Item 8: Cease & Desist
2/1/06

WILLIAM C. BIANCHI, PhD
4375 San Simeon Creek Road
Cambria, CA 93428
805-927-8006

Selica Potter
Acting Clerk to the Board
State Water Resourcees Control Board
P.O. Box 100
Sacramento, CA 95812-0100

Dear Ms. Potter,

Involved in the solution to the San Joaquin Valley's salt problems is the Bureau of Reclamation proposal to discharging selenium-laced drain water into Estero Bay, San Luis Obispo County. I presume that this will be part of your discussions. Not being certain that my comments to the EIS on this problem have been included in their submission to the Board, I have included them now.

In particular I am concerned about the quality of the water that will be collected and discharged to all of the alternatives that have been suggested, and I have included papers that were produced by our research in the field in western Fresno County when this area would become the Westlands Irrigation District when state water became available This area may be developing as the primary source of salinity that will have to be dealt with in the future.

I would like to call your attention specifically to the information we developed at our lab from core samples taken for us by the Department of Water Resources at the time that they were evaluating the soil profiles to depth along the proposed alignment of the canal, as well as some specific sites that we used in our research. The Dyer paper included, demonstrates the massive quantities of native nitrates that occur at depth yet above the perching layers that are causing the shallow drainage problem in the lower portions of the alluvial fans. These areas are now out of production.

Enclosed is my evaluation of the quantities of nitrates that could be mobilized in the future as irrigation continues in the area. The Bureau recognized this problem back in the 1960's, but I don't believe they appreciated the inventory of nitrates that are present in the vadose zone.

Also included is a study paper indicating that even prior to state water being delivered to the Westlands District, perch water tables were present in the area.

I have also included a list of the papers that we produced – a number of which pertain to the problems you are experiencing in the San Joaquin Valley.

Sincerely,

William C. Bianchi

William C. Bianchi, PhD

Inventory of NO_3^- in Panoche Profile:

From figure 1 + figure 5 of attached Dyer paper:
Aprox range NO_3^- 175 to 250 me/l in soil soln
Field moisture content ≈ 10% by volume

$1\ Cft^3_{soil} = 28.32\,l$

$28.32l \cdot .10 = 2.832l \times 175\ me/l = 495.6\ me/ft^3$
$\times 250\ me/l = 708.0\ me/ft^3$

$495.6\ me \times 62\ mg/eq = 30727.\ mg/ft^3$
$708.0\ me$ $43896.\ mg/ft^3$

$30.7\ gm/ft^3 = \times 2.205\times10^{-3} = 0.069\ lbs/ft^3$
$44.9\ gm/ft^3 = 0.099\ lbs/ft^3$

100 ft profile contains 6.9 to 9.9 lbs NO_3^-
1 ac foot of profile contains $43560 \times 0.069 = 3005.6$ lbs
$\times 0.099 = 4312.4$ lbs

Therefore the inventory of NO_3^- that is native to the Panoche soil deep profile is massive and only now being mobilized in the groundwater flow on the shallow clay perching layers.

William C. Bianchi Ph. D
4375 San Simeon Creek Road
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805-927-8006

8/18/2005

Gerald D. Robbins, Jr.
U. S. Bureau of Reclamation, Mid-Pacific Region
2800 Cottage Way, MP-720
Room, W-2930
Sacramento, CA 95825

Dear Mr. Robbins,

Please find enclosed my comments on the EIS for the San Luis Drainage Feature Re-Evaluation. Included are four pages of comments and conclusions, plus my resume, and publications, of which some relate to your project.

Relative to the in-Valley alternatives, when I was working under J. N. Luthin as a Research Assistant at the University of California, Davis, one of the applied research activities was associated with the salinity build-up in the Imperial Valley. The Extension Service and University had test plots where high furrows on saturated fields were accumulating surface salts which were of sufficient thickness to be harvested. This could be a technique to isolate and remove salts, particularly now when perforated plastic conduits are readily available. As you well know, air quality issues are involved in areas like the West side where wind velocities are significant and can lift anything off of open soil surfaces (Owens Lake is an excellent example of this). The high-bed furrows could well modify the particle lift significantly.

I wish you well in your endeavors. It was 45 years ago that we were thinking of this eventual conclusion to irrigation on the west side.

You will note from the publications list that Bill Johnston, late of Westlands Irrigation District, was out there with us on the West side, and he should confirm some of the conclusions that I have reached in my analysis of the EIS.

Sincerely,

William C. Bianchi

William C. Bianchi, Ph. D

Cc: Shirley Bianchi, Chair
Chair, San Luis Obispo County Board of Supervisors

Comments on the Draft Environmental Impact Statement for San Luis drainage - May 2005
Directed at the Ocean Disposal Alternative
William C. Bianchi Ph.D. (Resume attached)

OCCEAN ALTURNATIVE - COSTS

Section ES 3.2 - states that Reclamation's preferred alternative "is expected to be one of the In Valley alternatives". Having no access to the Plan Formation Report Addendum within this EIS as received brings into question justification for this conclusion and its origin. Thus one must assume that the Ocean Disposal Alternative could be of equal priority.

Section ES 3.2.6 Table ES 6 - one must assume that the minimum economic path for the ocean outfall would be to discharge the entire 97,000 acre-feet of collected water to the ocean. This will eliminate the regional reuse facilities which are not justified in light of the minor agricultural productivity, the increase cost and the added O&M costs. Federal subsidization is doubtful. This lowers Reclamation's projected costs of Ocean Disposal Alternative down to $484 mil. Well below any of the other alternatives.

ALSO;

Section 2.11.4.3 - this section acknowledges that the Ocean Disposal Alternative is the least expensive of the Out of Valley alternatives as evaluated. Yet it is indicated " in a second analysis" that In Valley disposal was still very close to the least cost Out of Valley alternative regardless of the amount of land retirement". In Section 2.15 - Preferential Alternatives, it states that the environmentally preferred alternative is defined as the one that promotes the "national environmental policy", whose "policy" and what national interests? Where in the suite of evaluations do the negative aspects of the Ocean disposal offset its low cost?

ALSO;

Section 2.12 - mitigation, easement acquisition costs for the Ocean Discharge Alternative pipe line are significant, yet costs ignored.

ALSO;

Table 2.13.1- estimates the energy consumption of the Ocean Disposal Alternative as 81.4 giga watt-hrs/yr. Where does this fit into the current power grid and California's production problems and were are the energy cost projections over the 50yr life of the project? This can not be defined as having "no significant effect" (Table 2.13.2).

OCEAN ALTURNATIVE - PIPELINE ALIGNMENT

Figure 5.1-8- indicates that the pipeline enters the watershed that feeds into Whale Rock Dam, part of the fresh water supply for the area. The drain water quality fits the definition of a hazardous waste and thus requires State regulation as such (so enter this into Table 4.1,pg 4-2, line 14&15) because of the potential for entry into the region's domestic surface and groundwater supply from possible pipeline failure. This also pertains where the pipe crosses the Salinas River and its tributaries that feed the groundwater use for domestic water supply.

ALSO;

Section 9.2.8 and Appendix H- Geology and Seismicity will have to be updated to relate new seismic data to the engineering of the pipeline from the Salinas River to Point Estero. The San Simeon seismic event of 12/23/03 resulted in major vertical displacement and slope failure along the proposed alignment. This is not covered in the current review. This will result in new construction standards and so costs must be revised accordingly.

ALSO;

The alignment chosen traverses some of the least stable slopes in the Santa Lucia Mountains. Here the experience on the stability of engineering structures is well documented and physically exhibited by Cal-Trans on HY46 west. The creation of "appropriate slope design" has yet to be achieved here even after many years. The HY46 project costs of "mitigation" will be continuing, very large and economically significant.
ALSO;
Should there be a pipeline rupture on the slopes of the Santa Lucia the results would be disastrous not only to the water supply, but also land forms and the view shed, very important to the tourist based economy of the area.

