ber of pesticides. Toxicology is an evolving science, and information that meets today's standards may be considered inadequate within a few years. If risk assessments are to guide regulatory policy, toxicology must be current and complete.

Concerns about the cancer risks posed by pesticides in the food chain have triggered calls for regulatory action and legislative reform. The choice of methods used to evaluate cancer risks and the criteria for establishing which risks are excessive should be made on the basis of the best scientific data available. Our analysis shows that lack of accurate data can impart great imprecision to the estimates of dietary risk. Probable risks based on likely pesticide use patterns and residues in foods indicate that the carcinogenic risks from pesticides may be well below earlier estimates. At the same time, it may be difficult to assess the effects on agriculture of modifying the use of specific pesticides. Eliminating a specific pesticide may increase pesticide expenditures by an estimated amount, as more expensive substitutes are employed, and yields and quality may be reduced, affecting supply and demand in a complex manner. In cases where no substitute chemicals are available, economic costs of use withdrawals would be higher. Economic impacts will depend on actual pesticide use patterns, benefits—including quality effects—from specific materials, and substitution possibilities.

Consideration should also be given to alternative risks to public health following removal of a specific pesticide. Elimination of specific fungicides, for example, could decrease the safety of the food supply by allowing the production of greater levels of naturally occurring fungal carcinogens. Better understanding of use patterns, benefits, and substitution possibilities remains critical to any reliable estimation of economic and health costs of pesticide withdrawals. Absence of actual data to estimate both risk and benefits of pesticides complicates and compromises the use of quantitative risk assessment as a regulatory tool.

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# Water seepage from unlined ditches and reservoirs

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***Seepage losses in the San Joaquin Valley's Westlands Water District were estimated at 27,000 acre-feet a year, or about 2% of the district's water supply. Ditch configuration and construction techniques appear to influence seepage rates.***

Irrigation of agricultural land on the west side of the San Joaquin Valley since the mid-1960s has led to rising groundwater tables and an increased need for on-farm drainage to sustain productivity. The presence of naturally occurring trace elements in the shallow groundwater, the result of decades of soil leaching, has compounded the drainage problem. Drainage return flows contaminated with selenium, when concentrated in surface impoundments, have adverse effects on fish and waterfowl.

Control of drainage flows at the source has been advocated by the San Joaquin Valley Drainage Program (SJVDP) and others as the most promising short-term strategy for managing the drainage problem. Deep percolation loss to the shallow groundwater, resulting from excessive pre-season and seasonal irrigations, is the major contributor to drainage flow. Another source affected by on-farm management is seepage from unlined ditch and reservoir facilities. To develop comprehensive plans for long-term management of drainage and drainage-related problems, the SJVDP needs to be able to assess the relative importance of these losses compared with the groundwater recharge caused by inefficient irrigation and varying soil infiltration rates in agricultural fields.

Preliminary field studies of ditch seepage losses performed in 1987 by Westlands Water District indicated that seepage losses from unlined ditches and reservoirs in the district could be as great as 50,000 to 70,000 acre-feet a year. Until now, however, there has been no rigorous study of the magnitude of these losses on a regional scale. Although the region chosen for this survey was Westlands Water District, it was envisaged that conclusions drawn from the analysis would have transfer value to other regions and water districts.

Westlands Water District (WWD) applies 1.2 million acre-feet of irrigation water annually, obtained from U.S. Bureau of Reclamation project supplies and groundwater sources within the district. Water is delivered to more than 600 agricultural users through a 1,035-mile pressure and gravity pipeline distribution system. From the pipeline, the water often flows through conveyance ditches or directly to a head ditch for surface application to fields. Tailwater is commonly recycled by pumping directly out of small reservoirs or regulating ditches into which tailwater flows are directed.

Although there is some use of gated pipe or permanent lining to reduce seepage losses from irrigation head ditches, on most farms seepage occurs from head ditches, tailwater ditches, conveyance ditches, and tailwater reservoirs. This seepage contributes directly to shallow groundwater levels. During October 1987, about 303,000 acres of land had saline water tables within 20 feet below the ground surface. The water table was within 10 feet below the ground surface on about 222,000 acres. WWD staff estimate that about 300,000 acres in WWD will eventually need subsurface agricultural drainage.

