PESTICIDE MOVEMENT TO GROUND WATER
EPA GRANT #009155-79

VOLUME III. USE OF AGRONOMIC VARIABLES TO PREDICT GROUND WATER CONTAMINATION IN THE SAN JOAQUIN VALLEY, CALIFORNIA

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E R R A T A

Page 6 Figure 2. Symbols missing from the legend are:

● = Uncontaminated soil core

◆ = Contaminated soil cores

△ = Contaminated well

□ = Uncontaminated well

Page 56 Figure 13. Symbols missing from the legend are:

△ = Contaminated well

□ = Uncontaminated well

Page 5 Figure 1. Correct legend should read: "Map of study area showing township-range <u>subunits</u> and identification matrix"

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ABSTRACT

This is the third volume of a study to sample the extent of pesticide contamination in four ground water basins in California (Volume I), to document the presence of pesticide residues in soil to ground water depths (Volume II), and to develop methods for predicting the occurrence of ground water contamination by pesticides in California (Volume III).

Two statistical methods, principal component analysis and discriminant analysis, were used to explore the potential of several agronomic variables in predicting ground water contamination. Data for agricultural acreage, root knot nematode damage, Storie Index, soil water capacity, infiltration rate, agricultural recharge and field application of DBCP, EDB, simazine and carbofuran were collected, or calculated, from existing soil series and land use maps.

The study encompassed a 144 square mile area of the San Joaquin Valley, California. Seven contaminated and three uncontaminated wells sampled in a previous study were used as the test population for assessing the predictive ability of principal component and discriminant models.

The model derived using principal component analysis was unable to segregate spatial units containing contaminated and uncontaminated wells. The discriminant model successfully classified all seven wells as contaminated or uncontaminated, using well depth, the depth of the upper casing perforation of each well, and the total deciduous fruit and nut acreage present in the well's spatial unit.

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INTRODUCTION

The presence of pesticides in ground water has been a major environmental and public health concern since 1979 when aldicarb and DBCP residues were detected in the aquifers of several states. Although it had been recognized for some time that pesticide residues could occur in surface waters as a result of agricultural practices, the specific threat to ground water posed by the use of pesticides had not received much attention. Many reasons may be forwarded for this lack of insight: pesticides, especially soil fumigants and herbicides, were not considered highly mobile through soil and most field studies were not designed to specifically address the possibility that these substances could travel to great depths. Soil studies of pesticide movement typically focused on product efficacy and soil residues to determine whether or not active ingredients remained in the root zone in sufficient concentrations to effect their biological targets, or dissipated in time to prevent injury to later crops. As a consequence, most studies failed to test for the presence of pesticides in soils at depths below 100 centimeters.

After the first incidences of pesticide detection in ground water were reported, the United States Environmental Protection Agency (EPA) reviewed over 1,000 pesticides to determine those with the highest potential of leaching to ground water. Since 1979, at least 16 pesticides have been detected in ground water throughout the United States. The detection of DBCP and EDB in ground water, in conjunction with the carcinogenic potency of these chemicals, accelerated their removal from the pesticide market. Two broad questions with major implications for future pesticide regulation and agricultural productivity were suggested by these incidences: 1) Are pesticides leaching from the soil surface to aquifers as a result of agricultural use?; 2) Are there any predictive methods that could alert scientists and regulators to agricultural settings and practices which might result in ground water contamination from applied pesticides?

By January, 1980, the California Department of Food and Agriculture (CDFA) and the EPA had established a design for a joint study to begin addressing these questions in California. The first phase of the project was a pilot study of the Santa Clara aquifer in California. During this phase, well sampling and residue analysis methods were developed and field tested. The second phase used the methods developed in the first part to survey the extent of ground water contamination in four California aquifers, identify physical mechanisms which influence the migration of pesticides through the soil to ground water, and identify agricultural conditions under which contamination is most probable. The results from studies performed during the second phase were reported in three volumes.

Volume I, "Survey of Groundwater Basins for DBCP, EDB, Simazine and Carbofuran", described the spatial distribution of contaminated and uncontaminated wells in four ground water basins (two in the Central Valley, two in coastal regions). Four pesticides were chosen as potential ground water contaminants based on screening conducted by the EPA and the use of these pesticides in California. Of 216 wells sampled, 35 (16%) contained detectable levels of the selected pesticides. Contaminated wells were found within two sampled ground water basins, both located in the Central Valley. Of the total sampled population, 181 wells (84%) were uncontaminated.

Volume II, "Pesticide Contamination in the Soil Profile at DBCP, EDB, Simazine and Carbofuran Application Sites", investigated mechanisms which influence the migration of pesticides through soil to ground water depths, and documented the presence of pesticide residues in soil profiles. Samples were collected from soil cores drilled on agricultural fields with known histories of pesticide application. EDB and simazine, two pesticides with very different chemical properties, were detected at depths down to 40 feet in soil profiles. Statistical analyses indicated that three variables were most important in predicting the presence of pesticides at sampled locations: time elapsed since the last pesticide application, organic content of the soil, and soil moisture. These findings raised additional questions about the migration of pesticides from the soil surface and the complex interaction between soil properties, cultural practices, and chemical properties of pesticides.

In the present volume, data for ten variables in an agricultural region were collected and examined for their ability to predict ground water contamination within spatial units. A quantitative land use 'data base' was developed for the agricultural acreage, nematode damage, Storie index, water capacity, infiltration rate, agricultural recharge, and theoretical pesticide application rates within a 144 square mile study area. In this report, the term 'contamination' denotes any detected residue in sampled media. Conversely, 'uncontaminated' is used with regard to any sample for which no measurable residue was indicated.

MATERIALS AND METHODS

This study examined the potential of regional agronomic variables as predictors of ground water contamination, using methods of spatial analysis similar to those employed in geological resource exploration (4, 5, 6, 8, 22, 23). 'Regionalized' variables are composite averages of data within arbitrary spatial units. Data for the variables in this study were based on two independent mapped data sources: land use and soil types. Many of the variables were expected to be highly intercorrelated because they were calculated from common sources. Therefore, the methods used in data collection present a source of cumulative error, as data sets were not derived independently. The data sets do, however, represent the best quantitative representation of land use in the study area known at the time, and may be partially corroborated by other information sources (31). There were no other agronomic data bases available to statistically characterize this region of California at the spatial resolution required by our analyses.

Experimental methods and statistical analyses similar to those selected for this study have been used in geochemical and mineral resource exploration with some success (4, 5, 22). In these applications, large tracts of land are divided by a regular grid into cells. Relevent variables are selected (e.g., mineral content of core samples or other lithological data) and regionalized data is collected or computed for each cell. Alternatively, data for groups of 'reference' cells may be collected, which have been extensively explored in past studies, and extrapolations made to adjacent areas (4). Areas 'explored' by these methods are typically much larger than the four township subunits used in the present study. In one mineral resource evaluation, the primary unit, or cell, was ten kilometers long on a side; approximately five times the length of a standard Public Lands Survey section (5). Cells with less than 25% regional data for a variable were not included.

Study area

The study area was located in the San Joaquin Valley of California, on the southern border of Fresno County overlapping Tulare County to a small extent (Figure 1). Irrigated agriculture occupies most of the acreage in the study

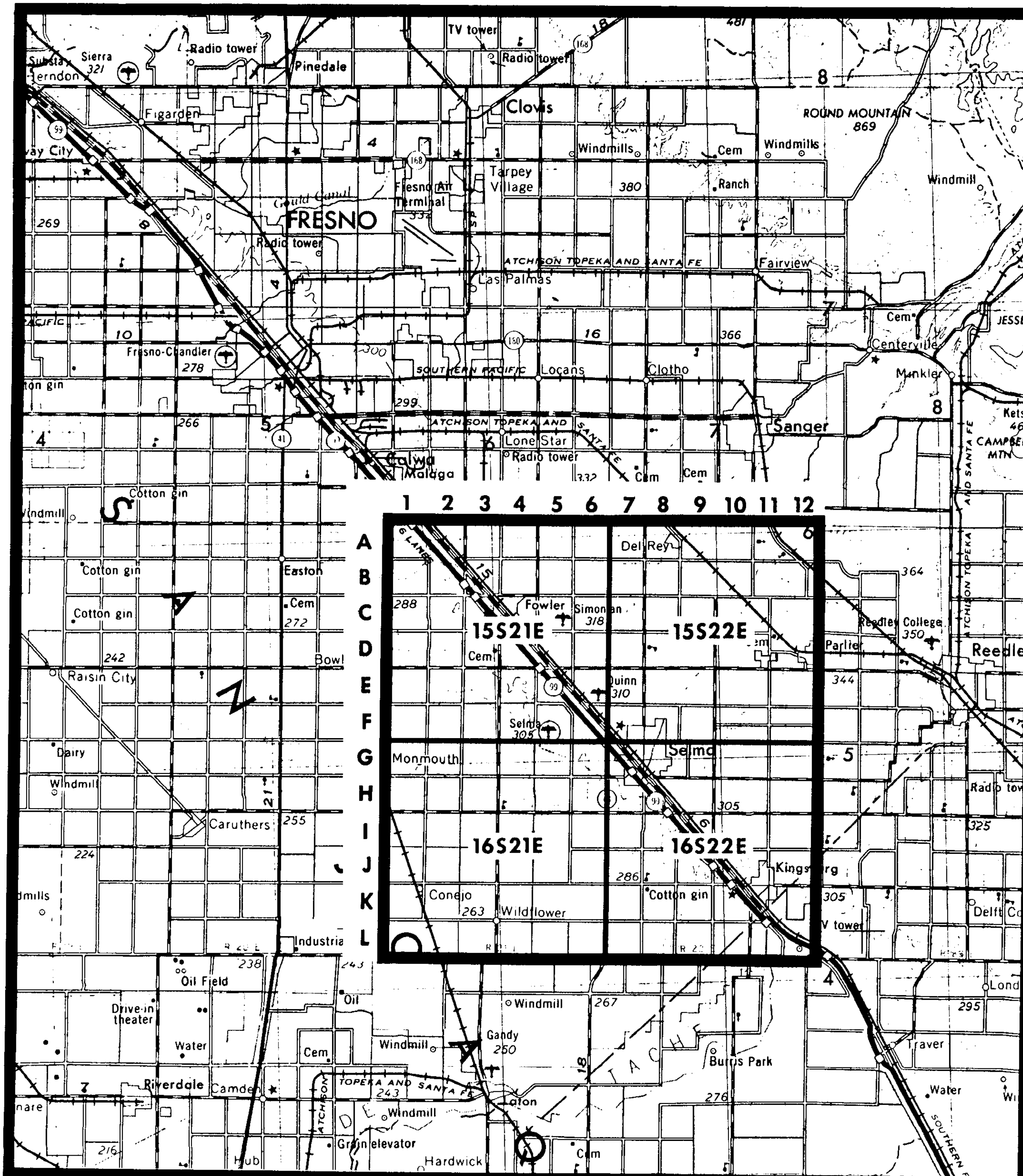


Fig. 1 Map of study area showing township-range submits and identification matrix.

