SIMULATED SOLUTE TRANSPORT THROUGH THE UNSATURATED ZONE OF AN URBAN ENVIRONMENT NEAR THE WAIAWA SHAFT, O'AHU, HAWAI'I

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SIMULATED SOLUTE TRANSPORT

THROUGH THE UNSATURATED ZONE OF AN URBAN ENVIRONMENT

NEAR THE WAIAWA SHAFT, O'AHU, HAWAI'I

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By

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We certify that we have read this thesis and that, in our opinion, it is satisfactory in scope and quality as a thesis for the degree of Master of Science in Geology and Geophysics.

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Affectionately dedicated to:

my spouse, Darlene J. Jacintho;

my parents, Jane Y. and Nobuo Miyahira;

and the memory of my grandmother, Kame Asato (1894-1988).

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ABSTRACT

The Pesticide Root Zone Model (PRZM), a one-dimensional finite difference model, was used as a predictive tool to estimate the amounts of chemicals that may leach through deep unsaturated profiles into the groundwater. These chemicals were simulated to originate from proposed urban developments which overlie the aquifer that provides the U.S. Navy with its primary source of potable water at Pearl Harbor, O'ahu, Hawai'i. Prior to these long-term (37 year) predictions, PRZM was compared with near-surface data collected from leaching experiments conducted at two field sites in central O'ahu.

Although PRZM accurately simulated the observed data on a few occasions, model evaluations employing graphical and residual error analyses revealed its limitations with respect to pesticide transformation and also chemical losses which may have been caused by lateral dispersion and preferential flow. Long-term meteorologic data were provided by a separate water balance model, and the simulated output from PRZM was input to a groundwater modeling effort presented in another study.

Long-term simulations of the movement of chlorpyrifos, diazinon, metribuzin, and nitrate under various recharge scenarios, and varying parameter values for chemical fate and profile characteristics, revealed that with the exception of chlorpyrifos, detectable levels of these chemicals may leach to the water table. However, the reliability of predictions was limited by a number of uncertainties: (1) inaccuracies revealed by the near-surface evaluation, which were propagated into the deep profile, 37 year simulations, (2) inadequate characterization of the deep unsaturated profiles, and perhaps most importantly (3) the absence of information on the behavior of pesticides at greater depths within the unsaturated Hawaiian profiles.

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CHAPTER I. INTRODUCTION

A. PROBLEM IDENTIFICATION

1. Proposed Developments

Proposed urban developments in Waiawa may pose a threat to the U.S. Navy's water supply. Waiawa is located in central O'ahu and overlies a section of the Pearl Harbor aquifer, recognized as one of the most important aquifers in the State of Hawai'i. The locations of the proposed developments and the Pearl Harbor aquifer are shown in Figure 1.

The first segment of a proposed community at Waiawa is the 565 ha Gentry Waiawa subdivision which calls for nearly 8,000 housing units, two 18-hole golf courses, and commercial/industrial areas to be built on Waiawa Ridge. The Navy also plans to build about 100 homes on 16 ha within Waiawa Valley. Part of the Gentry subdivision is expected to lie directly above the Navy's Waiawa Shaft while the proposed Navy housing would be adjacent to the shaft's entrance in the valley.

The Waiawa Shaft operates as an unlined basal groundwater skimming tunnel/well which provides approximately 57,000 m^3/day (0.66 m^3/s), making it the Navy's primary source of potable water. Figure 2 locates the proposed urban developments with respect to the Waiawa Shaft. A topographic map and geologic cross-section of the Waiawa area are shown in Figures 10 and 15 (Chapter III), respectively.

The Gentry Waiawa development is expected to present a larger contamination threat due to its larger size and location with respect to the pumping zone of influence. Approval to build this subdivision is dependent upon the state Department of Health's determination of whether or not the development will contaminate groundwater from the Waiawa Shaft (Yamaguchi, 1988).

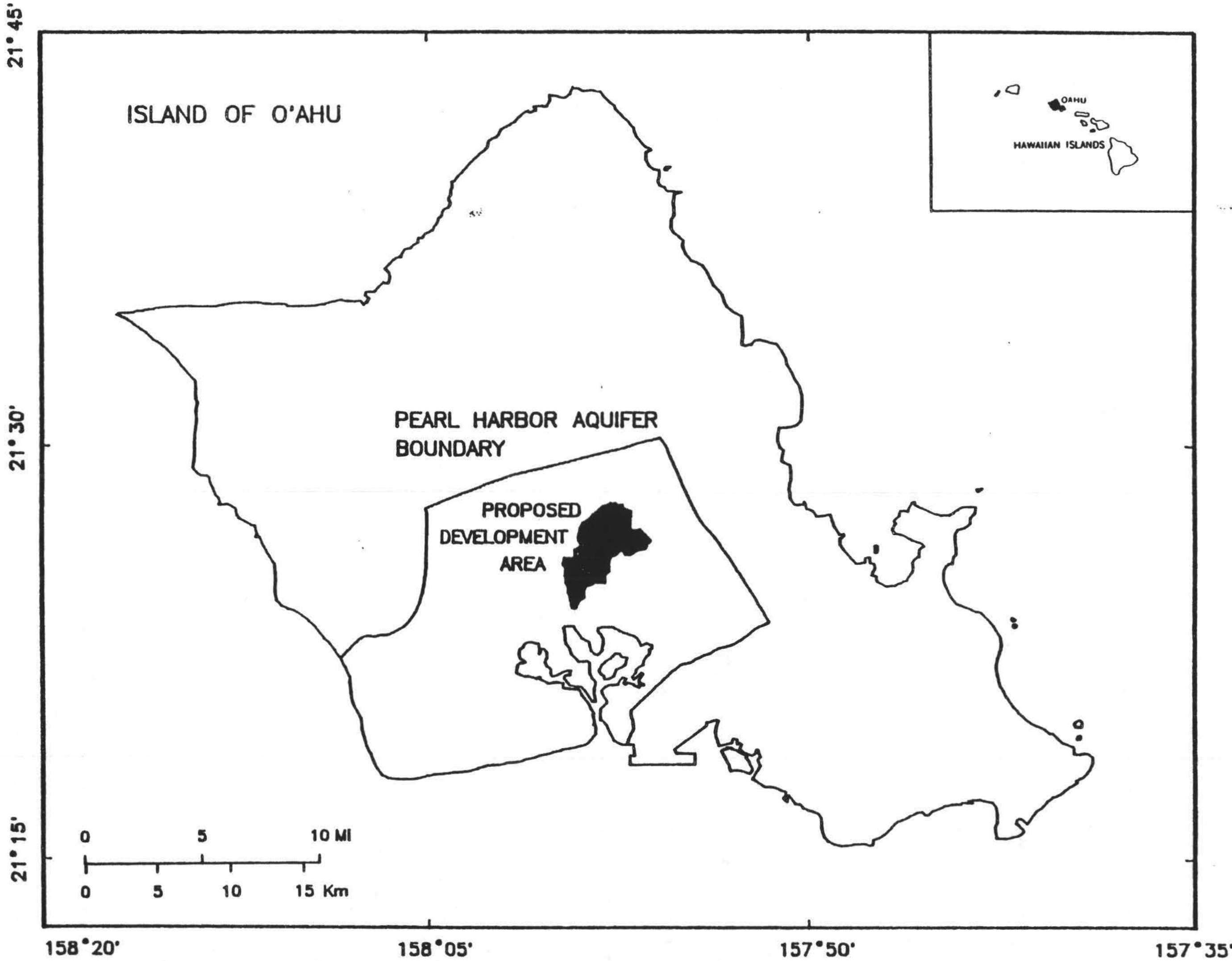


Figure 1. Location of proposed developments on the Pearl Harbor aquifer (after Oki *et al.*, 1990)

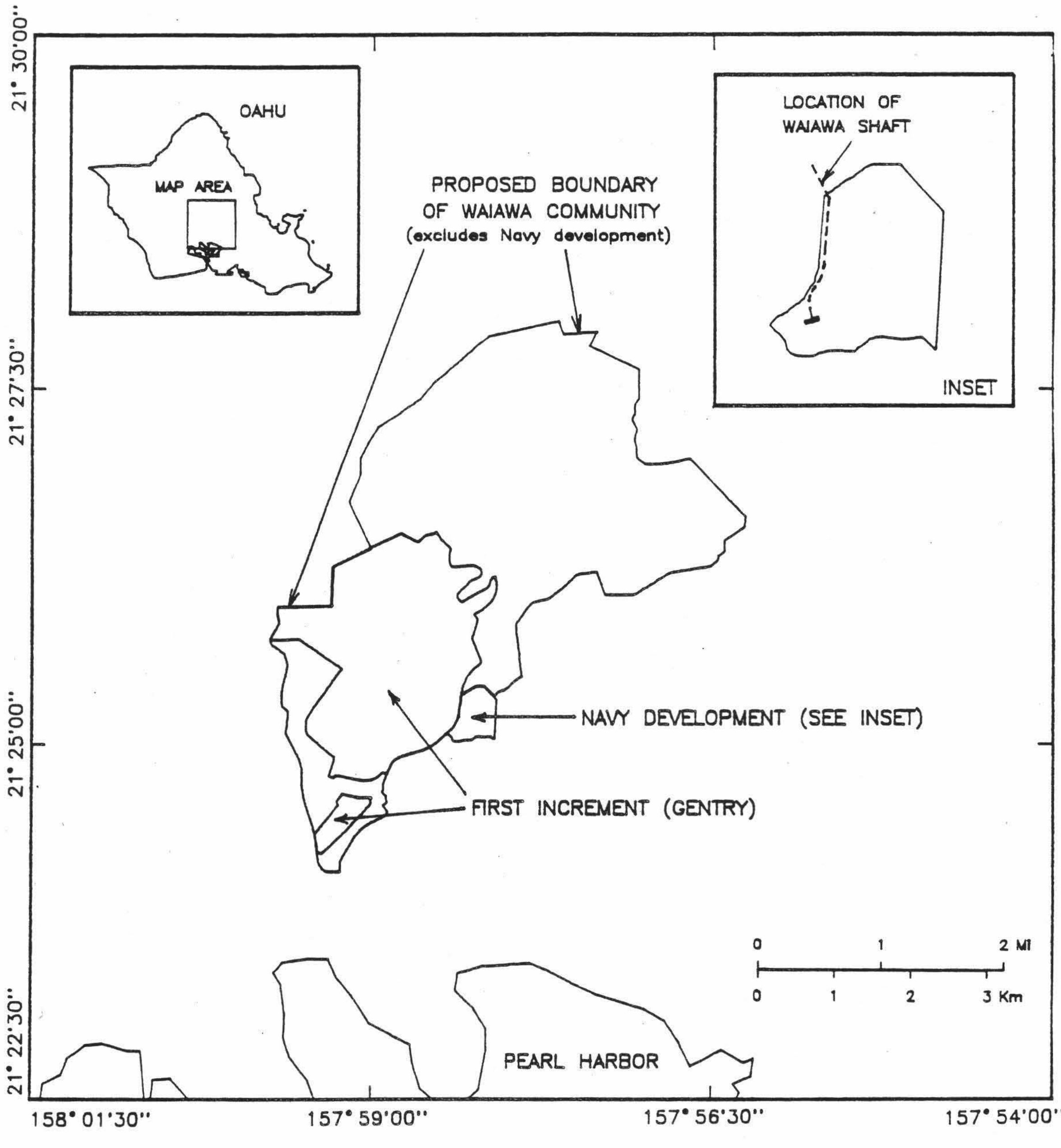


Figure 2. Location of proposed Gentry and U.S. Navy developments (after Oki *et al.*, 1990)

If approved, the developments will introduce a wide range of chemicals to the ground surface including: ground termiticides for housing developments; fertilizers and pesticides for golf courses; and various pesticides and fertilizers from household applications. These chemicals may contaminate the Waiawa Shaft by leaching from the surface, through the 50 to 250 m unsaturated zone, and into the groundwater (see Figure 3).

2. Groundwater Contamination in Hawai'i

The Department of Health (1989) has recently released maps which compile the types and quantities of chemicals which have been confirmed in Hawaiian groundwater. These chemicals include: 1,2-dibromo-3-chloropropane (DBCP); 1,2-dichloropropane (DCP); dieldrin; 1,2-dibromoethane (EDB); trichloroethylene (TCE); and 1,2,3-trichloropropane (TCP). The detected levels may not pose a significant health risk, but they do demonstrate the vulnerability of Hawai'i's groundwater resources (Burris, 1989). Figure 4 summarizes the extent of groundwater contamination on O'ahu.

DBCP and TCP contamination of groundwater on O'ahu is associated with nematicide use in pineapple cultivation while EDB contamination can be associated with nematicide use and/or pipeline leaks of aviation fuel (Oki and Giambelluca, 1987; and Lau and Mink, 1987). The groundwater contamination data base compiled by Giambelluca *et al.* (1987) includes a complete listing of the chemicals which have been tested for and detected in Hawai'i.

3. Waiawa Shaft

Construction of the Waiawa Shaft began in 1949 and was completed in 1951. The Waiawa Shaft consists of: a control building and entrance portal within Waiawa Valley on the southeastern edge of Waiawa Ridge at an approximate elevation of 43 m; a 77 m long inclined shaft (30° from horizontal) which leads down to the pump room at

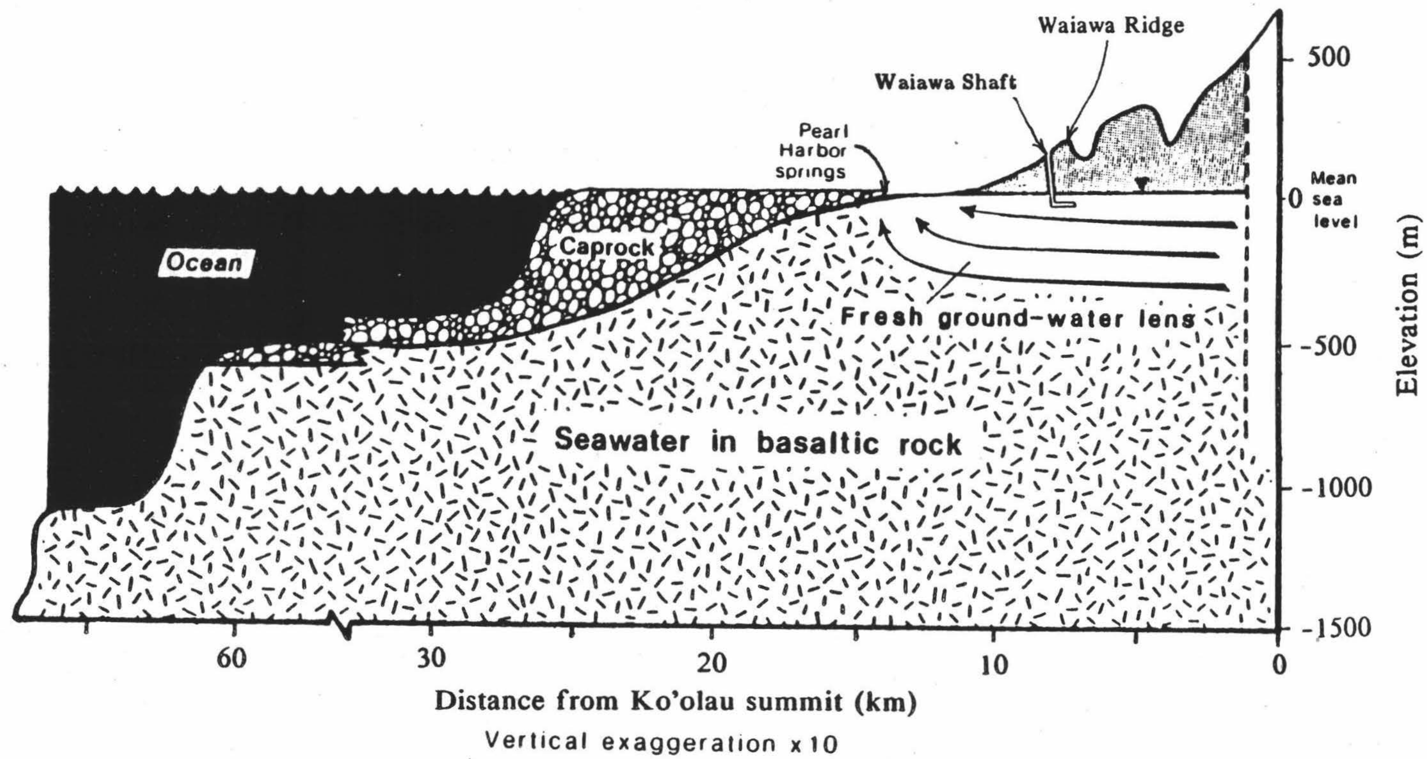
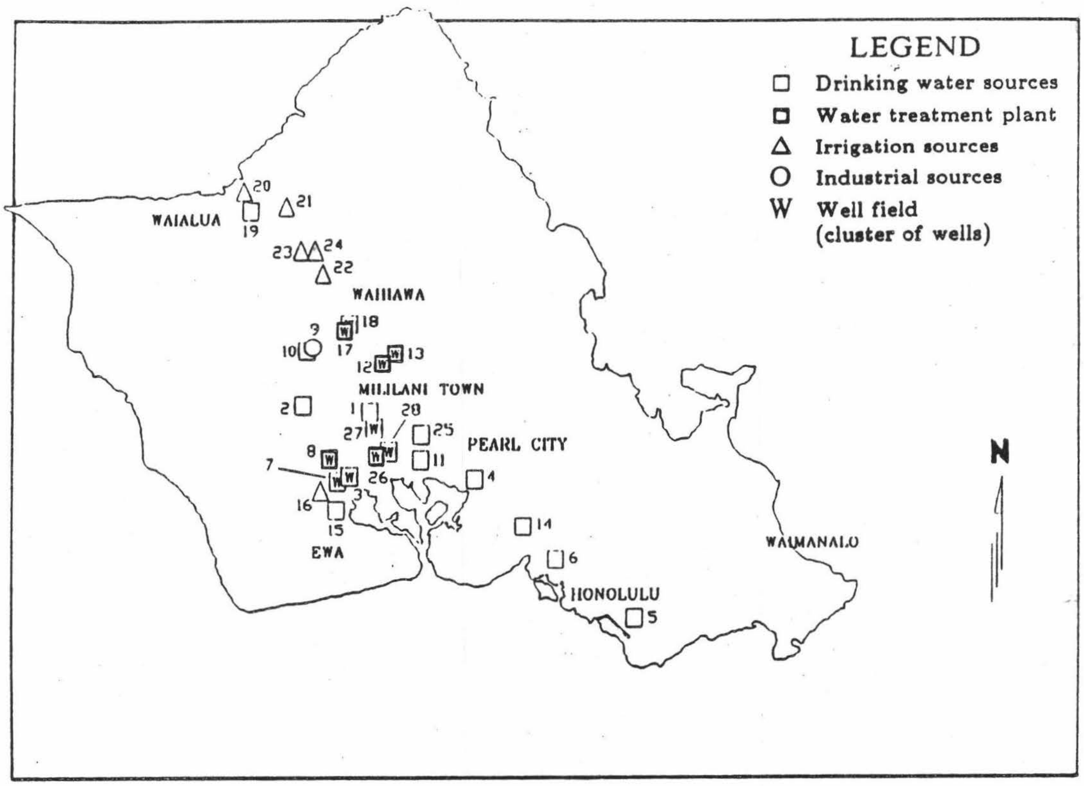


Figure 3. Hydrogeologic profile along Waiawa Ridge (after Eyre, 1983)



THIS MAP CONTAINS THE LAST CONFIRMED RESULTS FROM CONTAMINATED GROUNDWATER WELLS

NO.	CONTAMINANT		DETECTED LEVEL (in ppb)	APPLICABLE DRINKING WATER STANDARDS (in ppb)
1	TCE:		0.70	5.0
2	DBCP:		0.01	0.040
	PCE:		0.22	5.0
3	Atrazine:		0.114	3.0
	TCP:		0.20	0.800
4	PCE:		0.03	5.0
5	PCE:		0.03	5.0
6	Dieldrin:		0.008	0.002
7	Atrazine:		0.083	3.0
	TCP:		0.65	0.800
8	DBCP:	influent	0.02	
		effluent	<0.02	0.04
	TCP:	influent	0.65	
		effluent	<0.20	0.800
9	PCE:		1.65	5.0
	TCE:		3.70	5.0
10	Carbon Tetrachloride:		0.69	5.0
	DCE:		0.20	70.0
	TCE:		0.83	5.0
	PCE:		2.60	5.0
11	PCE:		0.03	5.0
12	DBCP:	influent	0.07	
		effluent	<0.02	0.040
	DCP:	influent	0.64	
		effluent	---	0.6
	TCP:	influent	1.50	
		effluent	<0.20	0.800
13	DBCP:	influent	0.07	
		effluent	<0.02	0.040
	DCP:	influent	0.74	
		effluent	---	0.6
	TCP:	influent	1.50	
		effluent	<0.20	0.800
14	Dieldrin:		0.009	0.002
15	Atrazine:		0.035	3.0
16	Atrazine:		0.100	3.0
17	TCE:	influent	8.50	
		effluent	<1.00	5.0
	PCE:	influent	0.37	
		effluent	<1.00	5.0
18	Carbon Tetrachloride:		0.58	5.0
	PCE:		0.38	5.0
19	TCP:		0.21	0.800
20	Lindane:		0.001	2.0
21	DBCP:		0.01	0.040
	TCP:		0.29	0.800
22	DBCP:		0.02	0.040
	TCP:		0.37	0.800
23	DBCP:		0.115	0.040
24	DBCP:		0.01	0.040
	TCP:		0.43	0.800
25	DBCP:		0.024	0.040
	TCP:		0.21	0.800
26	EDB:	influent	0.055	
		effluent	<0.02	0.002
	TCP:	influent	<0.20	
		effluent	<0.20	0.800
27	TCE:		0.55	5.0
	TCP:		0.25	0.800
28	TCP:		0.20	0.800

NOTES: Due to the number of wells in close proximity to each other, some sites are represented by wellfields and may contain several wells.

