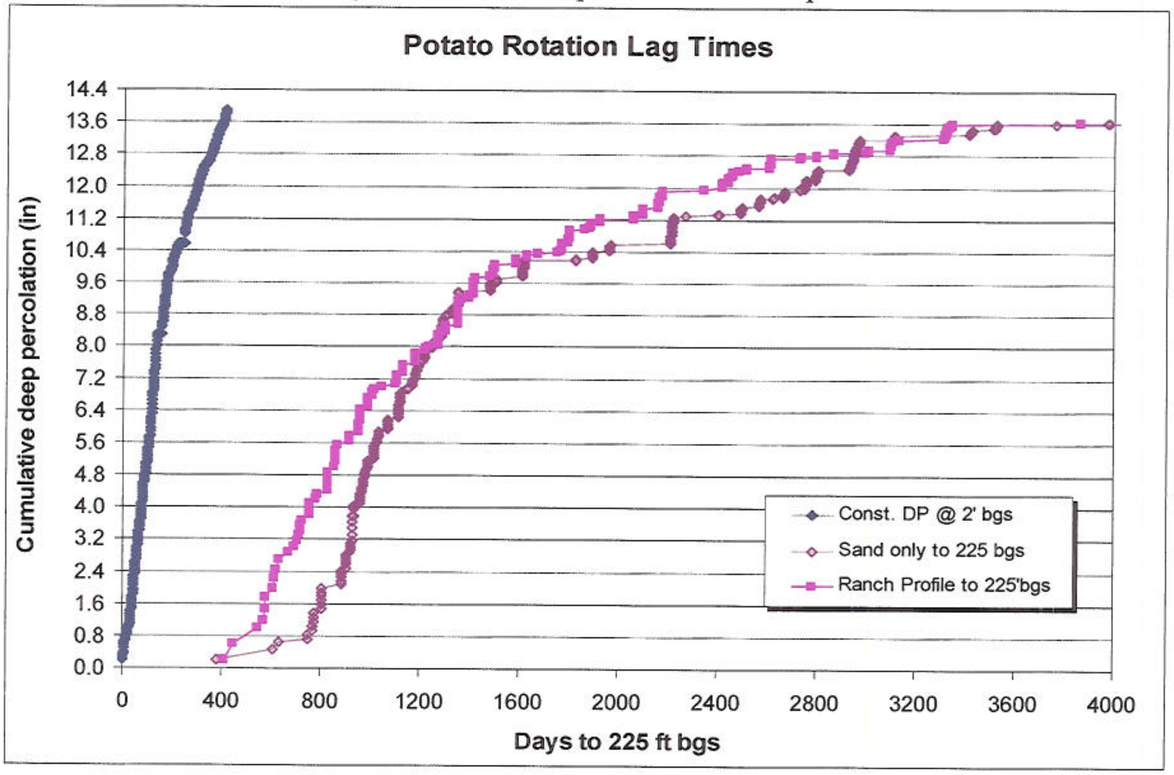


Figure 15. Cumulative potato rotation DP recharge as a function of depth and time for sand-only and Ranch composite subsurface profiles.



Summary & Conclusions

Subsurface recharge through unsaturated substrata is a complicated process in concept that is controlled largely by the seepage rates and also by the soil-water hydraulic properties of the intervening layers between surface and groundwater. Considering one-dimensional vertical deep percolation recharge from irrigated alfalfa hay, the times required for cumulative masses of DP recharge to reach depths of up to 245 ft bgs were determined. Lag-times for differing irrigation recharge conditions associated with varying ET and crop production as well as several different substrata profile cases were determined so as to ascertain the likely range of agricultural recharge lag times that may have occurred, or are occurring across the Antelope Valley. Table 4 summarizes the DP recharge center and total mass lag times in years for all the different combinations of irrigation and substrata cases considered here. Lag times to 225-245 ft bgs for DP mass centroids roughly range from 1-3 years, while significant "tailing" of slow percolating waters increases the total DP mass lag times for up to about 8 years after surface application in all but the 90% AE alfalfa hay production case through coarse sand. For the layered substrata conditions more likely to occur across the Valley, total DP mass lag times to 225 ft bgs are 3-4 years following surface application for alfalfa hay production and ~7 years for vegetable crop rotations. The greater total DP mass lag times associated with the vegetable crops is due to the shorter growing season and net smaller DP masses as compared to that for continuous alfalfa hay production. Comparison of DP center of mass lag times is likely more appropriate in terms of estimating groundwater recharge timing impacts from agriculture. Presence of clay layers in the subsurface profile tends to decrease DP lag times to depth as compared to sand-only profiles. Overall, the vadose zone flow calculations results suggest that surface recharge from irrigation of established alfalfa hay stands or vegetable crop rotations to unconfined aquifers at depths of 225 ft bgs in the Antelope Valley;