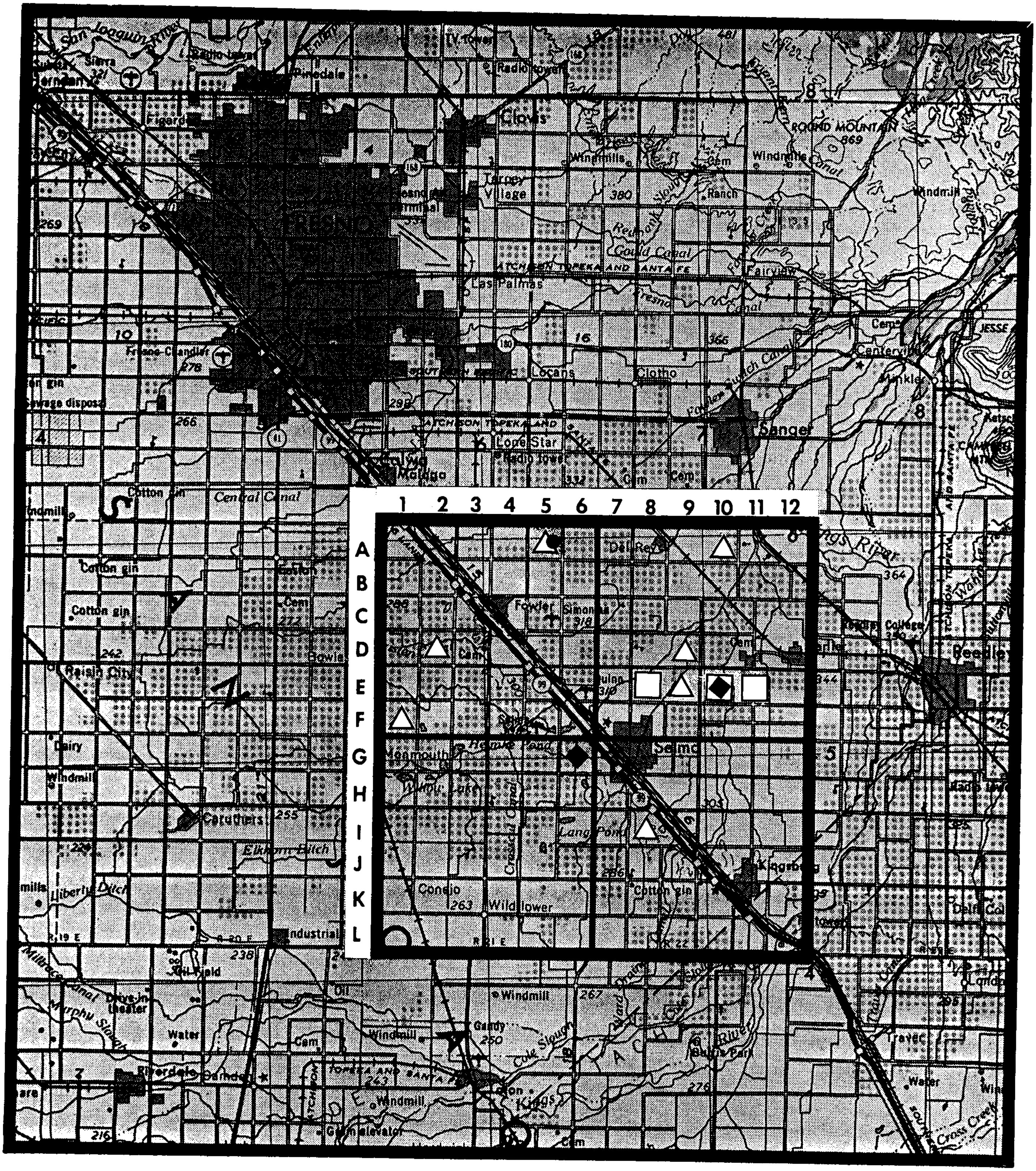


Fig. 2 Location of contaminated and uncontaminated wells reported in Volume I, and contaminated and uncontaminated soil cores reported in Volume II.

area, although several small urban centers were included. The city of Fresno is located to the northwest, and the area is bounded on the east by the Kings River.

Four adjoining township-range subunits of the Public Land Survey were selected, located in an area of known ground water contamination. Townships '15S 21E', '15S 22E', '16S 21E' and '16S 22E' (read as "15 south 21 east", etc.) represent a 12 mile by 12 mile area containing 144, one square mile sections. A geographical matrix labeled 'A' through 'L' (north to south), and '1' through '12' (west to east) provided a unique identifier for each section (Figure 1). The area includes ten wells and three of seven soil cores (Figure 2) reported in the first and second volumes of this project (9,10). Townships '15S 21E' and '15S 22E' correspond to cell '109' described in the first volume; township '16S 21E' corresponds to cell '115', and '16S 22E' to cell '114'. DBCP residues were detected in all of the positive wells, and the well in section E9 also contained simazine. The soil core located in section A5 was referred to as site 'D-1' in Volume II; cores in section E10 and G6 correspond to sites 'E-0' and 'E-1', respectively. EDB residues were detected within the soil cores at these two sites.

Alluvial fans form the main geomorphic units in this portion of the San Joaquin valley. The study area is situated over unconsolidated deposits of young and older alluvia of the Hanford-Delhi-Hesperia soil association. Soils in this association are typically deep, well-drained to excessively-drained sands and sandy loams (20). Poorly drained basin soils are present along the southwestern edge of the study grid. Terrain elevation is 250 to 350 feet above sea level, increasing along the northeast diagonal. The climate is typically hot and dry in summer with an average yearly rainfall of ten inches.

Agricultural acreage and related variables

There were eight major crop types in the study area. Acreages were estimated from 1979 land use maps (1:2400 scale) of the Malaga, Sanger, Conejo, Laton, Selma and Burris Park quadrangles. An acetate grid divided into 100 units was overlayed onto each section and the percent area occupied by each crop type was visually estimated. Multiplying each percentage by 640 gave the approximate acreage of each crop type in a section. Each crop type was required to occupy at least 32 acres (5%) of a section to be included in later calculations. In addition, at least 320 acres (50%) of land in agricultural use was required for a section to be included in the study. These thresholds were arbitrary, as no quantitative criteria were known which established appropriate units for agricultural systems.

Vineyards were the dominant crop type (74.8%) and were evenly distributed throughout the study area (Table 9). Deciduous fruit and nut crops constituted the second largest crop category (14.6%) (Table 4). These two crop categories occupied six time the acreage of all others combined. Field crops (4.2%), alfalfa (1.4%), pasture (1.1%), truck and berry crops (0.7%) and grain and hay crops (0.5%) were primarily located in the southern and southwestern sections (Tables 5-9). There was a single 64 acre planting of subtropical fruit (citrus) in section A6 (Table 10). Crop types, their mapping symbols, and estimated total acreages within the study area are listed in Table 1 (11). Acreage for the eight major crop types, by section, are shown in Tables 3 through 10. Data for five variables were calculated from the crop type acreages in each section: agricultural recharge, and the estimated application rates of DBCP, EDB, simazine and carbofuran.

Table 1. Major crops of the study area.

Crop Type	Mapping Symbol	Acres in Matrix
Vineyards	V	63168
Deciduous Fruits and Nuts	D	12320
Field Crops	F	3584
Alfalfa	P1	1600
Pasture (except alfalfa)	P2-P7	928
Truck and Berry Crops	T	576
Grain and Hay Crops	G	448
Subtropical Fruits	C	64

Table 2. Total agricultural acreage by section.[a]

	1	2	3	4	5	6	7	8	9	10	11	12
A	576	448	576	640	576	640	640	512	512	640	608	576
B	544	576	576	544	640	640	640	640	640	640	608	608
C	640	640	544	---	640	640	608	640	640	640	640	640
D	640	640	608	480	512	608	640	576	576	640	448	---
E	608	640	608	640	544	544	416	640	640	512	640	640
F	640	608	640	544	416	---	---	448	640	544	640	640
G	608	512	480	576	608	640	---	---	640	544	640	640
H	544	480	640	608	640	608	512	480	608	640	640	640
I	608	640	544	640	608	640	640	640	352	576	640	640
J	608	608	640	640	576	640	640	640	480	512	---	---
K	608	608	640	640	640	640	608	640	480	544	---	---
L	608	576	512	640	640	640	608	640	576	---	---	---

a. '---' indicates section excluded due to lack of soil data, or less than 50% of the section was in agricultural use.

Table 3. Vineyard acreage by section[a]

	1	2	3	4	5	6	7	8	9	10	11	12
A	512	256	448	480	512	576	544	448	320	608	416	256
B	544	576	544	512	512	384	544	512	576	544	384	320
C	512	640	416	192	608	576	544	544	544	384	384	448
D	608	512	512	416	448	480	288	512	480	480	256	192
E	480	512	480	480	480	512	352	608	608	384	448	384
F	544	512	640	480	352	224	96	384	384	448	480	352
G	608	448	416	512	608	576	96	192	480	352	480	448
H	512	448	608	608	576	608	512	448	480	512	608	352
I	448	448	544	448	416	608	512	576	352	512	608	544
J	384	192	320	384	480	576	576	608	416	480	320	448
K	192	96	---	32	416	512	384	512	416	352	128	512
L	192	---	192	192	416	384	128	576	544	544	480	256

a. '---' indicates less than 32 acres of crop type in section.

Table 4. Deciduous fruit and nut acreage by section[a]

	1	2	3	4	5	6	7	8	9	10	11	12
A	64	160	96	160	64	---	96	64	192	32	192	160
B	---	---	32	32	128	256	96	128	64	96	192	288
C	32	---	96	64	32	64	64	96	96	256	256	192
D	32	128	64	64	64	128	352	64	96	160	160	64
E	64	64	96	160	64	32	64	32	32	128	192	256
F	32	64	---	64	64	---	---	64	256	96	160	288
G	---	64	64	64	---	32	---	---	160	128	128	192
H	---	---	32	---	64	---	---	---	128	64	32	288
I	---	64	---	160	160	32	32	32	---	64	32	96
J	---	128	---	128	---	---	---	32	64	32	96	128
K	352	192	256	160	128	32	32	32	64	192	---	128
L	64	64	32	---	---	64	---	64	---	64	96	96

a. '---' indicates less than 32 acres of crop type in section.

Table 5. Field crop acreage by section[a]

	1	2	3	4	5	6	7	8	9	10	11	12
A	---	---	---	---	---	---	---	---	---	---	---	32
B	---	---	---	---	---	---	---	---	---	---	32	---
C	32	---	---	---	---	---	---	---	---	---	---	---
D	---	---	---	---	---	---	---	---	---	---	32	---
E	64	64	---	---	---	---	---	---	---	---	---	---
F	32	---	---	---	---	---	32	---	---	---	---	---
G	---	---	---	---	---	---	---	---	---	---	32	---
H	---	---	---	---	---	---	---	---	---	32	---	---
I	32	---	---	---	---	---	64	32	---	---	---	---
J	64	128	192	64	96	---	64	---	---	---	---	---
K	64	128	256	224	---	96	96	96	---	---	---	---
L	320	192	160	416	128	128	160	---	---	---	---	---

a. '---' indicates less than 32 acres of crop type in section.

Table 6. Alfalfa acreage by section[a]

	1	2	3	4	5	6	7	8	9	10	11	12
A	---	---	---	---	---	---	---	---	---	---	---	---
B	---	---	---	---	---	---	---	---	---	---	---	---
C	---	---	---	---	---	---	---	---	---	---	---	---
D	---	---	32	---	---	---	---	---	---	---	---	---
E	---	---	---	---	---	---	---	---	---	---	---	---
F	---	---	---	---	---	---	---	---	---	---	---	---
G	---	---	---	---	---	32	---	---	---	---	---	---
H	---	---	---	---	---	---	---	---	---	---	---	---
I	---	128	---	32	---	---	---	---	---	---	---	---
J	64	64	---	---	---	64	---	---	---	---	---	---
K	---	160	---	32	96	---	---	---	---	---	32	---
L	---	320	---	32	96	64	288	---	32	---	32	---

a. '---' indicates less than 32 acres of crop type in section.

Table 7. Truck and berry crop acreage by section[a]

	1	2	3	4	5	6	7	8	9	10	11	12
A	---	32	---	---	---	---	---	---	---	---	---	96
B	---	---	---	---	---	---	---	---	---	---	---	---
C	---	---	32	---	---	---	---	---	---	---	---	---
D	---	---	---	---	---	---	---	---	---	---	---	---
E	---	---	---	---	---	---	---	---	---	---	---	---
F	32	---	---	---	---	---	---	---	---	---	---	---
G	---	---	---	---	---	---	---	---	---	---	---	---
H	32	---	---	---	---	---	---	---	---	---	---	---
I	96	---	---	---	---	---	---	---	---	---	---	---
J	32	96	---	---	---	---	---	---	---	---	---	---
K	---	---	---	---	---	---	64	---	---	---	---	---
L	---	---	---	---	---	---	32	---	---	---	32	---

a. '---' indicates less than 32 acres of crop type in section.

Table 8. Grain and hay acreage by section.[a]

	1	2	3	4	5	6	7	8	9	10	11	12
A	---	---	---	---	---	---	---	---	---	---	---	---
B	---	---	---	---	---	---	---	---	---	---	---	---
C	---	---	---	---	---	---	---	---	---	---	---	---
D	---	---	---	---	---	---	---	---	---	---	---	---
E	---	---	---	---	---	---	---	---	---	---	---	---
F	---	---	---	---	---	---	---	---	---	---	---	---
G	---	---	---	---	---	---	---	---	---	---	---	---
H	---	32	---	---	---	---	---	---	---	32	---	---
I	---	---	---	---	---	---	---	---	---	---	---	---
J	64	---	---	64	---	---	---	---	---	---	---	---
K	---	32	---	192	---	---	---	---	---	---	---	---
L	32	---	---	---	---	---	---	---	---	---	---	---

a. '---' indicates less than 32 acres of crop type in section.

Table 9. Pasture acreage by section (except alfalfa).[a]

	1	2	3	4	5	6	7	8	9	10	11	12
A	---	---	32	---	---	---	---	---	---	---	---	32
B	---	---	---	---	---	---	---	---	---	---	---	---
C	64	---	---	---	---	---	---	---	---	---	---	---
D	---	---	---	---	---	---	---	---	---	---	---	---
E	---	---	32	---	---	---	---	---	---	---	---	---
F	---	32	---	---	---	32	---	---	---	---	---	---
G	---	---	---	---	---	---	---	---	---	64	---	---
H	---	---	---	---	---	---	---	32	---	---	---	---
I	32	---	---	---	32	---	32	---	---	---	---	---
J	---	---	128	---	---	---	---	---	---	---	---	---
K	---	---	128	---	---	---	32	---	---	---	---	---
L	---	---	128	---	---	---	---	---	---	---	---	64

a. '---' indicates less than 32 acres of crop type in section.