Possible natural contaminants such as nitrates have not been included.

note: ppb = parts per billion ≅ µg/l

Figure 4. Groundwater contamination on the island of O'ahu (after Department of Health, 1989)

an elevation of 9 m; an unlined sump, dug to an elevation of 6 m below sea level; a submerged 520 m infiltration tunnel which is connected to the sump and continues toward the north before turning 30° toward the north-northwest for the last 130 m of its length; and four turbine pumps which extract water from the sump and force it up through the inclined shaft (see Figure 5).

This kind of well, sometimes called a Maui-type well (Stearns, 1985), is able to supply large quantities of high quality water even in areas with thin basal lenses because it minimizes salt water encroachment by "skimming" water near the water table. Despite this advantage, Maui-type wells are no longer the preferred method of developing basal groundwater. The simpler, vertically drilled wells have become much more cost effective in terms of construction and operation. A brief description of Hawaiian hydrogeology is presented in Chapter III.

Flow measurements from the submerged infiltration tunnel (Oki *et al.*, 1990) at the Waiawa Shaft indicate that about half of the extracted groundwater flows through the walls of the sump, while the other half is obtained from the tunnel itself. Watson (1964) noted that after excavating the sump and first 180 m of the tunnel, only a small fraction of the final yield was developed. These observations indicate that the pumping zone of influence from the Waiawa Shaft may be larger than that which would be expected from a simple vertical well. This also implies that a larger surface area surrounding the shaft may contribute to its contamination.

Shaft type wells on O'ahu which have surrounding or nearby urban developments include the Halawa, Kalihi, Pearl City, and Wai'alae shafts. None of the analyzed water samples from these four wells have had pesticide levels above their respective detection limits. However, the Pearl City and Wai'alae Shafts have been tested for only a few pesticides (note: the Wai'alae Shaft has not been in operation since 1984 due to high operation costs). Also, the Kalihi, Pearl City, and Wai'alae Shafts

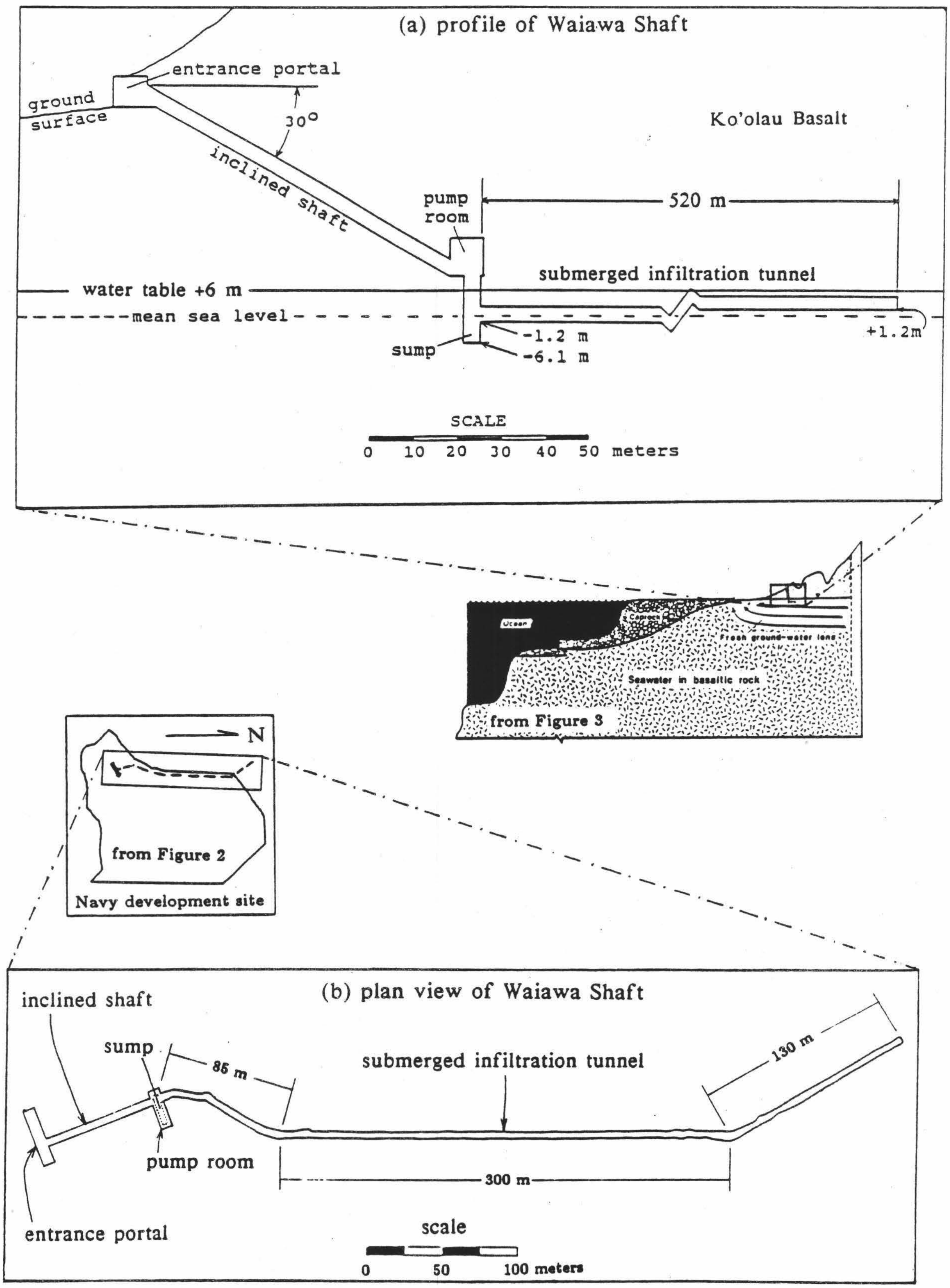


Figure 5. Waiawa Shaft (a) profile and (b) plan views (after Eyre, 1983; Oki, *et al.*, 1990; and Public Works Center, 1951)

have infiltration tunnel lengths of only 26, 2.4, and 20 m, respectively (Stearns, 1940). The length of the infiltration tunnel at the Halawa Shaft is 120 m (Board of Water Supply, 1945), which is still significantly shorter than the 520 m length of the Waiawa Shaft.

The above comparisons with drilled vertical wells and other shaft type wells do not necessarily indicate that shaft type wells are significantly more susceptible to contamination or that the Waiawa Shaft is similar to other shafts. Numerous other factors such as location, land use, pumping rates, local climate, and history of contamination must be taken into account for each individual well.

During the 1970's, increases in the chloride concentration of water from the Waiawa Shaft were observed. In 1979, the levels approached 300 mg/l. The cause of this chloride contamination was determined to be the irrigation of sugar cane on Waiawa Ridge with water having chloride concentrations exceeding 1,000 mg/l. Water intensive furrow irrigation methods increased the downward movement through the unsaturated zone and subsequently caused contamination of the basal water (Eyre, 1983).

Sugar cane has not been cultivated in this area since 1983. Consequently, the chloride levels in water pumped by the Waiawa Shaft dropped significantly, and are currently at about 50 mg/l (Public Works Center, 1989). Testing for chemicals such as chlordane, 2,4-D, diazinon, and malathion have been performed at the Waiawa Shaft but these chemicals were not found above their respective detection limits (Giambelluca *et al.*, 1987). However, upon initial testing for DBCP and TCP in 1983, trace levels of these compounds were detected. The surrounding fields, previously used for pineapple cultivation, are the suspected source. Table 1 provides a summary of the measured chemical concentrations at the Waiawa Shaft.

Table 1

Chemical Concentrations at Waiawa Shaft

Chemical	Date	Concentration	Reference
chloride	1960	65 mg/l*	1
chloride	1970	110 mg/l*	1
chloride	1979	270 mg/l*	1
chloride	1983	200 mg/l*	2
chloride	1989	50 mg/l**	3
DBCP	Jan. 28 and Feb. 23, 1983	0.01 μg/l	4
DBCP	Feb. 28 to July 21, 1983	0.02 to 0.025 μg/l	4
TCP	Oct. 17, 1983	0.063 μg/l	4
TCP	Oct. 20, 1983	0.21 μg/l	4

* Approximate annual average
** Approximate annual average through July 1989

References: 1 = Eyre, 1983
2 = Chinn *et al.*, 1984
3 = Public Works Center, 1989
4 = Giambelluca *et al.*, 1987

The previous occurrences of contaminants in water from the Waiawa Shaft show that it is a vulnerable water source. In view of this and the proposed urban developments, the Navy has become acutely aware of the potential for future contamination.

4. WRRC Project

In October 1987, the Navy contracted the University of Hawai'i Water Resources Research Center (WRRC) to assess the potential for groundwater contamination at the Waiawa Shaft due to expected chemical applications at the proposed development sites. The WRRC assessment (Oki *et al.*, 1990) is based upon estimates of pesticide and fertilizer use, groundwater recharge, and chemical transport through the unsaturated and saturated zones.

The types and quantities of pesticides and fertilizers expected to be used in the urban developments were determined by surveys of households in the nearby Waipi'o Gentry subdivision, local retail stores and termite control companies, and the existing literature. Groundwater recharge estimates were derived from water balance methods similar to those used by Giambelluca (1983). The Pesticide Root Zone Model (PRZM) (Carsel *et al.*, 1984) and Method of Characteristics (MOC) (Konikow and Bredehoeft, 1978) model were used to simulate transport in the unsaturated and saturated zones, respectively. Both of these models have been used previously in Hawai'i (PRZM: Khan and Green, 1988; Loague *et al.*, 1989a,b; Loague and Green, 1989a. MOC: Or and Lau, 1987).

Numerous soil samples were collected and analyzed to provide parameter estimates for input to PRZM. Chemical leaching experiments, which included monitoring of water balances, were used to evaluate PRZM's validity in the near-surface. Existing records on chloride concentrations and pumpage from the Waiawa Shaft were used to evaluate the MOC model.

Long-term simulations in conjunction with the field leaching experiments were used to provide an assessment of the potential for groundwater contamination by chemicals applied in the proposed developments. The WRRC project is described in detail by Oki *et al.* (1990). Figure 6 summarizes the sequence of activites encompassed by the WRRC project.

B. OBJECTIVES

The primary objective of this thesis was to estimate the amounts of chemicals originating from the proposed Waiawa developments which may leach through the unsaturated zone and into groundwater. This determination helped to fulfill part of the overall WRRC project objectives by providing the input necessary to simulate solute transport in the saturated zone.

A second objective of this thesis was to assist in establishing a protocol for similar investigations at other locations in Hawai'i. The scope of this thesis with respect to the WRRC project is defined by the shaded portions of Figure 6.

C. STRATEGY

1. Overview of Pesticide Fate in the Unsaturated Zone

As reviewed by Wagenet and Rao (1985) and Donigian and Rao (1986), the major processes which describe pesticide fate under field conditions are transport, transformation, retention, plant uptake, and volatilization. Transport includes surface runoff, erosion, and leaching. The leaching process is typically assumed to conform to Darcian principles, however the significance of leaching via preferential flow has received considerable attention.

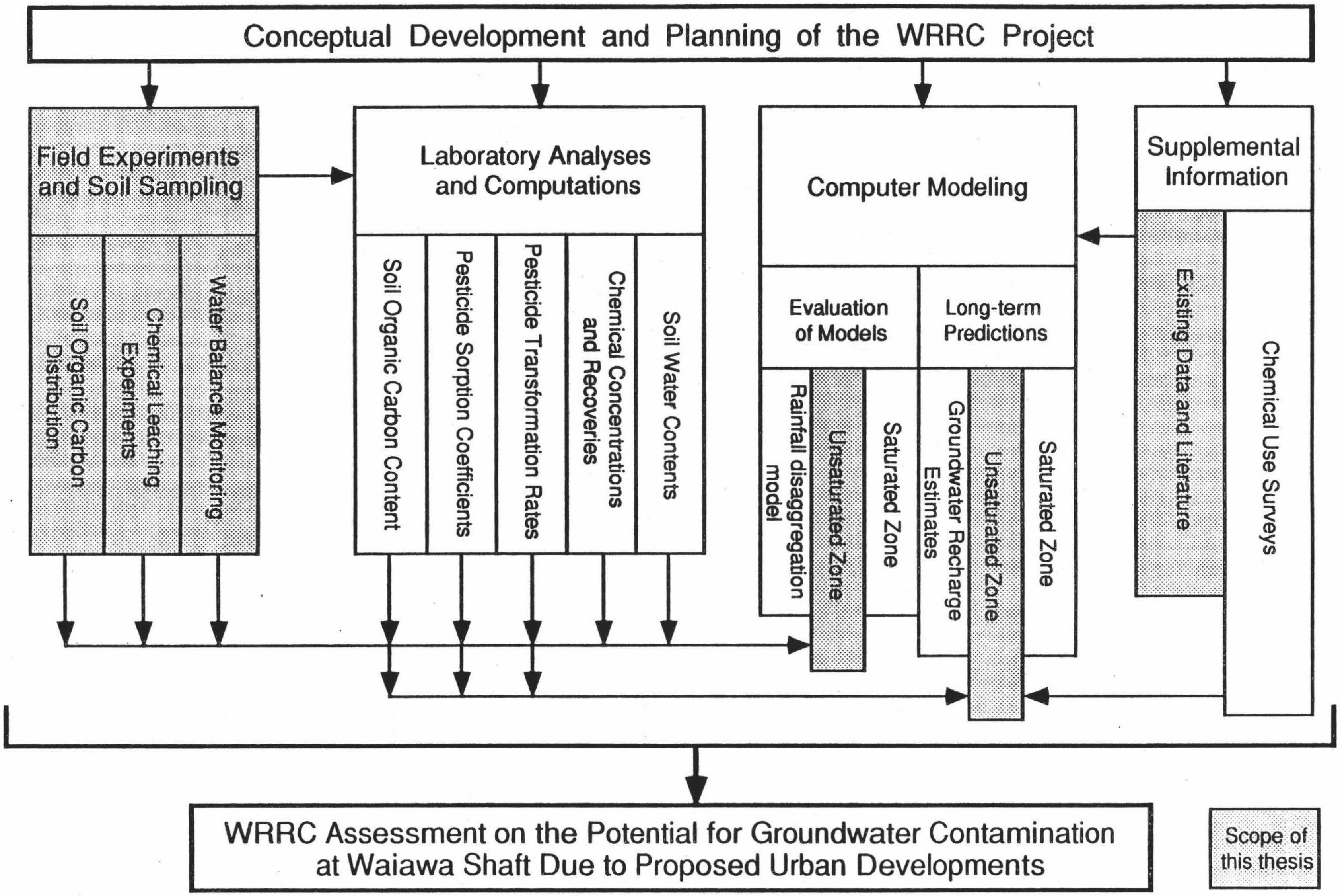


Figure 6. Scope of thesis in relation to WRRC project

Preferential flow through structured porous media involves flow through a network of continuous channels or macropores. A review paper by Beven and Germann (1982) indicates that structured flow through soils is not adequately described by a Darcian approach. White (1985) summarizes the possible effects on the leaching of fertilizers and pesticides via this by-passing mechanism. Data from scanning electron microscopy by Miller (1987) on central O'ahu subsoil and saprolite show that preferential flow occurs along joints and in channels between macropores. Loague *et al.* (1989a,b) discuss the need to characterize and account for preferential flow in Hawaiian soils.

Transformation of pesticides may occur via microbiological or chemical pathways which are spatially and temporally variable depending on factors such as soil type, soil water content, initial pesticide concentration, temperature, and pH. The transformation rate is commonly expressed as a first-order decay rate, k, or by the apparent half-life, $t_{1/2}$. Hydrolysis is a significant transformation process for organic compounds in aqueous environments (Harris, 1982). Hydrolysis becomes especially important below the soil layer where photolysis is negligible and biological pathways are retarded. It is important to keep in mind that the transformation process may result in degradation to nontoxic products as well as the production of toxic metabolites.

The retention of pesticides by porous media refers to the phenomenon of sorption, which includes the effects of absorption and adsorption. Sorption may be characterized by a linear sorption partition coefficient, K_d, which relates the sorbed and dissolved pesticide concentrations by equation 2-4 (Chapter II). Organic carbon content is recognized as the single most important soil characteristic influencing sorption of pesticides (Rao *et al.*, 1983). Organic carbon content is commonly expressed as f_{oc}, the mass fraction of organic carbon to dry soil. Due to the dominant effect of f_{oc} on sorption, the sorption partition coefficient is often based on soil organic carbon and expressed as K_{oc}. The relationship between K_{oc} and K_d is usually assumed to be linear, and expressed as:

$$K_d = K_{oc} f_{oc} \qquad (1\text{-}1)$$

However, the interactions between pesticides and clay, as reviewed by Green (1974), may also be significant. This may be of particular interest at greater depths, where f_{oc} is greatly diminished.