## Procedure

We selected 56 test sites, 18 of which were tested twice during the growing season (74 total tests). We also tested 19 reservoirs. Soil samples were collected from the top 1 foot in the bottom of each test ditch. Soil texture was determined by the standard particle size analysis (Bouyoucos hydrometer) procedure. Exchangeable sodium percentage (ESP) and salinity (electrical conductivity, $EC_e \times 10^3$) were also determined. The texture of the soil profile was determined through ribboning (manual evaluation) at 1-foot intervals from the surface to a depth of 6 feet adjacent to each ditch test site. If a shallow groundwater table was present in the top 6 feet of the soil profile, the depth was recorded.

Ditch dimensions were recorded for each test site. Before each test, the grower was interviewed to obtain additional information on ditch construction and management practices, such as the implement or implements used to construct each ditch, the machinery used to pull the implement and

At one of the 56 test sites in the Westlands Water District, UC Davis graduate student Amir Mansoubi conducts ditch seepage evaluations.

number of passes required, the duration and frequency of irrigations during which the ditch was used, and the crop grown on the field serviced by the ditch.

Testing was done by a ponding method. A section of ditch approximately 200 feet long was blocked on both ends by earthen dams or plastic tarpaulins. A staff gauge was placed in the ditch bottom. To begin each test, the ditch was filled rapidly with water using a 4-inch hose connected to a 10- or 12-inch discharge pipe. A 2-inch hose was connected to the base of the adjacent WWD water delivery turnout. A 3/4-inch water meter and 2-inch float valve were connected to the discharge end of the 2-inch hose and positioned across the ditch on wooden supports. The large discharge hose was disconnected after the initial filling, and the desired water level in the ditch was maintained by the float valve. Staff gauge and meter readings were taken frequently during the first day of testing and then daily for the remainder of the testing period. Each test was run a minimum of 3 days with most tests running for 5 days.

We tested reservoir seepage by first filling the reservoir and then installing staff gauges or by using an automatic surface level recorder. Readings were taken daily during the testing period. Tests were generally maintained for a minimum period of 1 week but varied from about 4 to 14 days because of irrigation management and reservoir use practices.

## Data analysis

We used a commercial spreadsheet program (SuperCalc 4) to manipulate the test data. Ditch dimensions entered in the spreadsheet were top width, bottom width, depth, height of the ditch bottom above ground surface, and length of test section. Test variables included date, time, meter reading, water depth, evaporation, and rainfall. Daily evaporation data came from three weather stations, all within the study area. We calculated daily evaporation using the modified Penman equation.

The wetted perimeter of each ditch was measured at each test site. Ditch geometry was trapezoidal with an average wetted perimeter of 7 feet. The average top width was 7.9 feet, the bottom width 2.2 feet, and the average side slope was 0.85. Calculations were made to determine the seepage rate in cubic feet per square foot per day ($ft^3/ft^2/day$), and cumulative seepage in $ft^3/ft^2$ (cumulative seepage based on 1/2 mile length of ditch used to irrigate a field for 50 days annually ). Actual seepage was calculated by measuring the water volume that flowed through the float valve and adjusting this volume for the small difference in water surface elevation from the float valve assembly and a reference water depth.

A regression model and an integration model (Kostiakov equations) were used to fit two models to the intake data. The Kostiakov equation ($I = Kt^m$: where $I$ is the instantaneous intake rate in inches per hour; $K$ and $m$ are constants from the numerical analysis; and $t$ is opportunity time in hours) was used to describe infiltration rates. A second form of the Kostiakov equation ($I = Kt^m + c$: where $c$ is the steady state infiltration rate) was used to account for steady state infiltration rates occurring after long intake opportunity times. The cumulative seepage over each irrigation period was obtained by substitution into the calibrated Kostiakov equation.

We then transferred the spreadsheet data to a Lotus 1-2-3 spreadsheet program for analysis. Unit seepage rates ($ft^3/ft^2/day$) and cumulative seepage ($ft^3/ft^2$) were compared with the variable data using inspection, paired regression, and multiple regression analysis to determine statistically significant relationships and data trends. Frequency of occurrence analyses were also performed on the data, and the results were graphed. Data trend relationships were established for depth of flow, number of tractor passes, soil moisture depletion, exchangeable sodium percentage (ESP), height of water above field, and bottom width of ditch.