Table 10. Subtropical fruit acreage by section[a]

	1	2	3	4	5	6	7	8	9	10	11	12
A	---	---	---	---	---	64	---	---	---	---	---	---
B	---	---	---	---	---	---	---	---	---	---	---	---
C	---	---	---	---	---	---	---	---	---	---	---	---
D	---	---	---	---	---	---	---	---	---	---	---	---
E	---	---	---	---	---	---	---	---	---	---	---	---
F	---	---	---	---	---	---	---	---	---	---	---	---
G	---	---	---	---	---	---	---	---	---	---	---	---
H	---	---	---	---	---	---	---	---	---	---	---	---
I	---	---	---	---	---	---	---	---	---	---	---	---
J	---	---	---	---	---	---	---	---	---	---	---	---
K	---	---	---	---	---	---	---	---	---	---	---	---
L	---	---	---	---	---	---	---	---	---	---	---	---

a. '---' indicates less than 32 acres of crop type in section.

Agricultural recharge (CV1)

The quantity of water flowing through the vadose zone is known to contribute to the transport of some pollutants to shallow ground water. In agricultural areas, irrigation water applied in excess of crop requirements and evaporation losses may be a significant source of recharge. Crop-specific values for applied water and evapotranspiration for each of the eight study crops were obtained from tables developed by the California Department of Water Resources (16). The average water excess and acreage for each crop type were combined to provide an estimate of water available for recharge from agricultural sources (CV1) in acre feet per agricultural acre (Equation 5, Table 12). This estimate did not include the contribution of rainfall or other sources to ground water recharge.

$$CV1 = \sum_{1}^{n} (NW_i)(\% \ crop_i) \qquad \text{(Equation 1)}$$

Where n= number of crop types in section

Table 11. Agricultural recharge of crop groups in study area

Mapping symbol	Crop	Unit applied water(b)	Unit evapotranspiration(b)	Net water	Average net water
C	Citrus and Olives	2.7	1.8	0.9	0.9
D	Almonds and Pistachios,	2.7	1.9	0.8	1.1
	Other Deciduous	4.0	2.6	1.4	
F	Cotton	3.8	2.5	1.3	1.3
	Sugar Beets	3.8	2.5	1.3	
	Corn	3.5	2.0	1.5	
	Other Field Crops	3.0	1.9	1.1	
G	Grain	1.4	1.0	0.4	0.4
P2-7	Pasture	6.3	3.2	3.1	3.1
T	Truck and Berry Crops	3.2	2.2	1.0	1.0
V	Vineyard	3.8	2.0	1.8	1.8
P1	Alfalfa	4.7	2.9	1.8	1.8

a. Estimated for Fresno County. Source: G. B. Sawyer, State of California Department of Water Resources (personal communication).

b. Units in acre-ft/acre.

Table 12. Agricultural recharge (CV1) by section (acre ft/acre).[a]

	1	2	3	4	5	6	7	8	9	10	11	12
A	1.72	1.49	1.76	1.63	1.72	1.71	1.70	1.71	1.54	1.77	1.58	1.50
B	1.80	1.80	1.76	1.76	1.66	1.52	1.70	1.66	1.73	1.70	1.55	1.47
C	1.87	1.80	1.62	----	1.77	1.73	1.73	1.70	1.70	1.52	1.52	1.59
D	1.77	1.66	1.73	1.71	1.71	1.65	1.42	1.72	1.68	1.63	1.51	----
E	1.67	1.68	1.76	1.63	1.72	1.76	1.69	1.77	1.77	1.63	1.59	1.52
F	1.70	1.79	1.80	1.72	1.69	----	----	1.70	1.52	1.68	1.63	1.49
G	1.80	1.71	1.71	1.72	1.80	1.77	----	----	1.63	1.79	1.64	1.59
H	1.75	1.71	1.77	1.80	1.73	1.80	1.80	1.89	1.65	1.64	1.77	1.59
I	1.70	1.73	1.80	1.63	1.68	1.77	1.78	1.74	1.80	1.72	1.77	1.70
J	1.55	1.41	1.91	1.47	1.72	1.80	1.75	1.77	1.71	1.76	----	----
K	1.34	1.40	1.58	1.03	1.66	1.69	1.66	1.69	1.71	1.55	----	----
L	1.39	1.56	1.93	1.48	1.77	1.63	1.62	1.73	1.80	----	----	----

a. '---' indicates section excluded due to lack of soil data, or less than 50% agricultural use.

Pesticide Application

A high incidence of pesticide contamination in ground water may be associated with areas of frequent pesticide use. To test this relationship, the quantity of pesticides (DBCP, EDB, simazine and carbofuran) that could be applied to each section was calculated. It was assumed that each of the eight crop groups present in a section would receive one treatment, and that application rates were equivalent to an average of rates recommended on several registered product labels (Table 13)(17). Average rates and crop distributions were used to calculate the total pounds of each active ingredient applied in a section (Equations 2-5, Tables 14-17).

Total pounds of DBCP per section (CV2): (Equation 2)

CV2 = 70.4(citrus acreage) + 60.3(deciduous fruit and nut acreage) + 17.8(field crop acreage) + 36.3(truck and berry crop acreage) + 60.3(vineyard acreage).

Total pounds of EDB per section (CV3): (Equation 3)

CV3 = 180(citrus acreage) + 180(deciduous fruit and nut acreage) + 69(field crop acreage)

Total pounds of simazine per section (CV4): (Equation 4)

CV4 = 2.4(citrus acreage) + 2.4(deciduous fruit and nut acreage) + 2(field crop acreage) + 2.7(truck and berry crop acreage) + 2.4(vineyard acreage) + 0.8(alfalfa acreage)

Total pounds of carbofuran per section (CV5): (Equation 5)

CV5 = 1.3(field crop acreage) + 0.37(grain acreage) + 1.5(truck and berry crop acreage) + 10(vineyard acreage) + 0.75(alfalfa acreage)

Table 13. Average pesticide application rates for crop groups in study area (lbs active ingredient/acre).

Crop	Average application rate			
	DBCP	EDB	simazine	carbofuran
Subtropical fruit	70.4	180	2.4	---
Deciduous fruit and nut	60.3	180	2.4	---
Field	17.8	69	2	1.3
Grain and hay	---	---	---	0.37
Pasture (except alfalfa)	---	---	---	---
Truck and berry	36.3	---	2.7	1.5
Vineyard	60.3	---	2.4	10
Alfalfa	---	---	0.8	0.75

Source: California Department of Food and Agriculture, Pesticide Registration Library.

Table 14. Total pounds of DBCP that could have been applied in one application (hundred lbs active ingredient/section)

	1	2	3	4	5	6	7	8	9	10	11	12
A	347.33	262.46	328.03	385.92	347.33	392.38	385.92	308.74	308.74	385.92	366.62	256.54
B	328.03	347.33	347.33	328.03	385.92	385.92	385.92	385.92	385.92	385.92	353.02	366.62
C	333.73	385.92	320.35	----(a)	385.92	385.92	366.62	385.92	385.92	385.92	385.92	385.92
D	385.92	385.92	347.33	289.44	308.74	366.62	385.92	347.33	347.33	385.92	256.54	------
E	339.42	385.72	347.33	385.92	328.03	328.03	250.85	385.92	385.92	308.74	385.92	385.92
F	364.64	347.33	385.92	424.51	250.85	------	------	270.14	385.92	328.03	385.92	385.92
G	366.62	308.74	289.44	347.33	366.62	366.62	------	------	385.92	289.44	372.32	385.92
H	320.35	270.14	385.92	366.62	385.92	366.62	308.74	270.14	366.62	353.02	385.92	385.92
I	310.69	308.74	328.03	366.62	347.33	385.92	339.42	372.32	212.26	347.33	385.92	385.92
J	254.56	250.59	227.14	320.13	306.53	347.33	358.72	385.92	289.44	308.77	------	------
K	339.42	196.45	199.94	155.65	328.03	345.12	291.17	345.12	289.44	328.03	------	------
L	211.33	72.77	163.55	189.82	273.63	292.93	117.28	385.92	328.03	------	------	------

a. Section excluded due to lack of soil data, or less than 50% agricultural use.

Table 15. Total pounds of EDB that could have been applied in one application (lbs active ingredient/section)

	1	2	3	4	5	6	7	8	9	10	11	12
A	11520	28800	17280	28800	11520	11520	17280	11520	34560	5760	34560	31008
B	0	0	5760	5760	23040	46080	17280	23040	11520	17280	36768	51840
C	7968	0	17280	---(a)	5760	11520	11520	17280	17280	46080	46080	34560
D	5760	23040	11520	11520	11520	23040	63360	11520	17280	28800	31008	-----
E	15936	15936	17280	28800	11520	5760	11520	5760	5760	23040	34560	46080
F	7968	11520	0	15520	11520	-----	-----	11520	46080	17280	28800	51840
G	0	11520	11520	11520	0	5760	-----	-----	28800	23040	25248	34560
H	0	0	5760	0	11520	0	0	0	23040	13728	5760	51840
I	2208	11520	0	28800	28800	5760	10176	7968	0	11520	5760	17280
J	4416	31872	13248	27456	6624	0	4416	5760	11520	5760	-----	-----
K	67776	43392	63744	44256	23040	12384	12384	12384	11520	34560	-----	-----
L	33600	24768	16800	28704	8832	20352	11040	11520	0	-----	-----	-----

a. Section excluded missing due to lack of soil data, or less than 50% agricultural use.

Table 16. Total pounds of simazine that could have been applied in one application (lbs active ingredient/section)

	1	2	3	4	5	6	7	8	9	10	11	12
A	1382.4	1084.8	1305.6	1536.0	1382.4	1536.0	1536.0	1228.8	1228.8	1536.0	1459.2	1062.4
B	1305.6	1382.4	1382.4	1305.6	1536.0	1536.0	1536.0	1536.0	1536.0	1536.0	1446.4	1459.2
C	1369.6	1536.0	1315.2	----(a)	1536.0	1536.0	1459.2	1536.0	1536.0	1536.0	1536.0	1536.0
D	1536.0	1536.0	1408.0	1152.0	1228.8	1459.2	1536.0	1382.4	1382.4	1536.0	1062.4	-----
E	1433.6	1510.4	1382.4	1536.0	1305.6	1305.6	998.4	1536.0	1536.0	1228.8	1536.0	1536.0
F	1532.8	1382.4	1536.0	1689.6	998.4	------	------	1075.2	1536.0	1305.6	1536.0	1536.0
G	1459.2	1228.8	1152.0	1382.4	1459.2	1484.8	------	------	1536.0	1152.0	1523.2	1536.0
H	1315.2	1075.2	1536.0	1459.2	1536.0	1459.2	1228.8	1075.2	1459.2	1446.4	1536.0	1536.0
I	1398.4	1331.2	1305.6	1484.8	1382.4	1536.0	1433.6	1523.2	844.8	1382.4	1536.0	1536.0
J	1187.2	1334.4	1152.0	1356.8	1344.0	1433.6	1510.4	1536.0	------	------	998.4	1382.4
K	1433.6	1075.2	1126.4	934.4	1382.4	1497.6	1363.2	1497.6	------	------	332.8	1536.0
L	1254.4	793.6	857.6	1318.4	1331.4	1382.4	944.0	------	------	------	1494.4	844.8

a. Section excluded due to lack of soil data, or less than 50% agricultural use.

Table 17. Total pounds of carbofuran that could have been applied in one application (lbs active ingredient/section)

	1	2	3	4	5	6	7	8	9	10	11	12
A	5120.0	2608.0	4480.0	4800.0	5120.0	5760.0	5440.0	4480.0	3200.0	6080.0	4160.0	2601.6
B	5440.0	5760.0	5440.0	5120.0	5120.0	3840.0	5440.0	5120.0	5760.0	5440.0	3881.6	3200.0
C	5161.6	6400.0	4208.0	----(a)	6080.0	5760.0	5440.0	5440.0	5440.0	3840.0	3840.0	4480.0
D	6080.0	5120.0	5144.0	4160.0	4480.0	4800.0	2880.0	5120.0	4800.0	4800.0	2601.6	------
E	4883.2	5203.2	4800.0	4800.0	4800.0	5120.0	3520.0	6080.0	6080.0	3840.0	4480.0	3840.0
F	5529.6	5120.0	6400.0	6400.0	3520.0	------	------	3840.0	3840.0	4480.0	4800.0	3520.0
G	6080.0	4480.0	4160.0	5120.0	6080.0	5784.0	------	------	4800.0	3520.0	4841.6	4480.0
H	5168.0	4491.8	6080.0	6080.0	5760.0	6080.0	5120.0	4480.0	4800.0	5173.4	6080.0	3520.0
I	4665.6	4576.0	5440.0	4504.0	4160.0	6080.0	5203.2	5801.6	3520.0	5120.0	6080.0	5440.0
J	4042.9	2278.4	3449.3	3946.9	4924.8	5808.0	5843.2	6080.0	4160.0	4800.0	------	------
K	2003.2	1258.2	332.8	706.2	4232.0	5244.8	4060.0	5244.8	4160.0	3520.0	------	------
L	2347.8	489.6	2128.0	2484.8	4398.4	4054.4	1752.0	5760.0	5464.0	------	------	------

a. Section excluded due to lack of soil data, or less than 50% agricultural use.