OCEAN DISCHARGE IMPACTS

Section 5.2.2-Modeling Method and Assumptions for Ocean Discharge make the definition of the performance of the ocean discharge plume uncertain at best. The assumed concentration of the effluent is qualified in Table D2-1 with the footnote "For purposes of this analysis the design TDS concentration of 19,000 ppm was assumed to be equivalent to the effluent salinity. Although this correlation is not perfect the assumption is reasonable given the preliminary nature of this analysis". This conditional statement also relates to the other constituents and designated pollutants that would be discharged in the effluent at point of release. This uncertainty reflects the fact that little historic data has been collected for a prediction. This brings into question the existing and projected future concentrations in the collected drain water. To correct this at the point in time requires ranges in concentration to be estimated, tabulated and used in this draft so that the reader is kept aware of how the degree of uncertainty relates to the conclusions drawn.
ALSO;
The same uncertainty is apparent in the description of how the pollutant plume would perform at the outflow structure. The wide spread existing oceanographic data collected for interpretation is recognized as site-specific and "they may not perfectly represent conditions at the proposed outfall location". "However, although neither a detailed long-term site-specific monitoring program nor a hydrodynamic modeling study of the project area has been conducted to date, it is our qualitative assessment that current data use for this analysis are reasonably representative of the diffuser site conditions"(Emphasis added). Important here also is that overlapping plumes in the near vicinity of the discharge point have not been treated, in particular that of the Moro Bay City – Duke Energy outfall and also that of the nearby abalone farm (see Section-5.2.12.8).
ALSO;
Section 5.2.13.6 – "Water quality in Point Estero would be degraded in the mixing zone around the diffuser. Outside of the mixing zone, water quality is not predicted to be exceed WQOs Water Quality Objectives resulting in no significant effect compared to the No Action a Alternative". Table 5.1-11 Selected Water Quality Objectives (emphasis added) fails to contain information on the limits for nitrate nitrogen, phosphates, and suspended solids. These three nutrient constituents (suspended soil particles can be a significant phosphate and pesticide source) could be extremely important to the biology of the Estero Bay.
ALSO;
Completely lacking in this EIS is a treatment in the detail as was provided for the Bay Delta of the probable biological impacts to the Ocean equal ecology of the drain discharge. For instance, the chromium ion on giant kelp, nutrients on micro flora, and sediment on benthic organisms.
ALSO;
Table C2-7 – Drain water Quality … must have been generated from groundwater modeling and the statistical treatment (Section C2.5.2) of the available chemical analysis for the project area.

This developed transport model is deficient in groundwater elevation historical data as no evidence of the recognition that sample well penetration depth and aquifer profile thickness, permeability, confinement, is treated as impacting sample well reliability, nor in the representation of drain water quality. The absence of any attempt at quantity and quality trend generation indicates that the data base was too limited for validation of the groundwater model and so the transport model. This is particularly important not only from the standpoint of the impact on quantity and quality of the staged construction the drainage farm systems and collection network itself but also from the standpoint of the probable relocation of irrigation water to lands up gradient from their current location (see US Fish and Wildlife Service letter of Nov 17 2004, "WATER NEEDS"). Currently new lands are being prepared for irrigation in the I-5 corridor above the aqueduct. Further supporting this concern is the statement in section 13.1 -- AFFECTED ENVIRONMENT "A large number of arable acres in Westlands are idle in dry years because of inadequate water supply". "The northerly area also has lands suitable for growing all crops and some lands suitable for growing salt tolerant crops".
ALSO; Figure 6-5 Geohydrology Section of the Western San Joaquin Valley, misrepresents the stratification present in the valley sediments and puts into question the groundwater flow assumptions used. Extensive field observations done by DWR, USBR, USGS, and the USDA-ARS(see publications #'s 7,8,12,13,14,16,20,21,and 25 – citations attached) in the late 1950's to 1960's showed extensive clay layering above the Corcoran Clay with hydraulic conductivity less than concrete causing shallow perched water tables even with the limited pre-Westland's irrigation. This has been ignored in the project geohydrologic analysis and leads to major questions as to the evaluation of water quality and quantity estimates used to design the Ocean Discharge Alternative.
ALSO;
No data is cited on the inventory of soluble constituents in the vadose zone that will be mobilized by existing and expand upland irrigation, particularly nitrates which are native to these profiles along with the gypsum recognized in this EIS.
ALSO;
Section 15 – Agricultural Production and Economics. No where in the treatment of salt balance is the importation of salt in the irrigation source water and fertilizer amendments treated. The Delta diversion is becoming more saline as it is pushed to its limits almost regularly and soluble amendments are applied regularly.

OCEAN IMPACTS

Section 7.2.8.2 - Aquatic and Wetland Resources - Ocean Effects states "Detailed operating plans and development schedules for the Ocean Disposal Alternative's major facilities have not yet been completed. Subsequently, the following evaluation of potential operational effects to aquatic and wetland resources is based on conceptual operating plans". Considering the greatest potential for impact of this toxic waste discharge will be at the point of release in the ocean **during operations** the above statement would indicate that until the operational impacts are evaluated Ocean Discharge should be abandoned as an alternative.

OCEAN ALTURNATIVE CONCLUSIONS

The cost evaluations should be further defined to include those that have been avoided by statements of mitigation and refined before any preferred alternative is selected on costs.

The design capacity of the operational system and future demands on it is yet to be determined. If constructed on current information only the IN VALLEY ALTURNATIVES alone provide the flexability to accommodate for increased capacity that has not been acknowledged by the current design.

The treatment of the geologic hazards "to be mitigated defined" along the alignment is out of date and absent of local historical experience on engineering structures in the Santa Lucia's.

The pollutant and salinity makeup of the effluent discharge is not fully described nor scaled in concentration in sufficient accuracy to predict what the impacts might be to public health and the ecological environment by this alternative.

Treatment of the ocean physical and ecological impacts is completely lacking.

The OCEAN ALTURNATIVE should be deleted as an alternative in favor of the IN VALLEY ALRURNATIVES selected because of their flexibility to accommodate all the above future uncertainties.

Publications

1. Luthin, J. N., Bianchi, W. C. Alfalfa and water table levels. Calif. Agr. 8(6):1954.

2. Henderson, D. W., Bianchi, W. C. Doneen, L. D. Ammonia loss from sprinkler jets. Agric. Eng. 36(6):398-399, 1955.

3. Bianchi, W. C., Tovey, Rhys. Method of obtaining continuous measurements of piezometric heads in shallow artesian aquifers. Agric. Eng. 41(8):516-157, 1960.

4. Tovey, Rhys, Bianchi, W. C. Positive water-level control in consumptive-use studies. Trans. ASAE, 4(1):126-127, 1961.

5. Bianchi, W. C., Tovey, Rhys. A farm drainage investigation on the alluvial fan of the Truckee River. Univ. of Nevada Agric. Experiment Sta. Tech. Bul. 218, 27 pages, 1961.

6. Bianchi, W. C., Haskell, E. E. Jr., Johnson, C. E. A positive action pump for sampling small bore wells. Soil Sci. Soc. Amer. Proc. 26(1):86-87, 1962.

7. Bianchi, W. C., Johnston, William R. An inexpensive water-stage recorder for use in determining hydraulic conductivity of soil by the auger hole method. Agric. Eng. 43(4):244-227, 1962.

8. Bianchi, W. C., Haskell, E. E. Jr., and Johnston, William R. A soil-drainage study in southwestern Fresno County. Hilgardia, 33(5):171-178, 1962.

9. Bianchi, W. C. Measuring soil moisture tension changes. Agric. Eng. "Instrument News" 43(7):398-399, 404, 1962. (Public patent application procedures started on device here described).

10. Haskell, E. E., Jr., Bianchi, W. C. Effect of prolonged irrigation on cotton, Agron. J. 55:202-203, 1963.

11. Dunn, L. E., Bianchi, W. C., Thran, L. W. Characteristics and reclamation of three Nevada salt affected soils. Agric. Exp. Sta. Univ. of Nevada Tech. Bul. 231, 1963.

12. Bianchi, W. C., Haskell, E. E. Jr. A strain gage pressure cell for the rapid determination of hydraulic conductivity of soil cores. Proc. ASTM 63:1227-1234, 1964.