The transport of pesticides by surface runoff and erosion is dependent upon the pesticide formulation, application method, and timing of rainfall/irrigation events. In general, the resulting losses are on the order of 0.5% or less of the amounts applied (Wauchope, 1978). The effects of plant uptake on pesticide fate are dependent upon characteristics of the vegetation, but few quantified results have been documented. The importance of volatilization is dependent on properties of the selected chemical and prevailing meteorologic conditions.

A useful tool for determining the leaching potential of chemicals is the attenuation factor (AF) described by Rao *et al.* (1985). The AF is a simple yet useful index which can be used to rank chemicals according to their potential to cause groundwater contamination. Chemicals with AF values close to 1.0 are expected to pose a significant threat whereas those with AF values approaching zero are generally considered safe. The AF does not account for hydrodynamic dispersion or temporal variations in recharge, but otherwise treats pesticide fate in a manner very similar to PRZM. Comparisons of AF with PRZM have shown that these two models often produce nearly identical rankings (Kleveno, 1990).

Table 2 ranks AF values of selected chemicals through a soil depth of 0.5 m assuming an average urban recharge rate of 1 m/year. Chemicals listed in Table 2 include those used in simulations for this study and, if estimates for the AF model

Table 2

Attenuation Factor (AF) of Selected Chemicals in Soil

CHEMICAL	K_{oc} m^3/kg	k $year^{-1}$	AF
nitrate	0.000	0.00	1.00
metribuzin	0.041	8.44	2.8×10^{-2}
dicamba	0.002	18.1	2.2×10^{-2}
diazinon	0.085	8.44	3.6×10^{-3}
fenamiphos	0.171	12.7	5.4×10^{-7}
2,4-D	0.020	50.6	1.5×10^{-7}
methiocarb	0.300	12.7	6.8×10^{-11}
triforine	0.500	12.1	3.6×10^{-16}
metaldehyde	0.240	25.3	1.9×10^{-17}
carbaryl	0.229	36.2	1.2×10^{-23}
acephate	0.100	84.4	3.3×10^{-28}
chlorothalonil	1.380	12.7	1.5×10^{-43}
MSMA	10.00	2.53	2.0×10^{-61}
petroleum oil	1.000	25.3	2.1×10^{-63}
chlorpyrifos	6.070	8.44	$<1.0 \times 10^{-99}$
glyphosate	10.00	8.44	$<1.0 \times 10^{-99}$
malathion	1.797	253	$<1.0 \times 10^{-99}$

K_{oc} and k values from Wauchope (1988), Ou *et al.* (1979), and Rao and Davidson (1979).

The following assumptions were made:
- bulk density = 1100 kg/m^3
- f_{oc} = 0.01 kg/kg
- θ_{fc} = 0.40 m^3/m^3
- depth of profile = 0.5 m
- recharge rate = 1.0 m/year

parameters were available, those chemicals currently used by residents of the Waipi'o Gentry subdivision (as determined by a household survey presented by Oki *et al.*, 1990). Rankings based on AF provide a general perspective on the relative leaching potential of different chemicals.

2. Computer Modeling

The modeling strategy for the unsaturated zone in this study is outlined in Figure 7. Before long-term predictions were made with PRZM, the model was evaluated with field observations. The evaluation of PRZM included calibration and validation efforts using field data obtained from experiments conducted on test plots in Waiawa Valley and at Poamoho, as described in Chapter IV. The calibration and validation procedure requires at least two sets of field data from each evaluation site.

The calibration process involves the adjustment of selected model parameters within their accepted ranges until the simulated results adequately describe the field data for a given time. Once the calibration is completed, another simulation for a different time is compared with a second, independent set of field data. If the second simulation adequately describes the second data set without further adjustment to the calibrated parameters, then the model is validated. If not, then the calibration process must be repeated with further adjustments before another attempt at validation is made. The validation process provides an independent check of model simulations versus field observations.

Donigian (1983) summarizes the model validation process and describes the need for calibration of empirical models to account for the various factors which are not sufficiently described by the model. These factors may include the effects of: spatial variation on parameter values; unrepresented, unquantifiable, or unknown functional

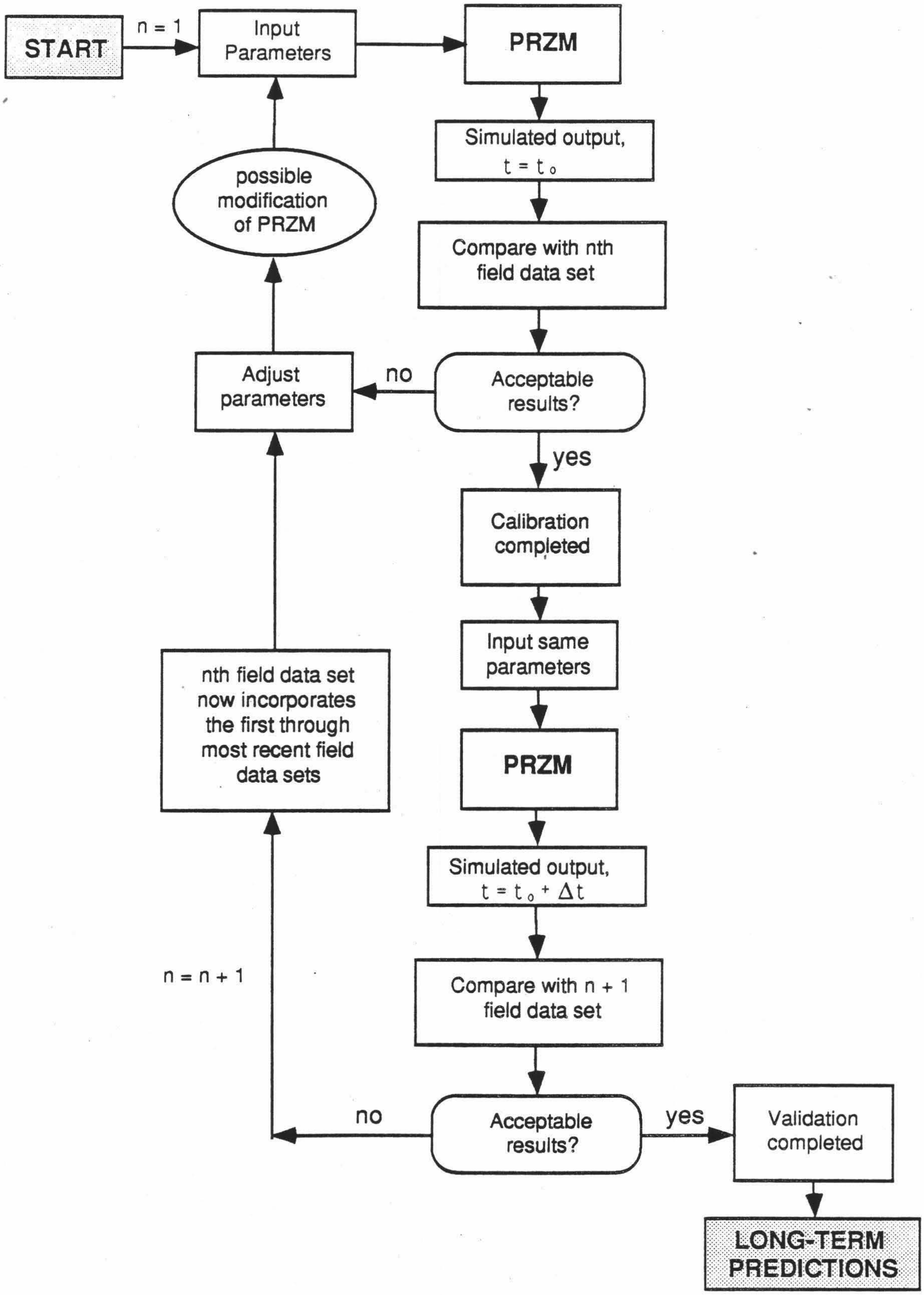


Figure 7. Flow chart of modeling strategy

relationships of parameters; and errors associated with the extrapolation of lab-measured parameters to actual field conditions.

3. Parameter and Variable Estimation

Field test plots received chemical applications followed by a sampling program which monitored their downward movement through the soil profile. Weather stations located near the plots were used to estimate the water balance.

Transects were established to determine the spatial distribution and variability of soil organic carbon, f_{oc}. In addition to the f_{oc} analyses, laboratory work included measurements of soil bulk densities (ρ_b), soil water contents (θ), chemical concentrations, pesticide sorption coefficients (K_{oc}), and pesticide transformation rates (k). These data were needed for PRZM simulations and the model evaluation process. Additional and supplemental data were taken from the existing literature (references cited in Chapters IV and V). The following chapter describes PRZM, its prior use, and its use in this study.

CHAPTER II. THE PESTICIDE ROOT ZONE MODEL (PRZM)

A. DESCRIPTION OF PRZM

1. General

PRZM (acronym for the Pesticide Root Zone Model) was developed by the U.S. Environmental Protection Agency to predict near surface pesticide movement to evaluate the potential for groundwater contamination. PRZM is a one-dimensional, deterministic-empirical, field-scale solute transport model which simulates soil water movement with an empirical drainage algorithm and chemical transport with the advection-dispersion equation.

The hydrologic component simulates runoff, erosion, evapotranspiration, and soil water movement. The chemical transport component simulates the effects of runoff, erosion, foliar loss (washoff), plant uptake, decay, sorption, advection, and dispersion. The soil profile of Figure 8 illustrates the processes which are simulated by PRZM. A comprehensive description of PRZM is found in the user's manual by Carsel *et al.* (1984). A summary of the parameters and variables used for PRZM simulations is shown in Table 3.

2. Hydrology

The water balance equation solved by PRZM is expressed as:

$$\theta_c = \theta_o + R_f - I + I_a - R_o - E_v - T \qquad (2\text{-}1)$$

where, θ_c = current θ, θ = soil water content
θ_o = initial θ
R_f = rainfall + irrigation + snowmelt
I = percolation out of layer
I_a = percolation in from layer above
R_o = surface runoff
E_v = evaporation
T = transpiration

with the following conditions:
I_a and $T = 0$ at the surface

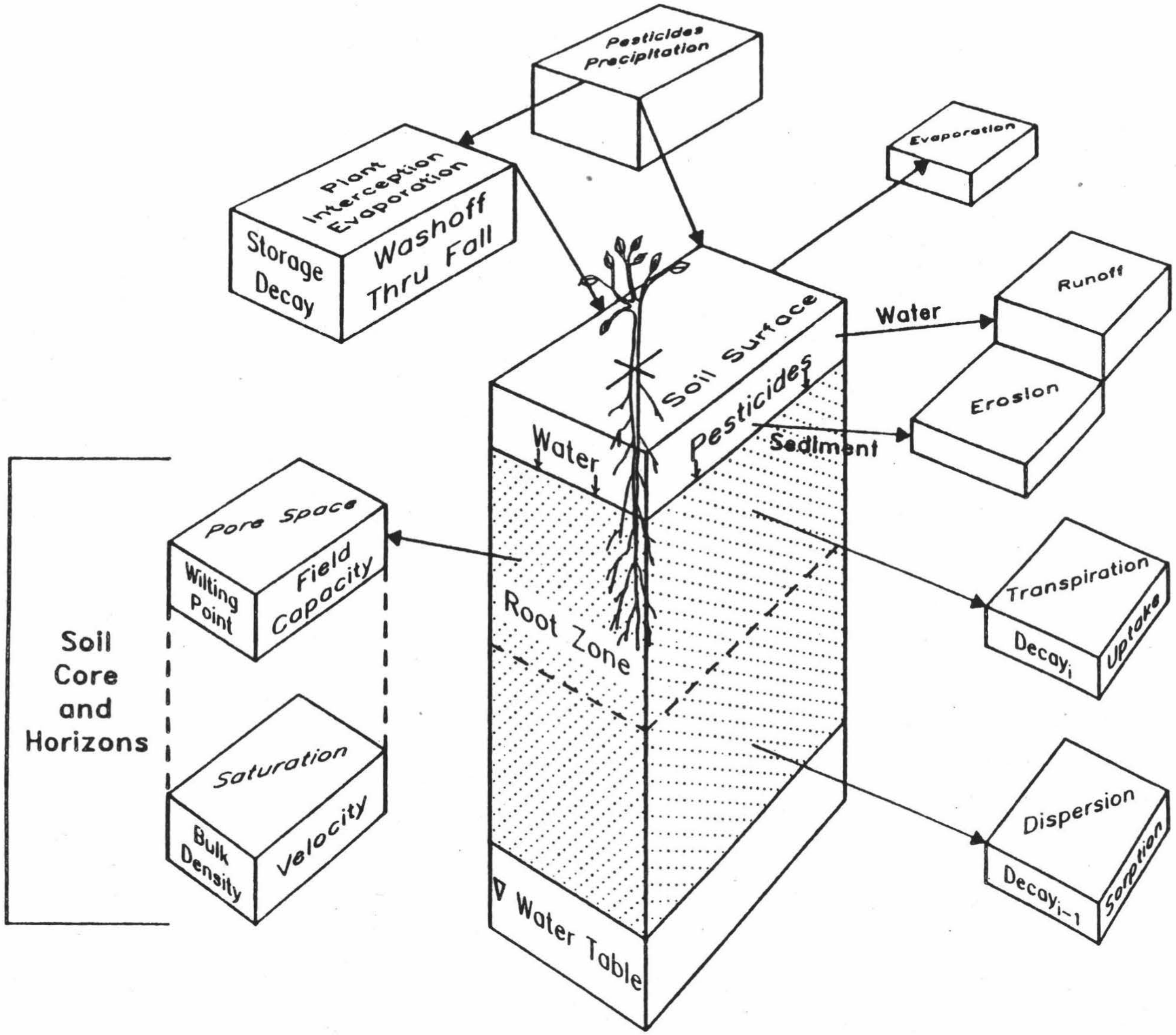


Figure 8. Processes simulated by PRZM (Carsel *et al.*, 1984)

Table 3

PRZM Input Parameters and Variables

HYDROLOGY	
	daily rainfall (mm)
	daily pan evaporation (mm)
	pan evaporation factor (*)
	runoff curve numbers (*)
PESTICIDES	
	application date (month-day-year)
	application rate (kg/ha)
	incorporation depth (m)
	decay rate (day^{-1})
	sorption partition coefficient (m^3/kg)
CROP	
	maximum areal coverage (m^2/m^2)
	maximum interception storage (mm)
	maximum root depth (m)
	cropping dates (month-day-year)
SOIL	
	organic carbon content (kg/kg)
	hydrodynamic dispersion coefficient (m^2/day)
	bulk density (kg/m^3)
	water content (m^3/m^3)
	@ wilting point
	@ initial conditions
	@ field capacity

* Dimensionless

R_f, E_v, and $R_o = 0$ below the surface
$T = 0$ below the root zone
percolation occurs when $\theta > \theta_{fc}$
evapotranspiration occurs when $\theta > \theta_{wp}$

where, $\theta_{fc} = \theta$ at field capacity
$\theta_{wp} = \theta$ at wilting point.

PRZM has two different drainage algorithms which govern soil water movement. The first assumes a freely draining soil which will drain all water in excess of the field capacity within one day. This first drainage option is most appropriate for sandy soils. The second option, for poorly permeable soils, requires the input of an empirical drainage parameter, λ, in the equation:

$$\theta_c = \theta_{fc} + (\theta_o - \theta_{fc})\, e^{(-\lambda \Delta t)} \qquad (2\text{-}2)$$

where,
θ_c = current soil water content
θ_{fc} = soil water content at field capacity
θ_o = soil water content during previous time step
λ = empirical drainage parameter
Δt = time increment.

The velocity of water movement, v, is calculated by dividing the amount of percolating water by the soil water content, θ, and then averaging over the time step of one day.

PRZM calculates surface runoff according to the Soil Conservation Service's curve number method (U.S. Department of Agriculture, 1972) which incorporates the effects of soil type, land use, and management practices. Evapotranspiration is estimated by PRZM from pan evaporation data or air temperatures, and crop information.

3. Chemical Transport

The simplified advection-dispersion equation used in PRZM is expressed as:

$$\frac{\partial[C(\theta + K_d\rho_b)]}{\partial t} = D\frac{\partial^2(C\theta)}{\partial z^2} - \frac{\partial(C\theta v)}{\partial z} + A - P_i + P_w - C[k(\theta + K_d\rho_b) + P_u + R_o + E_r] \qquad (2\text{-}3)$$

where,

C = dissolved concentration of solute
θ = volumetric soil water content
K_d = sorption partition coefficient
ρ_b = soil bulk density
t = time
D = hydrodynamic dispersion coefficient
z = depth
v = velocity of water movement
A = applied solute
P_i = plant interception
P_w = plant washoff
k = solute transformation rate
P_u = plant uptake
R_o = surface runoff
E_r = erosion.

The assumptions of a reversible and instantaneous equilibrium condition and a linear relation of the form:

$$C_s = K_d C \qquad (2\text{-}4)$$

where, C_s = sorbed concentration,

allows equation 2-3 to be expressed solely in terms of C, the dissolved concentration.

The pesticide transformation rate, k, is assumed to be a first-order constant which collectively represents the effects of biological, photochemical, and chemical decay. It is assumed to apply to both the sorbed and dissolved phases. The hydrodynamic dispersion coefficient, D, is assumed to be constant and to include the effects of both diffusion and mechanical dispersion.

The amount of applied pesticide, A, is partitioned between the soil surface and the plant canopy. Solute intercepted by the plant canopy, P_i, is allowed to be washed off, P_w, to the soil surface by R_f. Plant uptake of the solute, P_u, is assumed to be directly related to the transpiration rate.

The erosion of surface sediments along with its sorbed solute, E_r, is calculated by the Modified Universal Soil Loss Equation (MUSLE) which incorporates surface runoff and other estimated factors relating to the slope, land use, and soil erodibility and cover (described by Williams and Berndt, 1977).

Assuming low solute concentrations such that flow is not influenced by concentration gradients, the dispersion and advection terms (*i.e.* D and v) are assumed to be independent of each other, as shown in equation 2-3. This allows the solution of v and θ by equation 2-1 followed by the solution of equation 2-3 by an implicit finite difference scheme which employs the Thomas algorithm.

B. PRIOR USE OF PRZM

1. PRZM Outside of Hawai'i

Performance tests in Florida, Georgia, New York, and Wisconsin have shown that PRZM is useful in assessing the threat to groundwater from pesticides (Carsel *et al.*, 1984). PRZM was successfully calibrated with observed data through a depth of 2.5 m for the insecticide aldicarb at a site in New York (Carsel *et al.*, 1985). Hedden (1986) reports on PRZM's calibration with aldicarb and the herbicide metolachlor as used on a peanut crop in Georgia. Lorber and Offutt (1986) describe the calibration of PRZM with aldicarb data from tobacco fields in North Carolina and potato fields in Wisconsin. They suggest modifying PRZM's decay rate, k, to make it a function of temperature or time.

Carsel *et al.* (1988a) used PRZM in a Monte-Carlo simulation procedure to assess the leaching potential of aldicarb applied to corn grown in Ohio. PRZM has also been linked to a groundwater solute transport model to assess leaching of aldicarb applied to peanuts in North Carolina and its movement in groundwater (Carsel *et al.*, 1988b).

Long-term PRZM simulations were used by Dean *et al.* (1984) to develop the Leaching Evaluation of Agricultural Chemicals (LEACH) methodology. They performed sensitivity analyses with PRZM and observed that pesticide properties and climatic factors are more important than soil properties in determining the losses of pesticides by leaching. They also noted that the sorption partition coefficient, K_d, is the most important parameter affecting pesticide mobility.