Soil series and related variables

Soil types were grouped into soil series based upon USDA classifications (12). Soil series distributions for the study area were determined by the same visual overlay method for estimating crop acreages, using soil survey maps (1:2400 scale) (12). In this report, the areal percentage of a section occupied by a soil series will be termed the 'section fraction' of that series. Like the crop acreage thresholds, any particular soil series had to occupy a total of at least 32 acres (5%) of the section in order to be included in further calculations. The major soil series in the study area, their constituent soil types, mapping symbols, and total acreages are shown in Table 18.

Values for four agronomic variables were derived from soil series data: a Root Knot nematode damage index, Storie Index, soil water capacity, and infiltration rate. The Storie Index, infiltration rate, and water capacity for each series were obtained by averaging values reported for constituent soil types. Weighted section averages were calculated by multiplying the average value of each soil-related variable by every section fraction and summing the products.

Table 18. Major soil series in the study area[a]

Soil series	Acres	Mapping symbol	Soil type
Calhi	352	CfA	Calhi loamy sand 0-3% slopes
		CgA	Calhi loamy sand 0-3% slopes, moderately deep.
Delhi A[b]	7360	DeA	Delhi sand 0-3% slopes
		DeB	Delhi sand 3-9% slopes
Delhi B	16960	DhA	Delhi loamy sand 0-3% slopes
		DhB	Delhi loamy sand 3-9% slopes
		DlA	Delhi loamy sand 0-3% slopes, moderately deep.
Dello	1824	Dm	Dello loamy sand
		Dn	Dello sandy loam
El Peco	288	Ed	El Peco fine sandy loam
Exeter	1120	Ex	Exeter loam
		Es	Exeter sandy loam
Grangeville	128	Gd	Grangeville sandy loam, saline alkali
		Gf	Grangeville fine sandy loam
		Gg	Grangeville fine sandy loam, saline alkali
		Gh	Grangeville fine sandy loam, water table
		Gk	Grangeville fine sandy loam, water table, saline alkali

a. Source: USDA Soil Survey, Eastern Fresno County.
b. The Delhi series was split into two groups because of large differences in some parameters.

Table 18. Major soil series in the study area[a] (Con't)

Soil series	Acres	Mapping symbol	Soil type
Hanford	29984	Hc	Hanford sandy loam
		Hd	Hanford sandy loam benches
		Hg	Hanford sandy loam, silty substratum
		Hm	Hanford fine sandy loam
		Hr	Hanford fine sandy loam, hard substratum
		Ho	Hanford fine sandy loam, silty substratum
Hesperia	18624	Hsd	Hesperia sandy loam
		Hse	Hesperia sandy loam, saline alkali
		Hsm	Hesperia sandy loam, moderately deep
		Hsn	Hesperia sandy loam, saline alkali, moderately deep
		Hsr	Hesperia fine sandy loam
		Hss	Hesperia fine sandy loam, saline alkali
		Hst	Hesperia fine sandy loam, moderately deep
		Hsy	Hesperia fine sandy loam, moderately deep, saline alkali.
Pollasky	480	PmB	Pollasky sandy loam 2-9% slopes
		PmC	Pollasky sandy loam 9-15% slopes
		PnB	Pollasky fine sandy loam, 2-9% slopes
Tujunga	4384	TzbA	Tujunga loamy sand, 0-3% slopes
		TzbB	Tujunga loamy sand, 3-9% slopes

a. Source: USDA Soil Survey, Eastern Fresno County.

Root Knot nematode damage index (SV1)

Root Knot nematodes are often severe plant pests in areas associated with sandy, loose soils. An index of potential crop damage intensity by these nematodes was based upon soil series textures, with each series rated on a scale of '1' to '9', from lowest to highest intensity. The index, organized by Dr. Mike McKenry (7) was based upon past experience with plant nematode problems in the area, and present knowledge of soil-nematode relationships. This variable was included in the study to test for possible correlations between nematode activity and increased nematicide application. The damage ratings for soil series present are shown in Table 19. The regional damage for each section (SV1) was calculated from the series damage ratings (SDR) and section fractions (Equation 6). Table 20 shows the damage index for each section in the study area.

$$SV1 = \sum_{1}^{n} (SDR_i)(\%\ \text{soil series}_i) \qquad \text{(Equation 6)}$$

Where n= number of soil series present in section

Table 19. Root Knot nematode damage index levels for soil series[a]

Series	Soil types found in series	Root Knot damage index[b]
Calhi	CfA, Cga	7
Delhi A	DeA, DeB	9
Delhi B	DhA, DhB, DlA	7
Dello	Dm, Dn	7
El Peco	Ed	--[c]
Exeter	Ex, Es	3
Grangeville	Gd, Gf, Gg, Gh, Gk	3
Hanford	Hc, Hd, Hg, Hm, Hr, Ho	5 3
Hesperia	Hsd, Hse, Hsm, Hsn, Hsr, Hss, Hst, Hsy	5
Pollasky	PmB, PmC, PnB	3
Tujunga	TzbA, TzbB	7

a. Source: Dr. M. McKenry, University of California, Division of Agricultural Sciences, Kearney Field Station, Parlier, California(personal communication).

b. 9 = high intensity of Root Knot nematode damage, 1 = low intensity of Root Knot nematode damage.

c. Information was not available to rate this series.

Table 20. Root Knot Nematode damage index by section.[a]

	1	2	3	4	5	6	7	8	9	10	11	12
A	4.3	6.3	6.1	5.8	6.3	5.0	4.1	3.6	3.7	7.3	4.8	5.0
B	6.8	4.8	5.1	4.7	4.3	4.7	4.6	3.8	4.4	4.8	4.6	4.4
C	5.3	5.4	5.1	---	4.2	4.5	5.4	3.9	4.7	4.3	4.2	4.5
D	4.7	4.3	5.3	4.9	4.8	5.7	3.8	5.9	4.1	3.8	6.0	---
E	5.9	5.2	5.0	4.5	5.6	6.1	4.7	4.2	5.1	6.2	4.2	4.2
F	6.3	5.7	4.2	5.7	6.4	---	---	4.2	4.2	7.3	4.1	4.2
G	7.1	6.7	6.7	5.9	7.2	7.3	---	---	4.0	6.8	5.8	4.0
H	7.3	6.5	5.5	6.7	5.4	6.6	5.3	3.9	4.8	6.4	6.1	4.0
I	7.3	5.8	6.7	6.0	5.5	5.6	4.0	4.1	4.4	6.3	5.7	3.6
J	6.0	6.6	5.6	5.7	6.1	5.5	4.7	4.0	5.9	6.6	---	---
K	5.2	5.7	4.7	5.6	6.3	4.7	4.7	5.2	6.7	7.0	---	---
L	3.3	5.4	6.8	5.7	5.1	5.4	4.8	5.3	7.3	---	---	---

a. Section excluded due to lack of soil data, or less than 50% agricultural use.

Storie Index rating (SV2)

The Storie Index is a system that attempts to quantify the suitability of a soil for farming based upon soil properties and site attributes (12). Index ratings span a scale from '1' to '100' and are divided into six grades. Soils rating from 60 to 100 (grades '1' and '2') are considered highly suitable for farming. Four general factors are incorporated into index ratings: depth and characteristics of the soil profile, texture of the surface layer, slope, and the combination of drainage, pH, salts and erosion (7).

Regional Storie Index ratings (SV2) for each section were calculated from the average rating (ASI, Table 21) and section fraction of each soil series (Equation 7). All of the soils in the study area fell into grades '1' and '2', except for sections A9, G3 and H1; these were classified as grade '3' soils. Grade '3' soils are suited to a few specific crops that require special management (12). Calculated ratings for each section are shown in Table 22.

$$SV2 = \sum_{1}^{n} (ASI_i)(\%\text{soil series}_i) \qquad \text{(Equation 7)}$$

Where n= number of soil series present in section

Table 21. Average Storie Index ratings for soil types and series [(a)]

Soil series	Ave. Storie Index	Soil type	Storie Index
Calhi	75	CfA	72
		CgA	77
Delhi A	50	DeA	51
		DeB	49
Delhi B	72	DhA	72
		DhB	68
		DlA	77
Dello	62	Dm	58
		Dn	65
El Peco	23	Ed	23
Exeter	43	Ex	45
		Es	42
Grangeville	60	Gd	51
		Gf	90
		Gg	72
		Gh	60
		Gk	48
		Gp	36
Hanford	90	Hc	95
		Hd	86
		Hg	90
		Hm	100
		Hr	71
		Ho	95
Hesperia	82	Hsd	95
		Hse	71
		Hsm	90
		Hsn	50
		Hsr	100
		Hss	60
		Hst	95
		Hsy	95
Pollasky	58	PmB	57
		PmC	53
		PnB	63
Tujunga	72	TzbA	76
		TzbB	68

a. Source: USDA Soil Survey, Eastern Fresno County.

Table 22. Storie Index by section (SV2).[a]

	1	2	3	4	5	6	7	8	9	10	11	12
A	74.9	72.7	75.5	78.6	62.4	77.5	84.2	68.3	55.2	64.4	82.2	73.1
B	67.6	72.9	81.9	79.8	79.7	79.6	79.5	73.7	67.3	77.0	83.9	80.2
C	75.4	75.4	81.7	----	81.8	80.1	71.9	78.4	76.9	80.3	87.3	84.8
D	79.0	75.6	81.1	77.8	72.4	77.6	84.6	73.8	82.9	84.6	73.6	----
E	63.9	68.6	77.0	74.8	72.9	76.3	72.5	75.9	81.7	72.2	81.2	87.3
F	72.2	60.7	76.7	73.0	66.9	----	----	76.9	87.3	65.8	82.0	87.3
G	61.2	63.7	58.3	67.4	67.0	66.9	----	----	83.5	67.7	76.1	89.0
H	51.1	65.4	74.6	66.6	75.3	66.7	80.9	83.9	73.3	70.5	66.7	82.9
I	65.3	78.6	66.6	76.4	79.2	66.1	83.5	78.7	81.2	67.7	75.9	80.1
J	70.1	72.8	73.9	79.1	77.1	78.9	77.8	74.1	64.8	73.2	----	----
K	81.0	73.4	78.6	73.1	73.7	79.0	78.3	81.8	70.5	68.8	----	----
L	61.4	72.7	69.4	77.3	82.4	74.9	83.4	80.9	65.2	----	----	----

a. '---' indicates section excluded due to lack of soil data, or less than 50% agricultural use.

Soil Water Capacity (SV3)

The capacity of a soil to store water that can be readily absorbed by plants is affected by three soil properties: texture and pore size, textural stratification, and soil depth. Moisture holding capacities of soils may partially determine the final concentrations of pesticides reaching the saturated zone. Increased retention of recharge water containing pesticides would allow more time for degradation processes to occur, and for pesticide molecules to reach adsorption equilibrium with soil constituents.

Soil water capacities for each section (SV3) were calculated from the average water capacity (AWC, Table 23) and section fraction of each soil series (Equation 3). Calculated values for each section are shown in Table 24.

$$SV3 = \sum_{1}^{n} (AWC_i)(\%\ \text{soil series}_i) \qquad \text{(Equation 8)}$$

Where n= number of soil series present in section

Table 23. Average water capacity of soil series in study area[a]

Soil series	Ave water capacity (in/in soil)	Soil type	Water capacity (in/in soil)
Calhi	0.07	CfA	0.06-0.08
		CgA	0.06-0.08
Delhi A	0.05	DeA	0.04-0.06
		DeB	0.04-0.06
Delhi B	0.07	DhA	0.06-0.08
		DhB	0.06-0.08
		DlA	0.06-0.08
Dello	0.06	Dm	0.06-0.08
		Dn	0.04-0.06
El Peco	0.10	Ed	0.08-0.12
Exeter	0.14	Ex	0.13-0.15
		Es	0.13-0.15
Grangeville	0.17	Gd	0.16-0.18
		Gf	0.16-0.18
		Gg	0.16-0.18
		Gh	0.16-0.18
		Gk	0.16-0.18
		Gp	0.16-0.18
Hanford	0.13	Hc	0.10-0.12
		Hd	0.10-0.12
		Hg	0.10-0.12
		Hm	0.12-0.14
		Hk	0.10-0.12
		Ho	0.12-0.14
Hesperia	0.12	Hsd	0.12-0.14
		Hse	0.12-0.14
		Hsm	0.12-0.14
		Hsn	0.12-0.14
		Hsr	0.12-0.14
		Hss	0.12-0.14
		Hst	0.12-0.14
		Hsy	0.12-0.14
Pollasky	0.10	PmB	0.09-0.11
		PmC	0.09-0.11
		PnB	0.09-0.11
Tujunga	0.07	TzbA	0.06-0.08
		TzbB	0.06-0.08

a. Source: USDA Soil Survey, Eastern Fresno County.