13. Haskell, E. E., Jr., Bianchi, W. C., Pomeroy, C. R. Research in ground-water recharge - southwestern Fresno County, Calif. Calif. Agric. 17(9)2-3, 1963.

14. Haskell, E. E., Jr., Bianchi, W. C. Fixed-position device for sampling soil solution in depth. J. Amer. Water Wks. Assoc. 56(5):664-666, 1964.

15. Bianchi, W. C., Haskell, E. E. Jr. Field meausrement of soil water movement during artificial ground-water recharge. Trans. ASAE, 7(3):341-343, 1964.

16. Haskell, E. E. Jr., Bianchi, W. C. Development and dissipation of ground-water mounds beneath square recharge basins. J. Amer. Water Wks. Assoc. 57(3):349-353, 1965.

17. Behnke, Jerold J., Bianchi, W. C. Pressure distributions in layered sand columns during transient and steady state flows. Water Resources Research 1(4):557-562, 1965.

18. Bianchi, W. C., Haskell, E. E. Jr. Air in the vadose zone as it affects water movements beneath a recharge basin. Water Resources Research, 2(2):315-322, 1966.

19. Haskell, E. E., Jr., Leventhall, J. S., Bianchi, W. C. The use of tritium to measure the movement of groundwater toward irrigation wells in western Fresno County, California. J. of Geophys. Res. 71(16):3849-3859, 1966.

20. Haskell, E. E., Jr., Bianchi, W. C. The hydrologic and geologic aspects of a perching layer - San Joaquin Valley, western Fresno County California. Ground Water 5(4):1217, 1967.

21. Bianchi, W. C., Haskell, E. E., Jr. Field observations compared with Dupuit-Forchheimer theory for mound height under a recharge basin. Water Resources Research 4(5):1049-1057, 1968.

22. Bianchi, W. C., Tovey, Rhys. Continuous monitoring of soil moisture tension profiles. Trans. ASAE, 11:441-443, 447, 1968.

23. Bianchi, W. C., Tovey, Rhys. Soil moisture tension transients associated with evapotranspiration from a water table. Proc. Amer. Soc. of Soil Sci. 34(3):496-501, 1970.

24. Bianchi, W. C., Muckel, Dean C. Ground-water recharge hydrology. ARS 41-161, 62 pp, Dec. 1970.

25. Nightingale, H. I., Bianchi, W. C. Rapid measurement of hydraulic conductivity changes in slowly permeable soils. Soil Science 110(4):221-228, 1970.

26. Nightingale, H. I., Bianchi, W. C. Ground-water recharge for urban use: Leaky Acres Project. Ground Water 11(6):36-42, 1973.

27. Bianchi, W. C., Lang, Geo. J. The City of Fresno's Leaky Acres ground-water recharge project - construction and performance. Amer. Water Wks. Assoc. 66(3):176-180, 1974.

28. Bianchi, W. C. Powdered metal plates for constructing unsaturated flow cells. Proc. SSSA 38(4):683-4, 1974.

29. Nightingale, H. I., Bianchi, W. C. Ground-water quality related to irrigation with imported surface or local ground water. Jour. of Environ. Qual. 3(4):356-360, 1974.

30. Bianchi, W. C., H. I. Nightingale. Hammer seismic timing as a tool for artificial recharge site selection. Proc. Soil Sci. Amer. 39(4):747-751, 1975.

31. Bianchi, W. C., Haskell, Jr., E. E. Field observations of transient ground-water mounds produced by artificial recharge into an unconfined aquifer. USDA-ARS/Pub. No. W-27, August 1975.

32. Nightingale, H. I., Bianchi, Wm. C. Ground-water chemical quality management by artificial recharge. Ground Water, 15(1):15-21, 1977.

33. Nightingale, H. I., Bianchi, Wm. C. Ground-water turbidity resulting from artificial recharge. Ground Water, 15(2):146-155, 1977.

34. Bianchi, Wm. C. Artificial recharge and control of aquifer clogging during well recharge. Proceedings 11th Biennial Groundwater Conference, Fresno, Ca. September 1977. Published by UC Water Resources Center.

35. Nightingale, H. I., Bianchi, W. C. Environmental aspects of water spreading for ground-water recharge. U.S.D.A. Technical Bulletin No. 1568, Oct. 1977.

36. Bianchi, W. C. Artificial ground-water recharge - state of the art: Irrigation, Drainage and Flood Control, Vol. 1, pp. 331-355, 1978. Publication of the International Commission on Irrigation and Drainage.

37. Bianchi, Wm. C., Nightingale, H. I., McCormick, R. L. A Case history to performance evaluate water spreading projects. Jour. Amer. Water Works Association. 70(3):176-179, 1978.

38. Bianchi, W. C., Nightingale, H. I., McCormick, R. L. Fresno, Calif. - 1. subsurface drain collector - deep well recharge system. Jour. Amer. Water Works Association, 70(8):427-436, 1978.

Published abstracts - Technical Society Meetings

1) Bianchi, Wm. C., J. N. Luthin. Alfalfa ET induced water table fluctuations, ASA, SSSA meetings - 1953.

2) Bianchi, Wm. C. A transudcer for measuring soil moisture tension changes. ASAE meetings - 1962.

3) Bianchi, Wm. C., H. I. Nightingale. Shallow seismic timing as a technique for ground-water recharge site evaluation ASA, SSSA meetings - 1973.

4) Bianchi, Wm. C. Soil filtration of water prior to deep well injection. ASCE I&D Division Conference - 1976.

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Interpretation of Chloride and Nitrate Ion Distribution Patterns in Adjacent Irrigated and Nonirrigated Panoche Soils[1]

KENNETH L. DYER[2]

ABSTRACT

Salt profiles of sprinkler-irrigated soils, with known crop histories, were compared with those of adjacent soils which had not been irrigated. The methods described offer, for some areas, new techniques for estimating salt movements toward the water table and for evaluating past performance of irrigation projects.

Theoretical concentration curves obtained using van der Molen's application of the Glueckauf theory of chromatography were successfully fitted to Cl^- and NO_3^- concentration curves found in soils being leached under field conditions.

The accumulation of Cl^- in the soil profile was used in conjunction with Cl^- concentration in the soil solution to obtain an independent estimate of moisture dissipated by evapotranspiration. Evapotranspiration losses of sprinkler applied irrigation water were estimated by this method to range from 78 to 85% in the soils under investigation. Estimates of total applied irrigation water calculated from the accumulation of Cl^- in the soil profile were in general agreement with estimates made from crop history.

SUBSOILS ON THE west side of California's San Joaquin Valley contain large quantities of Cl^- and NO_3^- which may lower ground water quality when they are leached downward as a consequence of normal irrigation and/or artificial recharge. Predictions of the pattern in which these salts would be leached into the ground water reservoir under each alternative plan of land use should help assure the orderly development of the valley's agricultural potential. An urgent need exists for these predictions, therefore, to accelerate the development of a workable theory, irrigated fields with known crop histories were compared with adjacent land which had never been irrigated. These paired comparisons made it possible to rapidly accumulate information which would have required many years to obtain if the leaching process had been followed from the beginning of a field's irrigation history.

A complete history of Cl^-, NO_3^-, and water movements following the inception of irrigation was developed for selected soil profiles. This history allowed a study of the boundary conditions between leached and unleached soils and also permitted an independent estimate of average evapotranspiration during the years each site had been irrigated.

Van der Molen (9) studied the desalinization of Dutch soils by natural precipitation subsequent to their inundation by sea water and found that theoretical concentration curves could be satisfactorily fitted to the observed data using Glueckauf's theory of chromatography (4). Gardner and Brooks (3) and Nielsen and Biggar (7) studied the leaching of salts from soil columns under unsaturated moisture conditions and successfully used other formulas to describe the shape of the displacement front.