Villeneuve *et al.* (1988) performed sensitivity analyses of PRZM with respect to the sorption partition coefficient, K_d, and the decay rate, k, for aldicarb. Their results show that these two parameters are very sensitive, and therefore they emphasize the need for accurate field data to obtain reliable predictions with PRZM.

2. PRZM in Hawai'i

Khan and Green (1988) found that PRZM performed reasonably well in simulating the general shape and peak location of actual DBCP concentration profiles from two pineapple fields on the island of Maui. PRZM did not accurately simulate the DBCP concentrations with depth, but this was at least partly attributed to three factors: (1) PRZM was not calibrated, (2) volatilization was not simulated, and (3) the estimated water balance data input to PRZM were crude.

Loague *et al.* (1989a,b) also used PRZM in an uncalibrated mode to simulate EDB, DBCP, and TCP leaching at two pineapple fields in central O'ahu. They simulated volatilization by incorporating a separate model developed by Green *et al.* (1986). PRZM failed to simulate the shape of EDB concentration profiles but was fairly successful with the depth and time for peak concentrations (Loague *et al.*, 1989a). In general, PRZM performed reasonably well in predicting the deep leaching (up to 20 m) of these three pesticides. Loague *et al.* (1989a) suggest that with modification, extension, and further testing, PRZM may be a useful tool for making pesticide leaching assessments in Hawai'i.

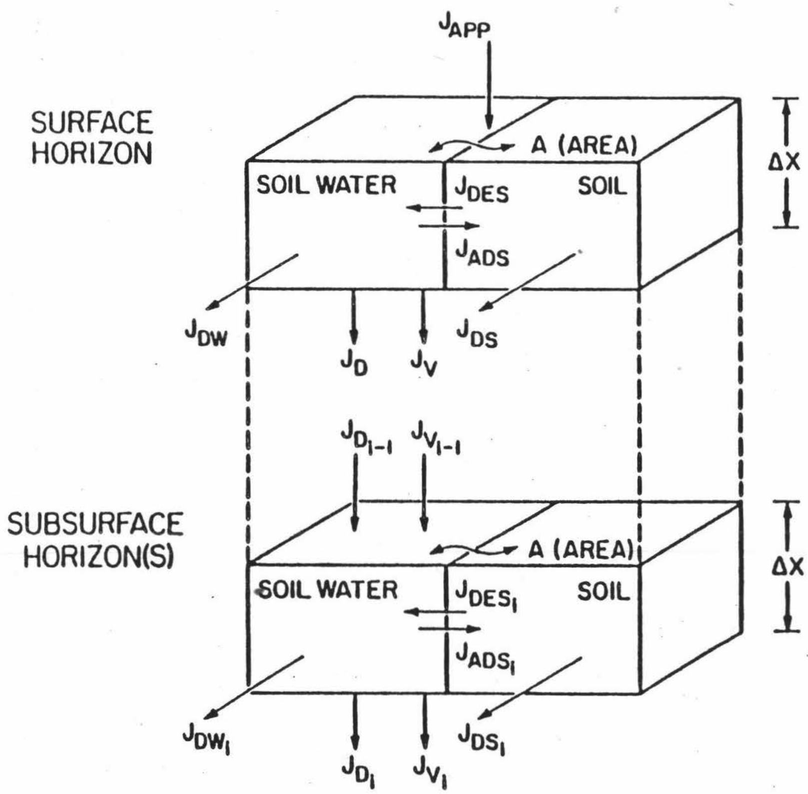
Loague and Green (1989a) added to the results of Loague *et al.* (1989a,b) with a series of 75 PRZM calibration simulations for the deep EDB profiles. Their results show that the parameters which yielded the best model calibration with the first observed data set (1983) gave poor model validation with the second set (1985). These results suggest it may not be possible to validate PRZM with those particular data sets and that in general, PRZM may be inappropriate for typical Hawaiian profiles. Unfortunately, this has been the only attempt at calibrating and validating PRZM with deep profiles in Hawai'i. Thus, the use of PRZM for predictive purposes through the typically deep unsaturated profiles of Hawai'i must be done with caution.

C. USE OF PRZM IN THIS STUDY

The simulations used to evaluate PRZM and those for long-term predictions employed PRZM's freely draining profile option. Chemical losses due to erosion, runoff, and plant uptake were always set to zero. The structure of PRZM as used in this study is represented by the compartmental soil profile in Figure 9.

During the evaluation process, daily potential evapotranspiration data were input either as pan evaporation with a pan factor, or directly as potential evapotranspiration. Daily recharge used in the long-term simulations was estimated with a separate water balance model (briefly described in Chapter IV) and input directly into PRZM. Table 4 summarizes the assumptions made during the PRZM modeling effort.

Additional test simulations were performed with a slight modification to PRZM. This modification, described in Chapter IV, was implemented to approximate preferential flow in soil. The following chapter describes the investigation sites which were simulated by PRZM.



1. **Mass flow due to advection and hydrodynamic dispersion, $J_{D,V}$ and $J_{Di,Vi}$**
   $J_{D,V}$ = Flow across upper boundary of compartment
   $J_{Di,Vi}$ = Flux across lower boundary of compartment
   Assumption: Hydrodynamic dispersion coefficient is constant

2. **Reversible Sorption, J_{ADS}, J_{DES} and J_{ADSi}, J_{DESi}**
   J_{ADS} = Adsorption of chemical to soil
   J_{DES} = Desorption of chemical from soil
   Assumption: Equilibrium between phases is reached instantaneously

3. **Chemical Decomposition, J_{DW}, J_{DS} and J_{DWi}, J_{DSi}**
   J_{DW} = Decay in the soil water phase
   J_{DS} = Decay in the soil phase
   Assumption: One first-order decomposition rate represents the sum of all processes in both soil water and soil phases

ΔX = Compartment size
J_{APP} = Application
J_{DES} = Desorption
J_{ADS} = Adsorption

J_{DS} = Decay in soil
J_{DW} = Decay in water
J_D = Dispersion
J_V = Advection

Figure 9. Compartmental model of PRZM's structure as used in this study (Carsel *et al.*, 1984; Loague *et al.*, 1989a)

Table 4

Assumptions of the Modeling Effort

Transport	
	advection-dispersion equation applies
	no preferential flow
	one-dimensional flow
	daily time step
	drainage algorithm based on θ_{fc}
	D is constant
Transformation	
	first-order decay rates
	constant decay rates
	$k_{sorbed} = k_{dissolved}$
	no volatilization
Retention	
	linear sorption isotherms
	linear relationship between K_d and f_{oc}
	constant K_d
	singularity of sorption-desorption
	instantaneous equilibrium (daily time step)

CHAPTER III. DESCRIPTION OF THE INVESTIGATION SITES

A. LOCATION, TOPOGRAPHY, AND LAND USE

1. Waiawa

The elevation of Waiawa Ridge within the proposed Waiawa community ranges from less than 50 to approximately 300 m above sea level. The proposed Navy development in Waiawa Valley has an elevation range of 30 to 50 m. The topographic map of Figure 10 can be compared to Figure 2 to get a general idea of the terrain in the development areas.

The Waiawa development sites are currently overgrown with guinea grass (*Panicum maximum*) and koa haole (*Leucaena leucocephala*), with occasional stalks of sugar cane on the ridge. The proposed Gentry development site on Waiawa Ridge is currently owned by the Bishop Estate and leased to O'ahu Sugar Company which has subleased some areas to Circle 6 Ranch for grazing cattle and horses. Most of the Waiawa Ridge area consists of abandoned sugar cane fields.

The proposed Navy development in Waiawa Valley has thousands of abandoned concrete structures, indicative of its prior use as a storage area during WWII. The western valley wall near the experimental plot (Figure 10) appears to have been cut to increase the storage area. Prior to its use as a storage area, pineapple and vegetable crops were cultivated there. Pacific Palisades, a residential community, is situated on the ridge which forms the eastern wall of Waiawa Valley.

2. Poamoho

Due to the difficulties encountered in obtaining permission to perform chemical leaching experiments on the proposed development site on Waiawa Ridge, the University of Hawai'i Poamoho Research Station (UHPRS) was selected as an alternate site. Figure 11 illustrates the location and topography of the area. The elevation at the

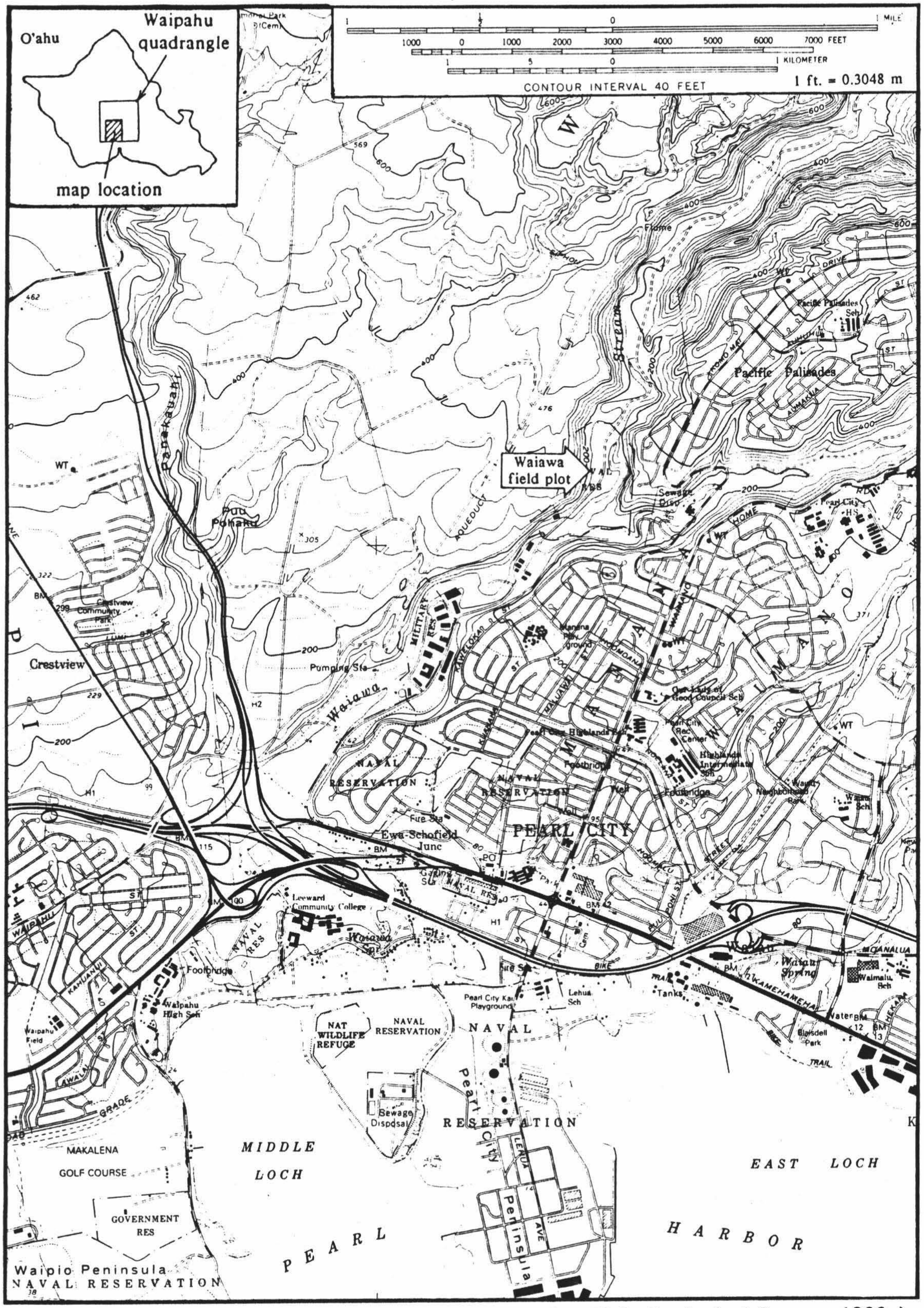


Figure 10. Topographic map of the Waiawa area (after U.S. Geological Survey, 1983a)

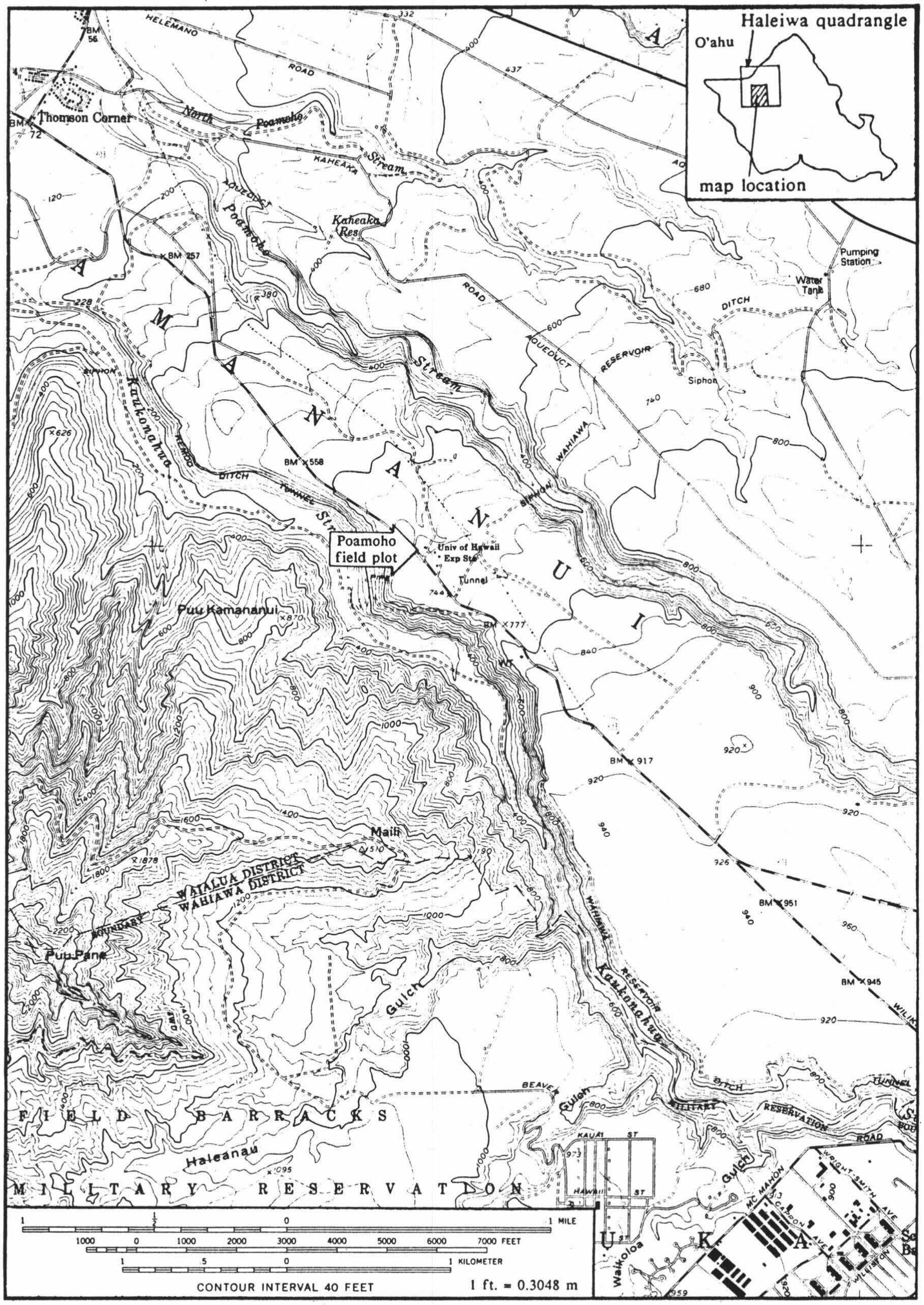


Figure 11. Topographic map of the Poamoho area (after U.S. Geological Survey, 1983b)

experimental plot is approximately 215 m. This site was fallow for about a year and a half prior to its use for this study. Before that, the site was used to grow corn.

B. GEOLOGY AND HYDROGEOLOGY

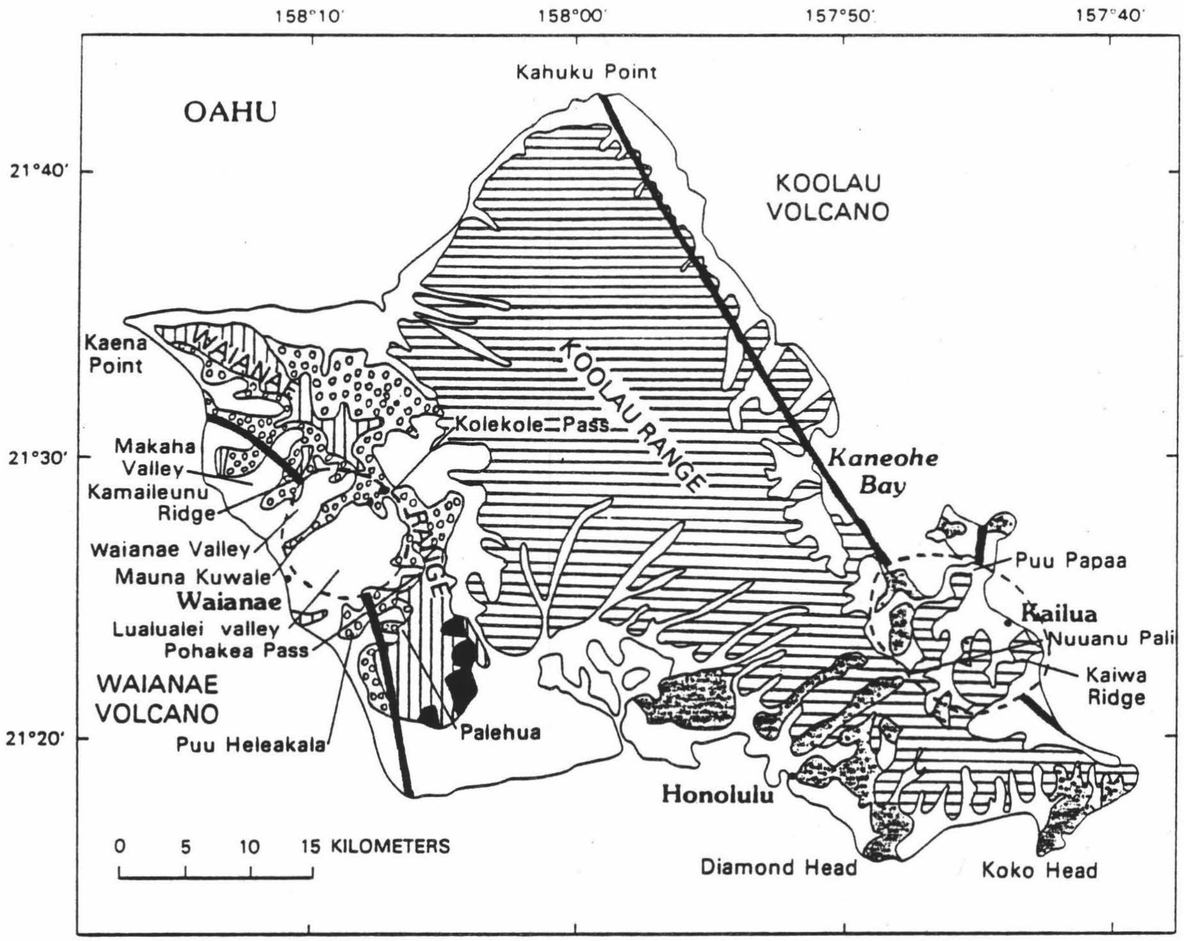
1. General

The Hawaiian-Emperor chain is recognized as being formed by north and northwestward movements of the Pacific plate over a relatively stationary hot spot. This hot spot is an anomalous melting source from deep within the Earth's mantle, presently centered near the southeast of the island of Hawai'i.