(a) is time dependent within the year and should not be considered as a single instance of recharge to the aquifer,

(b) smaller DP recharge rates associated with improved irrigation application efficiencies increases lag times,

(c) recharge hydrograph peaks or center of mass "pulses" most likely have occurred and occur in less than 3-4 years, particularly in decades past when application efficiencies were likely much smaller than that currently, and

(d) recharge lag times depend in part on the irrigation schedule, or DP recharge timing.

Table 4. Deep percolation (DP) lag times for the range of alfalfa hay and vegetable crop rotation irrigation and substrata conditions expected to occur in the Antelope Valley.

Crop	Description	Net ET_o% /AE%	Total Depth (ft)	S_y/λ Values	DP Masses Centroid (yr)	DP Masses Total (yr)
alfalfa	80'loam/20'cl/20'snd/40'cl/80'snd	100/70	245	10/2.0, 3/1.1 & 25/3.0	1.21	3.45
alfalfa	Coarsening sandy loam to fine sand	90/70	245	See Table 3	1.52	5.95
alfalfa	20' sand/100' t.clay/100' sand	100/70	225	25/3.0, 3/1.1 & 25/3.0	0.94	2.76
alfalfa	20' sand/100' t.clay/100' sand	90/70	225	25/3.0, 3/1.1 & 25/3.0	1.05	3.67
alfalfa	120' tight clay/100' sand	90/70	225	3/1.1 & 20/3.0	1.28	3.64
alfalfa	120' sand/100' tight clay	90/70	225	20/3.0 & 3/1.1	1.55	3.84
alfalfa	220' sand	100/70	225	20/3.0	1.81	3.71
alfalfa	220' sand	90/70	225	20/3.0	2.06	4.80
alfalfa	220' sand	90/80	225	20/3.0	2.87	6.40
alfalfa	220' sand	90/90	225	20/3.0	5.04	10.9
alfalfa	220' coarse sand	90/70	225	25/3.0	1.91	4.50
alfalfa	220' sand	100/70	225	20/3.0	1.79	3.71
alfalfa	220' sand	90/70	225	20/3.0	2.06	4.80
alfalfa	220' fine sand	90/70	225	17/2.5	2.24	5.24
alfalfa	220' sandy loam	90/70	225	15/2.0	2.43	5.72
alfalfa	220' loam	90/70	225	12/1.5	2.57	6.14
alfalfa	220' clay loam	90/70	225	10/1.1	2.68	6.58
alfalfa	220' clay loam	90/70	225	8/1.1	2.33	5.75
alfalfa	220' clay	90/70	225	5/1.1	1.59	4.10
alfalfa	220' tight clay	90/70	225	3/1.1	1.03	2.68
alfalfa	220' sand – pulsed DP	90/70	225	20/3.0	0.58	7.79[a]
carrot[b]	223' sand	100/84		20/3.0	3.09	7.53
carrot[b]	18' soil/80' c. loam/125' sand	100/84		15/2.0, 10/1.2 & 20/3.0	3.12	8.19
potato[b]	223' sand	100/81		20/3.0	2.74	7.12
potato[b]	18' soil/80' c. loam/125' sand	100/81		15/2.0, 10/1.2 & 20/3.0	2.39	7.48

[a] 99% of total mass.

[b] crop rotations of carrots or potatoes followed by green chop and winter wheat or barley.

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