EXPERIMENTAL AREA AND METHODS

Soils containing uniform salt distributions throughout their depth profiles are ideally suited for the study of leaching processes. Many unirrigated Panoche soils fit this description so experimental locations for detailed study were selected from among these soils. The alluvial deposits comprising the Panoche soils and substrata contain poorly consolidated mudflow material which is subject to shallow subsidence.[3] The texture of the soils in the study area

[1] Contribution from Soil and Water Conservation Research Division, ARS, USDA, in cooperation with the California Department of Water Resources. Presented before the Western Society of Soil Science, June 19, 1963 at Palo Alto, California. Received July 27, 1964. Approved Jan. 6, 1965.

[2] Soil Scientist (Chemistry), Fresno Field Station, Southwest Branch, Soil and Water Conservation Research Division, Fresno, Calif.

[3] Shallow subsidence is shallow in the sense that the subsiding or compacting strata are above both the present and historic water tables.

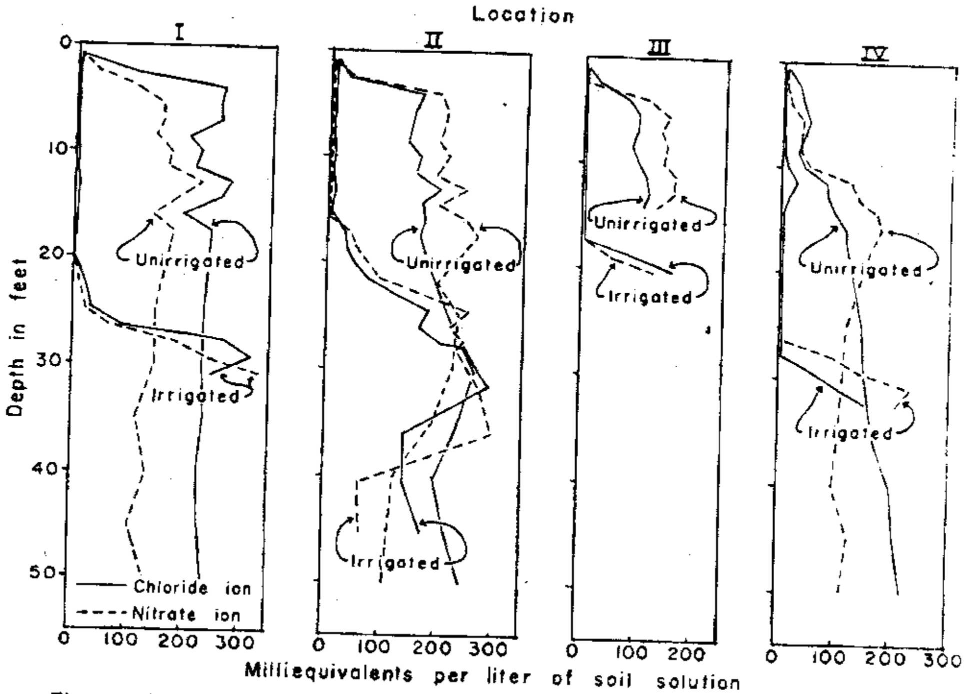

Fig. 1—Chloride and nitrate ion profiles on irrigated and unirrigated Panoche soils.

ranged from loam to clay loam or silty clay loam. Occasional gravels, chunks of gypsum, and silt "stones" occur throughout the profiles. The base exchange capacity of these soils ranges from 15 to 40 meq/100g and averages about 25 meq/100g.

Four locations were selected along the boundary separating irrigated and unirrigated Panoche soils.[4] All these sites are located where sprinkler irrigation is standard practice because of shallow subsidence problems and uneven topography. The distance separating the irrigated and unirrigated sampling sites ranged from 80 to 250 feet.

Unirrigated profiles were sampled initially to depths of about 20 feet, then three were later sampled to 50 feet. Each irrigated profile was sampled to a depth sufficient to include part of the zone of high Cl^- concentration corresponding to that found in the adjacent unirrigated profiles. At one location samples were deliberately taken to depths below those influenced by deep percolating irrigation water. Samples were taken continuously to 30 or 36 feet (to 20 feet in the unirrigated profiles) with a hand auger, each sample representing a 20-inch composited segment of the profile. Deeper core samples were taken at about 5-foot intervals with a small drill rig. All samples were collected during the summer of 1962 except for the unirrigated samples below 20 feet which were taken in October, 1964 with the drill rig.

The irrigated portions of locations I and II were first irrigated in 1953, and before sampling the soil had been in alfalfa 4 years and in barley 4 years. Land at location III was first irrigated in 1953 and before sampling had been cropped 3 years to alfalfa, 3 years to barley, and 1 year to cotton. Location IV was first irrigated in 1950 and before sampling this soil had been cropped 3 years to alfalfa, 4 years to barley, and 3 years to cotton.

Though the exchangeable Na percentage in these Panoche soils ranges from 5 to 20%, the high gypsum content is sufficient to keep all these soils in good physical condition.

The soil moisture contents (dry weight basis) were determined from 20-g subsamples dried at 105C for 4 hours. After the soil moisture percentages were calculated, sufficient distilled water was added to moist soil samples to make 1:1 soil-water mixtures totaling 300 g. These 1:1 mixtures were shaken 4 hours, then the equilibrium solutions extracted at 100 lb pressure using a baroid extractor and Whatman No. 50 filter paper. These extracts were analyzed for Cl^- and $NO_3^- + NO_2^-$.

[4] Appreciation is expressed to Russell Giffen and the Rabb Brothers for supplying crop histories and for permitting sampling operations on crop land.

Per cent soil moisture (volume basis) was estimated by multiplying the soil moisture per cent (dry weight basis) by an approximate volume weight factor of 1.35.

Chloride ion was determined electrometrically using a silver electrode and a standard saturated calomel electrode with a salt bridge. The $NO_3^- + NO_2^-$ were determined by a brucine procedure similar to the standard method (designated D 992-52) of the ASTM (1). The only important modification of this procedure was that the brucine was dissolved in methanol rather than chloroform.

The Cl^- and NO_3^- concentrations in the soil solution existing under field moisture conditions were estimated from concentrations found in the 1:1 soil-water extract. It was assumed that these concentrations varied inversely with soil moisture content.

Soil moisture suctions were estimated from pressure plate data and from moisture equilibrium data at different relative humidities established with various sulfuric acid dilutions.

RESULTS AND DISCUSSION

Chloride and Nitrate Ion Leaching Patterns

Observed Leaching Patterns

Figure 1 compares the Cl^- and NO_3^- profiles of the paired irrigated and unirrigated soils at each of the four locations. Deep percolating irrigation water leached the Cl^- and NO_3^- to considerable depths at all locations. No appreciable concentrations of NO_3^- and Cl^- were observed in samples from the surface 2 feet of soil. Soils from the first three unirrigated locations have probably been leached by natural rainfall. The fourth unirrigated location shows a somewhat deeper and more irregular leaching probably caused by localized natural flooding.

The Cl^- and NO_3^- reached a greater maximum concentration in the irrigated profiles than in the unirrigated ones. The reasons for the Cl^- accumulation in part of the irrigated profile have been discussed in connection with the occurrence of this phenomenon in a column of Panoche soil leached in the laboratory (2).

Richards et al. (8) observed less Cl^- in the soil solution than had been applied previously in the irrigation water; however, they did not sample that soil solution representing the advance front of the percolating irrigation water wherein Cl^- concentrations were probably sufficient to offset this deficit in the upper portion of the column. This explanation is consistent with the negative adsorption theory used by Richards et al. to explain the decreasing Cl^- concentration in soil solution associated with rising soil suction levels.

There was a close parallel between the leaching of Cl^- and NO_3^- in these Panoche profiles under irrigation; so, to avoid repetition of similar data, all further observations and calculations will be limited to the Cl^-.

Theoretical Leaching Patterns

Most of the transition zones shown in Fig. 1 have the characteristic sigmoid shape typical of break-through curves observed by many investigators working with the flow of salts and other tracers through soil and ion exchange columns.