The island of O'ahu is comprised of the remnants of the Wai'anae and Ko'olau Volcanoes, which are two of the numerous shield volcanoes erupted from the hot spot. Paleomagnetic and potassium-argon measurements by Doell and Dalrymple (1973) indicate ages of 2.4 to 3.8 Ma for the Wai'anae Volcano and 1.8 to 2.6 Ma for the Ko'olau Volcano. Since their formation the two volcanoes have been eroded into relatively narrow ridges, resulting in their present designations as the Wai'anae and Ko'olau Ranges. The Kolekole Volcanics and the more extensive Honolulu Volcanics represent post-erosional eruptions from the Wai'anae and Ko'olau Volcanoes, respectively. Figure 12 shows a generalized geologic map of O'ahu.

Hawaiian groundwater occurs most commonly as a basal lens which floats upon and partially mixes with the underlying, denser seawater. Other occurrences include high level groundwater bodies confined by dikes or perched above impervious layers such as ash beds, soil, or impermeable lava flows. Figure 13 illustrates the occurrence and development of groundwater in a typical Hawaiian island.

The Aquifer and Status Codes discussed below are described in detail by Mink and Lau (1987). The Pearl Harbor aquifer has been defined as an aquifer sector which displays hydrogeologic similarities. This sector is composed of several groundwater



EXPLANATION

Sedimentary deposits (Holocene and Pleistocene)

WAIANAE VOLCANO

Kolekole Volcanics (Pleistocene)

Waianae Volcanics (Pliocene)

Palehua Member

Kamaileunu and Lualualei Members, undivided (Kamaileunu Member includes Mauna Kuwale Rhyodacite Flow)

KOOLAU VOLCANO

Honolulu Volcanics (Holocene? and Pleistocene)

Koolau Basalt (Pleistocene? and Pliocene) (includes Kailua Member)

Contact

Caldera boundary

Rift zone (approximately located)

Figure 12. Geologic map of O'ahu (after Langenheim and Clague, 1987)

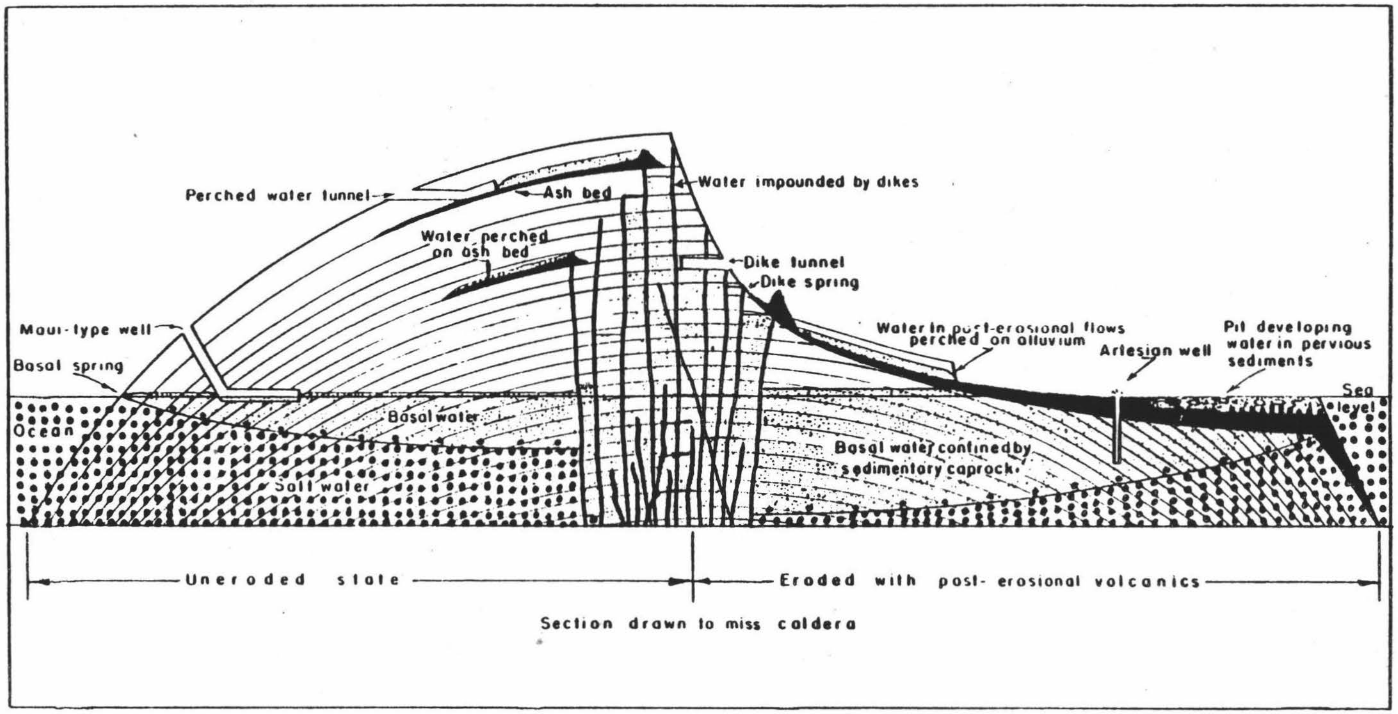


Figure 13. Occurrence and development of groundwater in a typical Hawaiian island (after Cox, 1954)

systems, each showing hydrogeologic continuity (Mink and Lau, 1987). Aquifer sectors and systems of O'ahu are shown in Figure 14. The aquifer system is then further defined into aquifer types, which differentiate distinctive hydrogeologic features. The Waiawa Shaft, therefore, is classified as withdrawing unconfined basal water from horizontally extensive lavas within the Waiawa Aquifer System of the Pearl Harbor Aquifer Sector. This classification system has been simplified to an eight-digit Aquifer Code which quickly identifies and describes the principal aquifers of the State. A similar five-digit Status Code which provides a quick description of an aquifer's vulnerability to contamination as well as its uniqueness, stage of development, utility, and current chloride concentration, has also been defined. The Status Code at Waiawa Shaft identifies a fresh drinking water source currently in use which is irreplaceable and highly vulnerable to contamination.

Descriptions of the general geology and hydrogeology of Hawai'i are presented by Macdonald *et al.* (1983) and Stearns (1985). Mink (1980), Wentworth (1951), and Stearns and Vaksvik (1935) give detailed descriptions of the Pearl Harbor area.

2. Waiawa

The Waiawa Shaft penetrates Ko'olau Basalt, the shield-building lava flows from Ko'olau Volcano. Ko'olau Basalt is composed of tholeiitic basalt, olivine tholeiitic basalt, and rare picritic tholeiitic basalt (Langenheim and Clague, 1987). The thin basaltic lava flows of pahoehoe and 'a'a, usually less than 3 m thick, which make-up the Ko'olau Basalt are very permeable and typical of the Hawaiian shield volcanoes.

The relatively unweathered basalt at depth grades into a highly weathered basalt, commonly called saprolite, as it approaches the surface. Saprolite then grades into soil near the ground surface. The depth to the boundary between the basalt and saprolite of Waiawa Ridge is approximately 25 m but as shallow as 10 m. These depths

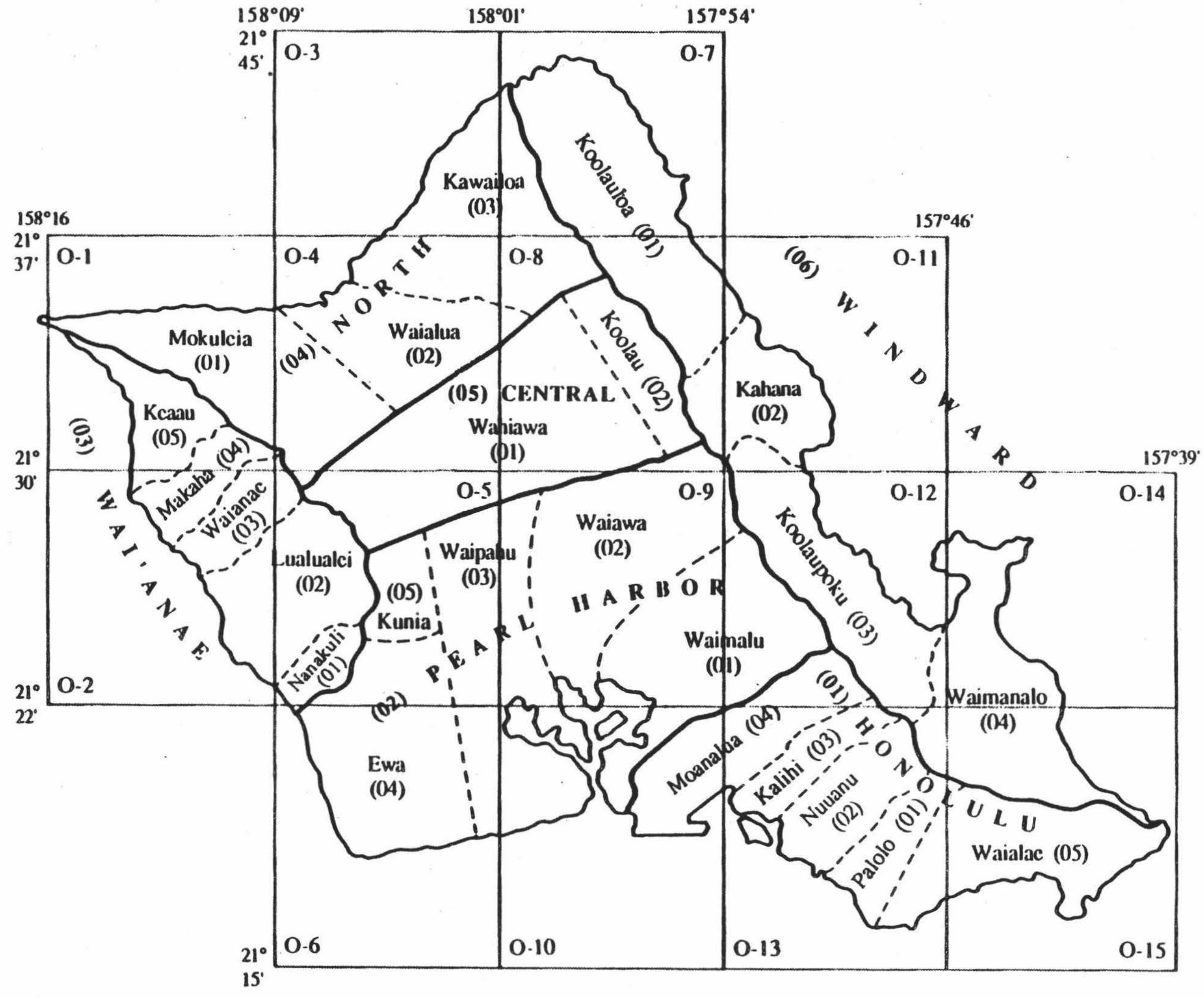


Figure 14. Aquifer sectors and systems of O'ahu (Mink and Lau, 1987)

were estimated from the logs of exploratory wells drilled in the vicinity of the Waiawa Shaft just prior to its construction (Public Works Center, 1951).

Beneath the Waiawa Stream lies a relatively thick layer of alluvium (see Figure 15). The relatively impermeable alluvium and weathered basalt beneath the valley floor create a small alluvial aquifer. Exploratory wells drilled near the stream (Public Works Center, 1951; and R.M. Towill Corp., 1978) reveal a water table about 15 m below the surface. Within the proposed Navy development this corresponds to an alluvial aquifer water table elevation of about 30 m above sea level. This is considerably higher than the basal water table which is at an elevation of about 6 m. However, the exact hydraulic relationship between this alluvial aquifer and the Waiawa Shaft or the basal groundwater is unknown.

3. Poamoho

The geology and hydrogeology of the Poamoho site is quite similar to that of Waiawa Ridge, but is of little concern beyond that because the selection of the Poamoho site was based primarily on its soil properties. Since the chemical leaching experiments performed on the Poamoho plot involved at most the top 3 m, properties of the profile below this depth were not relevant to this study.

C. CLIMATE AND SOILS

1. Waiawa

The isohyetal map of Figure 16 presents the average annual rainfall for the island of O'ahu. A similar map for pan evaporation is shown in Figure 17.

The average annual rainfall on Waiawa Ridge is near 0.8 m at the lower elevations and approximately 2.5 m near the higher elevations of the Ko'olau Range. The corresponding annual pan evaporation rates are 2 m at the lower, and about 1 m at

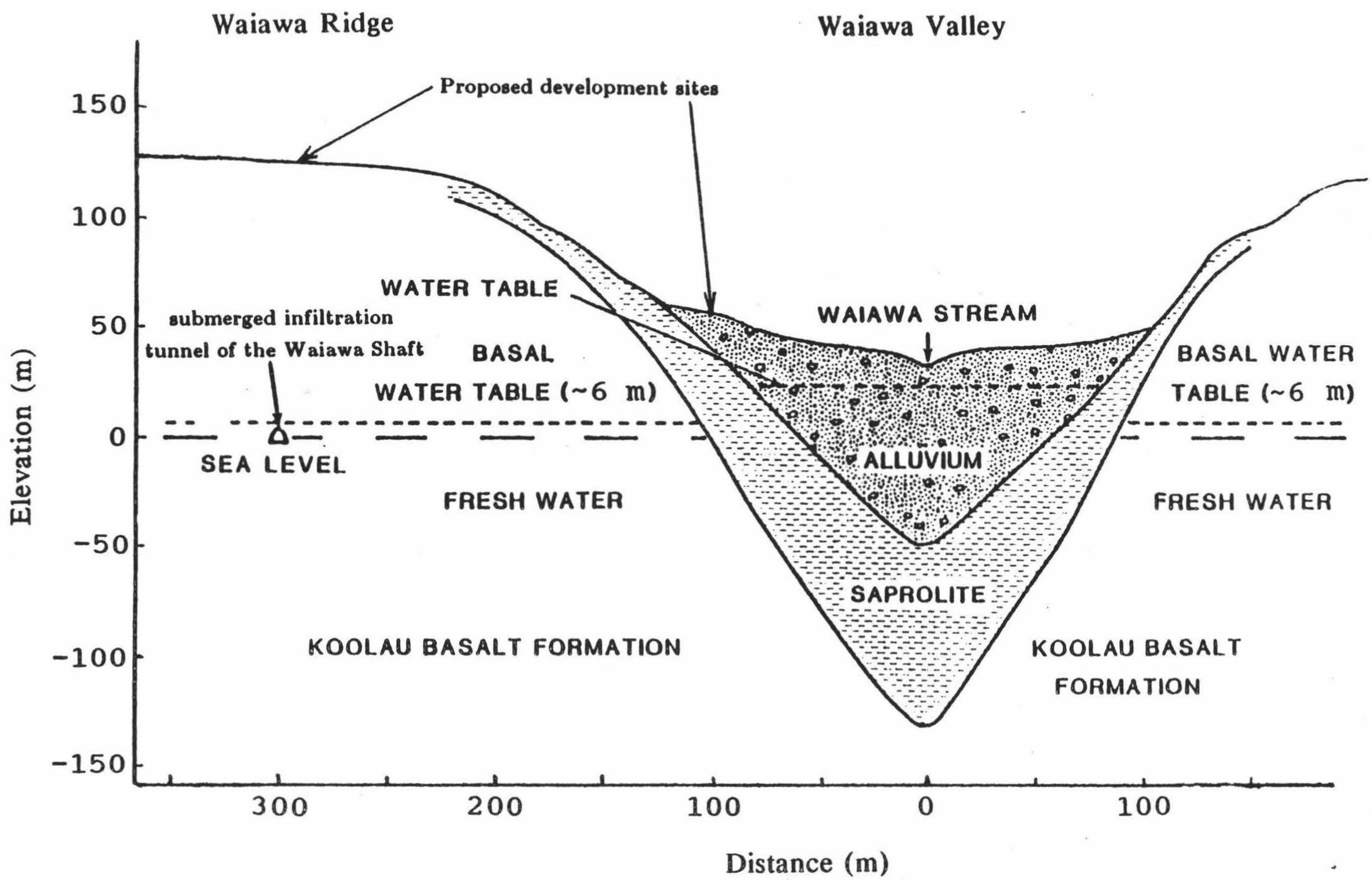


Figure 15. Profile across Waiawa Valley (after Mink, 1985)

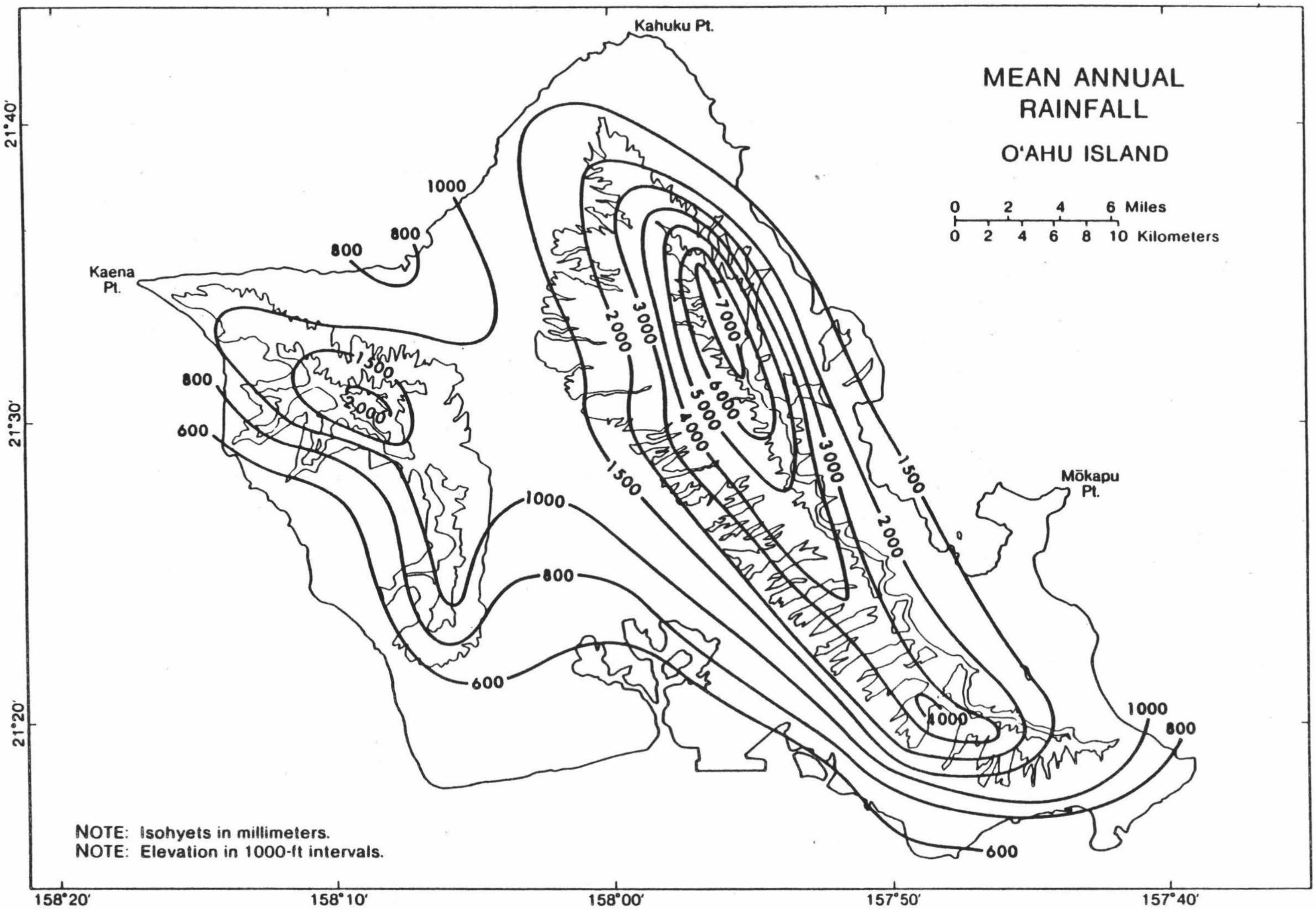


Figure 16. Mean annual rainfall on O'ahu (Giambelluca *et al.*, 1986)