## Effects on seepage rates

To establish which management variables had an effect on the rate of seepage, we initially used a graphic approach. This required dividing the data base into subgroups and plotting the seepage rate against the management variables using a scatter diagram. This approach allowed the visual inspection of the graphs for data trends that would not otherwise be evident using regression analysis. Initially, the entire data base was examined as a whole. Then we divided the data into incremental subgroups by various subsets such as Soil Conservation Service (SCS) soil classification series, location within the district, type of ditch, and soil texture. The initial data analysis showed that most of the data was not statistically related. The scatter diagrams indicated apparent data trends. Interpretation of the graphs was subjective. Multiple graphs were produced and analyzed for data trends.

None of the data analyses were statistically significant. They consistently resulted in low correlation coefficients as determined by the $r^2$ statistic. Some of the statistical analyses had $r^2$ values close to 0.70, but the majority had $r^2$ values less than 0.20. Multiple regression analyses were performed on a limited number of the independent variables with low $r^2$ values.

Since the independent variables did not show a high degree of variability, another approach was applied to check the data for significant trends. This involved separating the seven highest cumulative unit seepage values and calculating an average of all the variables for those seven test sections. These were then compared against the seven lowest cumulative unit seepage values. This was done for the entire data base. The new ditches were separated from the used ditches in the analysis to give three different sets of data.

Lower seepage rates resulted from increasing the water height in the ditch above the field surface. Another independent variable that appears to influence unit seepage rates is the bottom width of the ditch. The analysis of extremes indicates that wider ditch bottoms may have lower seepage rates. Since this is a manageable variable, a grower could choose to construct a wider ditch bottom for a lower seepage rate. This would facilitate greater compaction of the wetted perimeter.

The number of tractor passes and the channel side slope showed differences in the extremes analysis. Seepage rates differed significantly from the mean only at the high- and low-end values of the number of tractor passes. Seepage was lower with increased wheel traffic. This finding agrees with the scatter diagram analysis. The analysis also showed an apparent decrease in the seepage as the channel side slope decreased. The flatter slope of the ditch may allow for greater compaction of the region affected by the wetted perimeter.

The results showed that there was a statistically insignificant, but a visually positive possible relationship between unit seepage

**TABLE 1. Comparison of SCS permeability and unit ditch seepage rates**

| Soil series | SCS permeability range | 10-day intake rate* |
|---|---|---|
| | *inches/hour* | *inches/hour* |
| Lethent | <0.06 | 0.12 (avg)<br>0.08 (SD)<br>0.01 (V) |
| Ciervo | 0.06 - 0.20 | 0.17 (avg)<br>0.17 (SD)<br>0.03 (V) |
| Cerini | 0.20 - 0.60 | 0.24 (avg)<br>0.19 (SD)<br>0.04 (V) |
| Westhaven | 0.20 - 0.60 | 0.21 (avg)<br>0.10 (SD)<br>0.01 (V) |
| Excelsior | 0.20 - 0.60 | 0.27 (avg)<br>0.11 (SD)<br>0.01 (V) |
| Panoche | 0.60 - 2.0 | 0.13 (avg)<br>0.13 (SD)<br>0.02 (V) |

* Avg = average. SD = standard deviation. V = variance.

and the flow depth of the ditch. That is, when the flow depth in the ditch increased, the seepage increased. This is probably a result of more head pressure on the ditch that would act to increase the seepage losses. The seepage rate appeared to decrease, however, with an increase in: (1) the exchangeable sodium percentage; (2) height of water above the field grade; (3) the side slope of the channel; and (4) the number of tractor passes. Ditch construction is influenced by the type of tractor used, the plow type, and the number of tractor passes.