In Fig. 2 theoretical displacement curves were fitted to the observed Cl field profiles using Van der Molen's (9) application of the Glueckauf theory. Field data were insufficient to permit a proper test of the formulas used by Gardner and Brooks (3) or Nielsen and Biggar (7). Since curves fitted by any of these methods would be quite similar, it is improbable that data collected under field conditions would be sufficiently accurate to establish the superiority of one system over the others.

The Glueckauf theory assumes that the profile is divided into a series of theoretical plates of finite height in each of which an equilibrium condition develops before the solution moves on to the next plate. By varying the theoretical plate thickness, this theory adjusts to changes in the shape of the transition zone caused by finite grain size and diffusion of liquid between the grains.

The theoretical plate thickness calculated from the field data was 8 cm. This value contrasts sharply with the theoretical plate thickness of 1.3 cm found in a column of one of these same soils packed in the laboratory (2). One explanation for this discrepancy is that the slower average rate of leaching prevailing in the field would permit more diffusion and thus require a larger theoretical plate thickness. Soil structure and packing would also have much bearing on the theoretical plate thickness.

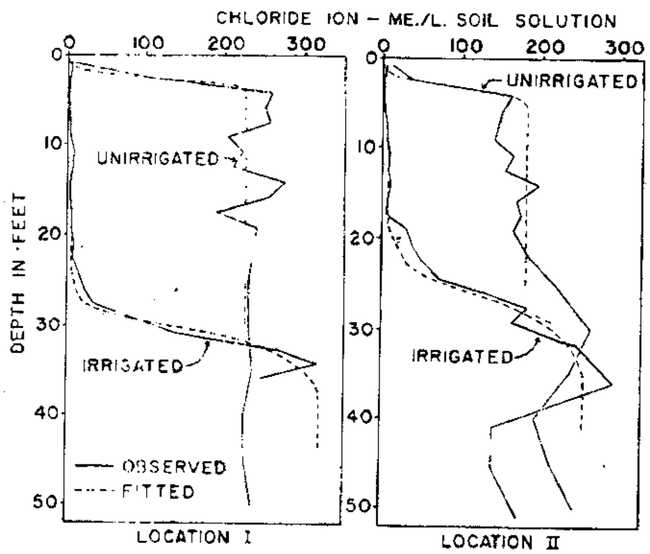

Fig. 2—Observed and fitted Cl^- distribution profiles at field locations I and II.

Once the theoretical plate thickness has been established for a given profile and irrigation regime it should be possible to use Van der Molen's procedure (9) to predict the shape and depth of the Cl^- and NO_3^- leaching fronts at future dates as long as the same general irrigation practices are continued.

Before the problems related to making these predictions of percolating water quality can be discussed it will be necessary to define two terms. The term "piston displacement" as used in this paper indicates that a sharp boundary exists between the solution being displaced and that displacing it, i.e., no diffuse zone of mixing. The term "retained water" is applied to that portion of the soil solution which appears to be "bound" to the soil particles and as such is distinct from the main free flowing body of soil solution. This term "retained water" has been introduced solely to simplify the calculations relating to the unsaturated flow of saline solutions through soils, and for soils under investigation it appears adequate (2). It is not intended that this concept should in any way supplant or contradict the more refined theories of salt and water movement such as those presented by Low (6) or Kemper (5). In calculations pertaining to salt leaching "retained water" was assumed to be immobile, free of Cl^- and NO_3^-, and to be a constant percentage of the volume or oven dry weight of each soil. The "retained" water levels were roughly estimated from soil moisture percentages and pF curves wherein the boundary between "retained" water and "normal" water was taken at pF 5.66 (2).

In using Van der Molen's method to predict the future Cl^- and NO_3^- concentrations of soil solutions deep in the profile it will be necessary to apply a correction factor to account for the greater salinity of the percolating water which will appear immediately beneath the leached zone compared to that previously present in the unirrigated soil. This can be accomplished by adjusting van der Molen's value for C_0 upward to correspond to the new tracer concentration which will prevail immediately beneath the displacement front of the irrigated soil. The extent of this increase in C_0 is dependent upon the increase in soil moisture percentage caused by irrigation and the consequent lowering of the proportion of water in the retained status. The relationship of C_0 to soil moisture changes is expressed by:

$$C_0' = C_0\left[\frac{(H_2O)_i - RET}{(H_2O)_u - RET} \times \frac{(H_2O)_u}{(H_2O)_i}\right]$$

wherein C_0' is the modified tracer concentration in the irrigated profile, C_0 is the tracer concentration in the unirrigated profile, RET is the average retained water percentage found in the tracer containing portion of the profiles, $(H_2O)_u$ is the average moisture percentage in the unirrigated profile, and $(H_2O)_i$ is the average moisture percentage in the tracer containing wetted portion of the irrigated profile. For the Panoche soils under study C_0' was found to be about 1.5 times greater than C_0.

The volume of water below the displacement front in which the concentration C_0' will prevail (zone F-G in Fig. 3) will depend largely upon the volume of water displaced downward from the zone traversed by the diffusion front, plus that water initially present in zone F-G. In Fig. 2

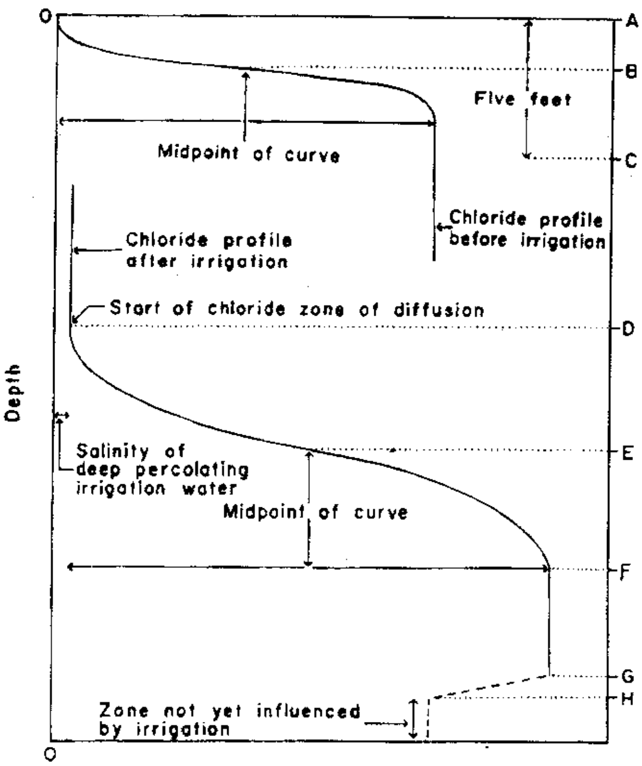

Fig. 3—Generalized Cl^- distribution curves illustrating points used in calculations.

this plateau region is not apparent because of infrequent sampling and because of the natural variability found under field conditions, but the plateau was clearly illustrated in a laboratory column study of a Panoche soil (2). The boundary between C_o and C_o' is located between points G and H on Fig. 3. This transition zone is located at the wetting front and its width is directly dependent upon the sharpness of this wetting front.

The presence of "retained" water permits salts to be leached to a greater depth than would have been possible under piston displacement, so this necessitates another adjustment in Van der Molen's procedure. This modification merely involves subtracting the retained water from the total soil moisture, i.e., "A" in Van der Molen's formulas. In this way the "retained" water is no longer considered as part of the soil solution.

The calculations described thus far are designed to give average Cl^- or NO_3^- concentrations found in the total soil solution at a given depth. The Cl^- and NO_3^- concentrations found in that portion of the soil solution percolating downward will be somewhat higher and may be calculated for any part of the profile from the equation:

$$C'' = \frac{C' \times H_2O}{H_2O - RET}$$

wherein C'' is the Cl^- or NO_3^- concentration of the percolating fraction of the soil solution, C' is the average concentration of the selected ion in the soil solution at a given spot in the profile, H_2O is the total moisture percentage of the sample under consideration, and RET is the retained moisture percentage contained in this same sample.