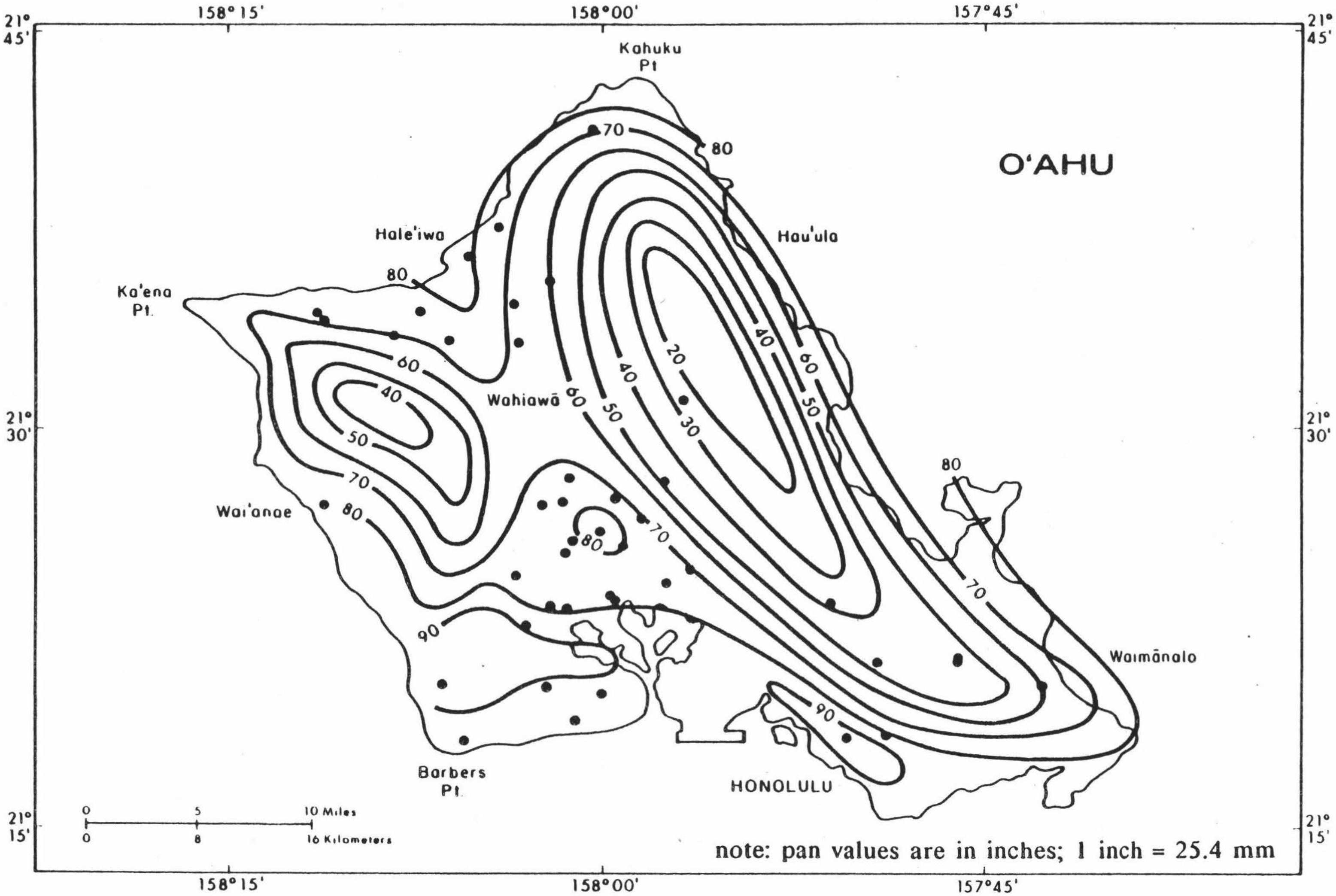


Figure 17. Mean annual pan evaporation on O'ahu (Ekern and Chang, 1985)

the higher elevations. Average annual rainfall at the Navy site in Waiawa Valley is approximately 1 m with a pan evaporation value of about 2 m.

Oxisols of the Wahiawa, Lahaina, and Moloka'i series are among the predominate soil types found within the proposed Gentry development on Waiawa Ridge. The Kawaihapai series, of the Mollisol order, is mapped as the most common soil type found within the proposed Navy development site. A description of the soil profile adjacent to the experimental plot in the valley, actually classified as an Entisol, is presented in Table 18 of Appendix A. Foote *et al.* (1972) provide extensive documentation of soil properties and distributions for the island of O'ahu.

Steady infiltration rates obtained by the double-ring method (as described by Bouwer, 1986) reveal significantly lower rates (typically an order of magnitude) at the Waiawa Valley plot versus Wahiawa soils on the ridge. During the drier summer months cracks were noticed at the surface of a more clayey soil about 100 m south of the valley test plot. These cracks, which could provide a pathway for the downward movement of chemicals, were up to 20 mm wide, extended laterally for a couple of meters, and were approximately 0.5 m deep.

2. Poamoho

Average annual rainfall at the experimental plot is approximately 1.2 m with an average annual pan evaporation of 1.8 m (Figures 16 and 17). The plot is located within the Wahiawa soil series. The description of a soil profile located less than 100 m from the field plot used in this study is presented in Table 19 (Appendix A).

In terms of elevation, climate, and soil type the Poamoho site is representative of mid-elevations on Waiawa Ridge. During the summer months the plot and surrounding areas exhibited an extensive network of surface cracks which typically extended to a depth of 0.5 m. Measured steady infiltration rates at the Poamoho plot and in Wahiawa soil on Waiawa Ridge coincide with those reported by Green *et al.* (1982) for Wahiawa soils.

The Poamoho site met two requirements for a second location which would be used to evaluate PRZM: (1) the site typified well-drained soils of the Wahiawa plateau, in contrast to the poorly drained Kawaihapai soil at the Waiawa test plot; and (2) the site was accessible and secure for the intended experimental work. The variations in soil properties between the Waiawa Valley and Poamoho field plots provided a relatively wide range over which PRZM could be evaluated. The methods used in the modeling, field, and laboratory efforts are discussed in Chapter IV.

CHAPTER IV. METHODOLOGY

A. COMPUTER MODELING

1. Evaluation of PRZM

The general approach to the evaluation process was discussed in Chapter I and outlined in Figure 7. PRZM simulations were compared with data obtained from field experiments described in section B of this chapter.

The effort to evaluate PRZM was simplified by isolating and reducing the number of pesticide fate processes involved. Isolating the transport of pesticides by leaching was accomplished by preventing surface runoff and erosion on the field plots. Losses due to volatilization were avoided by using nonvolatile chemicals. A conservative tracer was also applied to observe transport without the effects of sorption or transformation.

The evaluation of PRZM's performance included three cycles of the calibration and validation process, with each successive cycle involving a cumulative number of solute transport processes. The first cycle evaluated PRZM's water balance and advective transport. The second included the effects of dispersion, and the third included pesticide sorption and decay. Thus, the primary processes evaluated by this study are transport by leaching, and the effects of pesticide sorption and transformation.

The performances of PRZM's water balance and advective transport were evaluated by comparisons with observed soil water content profiles and the locations of peaks in observed tracer concentration profiles at selected times. Adjustments to the field capacity, θ_{fc}, and wilting point, θ_{wp}, were made until the simulated values approximated the observed field values. The pan factor could also have been varied to adjust the quantity of infiltrated water, but was not attempted in this study. The effect of hydrodynamic dispersion was evaluated with graphical comparisons of the shapes and distributions of tracer concentration profiles. The hydrodynamic dispersion coefficient was adjusted until the simulated results approximated the observed.

The final evaluation cycle compared the simulated pesticide concentration profiles with the observed. Methods used to compare the pesticide concentration profiles included the use of statistical criteria employed by Loague and Green (1989a,b) in addition to graphical comparisons.

The graphical criteria, as mentioned above, included comparisons of the peak chemical concentration locations between simulated and observed data, and qualitative comparisons of the concentration profiles' shapes. Statistical criteria included the maximum error (ME), root mean square error (RMSE), coefficient of determination (CD), modeling efficiency (EF), and coefficient of residual mass (CRM). These statistical criteria are defined in Table 5.

2. Long-term Simulations

Once the simulated results were compared with field data, PRZM was used to predict the long-term effects of chemical applications at the proposed Waiawa Ridge and Waiawa Valley developments. Although PRZM was evaluated with field data through a depth of only about 0.5 m, it was extended and used as a predictive tool for profiles up to 240 m thick. This extended use added more uncertainty to the long-term results because PRZM was not evaluated and therefore could not be validated for the greater depths. This is in addition to the already large degree of uncertainty currently associated with transport mechanisms and parameter estimates of deep Hawaiian profiles.

a. Selection of chemicals. The four nonvolatile chemicals used for the long-term PRZM simulations were: (1) chlorpyrifos, a termiticide; (2) diazinon, an

Table 5

Statistical Criteria Used to Evaluate PRZM (after Loague and Green, 1989b)

$$ME = \max |P_i - O_i| |_{i=1}^{n}$$

$$RMSE = \left[\frac{\sum_{i=1}^{n} (P_i - O_i)^2}{n} \right]^{0.5} \times \frac{100}{\overline{O}}$$

$$CD = \frac{\sum_{i=1}^{n} (O_i - \overline{O})^2}{\sum_{i=1}^{n} (P_i - \overline{O})^2}$$

$$EF = \frac{\sum_{i=1}^{n} (O_i - \overline{O})^2 - \sum_{i=1}^{n} (P_i - \overline{O_i})^2}{\sum_{i=1}^{n} (O_i - \overline{O})^2}$$

$$CRM = \frac{\sum_{i=1}^{n} O_i - \sum_{i=1}^{n} P_i}{\sum_{i=1}^{n} O_i}$$

where,

P = PRZM values (simulated)
O = observed values (field)
$\overline{O}$ = average of observed data
n = number of data points

insecticide; (3) metribuzin, an herbicide; and (4) nitrate, the assumed nitrogen component of fertilizers.

Chlorpyrifos was selected for the long-term simulations based on several factors: (1) it is the termiticide most commonly used by local treatment companies, (2) it is highly sorbed, in contrast to the other chemicals selected, but (3) is relatively persistent when applied at its typically high rates, and (4) although it is predominantly applied at the soil surface, it is also applied below the soil surface (*i.e.* below the highest concentrations of soil organic carbon). Diazinon was selected because of its relatively high persistence and mobility and its common usage, as revealed by a survey of 110 households conducted in the Waipi'o Gentry subdivision. The results of this survey are presented by Oki *et al.* (1990). Metribuzin, although used primarily on golf courses, was also selected because of its high mobility. Nitrate was chosen because it is recognized as the most mobile and persistent component of fertilizers and has been identified at elevated levels in Hawaiian groundwater (Green and Young, 1970).

b. Chemical Properties and Application Rates. The AF rankings in Table 2 show that nitrate, metribuzin, and diazinon have high leaching potentials through the soil relative to chlorpyrifos. It must be emphasized that the AF indices presented in Table 2 were calculated only for the top 0.5 m of soil. A more comprehensive AF ranking should include the entire unsaturated profile but is not presented here due to the scarcity of published data on chemical transformation rates at greater depths.

The application rate and incorporation depth used in the long-term chlorpyrifos simulations approximate the maximum allowable rates as they would be used to provide a vertical barrier to subterranean termites. The application frequency of two years represents a typical case of persistent termite infestation.

Rao and Davidson (1979) have shown that the K_{oc} values obtained by assuming a linear relationship between C and C_s at low concentrations will underestimate the mobility of pesticides applied at high concentrations. For this reason, the K_{oc} assigned to chlorpyrifos was decreased by an order of magnitude in the top 0.3 m of the profile. This decrease in magnitude was estimated by assuming a conservative value of 0.7 for N in the Freundlich equation, given as:

$$C_s = KC^N \qquad (4\text{-}1)$$

where, C_s = sorbed concentration
K = sorption partition coefficient
C = dissolved concentration
N = empirically fitted exponent

Diazinon application rates and frequencies were based upon those specified by the product label. The simulated applications of nitrogen fertilizers and metribuzin are based upon those typically used for golf courses (Murdoch and Green, 1989).

The actual amount of nitrate (as nitrogen) leached below the root zone and made available for transport to the water table was assumed to be 3% of the application rate, as measured by Handley and Ekern (1981) in a study on California grass. This leaching percentage was simulated by reducing the actual application of nitrate to 3% of its surface application rate and then treating it as a conservative chemical. Nitrate was modeled as a conservative chemical that does not sorb or decay, although retarded leaching has been observed in Hawaiian soils (Balasubramanian *et al.*, 1973).

The values used for K_{oc} and pesticide decay rates in soil are conservative yet reasonable estimates from Wauchope (1988), Rao *et al.* (1983), and Ou *et al.* (1982). Below a depth of 0.5 m, hydrolysis was assumed to be the only process contributing to decay of pesticides. Unfortunately very few published hydrolysis rate data were found for pesticides. Hydrolysis rates used for the long-term PRZM simulations were obtained from published laboratory experiments conducted in the dark with distilled water at temperatures and pH values consistent with those found in natural groundwater systems. These conditions eliminate the effects of biological and photochemical decay.

The 100-day apparent hydrolysis half-life of chlorpyrifos is a conservative estimate based on the results of Freed *et al.* (1979), Macalady and Wolfe (1983), and Meikle and Youngson (1978). The hydrolysis half-life of 200 days ($k = 0.0035$ day^{-1}) for diazinon is a value estimated from Harris (1982). The hydrolysis rate of metribuzin was not readily available so a half-life of 1 year was estimated based on transformation studies with sterilized soils kept in the dark (Savage, 1977; Webster *et al.*, 1978). Due to the uncertainty of this estimated half-life for metribuzin, a set of conservative long-term simulations assuming an infinite half-life ($k = 0$) was also simulated. Table 6 summarizes the chemical properties used in the long-term simulations.

c. Unsaturated profiles. Three different unsaturated profiles, presented in Table 7, were used to approximate various surface and subsurface conditions. The profiles represent different degrees of surface grading, which affect the amount of organic carbon in the profiles. Profiles 1, 2, and 3 assume that the top 0.0, 0.2, and 0.5 m of soil will be lost during surface grading, respectively. The f_{oc} values above a depth of 1.0 m were estimated from organic carbon transects on Waiawa Ridge (described in next section), while data from Peterson *et al.* (1985) were used below a depth of 1 m. The organic carbon content of unweathered basalt was assumed to be negligible.

Bulk densities and field capacities above the unweathered basalt were based on the work of Green *et al.* (1982) and Miller (1987). The bulk density of basalt was obtained from a gravity survey at the Schofield Shaft #4 (Huber and Adams, 1971). The field capacity of basalt was assumed to be equal to its specific yield which was estimated from Visher and Mink (1964), and Williams and Soroos (1973).

Table 6

Chemical Properties Used in Long-term Simulations

CHEMICAL	chlorpyrifos	diazinon	metribuzin	nitrate*
USE	termiticide	insecticide	herbicide	fertilizer
APPLICATION RATE (kg/ha)	3125	2.242	0.841	2.20**
APPLICATION FREQUENCY	every 2 years	4 times per year	2 times per year	6 times per year
K_{oc} (m^3/kg)	6.070	0.085	0.041	0
$t_{1/2}$ (days)				
0-0.3 m	30	30	30	∞***
0.3-0.5 m	60	60	60	∞
>0.5 m	100	200	365 & ∞	∞

* Nitrate expressed as nitrogen
** Nitrate application rate reflects reduction to 3%
*** Assumes no decay
Note: references are cited within the text

Table 7

Characteristics of Unsaturated Profiles Used in Long-term Simulations

DEPTH (m)	f_{oc} (kg/kg)	ρ_b (kg/m³)	θ_{fc} (m³/m³)	D (m²/day)	DESCRIPTION
PROFILE #1: no loss of soil from grading; 20 m saprolite					
0.0 - 0.1	0.022	1100	0.38	0.001	soil
0.1 - 0.3	0.017	1100	0.38	0.001	soil
0.3 - 0.5	0.010	1200	0.40	0.001	soil
0.5 - 1.2	0.005	1350	0.42	0.001	subsoil
1.2 - 2.7	0.002	1400	0.42	0.001	subsoil
2.7 - 5.2	0.001	1400	0.42	0.001	subsoil
5.2 - 25.0	0.0002	1100	0.50	0.003	saprolite
> 25.0	0.0000	2400	0.05	0.010	basalt
PROFILE #2: loss of 0.2 m soil from grading; 20 m saprolite					
0.0 - 0.3	0.010	1200	0.40	0.001	soil
0.3 - 1.0	0.005	1350	0.42	0.001	subsoil
1.0 - 2.5	0.002	1400	0.42	0.001	subsoil
2.5 - 5.0	0.001	1400	0.42	0.001	subsoil
5.0 - 25.0	0.0002	1100	0.50	0.003	saprolite
> 25.0	0.0000	2400	0.05	0.010	basalt
PROFILE #3: loss of 0.5 m soil from grading; 10 m saprolite; lower θ_{fc}					
0.0 - 0.5	0.005	1300	0.40	0.001	subsoil
0.5 - 2.0	0.002	1400	0.40	0.001	subsoil
2.0 - 4.5	0.001	1400	0.40	0.001	subsoil
4.5 - 14.5	0.0001	1100	0.45	0.003	saprolite
> 14.5	0.0000	2400	0.04	0.010	basalt

Note: f_{oc} = mass fraction of organic carbon
ρ_b = bulk density
θ_{fc} = volumetric water content at field capacity
D = hydrodynamic dispersion coefficient

The hydrodynamic dispersion coefficient, D, was estimated to be 0.001 m^2/day in soil and subsoil. This value is somewhat smaller than the values used to simulate the field data, but the larger compartment size used in the long-term simulations increased the numerical dispersion by an approximately equal amount. Khan (1979) reports values close to 0.001 m^2/day for a Hawaiian soil. The values of 0.003 and 0.01 m^2/day for saprolite and basalt, respectively, are consistent with those used by Loague and Green (1989a) for deep PRZM simulations in Hawai'i.

Profile 3 utilizes conservative (*i.e.* conducive to leaching) yet realistic estimates for field capacity (θ_{fc}), f_{oc} in saprolite, and saprolite thickness. The saprolite thickness was estimated from logs of exploratory wells drilled in the vicinity of the Waiawa Shaft just prior to its construction (Public Works Center, 1951).