Table 24. Water capacity of soil (SV3) by section (in/in soil).[a]

	1	2	3	4	5	6	7	8	9	10	11	12
A	.106	.094	.094	.099	.069	.105	.121	.135	.106	.072	.106	.097
B	.083	.096	.115	.119	.125	.108	.106	.120	.120	.106	.112	.116
C	.102	.106	.116	----	.120	.114	.088	.111	.097	.109	.124	.115
D	.112	.111	.108	.109	.097	.099	.124	.085	.118	.124	.087	----
E	.077	.091	.106	.104	.093	.085	.090	.102	.110	.088	.112	.124
F	.088	.070	.105	.089	.074	----	----	.107	.124	.071	.115	.124
G	.069	.072	.062	.072	.074	.072	----	----	.122	.075	.096	.130
H	.055	.075	.095	.071	.096	.074	.107	.123	.097	.082	.081	.118
I	.075	.099	.071	.097	.104	.085	.122	.114	.112	.082	.098	.117
J	.089	.083	.094	.102	.092	.106	.109	.108	.072	.080	----	----
K	.115	.092	.115	.094	.092	.112	.111	.113	.078	.076	----	----
L	.113	.096	.084	.106	.113	.099	.122	.110	.071	----	----	----

a. '---' indicates section excluded due to lack of soil data, or less than 50% agricultural use.

Infiltration rate (SV4)

Soil permeability determines the rate at which liquids and gases may enter and pass through soil. If the infiltration capacity is exceeded by the amount of water being applied at one time, some of the water will be lost to surface runoff. Thus, the infiltration rate will determine how much recharge will enter the soil of a site. In permeable soils, the speed of the wetting front will be higher and solutes may be transported more quickly to ground water depths.

Regional infiltration rates for each section were determined from the average infiltration rate (AIR, Table 25) and section fraction of each series (Equation 9). Section rates are shown in Table 26.

$$SV4 = \sum_{1}^{n} (\,AIR_i\,)(\,\%\ \text{soil series}_i\,) \qquad \text{(Equation 9)}$$

Where n= number of soil series present in section

Table 25. Average infiltration rates of soil series[a]

Soil series	Ave. infiltration (in/hr)	Soil type	Infiltration (in/hr)
Calhi	7.5	CfA	5.0-10.0
		CgA	5.0-10.0
Delhi A	20.0	DeA	> 20.0
		DeB	> 20.0
Delhi B	7.5	DhA	5.0-10.0
		DhB	5.0-10.0
		DlA	5.0-10.0
Dello	20.0	Dm	> 20.0
		Dn	> 20.0
El Peco	3.75	Ed	2.5-5.0
Exeter	3.75	Ex,Es	2.5-5.0
Grangeville	3.75	Gd	2.5-5.0
		Gf	2.5-5.0
		Gg	2.5-5.0
		Gh	2.5-5.0
		Gk	2.5-5.0
		Gp	2.5-5.0
Hanford	3.75	Hc	2.5-5.0
		Hd	2.5-5.0
		Hg	2.5-5.0
		Hm	2.5-5.0
		Hk	2.5-5.0
		Ho	2.5-5.0
Hesperia	3.75	Hsd	2.5-5.0
		Hse	2.5-5.0
		Hsm	2.5-5.0
		Hsn	2.5-5.0
		Hsr	2.5-5.0
		Hss	2.5-5.0
		Hst	2.5-5.0
		Hsy	2.5-5.0
Pollasky	3.75	PmB	2.5-5.0
		PmC	2.5-5.0
		PnB	2.5-5.0
Tujunga	7.5	TzbA	5.0-10.0
		TzbB	5.0-10.0

a. Source: USDA Soil Survey, Eastern Fresno County.

Table 26. Infiltration rate (SV4) by section (in/hr).[a]

	1	2	3	4	5	6	7	8	9	10	11	12
A	3.75	9.19	6.88	5.44	8.50	4.50	4.13	3.75	4.13	13.00	5.25	7.50
B	12.25	4.50	4.31	4.31	4.13	4.50	4.69	3.94	5.75	6.38	4.88	4.69
C	4.50	5.80	4.13	----	3.57	3.94	9.38	3.75	5.25	4.50	4.13	4.69
D	3.94	3.38	4.88	4.13	4.31	7.31	3.56	8.88	3.94	3.56	8.69	----
E	8.56	5.75	4.31	3.94	7.13	6.56	5.06	4.31	6.13	10.38	4.31	4.13
F	10.38	7.94	4.13	6.88	10.13	----	----	3.94	4.13	12.56	4.13	4.13
G	12.00	11.00	11.38	6.19	11.13	11.31	----	----	3.56	12.38	8.13	3.75
H	15.75	10.56	5.06	8.44	5.06	8.88	6.31	3.56	4.50	11.38	10.19	3.94
I	12.81	5.44	8.44	6.68	6.31	7.38	3.56	4.31	4.31	11.81	8.56	3.38
J	7.13	7.63	5.06	5.25	6.00	6.13	4.13	3.56	8.50	8.00	----	----
K	4.13	5.25	3.56	6.31	7.50	3.94	3.94	4.50	10.50	10.50	----	----
L	3.75	5.44	9.75	5.94	4.50	4.69	3.75	4.69	13.19	----	----	----

a. '---' indicates section excluded due to lack of soil data, or less than 50% agricultural use.

Statistical methods

Two multivariate statistical analyses were chosen to explore the association between study variables:

1. Principal component analysis was used to identify sources of variation and correlation trends in the data set (30). Principal component analysis is a multivariate statistical analysis that groups variables with common trends in correlation into component axes. The first axis, or principal component, is a vector of maximum variablility in the data space. Subsequent components indicate the next largest vectors of variability in the data and are independent of one another. The relative contribution of each variable to the component is indicated by the magnitude of component 'loadings', and the sign of a loading indicates whether variables are positively or negatively correlated to one another in the component. Underlying 'processes' suggested by a component may be interpreted from the combination of correlated variables with significant loadings.

Data for ten agronomic variables from 131 sections in the study area were submitted for principal component analysis, using the BMDP statistical package (14). The data were derived from soil surveys and crop distributions as described above.

2. Discriminant analysis is a step-wise linear regression technique used to describe the segregation between two or more groups in a population. Each group is described by a classification equation, or function. The variable that contributes the most to the separation of groups is added to the equation first, then the next most discriminating variable from those remaining and so on until a significant equation is derived. After the final step, the classification function may be validated by 'jackknifing', in which the value of each case is tested against the remaining group mean in rotation.

The discriminant analysis program in the BMDP statistical package was used in this study (14) to calculate classification equations for ten sections in the study area, using physical well characteristics (total depth, depth of casing perforations, and casing depth) from seven contaminated, and three uncontaminated, wells reported in Volume I, plus data for the original ten agronomic variables compiled in this study.

RESULTS

Summary statistics and correlations

Summary statistics (Table 27) and a correlation matrix (Table 28) of the agronomic variables used in this study were compiled prior to the calculation of principal components. The summary statistics and correlation matrix display distributions around the means, as well as relationships among variables.

The summary statistics highlight some interesting observations about the variables. Crop-related variables include agricultural acreage, agricultural recharge, and the four pesticide application rates. Agricultural acreage is very high in every section and evenly distributed throughout the area, averaging 92.9% of each square mile section. Among the four pesticides, DBCP accounted for 63% of the average calculated use, greater than EDB (25% of total), carbofuran (9%) and simazine (2.5%). EDB use varied the most, probably because crops for which EDB was registered were not uniformly distributed over the study area, and EDB was not registered for use on as many crops as the other three pesticides. The relative use rate among pesticides (DBCP>EDB>carbofuran>simazine) is consistent with the reported incidence of well contamination. Previous sampling of 38 wells in Fresno County did not locate any wells contaminated by carbofuran, but 23.6% were contaminated by DBCP, 5.2% by EDB, and 2.6% by simazine (9).

Storie Index, infiltration rate, water capacity and nematode damage index were soil-related variables calculated from soil series data. Values for these parameters were uniform over the study area. The high mean Storie Index indicates that the area is suited to agriculture. Low variablility among these data may reflect the physical similarity among the soil types present. One exception is infiltration rate, which varies by 45% over the study area.

An unfortunate peculiarity of the correlation matrix is that variables derived from the two basic sources, soil series and land use, are not strongly intercorrelated. This is probably an artifact of the methods used in data calculation. As a result, relationships between certain variables (e.g., nematode damage index vs. DBCP application, and infiltration rate vs. agricultural recharge) could not be reliably tested. A small but significant

Table 27. Summary statistics of variables used in principal component analysis.

Variable	Mean	Standard deviation	Coefficient of variance
Soil-related variables:			
Storie Index	74.85	7.14	0.10
infiltration rate	6.37	2.84	0.45
water capacity	0.10	0.02	0.20
nematode damage index	5.30	1.02	0.19
Crop-related variables:			
agricultural acreage	594.81	61.34	0.10
agricultural recharge	1.67	0.12	0.07
simazine applied	1464.00	109.72	0.07
carbofuran applied	5733.29	720.86	0.13
DBCP applied	36370.59	2864.15	0.07
EDB applied	14486.39	9129.67	0.63

Table 28. Correlation Matrix of agronomic variables[a].

	1	2	3	4	5	6	7	8	9	10
Storie index	1.000									
Infilt. rate	-0.719	1.000								
Water capac.	0.819	-0.859	1.000							
Ag. acreage	0.334	-0.301	0.331	1.000						
Ag. recharge	-0.205	0.210	-0.246	-0.137	1.000					
Nema index	-0.625	0.889	-0.886	-0.255	0.212	1.000				
Simazine	0.209	-0.144	0.203	0.758	0.222	-0.194	1.000			
Carbofuran	-0.077	0.102	-0.102	0.268	0.686	0.046	0.729	1.000		
DBCP	0.169	-0.076	0.139	0.476	0.310	-0.179	0.886	0.826	1.000	
EDB	0.371	-0.307	0.384	0.216	-0.804	-0.336	-0.080	-0.664	-0.130	1.000

correlation was indicated between infiltration rate, agricultural recharge and EDB application.

Variables within the soil-related group were more strongly correlated to each other. Storie Index was negatively correlated with infiltration rate, surprising in view of the fact that farm land suitablility is partially determined by good soil drainage. Possible causes for correlation among the crop-related variables were more obscure than correlations in the soil-related group. Agricultural recharge was more highly correlated with simazine application than with any other pesticide, but simazine was registered for more crops than any other pesticide (Table 13). Carbofuran application was positively correlated with DBCP and simazine use, and with agricultural recharge. The positive association of these three pesticides may be influenced by their high application rates on the two major crop types.

Principal component analysis

In this study, principal components were used both to describe the variation of agronomic variables in the study area, and to test the power of the variables in predicting positive or negative sections. Four principal components were calculated from ten agronomic variables in 133 sections. Only the first four components were chosen for interpretation because they contained 89% of the total variance in the data set.

Principal component '1' was interpreted as a 'soil type' component with high loadings on Storie Index, infiltration rate, water capacity and nematode damage index (Table 29). These variables are highly intercorrelated, and data values are primarily determined by sand content and soil structure. This component accounted for 31% of the total variability in the study area (Table 29). High scores on this component indicate sections where infiltration rates and potential nematode damage are high, and Storie Index and soil water holding capacities are low. Sections with high scores would be at great risk for ground water contamination due to the ease with which pesticides could move through the profile as solutes. However, a map of contaminated well locations overlayed on section scores of this component did not reveal any correspondence between sections at risk and well contamination (Figure 3).

Table 29. Significant principal components and the contribution of each agronomic variable to the component (loading).

Variable	PC1	PC2	PC3	PC4
Storie Index	-.605			
infiltration rate	.935			
water capacity	-.885			
nematode damage index	.969			
applied simazine		.834		.500
applied carbofuran		.780	.604	
applied DBCP		.977		
agricultural acreage		.361		.902
agricultural recharge			.905	
applied EDB			-.925	
% Total variance	31%	25%	21%	12%
% Cumulative variance	31%	56%	77%	89%

Principal component '2' had high loadings on DBCP, simazine and carbofuran application rates (Table 29). The small contribution of agricultural acreage to component '2' was probably due to the high percentage of agricultural acreage in all sections, and its high correlation with simazine use. EDB was not categorized in the same principal component as the three other pesticides. Principal component '2' accounted for 25% of the total variability in the data set. Most sections in the study area fell into the medium range of component scores, indicating that these pesticides as a group were uniformly distributed (Figure 4). Low scoring sections in the central and southwestern portions of the study grid indicate areas of lower projected simazine, DBCP and carbofuran application coinciding with higher concentrations of alfalfa, and field and grain acreage. One contaminated well was located in the only high scoring section, but it is impossible to determine whether this is a meaningful occurrence.