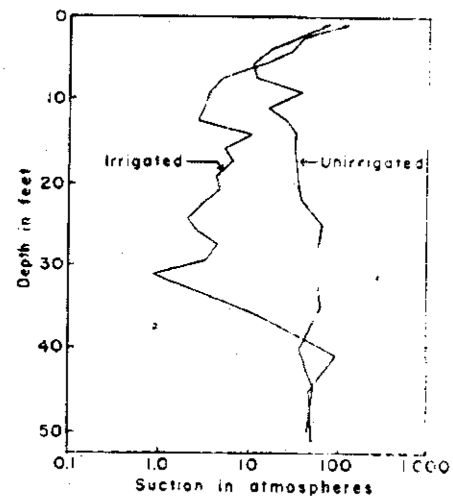

Fig. 4—Soil moisture suctions at field location II.

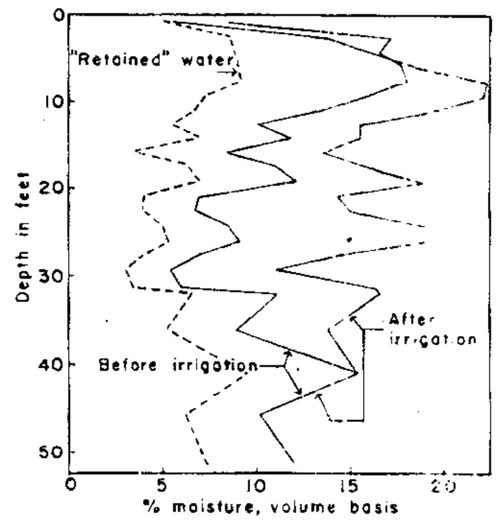

Fig. 5—Soil moisture distribution before and after irrigation at field location II.

The concentration of Cl^- and NO_3^- in the leachate moving toward the water table in these field sites was about 2.3 times that of the average soil solution in the unirrigated soil profiles (between 3 and 25 feet) and about 1.5 times that found in the Cl^- accumulation zone in the irrigated soils.

Soil Moisture Patterns

Soil moisture suctions found in the irrigated and unirrigated profiles at field location 2 are shown in Fig. 4. These suctions were much lower in the irrigated profile at depths between 5 and 40 feet than they were in the unirrigated profile, a condition caused by deep percolating irrigation water in the irrigated profile. The top 5 feet of the irrigated soil had been dried to near the wilting percentage by transpiration of the previous crop and the top 2 feet of soil had been dried further by evaporation. It is apparent that the effects of irrigation on soil moisture do not yet extend below the 40-foot depth. The other sites were not sampled deeply enough to include the entire zone affected by irrigation water.

The distribution of moisture in the irrigated profile at field location 2 before and after irrigation is illustrated in Fig. 5. The soil moisture labelled "after irrigation" was determined directly from the soil samples. The "before irrigation" moisture was calculated from pF curves of each soil sample and the moisture suction for each corresponding sample from the unirrigated profile shown in Fig. 4. In these calculations it was assumed that the suction curve in the irrigated profile prior to irrigation was the same as that in the unirrigated profile at the time it was sampled. The "retained" water was calculated from the same pF curves on the assumption that the boundary between "free" and "retained" water was pF 5.66 (2).

It has been theorized by Wang et al. (10) that the absolute quantity of retained water (termed inactive water by them) decreases somewhat at higher moisture contents. However, since a definitive study regarding this matter had not been made, they chose to assume that the inactive water was a constant quantity in their recently developed approach to the analysis of unsaturated flow in soils.

Interpretation of Cl^- Leaching Patterns

The interpretation of the leaching patterns observed at these field locations will be based largely on the leaching performance of a Panoche sandy clay loam column discussed in an earlier paper (2). The depth over which the chloride front at location II would have been leached under theoretical "piston" displacement was calculated to be 16.1 feet (from the initial 3-foot depth to the theoretical depth of 19.1 feet). These calculations were based on a redistribution of those chlorides which irrigation caused to accumulate in the zone between 27 and 40 feet in excess of 180 meq/liter. The Cl^- concentration of 180 meq/liter was assumed to have been in solution throughout the profile below 3 feet prior to irrigation. For an illustration of this calculation see Fig. 4 of Dyer (2). The total quantity of water above 19.1 feet, less that initially present in the unirrigated soil above the original chloride front at 3 feet, should be equivalent to water added to the soil profile by irrigation, and in this case amounted to 2.76 feet. The actual depth of effective leaching of Cl^- and NO_3^- in this profile was 49% (24 versus 16.1 feet) greater than would have occurred under piston displacement, an amount considerably greater than the 35% (53.5 versus 39 inches) observed in the laboratory column (2). Water in an apparently "retained" state accounted for 55% of the moisture postulated to exist in the profile at location II between the 3.5 and 27 feet depths before irrigation and for 37% of that found after irrigation. Corresponding values in the column study were 50% and 27%. The main reason for the preceding discrepancies is that the slow leaching in the field necessarily occurred at higher moisture suctions than the faster leaching in the column study. Since the "retained" water remains essentially constant in volume it becomes proportionately more significant as soils reach higher moisture suctions and lower total moisture contents. Consequently as soils drain to these higher suctions, salts dissolved in the soil moisture will be leached to greater depths in accord with continued moisture movement.

Irrigation Performance as Deduced from Chloride Ion Leaching Patterns

Direct comparisons of the Cl^- and NO_3^- concentrations in irrigated and unirrigated profiles as shown in Fig. 1 and 2 gave much useful information but fell short of a full interpretation of the data. Additional information was gleaned by using calculations which corrected or bypassed the major imperfections of direct comparison. Briefly, this system made it possible to mathematically separate the irrigation water added to the soil from the native soil solution. With this accomplished it was possible to calculate both the quantity of irrigation water accruing in the soil and its Cl^- content. Since the quality of irrigation water applied to the profiles was known it was then possible to calculate the total irrigation water applied to each profile and the per cent of this water lost from each profile by the process of evapotranspiration.

Existing theories of leaching indicate that the gradual increase in Cl^- and NO_3^- with depth in the unirrigated plot at location IV could not have been transformed by the leaching process into the abrupt front found in the irrigated profile (Fig. 1). The salts on the unirrigated plot probably were leached long ago by a local stream flow which did not affect the presently irrigated plot. For the purpose of the following calculations this original depth of leaching has been arbitrarily set at 40 inches below the soil surface, a depth similar to that found at the other unirrigated locations.

Several steps were needed to convert the raw field data into an estimate of the Cl^- in the irrigation water in the profile. A correction of the Cl^- analysis data was necessary to adjust for the small amount of Cl^- which some soils release into solution when they are mechanically shaken. This release of Cl^- can be explained in part by the fact that the clays in Panoche soils have been partly consolidated prior to their redeposition in the San Joaquin Valley. Mechanical agitation can break some of these clay pockets thus physically releasing small quantities of salts. Panoche soils, which had been thoroughly leached with gypsum saturated distilled water, were mechanically shaken in a 1:1 soil-water suspension for 4 hours. The Cl^- thus released amounted to about 0.41 meq/liter when calculated on the basis of the moisture retained by the soil after draining to 1 atm suction.

Estimates of Cl^- added to these Panoche profiles by irrigation water based on differences in total Cl^- content of adjacent irrigated and unirrigated profiles would have been unreliable. Small sampling errors or small variations in the natural deposition of the Cl^- initially present would have been sufficient to obscure the comparatively small changes in total Cl^- content of the profiles caused by irrigation.

The generalized displacement curves shown in Fig. 3 illustrate the method used in calculations pertaining to past irrigation performance. Average Cl^- concentrations were calculated for the soil solution from the surface to the start of the leaching front (zone AD of Fig. 3) and from the 5-foot depth to the start of the leaching front (zone CD of Fig. 3). These averages were calculated for each zone from the formula:

$$\overline{Cl} = \frac{\sum_{i=1}^{i=N} [(Cl^- - J)(H_2O)]_i}{N \times \sum_{i=1}^{i=N} (H_2O)_i}$$

wherein $\overline{Cl}$ is the average Cl^- concentration in meq/liter, Cl^- are the individual Cl^- concentrations in meq/liter, J is the correction for Cl^- released into solution during chemical analysis in meq/liter (a constant value of 0.41 meq/liter was used for the Panoche soils described in this study), N is the number of samples in the zone being averaged, and H_2O is the per cent water measured on a volume basis.