The proposed Navy development site was treated as a special case because of the alluvial aquifer located at about 30 m above sea level (as mentioned in Chapter III). In this case PRZM was used to simulate the 15 m of unsaturated profile from soil surface to the top of the alluvial aquifer. It was assumed that the parameters used for saprolite also apply to the alluvium which, in the valley, extends below this 15 m depth.

The thicknesses of other unsaturated profiles used in the long-term simulations are listed in Table 8. The representative surface elevation for each of these profiles is about 5 m more than the profile thickness due to the basal water table elevation of approximately 5 m. The method of distributing water through the profiles of land areas with impermeable surfaces was also varied. Figure 18 illustrates the two scenarios. In case (a) of Figure 18 the wetting front of recharge from permeable surfaces is evenly distributed at the top of the saprolite over the entire areal extent of the profile. This allows at least a rough approximation of the effects of lateral water movement and dispersion which would otherwise be unaccounted for by PRZM's one-

Table 8

Thicknesses of Waiawa Ridge Profiles Used in Long-term Simulations

Cell I.D. (x,y)*	Thickness (m)	Cell I.D. (x,y)	Thickness (m)
33	85	55	115
34	100	56	210
35	135	57	240
43	50	63	85
44	100	65	115
45	140	66	215
46	190	73	85
53	55	75	155
54	115		

* Coordinates are from the water balance grid (see Figure 19)

Note: the rationale used to select the above cells is discussed in the next sub-section (d)

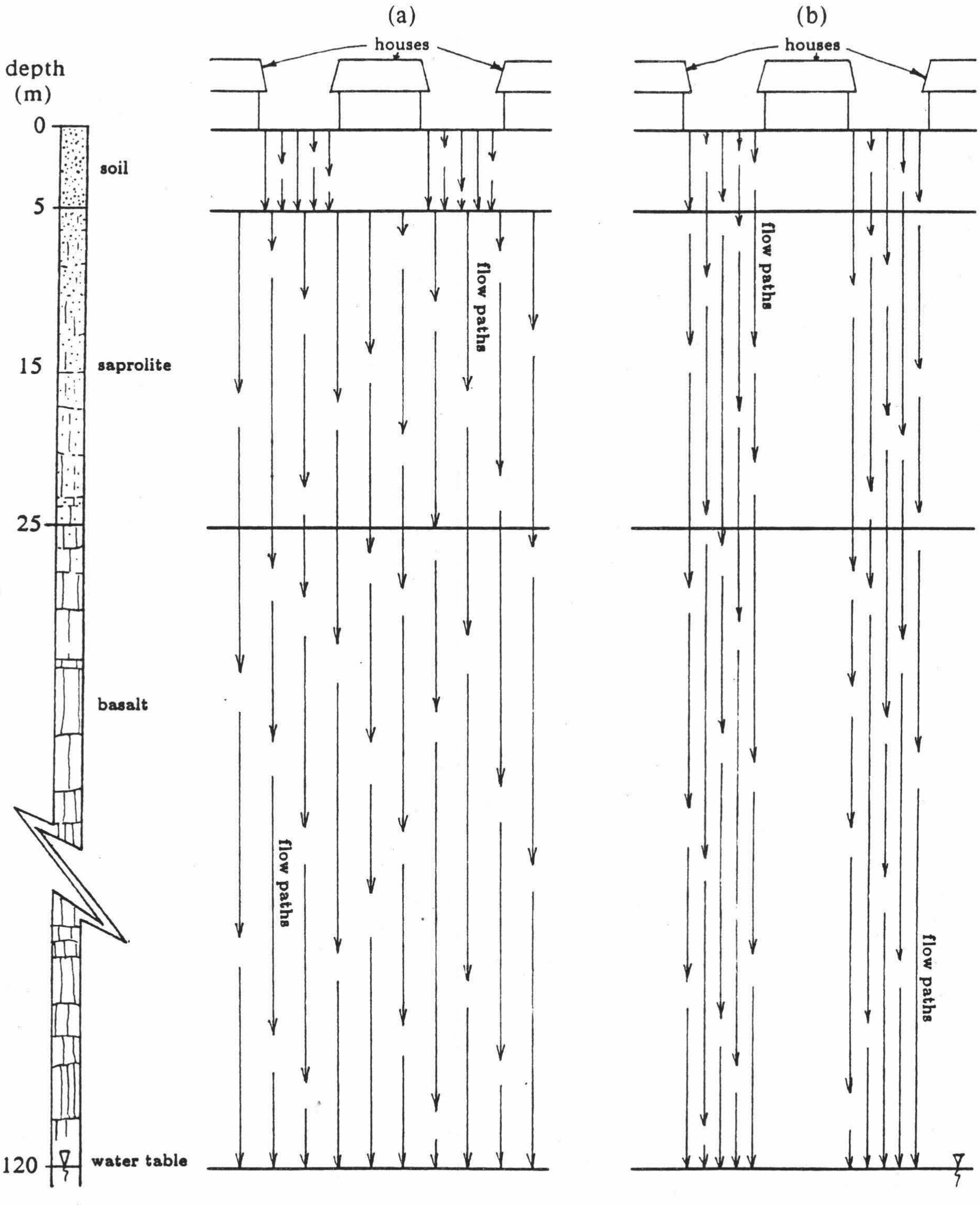


Figure 18. Cross-section of water distribution methods: (a) distributed at top of saprolite; (b) advection dominated (distributed at water table)

dimensional algorithm. The top of the saprolite was chosen because it marks a relatively impermeable boundary with the overlying subsoil (Miller, 1987). Case (b) represents an advection dominated profile which does not allow the infiltrating water and solutes to be distributed laterally until the water table is reached. This is equivalent to a case where near surface water inputs are concentrated and transported through a vertical column connecting the ground surface with the water table.

Case (a) required the execution of two PRZM simulations for each profile. The first assumed advection dominated transport through the soil and subsoil. The second simulation then modeled transport to the water table. This was accomplished by using the groundwater recharge and solute flux output from the bottom of the subsoil (first simulation) as input to the top of the saprolite for the second simulation. The recharge and solute flux output from the subsoil were evenly distributed to the top of the saprolite by using a reduction factor, equivalent to the fraction of total area which is paved.

d. Water balance. The long-term recharge estimates used by PRZM were calculated by Giambelluca and Oki, as presented by Oki *et al.* (1990). The following description is a brief summary of their work.

Before the recharge estimates were made, a water balance grid was created to define the area of interest. The cells within this grid had to meet two criteria: (1) they had to be small enough to accurately represent spatial variations in climate, soil types, and land uses, yet (2) recognizing that PRZM is a one-dimensional model which requires a separate simulation for each cell of interest, the number of cells needed to be minimized to keep the number of simulations at a reasonable level.

The selected 9 x 10 rectangular grid (Figure 19) with each of its 90 cells having dimensions equal to 37.5" of longitude by 40" of latitude (*i.e.* an area of approximately 1.3 km^2) represents a compromise between the two criteria. Groundwater recharge was

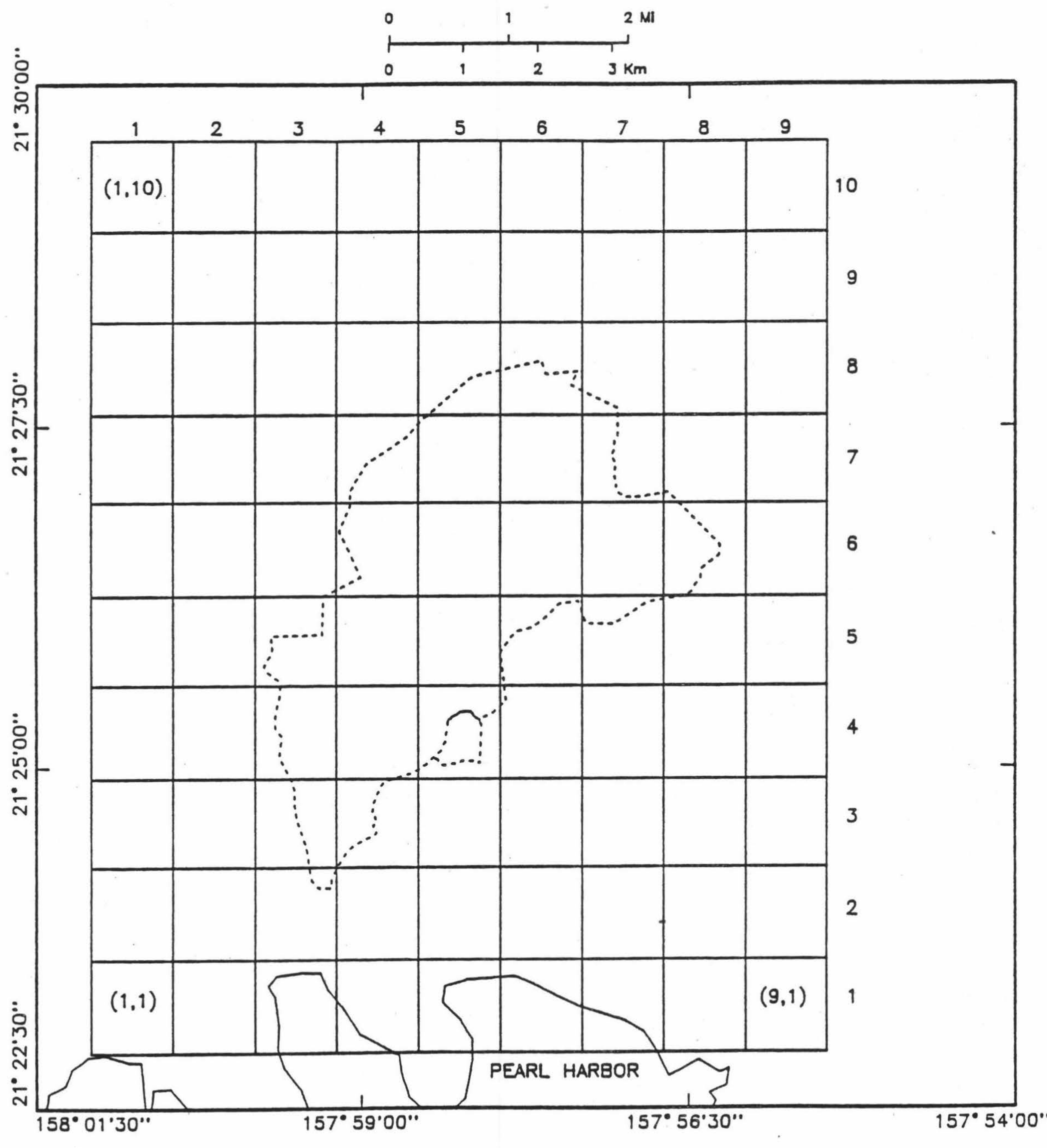


Figure 19. Water balance grid used for long-term simulations (Oki *et al.*, 1990)

estimated for a 37-year period, which was considered long enough to allow transport through the vadose zone followed by movement in the saturated zone. Historical climatologic data were used with the assumption that they will be representative of future conditions.

Using an hourly time step as a standard, Giambelluca and Oki (1987) found that the use of a monthly time step significantly underestimated the amount of recharge and was not able to differentiate individual recharge events. The use of a daily time step however, resulted in only a slight underestimation of recharge and was able to distinguish individual events. For this reason, a daily time step was selected for the water balance simulations.

The water balance model used to estimate the spatial and temporal variations in groundwater recharge at Waiawa utilizes a modified version of the Thornthwaite and Mather (1955) bookkeeping procedure. This model incorporates rainfall, irrigation, evapotranspiration, and runoff. Most of the required input data were recorded on a monthly or annual basis, so several disaggregation methods were applied.

Historical monthly rainfall data from 1946-1982 were used to interpolate the monthly rainfall in each of the 90 water balance cells. These monthly values were then distributed to each of the days using a simulated fragments (SF) disaggregation model (Oki and Giambelluca, 1989) which incorporated the statistical characteristics of daily rainfall from a nearby station. The SF model was then calibrated and validated with three O'ahu stations which have daily rainfall data.

Annual irrigation rates based on a survey of golf courses by Hollyer and Cox (1988) were used to derive an empirical equation which placed an upper boundary on the relationship between annual rainfall and irrigation. The estimated annual irrigation rates were then distributed to the days of the months which were most likely to be irrigated (*i.e.* those with lower rainfall). This method of estimation was applied to all land uses which were expected to receive irrigation.

Potential evapotranspiration (PE) represents the maximum amount of evapotranspiration (ET) that would occur under existing atmospheric and surface conditions if the soil water stress is not a limiting factor (Giambelluca, 1983). Spatial and monthly variations in PE were estimated from Giambelluca (1983) and uniformly distributed to each day of the month. Actual ET was determined as a function of PE and available soil water with the model utilized by Giambelluca (1983).

Surface runoff was estimated using the Soil Conservation Service curve number method (U.S. Department of Agriculture, 1972). Estimates on the fraction of paved surfaces for residential and apartment land uses are 0.57 and 0.64, respectively, as determined by Murabayashi and Fok (1979). Commercial and industrial areas were assumed to have a paved fraction of 0.85.

The water balance model described above, with its various components, was used instead of PRZM's water balance because of its more accommodating structure and previous success with applications in Hawai'i. Daily recharge from the water balance model was input directly to the soil surface for PRZM simulations and not allowed to runoff or be extracted by ET (since runoff and ET were already accounted for by the water balance model). The only foreseeable error introduced by this linkage with PRZM was an underestimated amount of infiltration above the maximum depth of ET extraction (0.3 m depth). This linkage assumes that the amount of water infiltrated throughout the top 0.3 m of the soil profile is constant, when in reality the amount will be higher at the surface and decrease with depth as water is extracted by ET. Therefore, the chemicals may actually leach more rapidly to the 0.3 m depth than reflected by results of the long-term PRZM simulations. However, this effect was assumed to be minimal when compared with the extended depths which were simulated.

The number of water balance cells used for the long-term PRZM simulations was reduced by using only those cells which are expected to receive chemical applications, and which are located within the MOC (groundwater model) grid (Figure 20). Using these two criteria, the 17 selected cells are shown in Figure 21 with their designated land uses. The assignment of land uses to each of the cells was based upon plan maps of the proposed developments. Cells 5,3; 6,3; and 7,3 (where the first numeral corresponds to the horizontal, or x-axis, and the second numeral to the vertical, or y-axis) of Figure 21 lie outside of the proposed developments, but were simulated by PRZM because they are within the MOC grid and were used to estimate background chemical concentrations that may be contributed by existing developments in the area. Other cells (*e.g.* 6,4; 6,7; 7,4; and 7,6) lie within the MOC grid but were not modeled by PRZM because they represent open areas which are not expected to receive any chemical applications. These open cells provided only recharge as input to the MOC model.

Beside the distributed land use pattern shown in Figure 21, a second scenario was simulated. It assumed that each of the 17 cells were unpaved lawns that did not allow runoff. This scenario was simulated to represent a case with the highest foreseeable recharge rate. Tables 9 and 10 summarize the recharge, in the form of annual rates, from the 17 cells for each of the two scenarios mentioned above.

The chlorpyrifos simulations received a special recharge scenario which considered unique and localized applications. Recharge was increased along the foundation of a house (where chlorpyrifos is applied) to account for the concentration of rainfall from rooftops.

Chemical losses due to runoff, erosion, and plant uptake were assumed to be negligible for all long-term simulations. The entire PRZM modeling effort reported

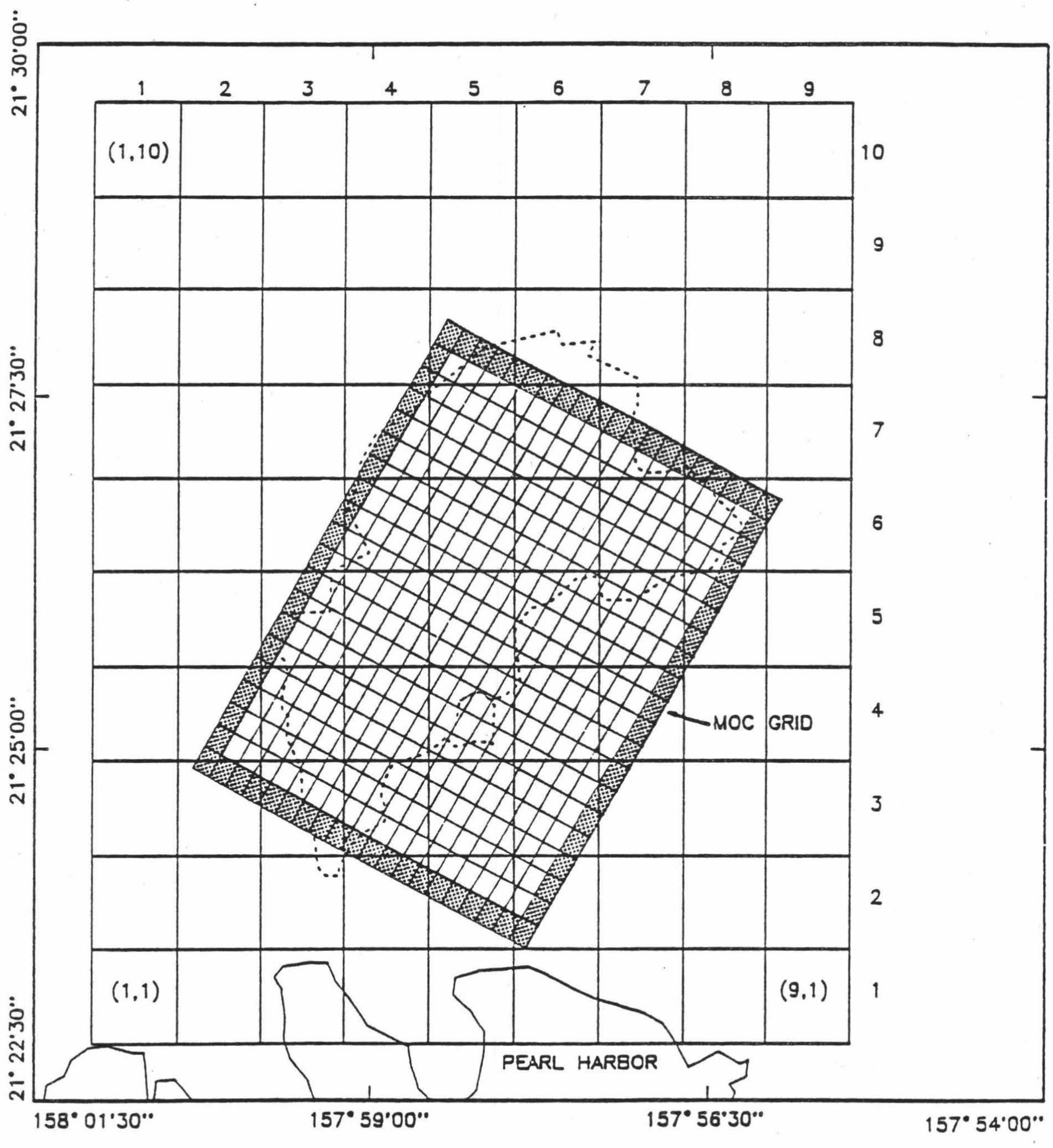


Figure 20. Placement of the MOC grid -- saturated transport model (Oki *et al.*, 1990)