Principal component '3' had a high positive loading on agricultural recharge, and a high negative loading on EDB application. Crops for which EDB is registered have less agricultural recharge (excess water) available than crops for which EDB is not registered (Table 13). This component accounted for 21% of the variability in the study area. High scores indicate sections with high agricultural recharge and carbofuran use. Low scores indicate sections where projected EDB use was highest (Figure 5).

Principal component '4' was characterized by a high total agricultural acreage loading and a moderate simazine loading. This component accounted for 12% of the total variation in the study area. High scores on this component indicate sections where total agricultural acreage and simazine use were highest (Figure 6).

The relationship between principal component axes and sections containing contaminated or uncontaminated wells was examined using a series of graphs (Figures 7-12). All combinations of the four principal components were used, and the component scores of each section were plotted against component axes.

The plots did not reveal any 'clustering' or segregation of contaminated and uncontaminated sections. Such clustering would indicate that the components could be used to predict sections at risk. Although the principal components

Figure 3. Spatial distribution of principal component 1 scores.

Variable	loading
Storie index	-0.605
infiltration rate	0.935
water capacity	-0.885
Root Knot nematode damage index	0.969

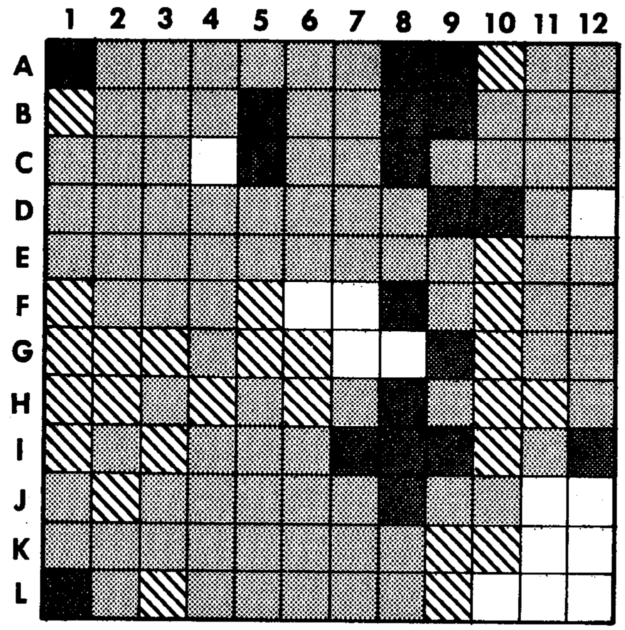
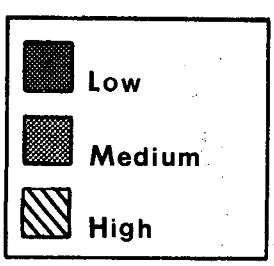


Figure 4. Spatial distribution of principal component 2 scores.

Variable	loading
simazine applied	0.834
carbofuran applied	0.780
DBCP applied	0.977



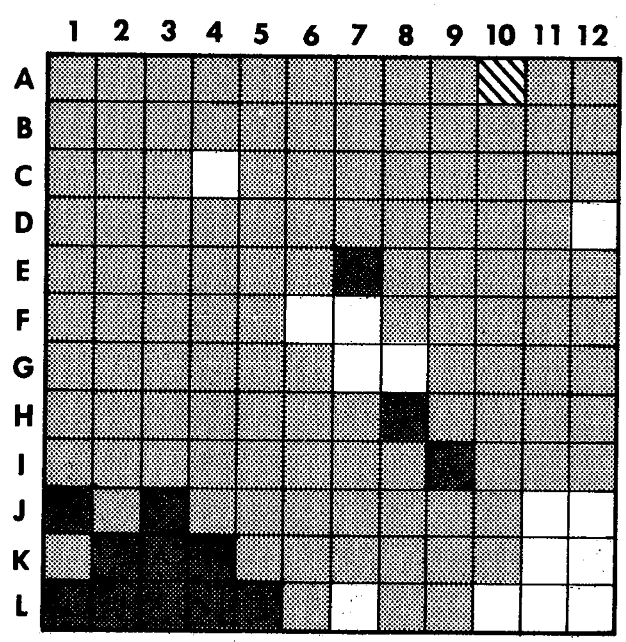


Figure 5. Spatial distribution of principal component 3 scores.

Variable	loading
carbofuran applied	0.604
agricultural recharge	0.905
EDB applied	-0.925

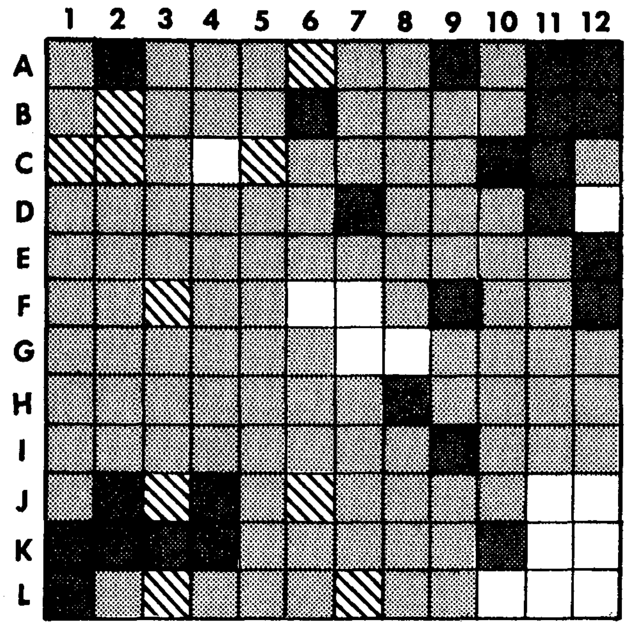
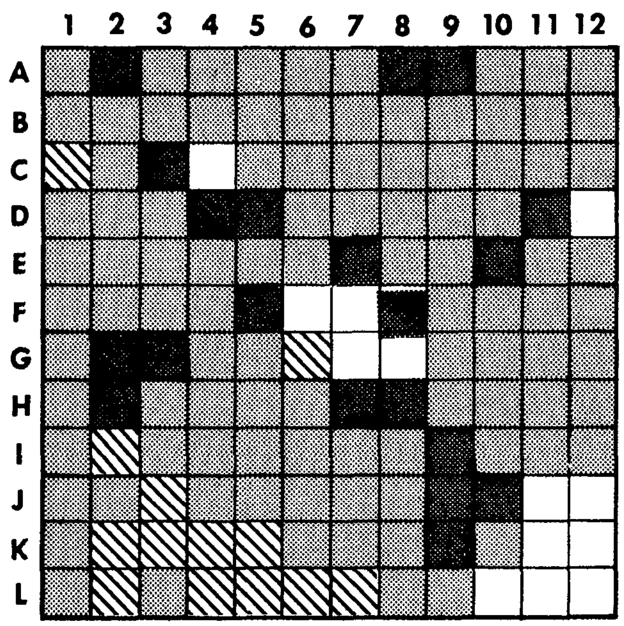


Figure 6. Spatial distribution of principal component 4 scores.

Variable	loading
simazine applied	0.500
agricultural acreage	0.902



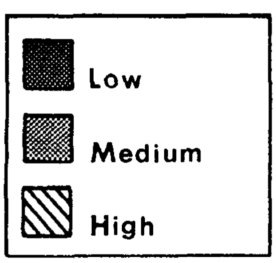


FIGURE 7

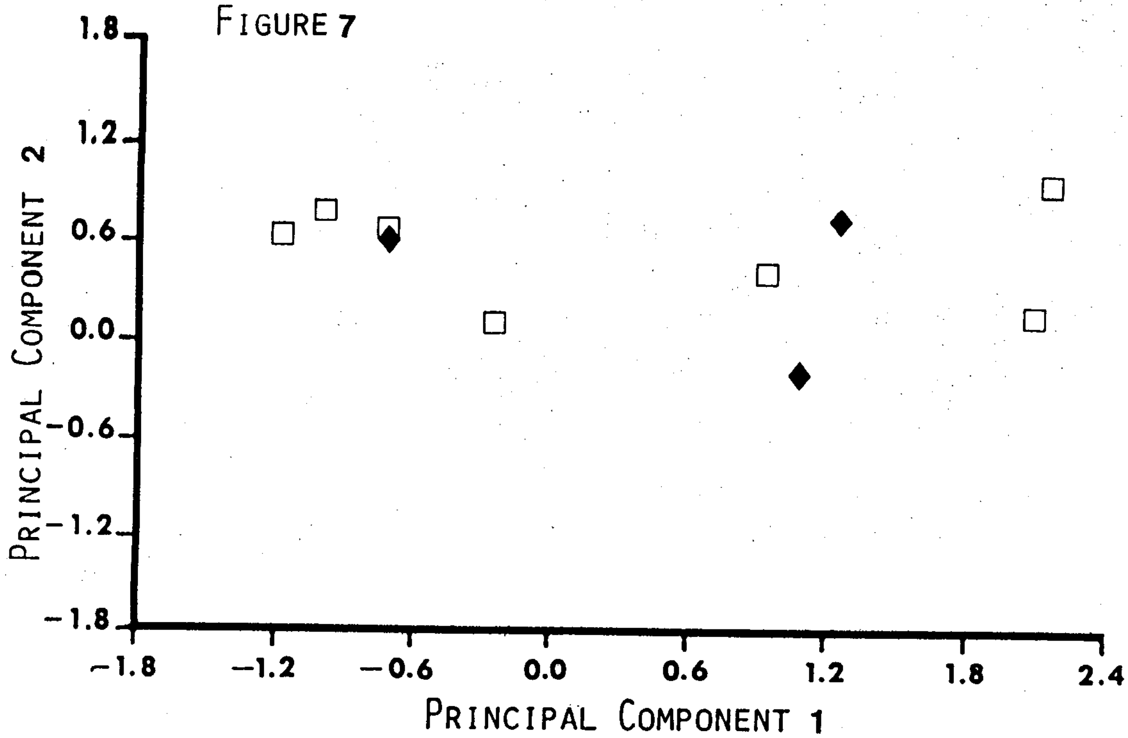
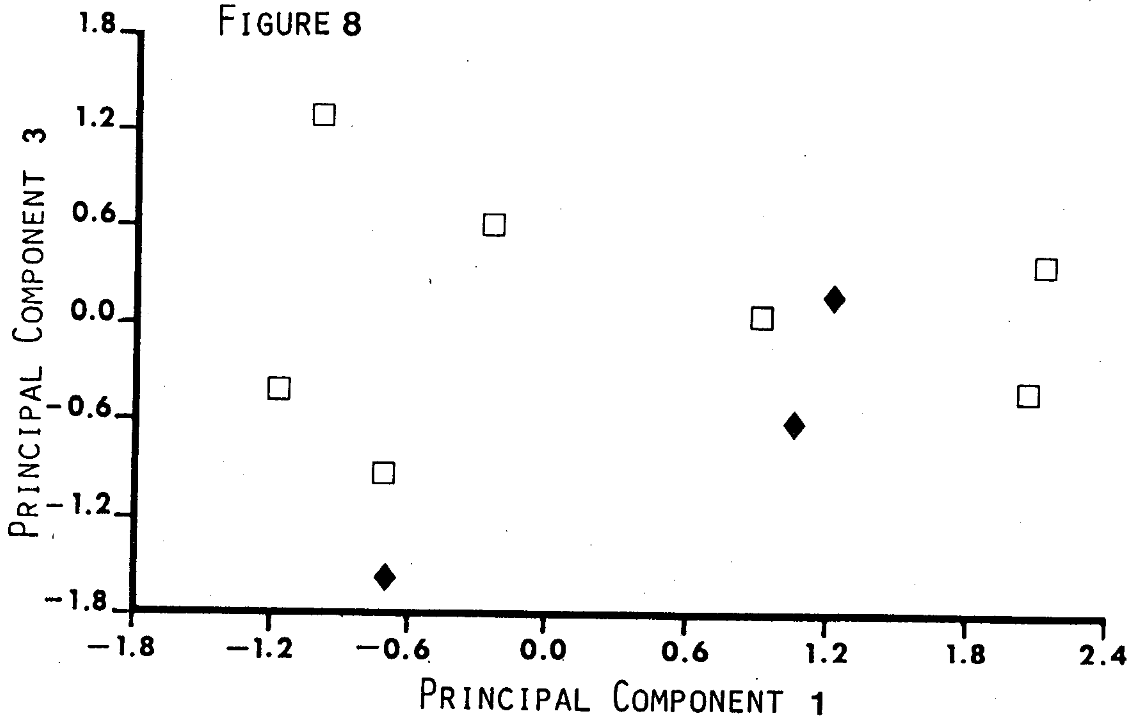
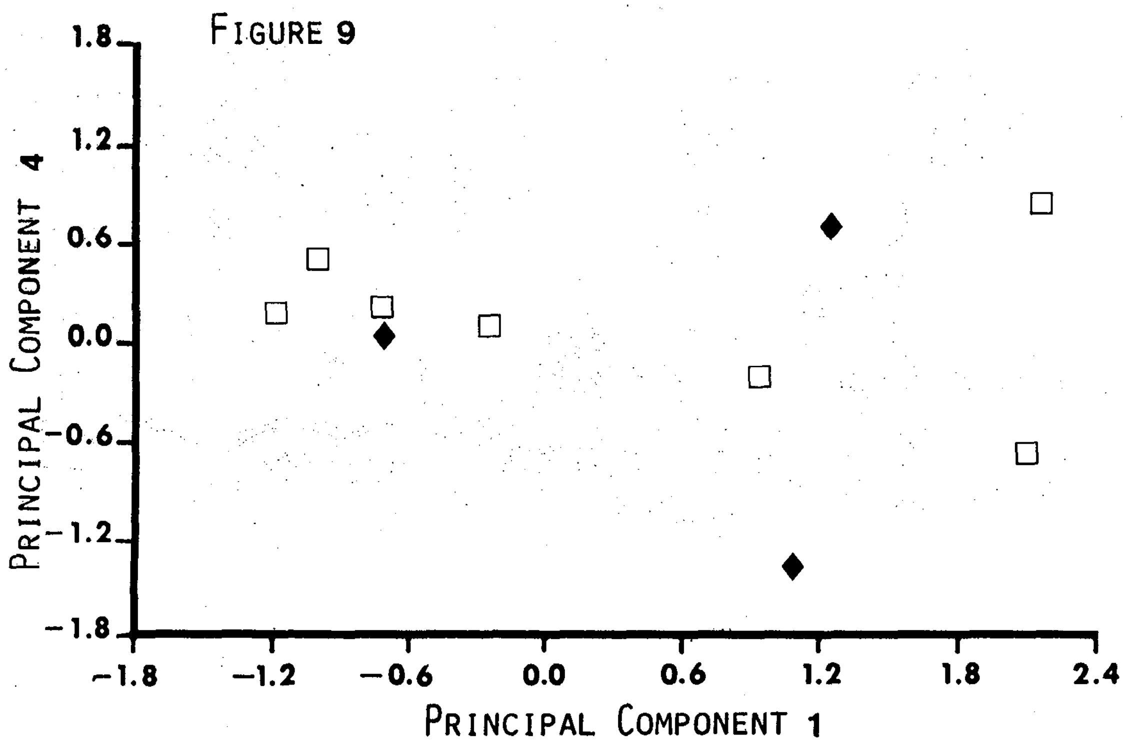
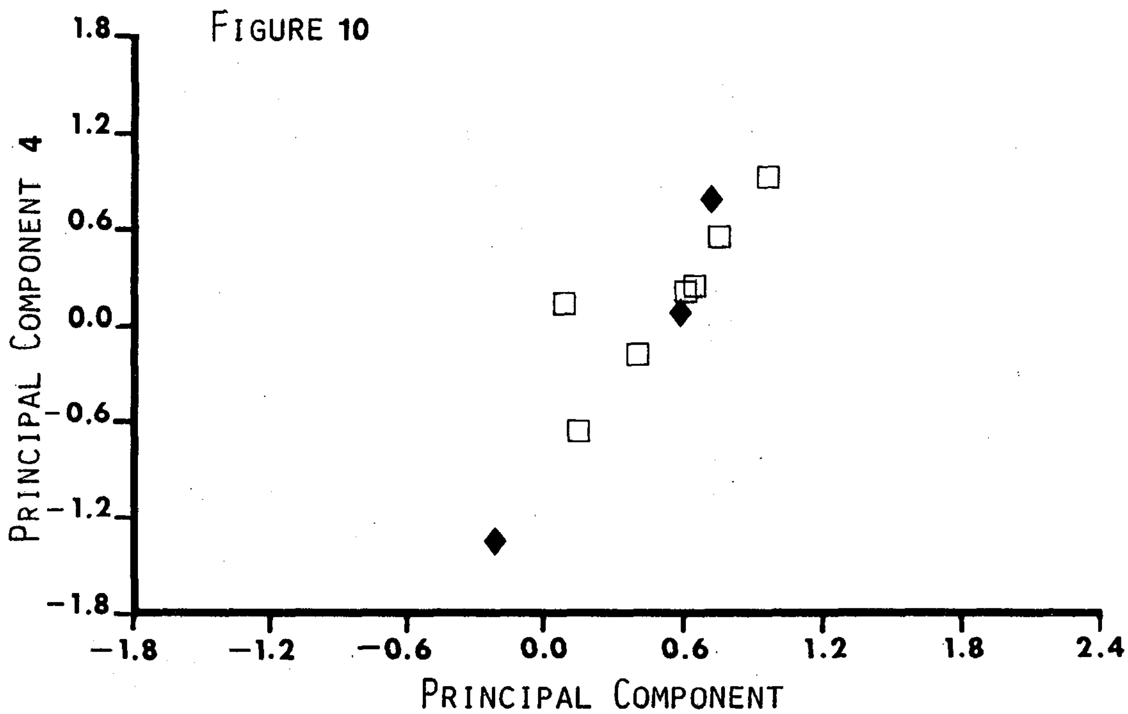