The irrigation water accruing in the zone of diffusion (zone D-F of Fig. 3) plus the associated retained water (equivalent to that in zone D-E in this case) was assumed to be equal in quantity to the water in zone D-E and was assumed to have an overall Cl^- concentration equal to that found in zone C-D. Thus $\overline{Cl}_{de} = \overline{Cl}_{cd}$ wherein the double subscripts indicate the zone of Fig. 5 described. Zone C-D was used in this estimate rather than zone A-D because the salt concentrations in the surface 5 feet of soil were still under the strong influence of evapotranspiration. These calculated Cl^- concentrations of zones A-D and D-E were weighed according to their moisture contents and averaged together to give $\overline{Cl}_{ae}$.

The quantity of irrigation water in the profile was calculated by subtracting from the total quantity of water above point E on Fig. 3 the retained water in the zone traversed by the Cl^- diffusion front (zone B-E on Fig. 3) plus the quantity of soil solution initially present above point B, the site of the Cl^- diffusion front before the soil was irrigated. Thus:

$$S = R - UAB - RET'(R - IAB)$$

wherein S is the total irrigation water in the irrigated profile, R is the total water in the irrigated profile above the center of the Cl^- diffusion front, UAB is the total water in the unirrigated profile in zone A-B of Fig. 3 and IAB is the total water found in the irrigated profile in zone A-B. The term RET' represents the fraction of retained water in the soil solution in the irrigated profile between depths B and E of Fig. 3 and was estimated from field data from location II to be approximately 0.37. Since soil moisture tensions at these depths were similar at each of the four locations it was presumed that 0.37 would be an adequate estimate of the retained water fraction between depths B and E at all the irrigated sites.

At this point the Cl^- added to the profile by irrigation can be mathematically distributed in the irrigation water remaining in the profile with the formula:

$$P\overline{Cl} = \overline{Cl}_{ae} \times R/S$$

wherein $P\overline{Cl}$ is the Cl^- concentration of irrigation water accumulating in the profile, in meq/liter.

The evapotranspiration percentages were calculated from the formula:

$$ET = 100 - \frac{I\overline{Cl} \times 100}{P\overline{Cl}}$$

wherein ET is the evapotranspiration percentage and $I\overline{Cl}$ is the average Cl^- concentration of the irrigation water applied in meq/liter (1.6 meq/liter in the area under investigation). Values of ET calculated for the four field locations are given in Table 1 and ranged from 78 to 85% of the applied water. In all the preceding calculations water added as precipitation has been ignored since it is essentially salt free, but it can easily be accounted for at this point. If the natural rainfall of about 7 inches per year is added to the total applied irrigation water for each crop year, then the calculated evapotranspiration rates would be in the somewhat higher range of 83 to 89% for these four sites.

Table 1—Percentage of irrigation water lost by evapotranspiration and a comparison of two separate estimates of total irrigation water applied

	Location			
	I	II	III	IV
Percent of applied irrigation water lost from profile by evapotranspiration	79.8%	85.3%	81.[illegible]%	78.3[illegible]
Total applied irrigation water as estimated from Cl^- accumulation in profile	20.3 feet	19.8 feet	20.[illegible] feet	2[illegible].4 feet
Total applied irrigation water as estimated from crop history	20.2 feet	20.2 feet	18.[illegible] feet	2[illegible].7 feet

At this point it should be mentioned that the evapotranspiration percentages calculated for location III were biased by an irrigation which immediately preceded the sampling of the irrigated plot. This recently added water was estimated from moisture analyses to total 0.7 feet and was all contained within the top 3 feet of the profile. The bulk of this moisture would undoubtedly have soon been dissipated as evapotranspiration so the long term evapotranspiration percentage was recalculated on the assumption that 0.6 feet of this recently added water would soon be lost from the profile. The evapotranspiration rate thus recalculated for location III was 84.2%.

The total quantity of irrigation water applied to each profile since the inception of irrigation was calculated from the total Cl^- added by irrigation water to the profile with the formula:

$$IRR = \frac{S \times P\overline{Cl}}{I\overline{Cl}}$$

The applied irrigation water depths thus calculated are given in Table 1.

The total applied irrigation water was also estimated from the crop history of each of the locations under study and also reported in Table 1. In these estimates 1.4 acre-feet of water was alloted to each barley crop, 2.7 acre-feet for each cotton crop, and 4.0 acre-feet for each year of alfalfa.

The calculated and estimated quantities of irrigation water applied at each site agreed within 10%. Compensating errors may have contributed to this deceptively good correlation because some of the measurements and estimates used in the calculations were themselves subject to errors of 10% or more.

The preceding calculations all assume a material balance of the water and Cl within the soil profile and do not consider two partially compensating and presumably small sources of error to the Cl balance. The process of mineral decomposition probably releases some Cl into the soil solution with passage of time. Also, some Cl is taken up by plants and permanently removed with the crop harvest. It is unlikely that any significant amount of Cl has been applied to the land with fertilizers.

Retained water has been shown to have a major effect on the leaching process in soils with moisture levels originally at, or somewhat below, the permanent wilting percentage. Further study will be required to satisfactorily assess the effect of retained moisture when soils at other moisture suctions are leached, but in general its effect will diminish at lower moisture suctions and increase at higher suction levels.

LITERATURE CITED

1. American Society for Testing Materials. 1957. Manual on Industrial Water. ASTM Special Publication No. 148-C. American Society for Testing Materials. Philadelphia.
2. Dyer, Kenneth L. 1965. Unsaturated flow phenomena in Panoche sandy loam as indicated by leaching of chloride and nitrate ions. Soil Sci. Soc. Amer. Proc. 29:121–126 (this issue).
3. Gardner, W. R., and Brooks, R. H. 1957. A descriptive theory of leaching. Soil Sci. 83:295–304.
4. Glueckauf, E. 1949. Theory of Chromatography: PVI. J. Chem. Soc. 3280–3285.
5. Kemper, W. D. 1960. Water and ion movement in thin films as influenced by the electrostatic charge and diffuse layer of cations associated with clay mineral surfaces. Soil Sci. Soc. Amer. Proc. 24:10–16.
6. Low, Philip F. 1961. Physical chemistry of clay-water interaction. Advan. Agron. 13:269–327.
7. Nielsen, D. R., and Biggar, J. W. 1962. Miscible displacement: III. Theoretical considerations. Soil Sci. Soc. Amer. Proc. 26:216–221.
8. Richards, L. A., Gardner, W. R., and Ogata, Gen. 1956. Physical processes determining water loss from soil. Soil Sci. Soc. Amer. Proc. 20:310–314.
9. van der Molen, W. H. 1956. Desalinization of saline soils as a column process. Soil Sci. 81:19–27.
10. Wang, Flora Chu, Hassan, Nabil A., and Franzini, Joseph B. 1964. A method of analyzing unsteady, unsaturated flow in soils. J. Geophys. Res. 69:2569–2577.

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The Hydrologic and Geologic Aspects of a Perching Layer—San Joaquin Valley, Western Fresno County, California

by E. E. Haskell, Jr., and W. C. Bianchi

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The Hydrologic and Geologic Aspects of a Perching Layer—San Joaquin Valley, Western Fresno County, California[a]

by E. E. Haskell, Jr., and W. C. Bianchi[b]

ABSTRACT

A shallow, widespread perching layer was isolated in the alluvial profiles of western Fresno County, California. Geologic and hydrologic interpretations are given, based on field and laboratory measurements of the physical properties of this layer. Some of the approaches investigated included using existing electrical logs from irrigation wells, head loss observations in wells and piezometers, core drilling, and core analysis. Differences in alluvial profile permeabilities are shown which result in perched water under the existing field flow conditions. The quantity of vertical flow through the layer is estimated using core permeabilities and hydraulic gradients observed in the field.