## Soils analysis

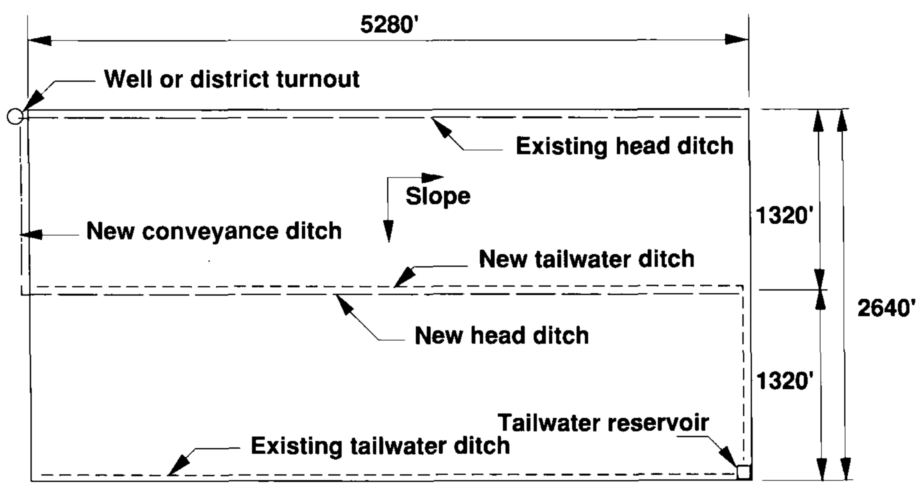
We reviewed unpublished data from the SCS soil survey for western Fresno County (in progress) to determine if there is a relationship between SCS soil permeability rates and observed unit seepage rates. Table 1 summarizes SCS permeability ranges and the average unit ditch seepage rates for the appropriate soil series. The SCS permeability range selected for each soil type was based on the layer of slowest permeability in the profile.

The unit seepage rates generally fall within the range of the SCS permeability values, except for the Lethent and Panoche series soils. The difference in SCS permeability rates and unit seepage rates was very small for the Lethent soil but was large for the Panoche soil. The difference observed for the Panoche soil may have been the result of a more restrictive soil layer below 5 feet or shallow groundwater conditions that affected unit ditch seepage rates.

This is an important relationship, since it may be possible to estimate the magnitude of the total seepage losses in other areas by analyzing the SCS permeability data. We did not have enough test data to confirm this relationship.

## Seepage vs. deep percolation

The 1986-87 California Department of Water Resources, Office of Water Conservation, Water Conservation and Drainage




**FACILITIES**

**320 acres**
**1 mile existing head ditch**
**1 mile existing tailwater ditch**
**1 existing tailwater reservoir**
**1/2 mile new conveyance ditch**
**1 mile new head ditch**
**1 1/4 mile new tailwater ditch**

Fig. 1. Ditch layout required to cut furrow run length in half.

Reduction Program estimated deep percolation in western Fresno County to be about 0.8 acre-foot per acre on an annual basis. Improvements in the distribution uniformity of irrigation applications from an average of 71% to 80% could decrease deep percolation by 0.4 acre-foot per acre per year. The recommendation most frequently cited by program advisors to improve the distribution uniformity was to reduce furrow run length. The following discussion illustrates the relationship between deep percolation losses and furrow row length.

Figure 1 shows a typical field layout using sloping furrows. It was assumed that cutting furrow run length in half would result in a 0.4-acre-foot-per-acre decrease in deep percolation. For 320 acres, the total water savings could be about 128 acre-feet. Reducing run length and assuming a 1- by 0.5-mile rectangular field would require at least 1 mile of new head ditch (9.2 acre-feet per mile seepage loss), 1 mile of tailwater ditch (2.3 acre-feet per mile seepage loss), and 0.5 mile of conveyance ditch (33.3 and 8.3 acre-feet per mile seepage loss for head and tail ditches, respectively). The total amount of seepage lost due to the extra ditches, assuming 50 days of operation annually, would be an additional 17 acre-feet. Reducing run length would result in a net water savings of about 111 acre-feet per year.

## District-wide seepage loss

We estimated the total volume of seepage loss in WWD, based on the calculated average loss per mile of ditch for each type of ditch and reservoir area (table 2). This estimate assumes that the distribution of systems surveyed in the study is representative of conditions in the entire district.

The study also assumes that head ditches are operated an average of 50 days per year with 55% of the volume capacity of each ditch used during the irrigation cycle. Conveyance ditches are estimated to operate 100 days a year. Based on the WWD 1987 ditch/reservoir survey, it is estimated that 50% of the conveyance ditches are used for water distribution and 50% for tailwater conveyance. The wetted perimeters shown in table 2 for conveyance ditches are adjusted to reflect this relationship. Tailwater ditches are operated in a similar fashion to head ditches. It was assumed that reservoirs contain water an average of about 150 days per year. These foregoing assumptions were based on grower interviews, WWD experience, review of WWD water delivery records, and review of Westside Resource Conservation District reports and data.