FIGURE 8



□ = CONTAMINATED, ◆ = UNCONTAMINATED





□ = CONTAMINATED, ◆ = UNCONTAMINATED

FIGURE 11

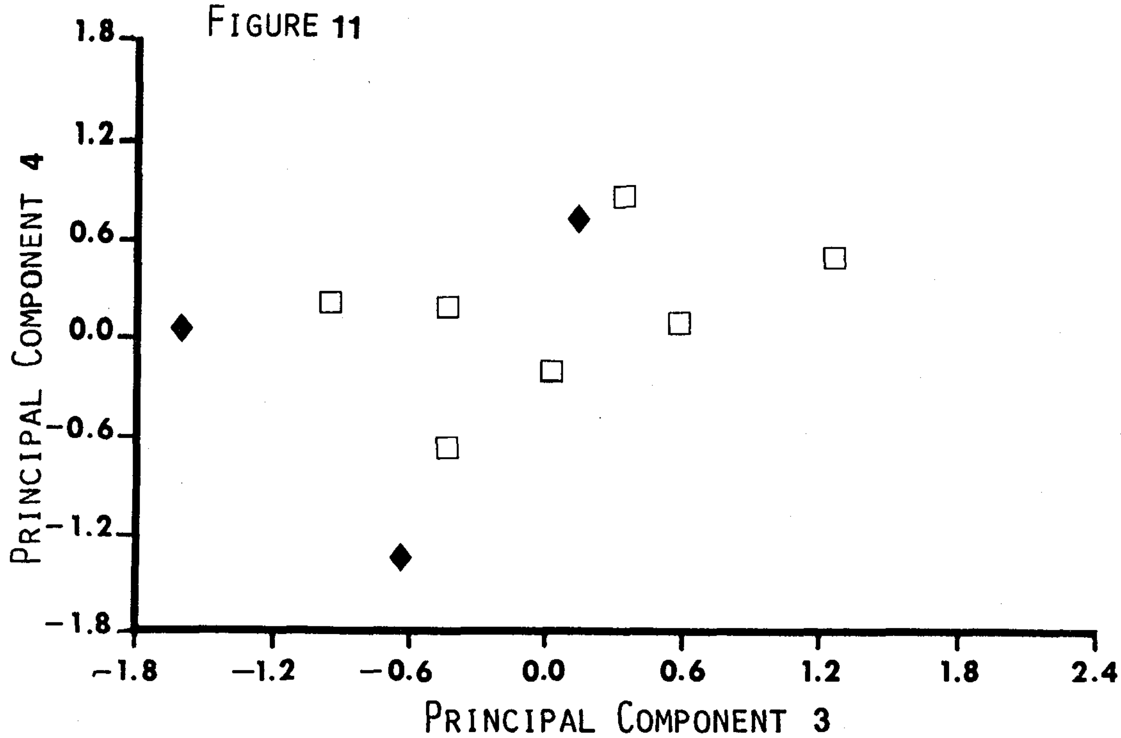
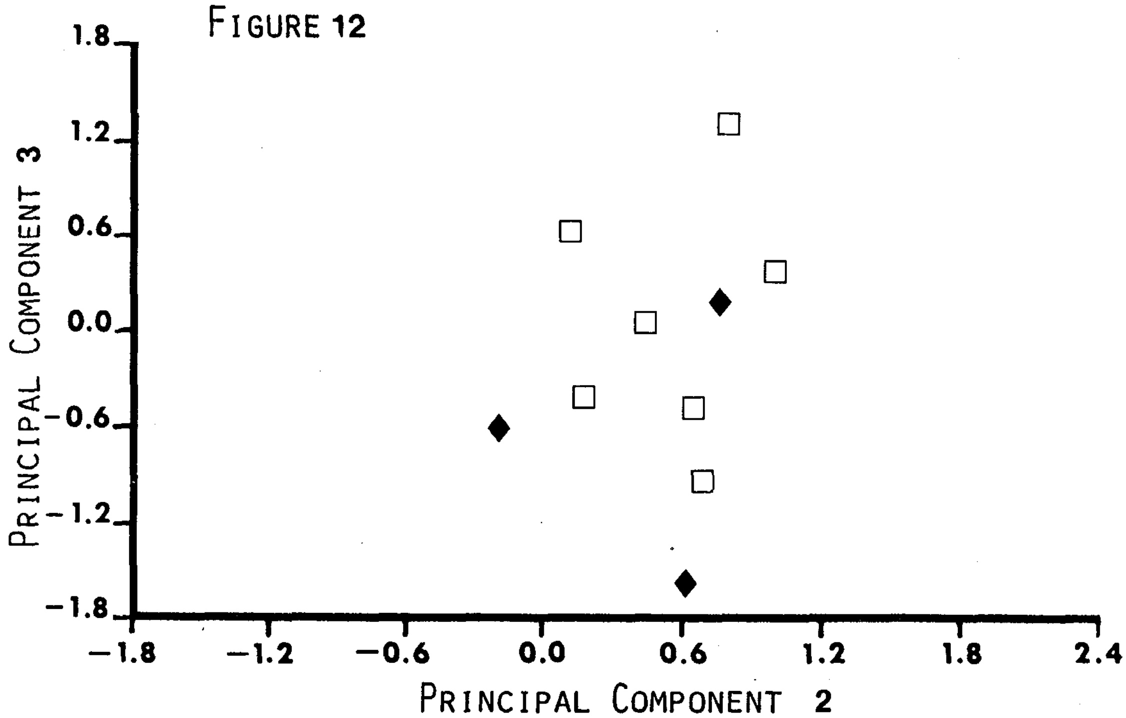


FIGURE 12



□ = CONTAMINATED, ◆ = UNCONTAMINATED

accounted for most of the variability present in the data set, the agronomic variables were not effective in distinguishing between sectionsd containing contaminated or uncontaminated wells, and alone have no predictive value.

Discriminant analysis

Discriminant analysis uses regression techniques to classify groups. In this study, the analysis was used to discriminate between contaminated and uncontaminated wells in the study area. Variables describing each of ten wells reported in Volume II (9), and the agronomic variables developed in this study were included in the analysis. Physical data on well construction were obtained from well logs collected during previous sampling (9) and included total well depth, the top and bottom casing perforation depths, and total casing depth. A preliminary examination of the data indicated that vineyard and deciduous fruit and nut acreage were more valuable agronomic variables than total agricultural acreage. Final discriminant analysis was performed using 16 variables (Table 30). The ten wells were located in sections A5, A10, D2, D9, E8, E9, E10, E11, F1 and I7 (Figure 2).

Four significant predictor variables were identified by step-wise discriminant analysis. Deciduous fruit and nut acreage was chosen at the first selection step as the single best predictive variable. Agricultural recharge was excluded from the process at this point because of its high correlation with deciduous fruit and nut acreage (-0.936). Well depth was the second predictor variable chosen by the procedure. A significant classification equation ($p<0.01$) was derived at the third step of analysis when the top well casing perforation depth was incorporated into the model (Table 32a). The values for each significant variable used and corresponding section locations are shown in Table 31. All ten wells were correctly classified by the discriminant equation (Table 32b).

Table 30. Summary statistics for 16 variables used in discriminate analysis.

Variable	Mean	Standard deviation	Coefficient of variance
Storie Index	75.18	7.89	0.10
infiltration rate	6.79	3.70	0.54
water capacity	0.10	0.02	0.20
agricultural acreage	614.40	45.79	0.07
agricultural recharge	1.71	0.06	0.04
nematode damage index	5.20	1.27	0.24
applied simazine	1464.00	109.72	0.07
applied carbofuran	5233.30	720.86	0.14
applied DBCP	36370.60	2864.16	0.79
applied EDB	14486.40	9129.68	0.63
well depth	103.20	19.39	0.19
perforation depth (top)	80.20	21.87	0.27
perforation depth (bottom)	99.10	17.53	0.18
casing depth	99.10	17.53	0.18
vineyard acreage	521.60	72.32	0.14
deciduous fruit and nut acreage	76.80	52.49	0.68

Table 31. Summary of data used in discriminant analysis.