Hydraulic properties and descriptions for the perched zone are presented which can be used to delineate profile flow limitations at other locations in the San Joaquin Valley. The study may be used in estimating the rate at which this perched water table could rise if, in the future, imported water and changes in irrigation patterns cause a large quantity of water to flow vertically.

INTRODUCTION

Alluvial profiles within which water is perched present a major restriction to the vertical flow. Such a restriction results in a saturated zone above the perching layer and an unsaturated zone below. This unsaturated zone separates the perched water table hydraulically from the ground water below. The perched water table can be beneficial, depending on the ground-water regime; in many cases the perched zone produces water through wells or prevents the pollution of the main ground-water body. However, shallow perching layers may be detrimental by impeding ground-water recharge to deep aquifers, or by causing the perched water table to rise near the surface resulting in drainage problems and dewatering problems during foundation excavation of engineering structures.

This study shows evidence that shallow, fine-textured layers are impeding the vertical flow of ground water in the unconsolidated alluvial sediments of parts of the San Joaquin Valley. Hydraulic properties of such a layer are presented and could be used in estimating the rate at which this shallow perched water table will continue to rise under present irrigation practices or would rise if irrigation were increased. The study also exemplifies how a minimum amount of field data can be interpreted to isolate impeding layers in alluvial profiles.

PHYSICAL SETTING

The area of interest is approximately 375 square miles on the western margin of the San Joaquin Valley within western Fresno County, California (Figure 1). The area supports an intensively irrigated agriculture, with deep wells supplying nearly all of the irrigation water. The basic surface features are gently sloping alluvial fans, deposited by streams coming from the Mount Diablo Range. Bull (1964a and 1964b) has presented a physical description and geomorphology for these alluvial fans. Previous studies by Davis and Poland (1957) and Davis et al. (1964) give the general geology and hydrology related to this study area. Croft (1965) and Glavinovich (1964) have pointed to the existence of other extensive clay deposits in the alluvial profiles of the San Joaquin Valley. Profile and water table observations were made throughout the study area shown in Figure 1. Field work involving continuous core drilling and piezometric observations was done on the Cantua Creek fan in T. 15 S., R. 16 E. Mount Diablo Base Line Meridian.

HYDROLOGIC CONDITIONS PERTINENT TO THE PERCHING LAYER

Water Table Contours

Figure 1 shows equal elevation contours drawn at 10-foot intervals on the free water table surface in the study area (year, 1965). Observations were made in more than 50 wells installed by various federal and private agencies. Care was taken to use wells that did not intersect a large depth of the saturated profile, thus giving a water table elevation which characterized the perched zone.

The water table contours in Figure 1 are uniform and smooth over the entire area. The perching layer or base for this water table is not lense-like but continuous, as large depressions or sinks do not appear in the ground-water contours. The steep contours on the west (C-3) indicate the edge of the layer or that it is more permeable to the west. Also, the contours in the vicinity of H-2 start to close, which may indicate

[a] Contribution from Soil and Water Conservation Research Division, Agricultural Research Service, U. S. Department of Agriculture, in cooperation with the California Department of Water Resources.

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Discussion open until March 1, 1968.

a source. Generally, the water table is near the surface (along the valley sloughs) and becomes deeper toward the west. Observations on this shallow water table by Biarchi et al. (1962) show the main source to be water which is applied in excess of crop use.

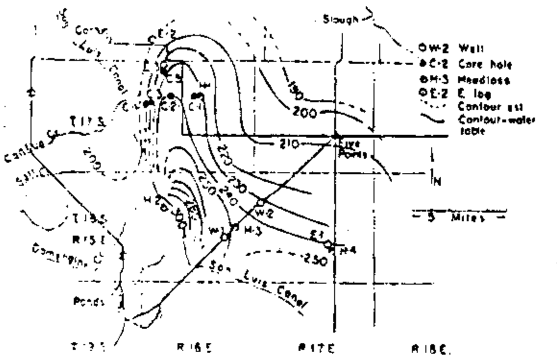

Fig. 1. Ground-water elevation contours map of the perched zone within the study area.

Water Table Rise

Figure 2 is a plot of the water table rise at two points in Figure 1 (W-1 and W-2). The water table is rising at a constant rate of 8 to 12 inches per year at these locations. This shallow water table developed and has continued to rise since irrigation was started in the 1940's.

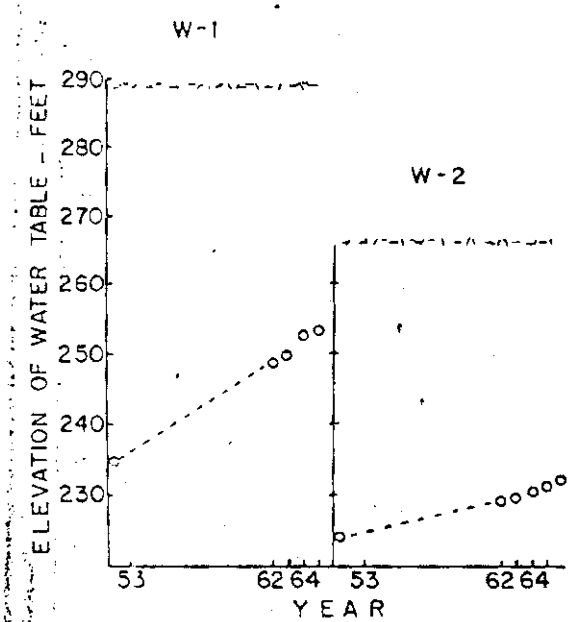

Fig. 2. Water table rise with time at locations W-1, and W-2.

Ground-Water Quality

The poor quality of the water in this shallow table makes it undesirable for irrigation. Water samples with 2,400 ppm dissolved solids and 3.4 ppm boron have been obtained in the northern part of the study area (Cantua Creek Fan) and samples with 4661 ppm dissolved solids with 11 ppm boron, in the southern portion (H-2). Irrigation wells are not generally perforated in this shallow water table; the deep irrigation wells take better quality water from artesian aquifers 500-2,000 feet deep.

Electric Logs of Irrigation Wells

Many of the irrigation wells are electrically logged when drilled. These logs, used to observe relative textural and water quality changes with depth, help in the placement of perforated casing in the well. Use of these logs for lateral correlation of perching layers may not always be possible. Often, thin clays which are hydraulically important are difficult to define on the electric logs. However, recent improvements in technique and equipment have made such logs of more value. Also zones of unsaturation which are present under major profile limitations are not seen if near saturation. These electric logs may illustrate a possible profile limitation at depth, and when interpreted in conjunction with a field coring program, can be used for lateral correlation.

The existence of a thin, fine-textured layer in the profiles of the study area is indicated by some of the electric logs of irrigation wells. The number of logs and the quality of the logs are not sufficient for lateral correlation. Figure 3 shows spontaneous-potential (millivolts) and resistivity (ohm-m²/m) logs of two irrigation wells (E-1, E-2, Figure 1). No attempt has been made to separate these profiles into textural classes by use of these logs. However, a relatively fine material can be seen at approximately the 100-foot depth on each of the logs. These and other logs show that a fine-textured layer usually less than 10 feet thick is prevalent at approximately 100 feet throughout the general area associated with the shallow water table.

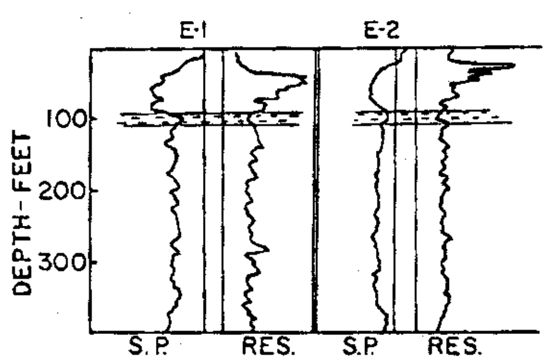

Fig. 3. Electric logs of irrigation wells at locations E-1 and E-2.

Toward the valley slough, in the southeastern part of the study area, another fine-textured layer at approximately the 60-foot depth is represented on electric logs (E-1).