## Conclusions

Preliminary field studies performed in 1987 by WWD indicated that annual seepage losses from ditches and reservoirs in the district were approximately 50,000 to 70,000 acre-feet. The results of this 1988 study estimated these seepage losses at 27,000 acre-feet, accounting for only about 2% of the total average annual WWD surface water supply (based on 1.2 million acre-feet annual delivery to WWD). This estimate is based on surveys of facility use and an average seepage rate of 0.39 cubic foot per square foot per day, after 10 days (which was taken as the steady-state [long-term, constant] infiltration rate) for all unlined ditches surveyed in the study area. The average rate of seepage from reservoirs was found to be 7.89 acre-feet per acre per year.

Seepage losses from on-farm conveyance ditches were 2.2 times higher than those from head ditches. Conveyance ditches accounted for about 43% of the total seepage loss from all facilities. Seepage losses from head and tailwater ditches combined accounted for about 31% of the total losses. These findings are significant, considering that most other irrigation districts in the western San Joaquin Valley use unlined ditches for off-farm delivery and make more intensive use of on-farm conveyance ditches.

Unfortunately, no single factor explained the difference in seepage rates between sites. A combination of factors appears to control seepage loss rates. Variability of seepage rates along the ditch length was not assessed in this study. This factor, had it been determined, might have shed additional light on the lack of significant correlations between variables reported in the regression analyses.

From a regional planning point of view, the difficulty we experienced in modeling ditch and reservoir seepage losses from Westlands Water District means that such losses will need to be independently assessed in each water district affected by drainage problems, if source control is to be evaluated as a drainage management option. In the short term, districts faced with these problems would be wise to improve current management practices to reduce seepage rates. These improvements include modifying the ditch geometry and method of construction, using gated pipe to replace head ditches, decreasing the length of the fields, using concrete linings or piping for conveyance ditches, and increasing the number of district service turnouts in areas where existing turnouts supply water to more than about 160 acres. Ditch geometry and construction methods appear to influence unit seepage rates.

**TABLE 2. Summary of estimated annual seepage losses in Westlands Water District**

| Facility[*] | Miles | Acres | Wetted perimeter | Days of operation[†] | Ditch use factor[§] | Avg loss[¶] | Total[#] |
|---|---|---|---|---|---|---|---|
| | | | *ft* | | *%* | *ac-ft/unit/yr* | *ac-ft/yr* |
| Head ditch | 594.2 | — | 7.04 | 50 | 55 | 9.2 | 5,470 |
| Conveyance ditch | | | | | | | |
| Head | 279.5 | — | 7.04 | 100 | 100 | 33.3 | 9,310 |
| Tailwater | 279.5 | — | 1.76 | 100 | 100 | 8.3 | 2,320 |
| Tailwater ditch | 1,294.4 | — | 1.76 | 50 | 55 | 2.3 | 2,980 |
| Sump | — | 887.1 | — | 150 | — | 7.9 | 7,000 |
| Total | 2,447.8 | 887.1 | — | — | — | — | 27,080 |

NOTE: Ditch length and reservoir area are based on a field survey conducted by Westlands Water District in 1987.

[*] Head ditch = on-farm ditch at the head of a field that supplies water directly to furrow or border irrigation systems. Conveyance ditch = on-farm ditch that transports water to and from the field; conveyance ditches are used on a relatively continuous basis during the irrigation season. Tailwater ditch = ditches at lower end of furrow or border that transport tailwater to the tailwater conveyance ditches.

[†] Days vary for head ditches from less than 40 to over 60 days per year, depending on crop type, field size, management and other factors. Values selected are thought to represent average conditions in WWD.

[§] The entire ditch length is not used continuously because of irrigation management factors. An operational analysis was performed to estimate the percentage of time that the equivalent ditch length could be considered used.

[¶] The average losses (acre-feet per unit per year) can be altered to emulate shorter or longer operational periods to obtain site-specific seepage estimates.

[#] The average ditch unit seepage rate was 0.39 $ft^3/ft^2$/day. Reservoirs had an average seepage loss of 7.89 acre-feet/acre/year. The wetted perimeter of the tailwater ditch was assumed to be 25% of the wetted perimeter of the head ditch. Total seepage loss values are rounded.

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