Section	Actual[a] status	Well depth (ft.)	Top of perforation (ft.)	Deciduous fruit and nut acreage
A05	C	84	60	64
A10	C	84	48	32
D02	C	131	98	128
D09	C	100	60	96
E08	U	91	84	32
E09	C	99	78	32
E10	U	80	69	128
E11	U	113	93	192
F01	C	120	102	32
I07	C	130	110	32

a. 'C' signifies contaminated, 'U' signifies uncontaminated.

Table 32a. Results from discriminant analysis of contaminated and uncontaminated wells: regression coefficients.

Variable	Coefficients: Uncontaminated	Coefficients: Contaminated	Standard regression efficient
Well depth	0.69995	1.59718	1.530
Well casing perforation (top)	-0.39975	-1.12921	-1.338
Deciduous fruit and nut acreage	-0.03450	-0.15010	0.538
Constant	-15.41056	-36.72238	

Table 32b. Results from discriminant analysis of contaminated and uncontaminated wells: data and classification scores.

Section	Actual status[a]	Classification scores[b]: Uncontaminated	Classification scores[b]: Contaminated	Predicted status
A05	C	17.19	20.08	C
A10	C	23.09	38.43	C
D02	C	32.69	42.63	C
D09	C	27.29	40.83	C
E08	U	13.60	8.96	U
E09	C	21.60	28.52	C
E10	U	8.59	-6.08	U
E11	U	19.88	9.92	U
F01	C	26.70	34.96	C
I07	C	30.51	41.89	C

a. C= contaminated, U= uncontaminated

b. The highest relative score indicates the predicted contamination status.

DISCUSSION

This is the third volume of a study designed to examine factors influencing pesticide movement to ground water. In Volume I (9), the presence or absence of pesticide contamination in four shallow, unconfined aquifers was surveyed. In Volume II (10), data sets were developed to relate soil profile characteristics with the presence or absence of pesticides in the soil to ground water depths. The objectives of the study phase reported in this third volume were to develop a land use data base from existing sources, and to incorporate this data with the results of earlier monitoring (9,10) to produce statistical models that might predict ground water contamination sites.

After data collection and analyses for this study had been completed, well logs were located for sites previously sampled for DBCP in an independent study (29). This data was used as an independent test of the discriminant model derived in the present study. A summary of well depth, depth of top casing perforation, and deciduous fruit and nut acreage for sites in the independent data set are shown in Table 33, along with the contamination status as predicted by the discriminant model. Locations of the wells in the independent data set are shown in Figure 13.

The model correctly classified 38 out of 40 contaminated wells, but only one out of 13 negative wells; 12 negative wells were misclassified as positive. The inability of the model to correctly predict negative wells may be attributed to the small sample size and the preponderance of positive wells in the small data set on which the model was based. Those wells correctly predicted as positive sites had significantly deeper average well depths ($p<0.025$), slightly deeper perforation depths ($p<0.20$) than negative wells, and were located in sections with lower total deciduous fruit and nut acreage ($p<0.01$)(Table 33). These findings are independent of the discriminant model, and counter-intuitively suggest that ground water contamination in this area is more likely to occur in deeper wells, averaging 196 feet deep. Since 20 domestic and 18 irrigation wells are represented in this sample, it is difficult to attribute this situation to local effects caused by high pumping rates or irrigation wells.

Positive wells occurred in sections with lower than average total fruit and nut acreage. It is impossible from this study to determine whether fruit and nut

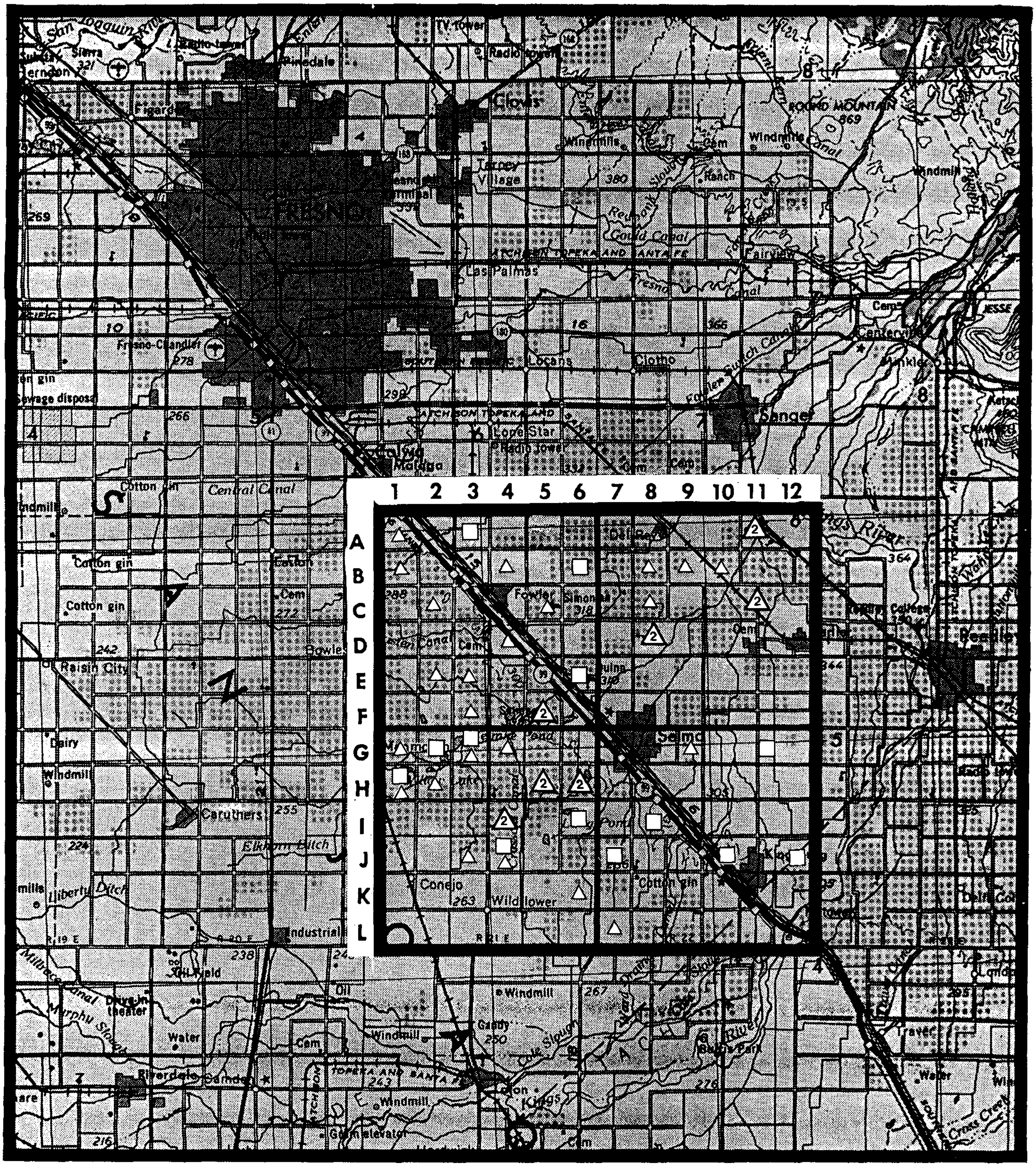


Fig. 13 Location of wells in independent data set (= contaminated, = uncontaminated).

Table 33. Summary of the independent well data set.

Predicted contamination	Well depth			Depth of perforation (top)			Deciduous fruit and nut acreage		
	mean	SD	CV	mean	SD	CV	mean	SD	CV
all wells (n=53)	192.1	71.2	0.37	135.7	117.9	0.86	70.2	65.8	0.93
negative classified as positive (n=12)	185.8	68.4	0.36	116.3	31.7	0.21	61.3	48.2	0.78
positive classified as negative (n=2)	122.0	9.9	0.08	115.5	0.71	---	224	45.3	0.20
correctly classified negative (n=1)	136	---	---	116	---	---	256	---	---
correctly classified positive (n=38)	196.3	71.7	0.36	124.7	57.7	0.46	66.1	64.0	

acreage correlates with other environmental processes or cultural practices which would influence pesticide migration to ground water. However, during the selection of variables in discriminant analysis, deciduous fruit and nut acreage was included rather than agricultural recharge because it had a slightly higher correlation with contaminated wells. Because there was also a high negative correlation with agricultural recharge, both variables could not be included. This was an unfortunate choice for two reason: first, the use of deciduous fruit and nut acreage as a regression variable limits the applicability of this particular model to other agricultural regions. Second, agricultural recharge is a more conceptually convenient tool for explaining high contamination probabilities. More water is available for recharge where there is less fruit and nut acreage, therefore, contaminated wells could be predicted to occur in locations of higher recharge. This relationship is consistent with current knowledge of mass soil water flow and pesticide transport.

In a study of the Sacramento Valley conducted by the United States Geological Survey (USGS) high nitrate concentrations in ground water were associated with orchards (8). In the USGS study, orchard plantings occurred in light textured (sandy) soils. A heavy fertilizer application was often made in the fall, after the last scheduled irrigation. As a consequence, there was not enough moisture available for nitrates to be incorporated in the root zone or absorbed by the trees before the rainy season. A USDA investigation of nitrates and cropping patterns in an area just north of, and overlapping the study location, indicated again that higher soil nitrate concentrations were associated with orchards, and row and truck crops (31). Soils under orchards were finer textured in the first five feet than soils at the same depth under vineyards, but the pattern was reversed for soils between five and 20 feet. Lower water holding capacities and higher hydraulic conductivities in orchard soils below five feet implied that higher irrigation frequencies and fertilizer application rates allowed nitrates to percolate more deeply in this setting. The study also concluded that although there was a positive correlation between nitrate concentrations in soil and ground water, there was not a clear relationship between the amount of nitrate applied and ground water concentrations. These observations suggest that the relationship between the timing of pesticide applications, irrigation, seasonal weather patterns, and the movement of pesticides in the soil deserve more attention.

Some physical soil properties and their relationship to pesticide occurrence within and between soil cores drilled in the study area were reported in Volume II (10). Three soil cores, with and without detected pesticide residues, were distinguished by the time which had elapsed since the last application, the amount of organic matter present, and soil moisture content. Two contaminated soil cores were located in sections which scored very high on the first principal component derived in the present study (section E10, G6), indicating areas of high infiltration and low water holding capacity (Figure 3). One uncontaminated soil core was located in a section which scored moderately on component '1'.

The depth to the ground water table and subsurface geology of a site are important environmental determinants of pesticide movement and ground water contamination. The study area is located over a shallow unconfined aquifer with average surface to ground water depths ranging from 10 to 30+ feet and a high regional specific yield (24, 26). Historical records of one well in section D11 indicate a ten year average ground water depth of 38.2 feet in the spring and 40.9 feet in the fall, with fluctuations up to eight feet between seasons. The water table has risen at this site from a low of 61.6 feet below the surface in 1977, to 19 feet in 1984 (25). If shallow ground water is more easily contaminated by agricultural uses of pesticides as claimed, then this area and others like it may become increasingly vulnerable to contamination through the use of water management practices which elevate the water table.

The alluvial plain setting of the study area is often considered as a homogenous unit, and the simplifying assumptions of most predictive soil models have reinforced this artificial concept. The four township subunits are located on at least two distinct stratigraphic units. Although the alluvial soils have similar textures, infiltration rates and water capacities, they were deposited at different times under different conditions, and originate from varying sources. The western half of the study area contains a 20 to 30 foot sand dune layer on top of older, oxidized alluvium deposits originating from the Kings River. The eastern half of the area lacks the sand dune deposit and lays directly on older alluvium which extends 600 to 700 feet below sea level (20). The interface between deposits may have a strong influence on the lateral and vertical movement of water (27).

Detailed cross sectional maps of the study area were not available. However, driller calls from well logs collected in the independent data set indicate the presence of alternating sand and clay layers in the upper 100 feet (29). Soil profiles at 13 uncontaminated well sites had an average of 4.5 distinct clay or hardpan layers between the surface and top well casing perforation. Uncontaminated well sites were indistinguishable from 41 contaminated wells in the number of clay layers encountered within a similar depth interval. The presence of pesticide residues in these wells cannot be related to homogenous sandy profiles which would allow uninhibited solute transport.

The greatest weakness in using the selected experimental methods and statistical techniques in this study was the lack of available, independent data. All data were calculated from either soil type or land use maps. Although values for some of the soil parameters were partially corroborated by other sources (17, 20, 26, 31), the calculated values of pesticide use were not. Records of EDB and carbofuran use for 1979-1981 were collected from the Fresno County Department of Agriculture. Total documented use for a three year period was several times lower than the average calculated yearly application for a single section. Only 18 EDB applications were recorded during this period, most occurring on fallow fields. All 15 carbofuran applications were made on alfalfa. One must conclude that the methods used for calculating pesticide use were grossly unsuccessful both in terms of quantities applied and spatial distribution. However, while these observations may invalidate the interpretation of pesticide use patterns and principal components presented in the Results section of this report, they do not significantly alter the results of the discriminant analysis.

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