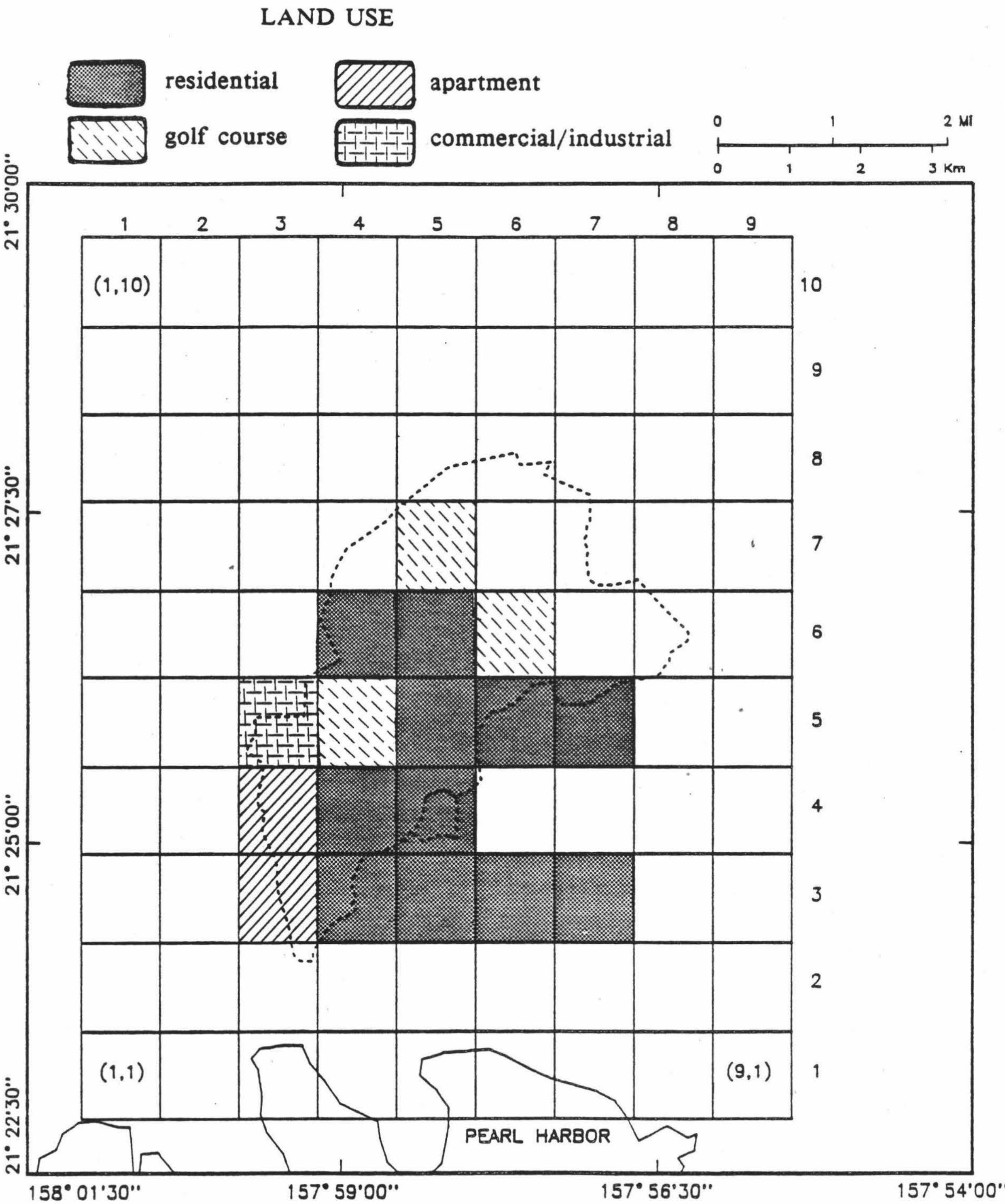


Figure 21. Water balance cells used in long-term simulations (after Oki *et al.*, 1990)

Table 9

Annual Recharge for Long-term PRZM Simulations, Land Use 1

	RECHARGE CASE*																
YEAR	133	134	135	143	144	145	157	146	153	154	155	156	163	165	166	173	175
1	0.95	1.07	1.16	1.02	1.07	1.11	1.11	1.24	1.11	1.18	1.20	1.08	1.18	1.06	0.90	1.16	0.98
2	0.82	0.96	1.08	0.89	0.94	0.99	1.02	1.15	1.01	1.02	1.04	0.96	1.11	0.89	0.73	1.12	0.84
3	1.06	1.21	1.26	1.19	1.38	1.26	1.35	1.40	1.44	1.43	1.23	1.20	1.48	1.23	1.04	1.43	1.25
4	1.11	1.22	1.37	1.17	1.16	1.46	1.64	1.57	1.33	1.23	1.19	1.50	1.35	1.35	1.58	1.30	1.42
5	1.25	1.31	1.39	1.37	1.41	1.53	1.82	1.64	1.52	1.46	1.40	1.67	1.49	1.61	1.87	1.45	1.69
6	1.53	1.62	1.72	1.63	1.66	1.82	2.20	2.00	1.98	1.80	1.76	2.06	1.90	1.96	2.28	1.86	2.06
7	0.76	0.78	0.82	0.85	0.85	0.92	1.30	1.11	1.17	0.96	0.85	1.10	1.07	1.05	1.27	1.01	1.25
8	0.67	0.73	0.82	0.70	0.68	0.82	0.97	0.94	0.84	0.77	0.68	0.86	0.86	0.82	0.91	0.78	0.88
9	1.17	1.26	1.47	1.37	1.32	1.51	1.90	1.66	1.44	1.39	1.24	1.65	1.53	1.62	1.91	1.55	1.81
10	1.49	1.55	1.61	1.51	1.63	1.62	1.86	1.76	1.70	1.69	1.63	1.77	1.72	1.76	1.84	1.73	1.77
11	1.18	1.15	1.18	1.21	1.17	1.12	1.52	1.28	1.17	1.16	1.13	1.36	1.22	1.35	1.60	1.26	1.47
12	1.21	1.25	1.30	1.27	1.32	1.21	1.39	1.42	1.35	1.36	1.30	1.39	1.40	1.42	1.47	1.39	1.37
13	1.25	1.30	1.30	1.28	1.45	1.27	1.61	1.41	1.39	1.43	1.44	1.50	1.43	1.49	1.62	1.45	1.54
14	0.83	0.84	0.87	0.81	0.87	0.84	1.09	0.97	0.87	0.88	0.87	0.92	0.92	0.85	0.90	0.88	0.88
15	0.96	0.93	0.92	0.83	1.00	0.89	0.91	0.94	1.05	1.11	1.07	0.89	1.13	1.05	0.90	1.10	1.16
16	0.80	0.85	0.93	0.77	0.85	0.89	0.93	0.95	0.97	0.97	0.95	0.95	1.04	1.03	1.10	1.05	1.14
17	0.97	0.96	0.98	1.00	0.95	0.95	0.85	1.03	1.11	1.03	0.95	0.93	1.09	0.97	0.94	1.00	0.95
18	1.48	1.48	1.55	1.47	1.46	1.54	1.90	1.70	1.55	1.54	1.51	1.65	1.56	1.58	1.69	1.48	1.64
19	0.98	1.08	1.21	1.08	1.14	1.20	1.38	1.34	1.17	1.28	1.45	1.46	1.24	1.48	1.59	1.23	1.46
20	1.68	1.72	1.71	1.68	1.76	1.91	1.86	1.79	1.87	1.94	2.05	1.92	1.95	1.97	1.95	1.90	1.94
21	1.35	1.49	1.53	1.33	1.46	1.56	1.57	1.49	1.38	1.52	1.61	1.53	1.43	1.42	1.41	1.31	1.28
22	1.52	1.73	1.76	1.52	1.72	1.88	1.82	1.83	1.41	1.69	1.90	1.84	1.48	1.66	1.72	1.45	1.43
23	1.51	1.69	1.76	1.61	1.68	1.73	1.58	1.65	1.47	1.66	1.76	1.61	1.59	1.61	1.53	1.59	1.53
24	1.11	1.28	1.30	1.17	1.24	1.27	1.34	1.31	1.21	1.32	1.39	1.32	1.25	1.28	1.27	1.19	1.22
25	0.98	1.07	1.11	0.96	0.95	0.99	1.28	1.15	0.95	0.94	1.12	1.20	1.04	1.09	1.20	1.02	1.09
26	1.32	1.44	1.51	1.30	1.27	1.26	1.47	1.33	1.32	1.27	1.36	1.36	1.44	1.39	1.39	1.48	1.47
27	1.18	1.24	1.24	1.19	1.16	1.13	1.04	1.16	1.21	1.19	1.19	1.07	1.23	1.07	0.93	1.15	0.98
28	0.59	0.81	0.98	0.69	0.80	0.86	0.90	0.91	0.80	0.91	0.98	0.89	0.86	0.94	0.87	0.90	0.95
29	1.21	1.49	1.69	1.41	1.56	1.68	1.78	1.76	1.65	1.76	1.84	1.76	1.82	1.79	1.69	1.82	1.78
30	1.08	1.14	1.16	1.17	1.12	1.02	1.17	0.98	1.28	1.24	1.16	1.02	1.35	1.13	1.02	1.30	1.15
31	0.78	0.93	1.05	0.87	0.93	0.94	1.00	0.97	0.94	1.03	1.07	0.97	0.97	1.02	0.97	0.93	0.95
32	0.76	0.87	0.94	0.81	0.84	0.82	0.91	0.84	0.84	0.91	0.94	0.86	0.84	0.89	0.84	0.80	0.84
33	1.10	1.20	1.27	1.19	1.20	1.17	1.20	1.18	1.29	1.32	1.30	1.18	1.33	1.23	1.14	1.23	1.18
34	1.05	1.14	1.19	1.11	1.10	1.04	1.06	1.06	1.16	1.16	1.11	0.98	1.17	0.99	0.86	1.05	0.92
35	1.35	1.52	1.65	1.46	1.54	1.59	1.82	1.69	1.58	1.68	1.74	1.70	1.65	1.71	1.68	1.58	1.67
36	0.93	1.14	1.32	1.07	1.18	1.28	1.42	1.45	1.20	1.31	1.39	1.34	1.27	1.28	1.16	1.19	1.19
37	1.77	1.87	1.94	1.89	1.91	1.91	2.10	1.99	2.01	2.06	2.09	2.00	2.08	2.04	1.94	2.01	2.01
Average	1.13	1.22	1.30	1.18	1.24	1.27	1.41	1.35	1.29	1.31	1.32	1.34	1.34	1.33	1.34	1.30	1.33
Minimum	0.59	0.73	0.82	0.69	0.68	0.82	0.85	0.84	0.80	0.77	0.68	0.86	0.84	0.82	0.73	0.78	0.84
Maximum	1.77	1.87	1.94	1.89	1.91	1.91	2.20	2.00	2.01	2.06	2.09	2.06	2.08	2.04	2.28	2.01	2.06

* 1st digit identifies land use; 2nd and 3rd identify x and y coordinates of water balance cell (see Figure 19)
land use 1 = irrigated lawn, no runoff

Note: recharge is in meters

Table 10

Annual Recharge for Long-term PRZM Simulations, Distributed Land Use

	RECHARGE CASE*																
YEAR	533	534	635	443	444	245	257	446	453	454	455	456	463	465	266	473	475
1	0.73	0.84	0.80	0.81	0.91	1.10	1.09	1.09	0.87	0.97	1.05	1.06	0.94	1.02	0.88	0.98	1.02
2	0.63	0.77	0.79	0.70	0.80	0.98	1.00	1.06	0.78	0.85	0.94	0.99	0.87	0.91	0.72	0.96	0.93
3	0.79	0.93	0.83	0.91	1.09	1.20	1.24	1.15	1.09	1.11	1.01	1.09	1.13	1.08	0.98	1.13	1.13
4	0.73	0.83	0.73	0.83	0.87	1.38	1.52	1.19	0.97	0.92	0.93	1.22	0.98	1.12	1.47	1.01	1.22
5	0.85	0.89	0.80	0.96	1.00	1.44	1.73	1.32	1.11	1.10	1.12	1.44	1.12	1.38	1.77	1.16	1.49
6	1.01	1.08	0.88	1.07	1.13	1.64	1.80	1.40	1.31	1.20	1.22	1.46	1.24	1.37	1.82	1.24	1.45
7	0.55	0.60	0.58	0.66	0.70	0.92	1.25	1.00	0.92	0.80	0.77	1.10	0.85	1.03	1.22	0.88	1.24
8	0.49	0.56	0.58	0.53	0.57	0.82	0.97	0.86	0.66	0.64	0.63	0.93	0.69	0.88	0.91	0.69	1.00
9	0.83	0.90	0.84	0.96	0.99	1.41	1.71	1.31	1.07	1.05	1.01	1.37	1.15	1.34	1.65	1.20	1.50
10	0.91	1.01	0.88	0.97	1.06	1.49	1.63	1.31	1.07	1.08	1.10	1.34	1.12	1.26	1.53	1.15	1.35
11	0.82	0.87	0.76	0.88	0.92	1.10	1.43	1.09	0.85	0.92	0.96	1.23	0.94	1.19	1.49	1.04	1.30
12	0.77	0.83	0.70	0.84	0.94	1.13	1.24	1.07	0.90	0.96	0.97	1.11	0.97	1.11	1.28	1.02	1.13
13	0.84	0.89	0.74	0.90	1.04	1.21	1.51	1.14	0.99	1.06	1.10	1.26	1.05	1.24	1.50	1.12	1.34
14	0.63	0.66	0.60	0.63	0.73	0.84	1.07	0.88	0.67	0.73	0.79	0.94	0.72	0.85	0.87	0.76	0.94
15	0.73	0.71	0.64	0.65	0.81	0.87	0.89	0.83	0.79	0.87	0.88	0.92	0.86	1.02	0.89	0.89	1.15
16	0.61	0.68	0.68	0.61	0.74	0.89	0.92	0.89	0.77	0.83	0.87	0.96	0.86	1.00	1.05	0.93	1.13
17	0.76	0.77	0.71	0.80	0.82	0.95	0.85	0.96	0.89	0.87	0.87	0.98	0.88	0.99	0.92	0.88	1.05
18	0.95	0.98	0.82	1.02	1.03	1.39	1.60	1.20	1.07	1.08	1.09	1.25	1.08	1.23	1.47	1.09	1.32
19	0.71	0.80	0.75	0.79	0.89	1.15	1.28	1.11	0.88	1.00	1.16	1.26	0.94	1.26	1.43	0.99	1.33
20	1.04	1.10	0.90	1.10	1.19	1.66	1.59	1.29	1.26	1.31	1.41	1.38	1.32	1.40	1.60	1.33	1.43
21	0.85	0.95	0.76	0.88	0.99	1.37	1.33	1.05	0.92	1.02	1.11	1.10	0.97	1.04	1.18	0.94	0.99
22	1.13	1.28	1.04	1.18	1.36	1.81	1.72	1.50	1.10	1.35	1.54	1.58	1.18	1.46	1.61	1.21	1.38
23	1.04	1.15	0.89	1.08	1.18	1.57	1.44	1.25	1.03	1.18	1.28	1.29	1.15	1.25	1.34	1.20	1.31
24	0.75	0.89	0.77	0.82	0.91	1.15	1.26	1.08	0.84	0.97	1.10	1.18	0.90	1.12	1.17	0.96	1.17
25	0.68	0.77	0.65	0.70	0.73	0.94	1.19	0.90	0.72	0.74	0.89	1.00	0.78	0.93	1.07	0.82	0.95
26	0.95	1.05	0.89	0.96	0.97	1.17	1.35	1.04	0.97	0.95	1.09	1.19	1.08	1.20	1.29	1.16	1.31
27	0.90	0.95	0.80	0.94	0.95	1.10	1.01	1.01	0.95	0.97	1.02	1.04	0.97	1.01	0.90	0.96	1.02
28	0.41	0.64	0.71	0.52	0.68	0.86	0.90	0.84	0.61	0.76	0.89	0.93	0.68	0.95	0.86	0.78	1.02
29	0.88	1.05	0.90	1.07	1.19	1.58	1.59	1.35	1.22	1.32	1.40	1.41	1.30	1.42	1.53	1.34	1.41
30	0.73	0.80	0.68	0.85	0.86	1.00	1.09	0.83	0.93	0.95	0.97	0.96	1.00	1.01	0.95	1.00	1.05
31	0.55	0.68	0.64	0.65	0.73	0.92	0.94	0.82	0.70	0.81	0.89	0.89	0.73	0.91	0.90	0.77	0.90
32	0.55	0.66	0.61	0.61	0.69	0.81	0.87	0.74	0.64	0.75	0.84	0.85	0.65	0.87	0.81	0.67	0.88
33	0.75	0.88	0.72	0.87	0.94	1.14	1.16	0.96	0.94	0.99	1.04	1.05	0.97	1.04	1.09	0.97	1.07
34	0.73	0.83	0.74	0.82	0.86	1.02	0.98	0.89	0.87	0.90	0.93	0.92	0.90	0.92	0.81	0.87	0.93
35	0.94	1.05	0.86	1.07	1.14	1.49	1.65	1.25	1.15	1.22	1.28	1.34	1.23	1.33	1.52	1.22	1.34
36	0.73	0.91	0.87	0.87	0.99	1.26	1.39	1.26	0.96	1.09	1.21	1.28	1.03	1.20	1.13	1.02	1.20
37	1.23	1.28	1.00	1.36	1.39	1.73	1.85	1.43	1.46	1.50	1.51	1.52	1.51	1.57	1.72	1.49	1.59
Average	0.79	0.88	0.77	0.86	0.94	1.20	1.30	1.09	0.94	1.00	1.05	1.16	0.99	1.13	1.22	1.02	1.19
Minimum	0.41	0.56	0.58	0.52	0.57	0.81	0.85	0.74	0.61	0.64	0.63	0.85	0.65	0.85	0.72	0.67	0.88
Maximum	1.23	1.28	1.04	1.36	1.39	1.81	1.85	1.50	1.46	1.50	1.54	1.58	1.51	1.57	1.82	1.49	1.59

* 1st digit identifies land use; 2nd and 3rd identify x and y coordinates of water balance cell (see Figure 19)
land use 2 = golf course, 4 = residential, 5 = apartment, 6 = commercial/industrial

Note: recharge is in meters

here was executed on either a Sun 4/110 Workstation or the University of Hawai'i IBM 3081 Mainframe computer.

3. Modification of PRZM

Two new variables were introduced into the algorithm of drainage option 1 (discussed in Chapter II) to approximate preferential flow. The first is a macropore multiplier, MPM, which defines a threshold soil water content that will trigger drainage by preferential flow. The field capacity multiplier, FCM, is a second variable which decreases the field capacity to allow increased drainage during a period of elevated water input as defined by MPM.

The analogy of a pore volume can be applied to MPM. For example, if during any time increment (one day in this case) the amount of water infiltrating into the soil is greater than a predetermined fraction or multiple of the saturated soil water content, or pore volume, then preferential flow will be approximated by allowing a greater amount of water to be drained. The amount of water being drained during preferential flow will be determined by FCM, which will decrease the field capacity to increase the amount drained. This particular event of preferential flow will continue until the amount of infiltrating water is below the threshold value as defined by MPM. The FORTRAN code of the modified algorithm is listed in Appendix B.

This modification of PRZM is a highly simplistic and empirical method of approximating preferential flow. An obvious weakness is its assumption that either preferential flow or matrix flow alone dominates at any given time when in reality these two transport mechanisms occur simultaneously. The time step of one day may also be inadequate and may need to be decreased to better define those recharge events which may trigger preferential flow.

B. FIELD EXPERIMENTS

1. Chemical Leaching

a. Preparation of field plots. Field plots were set aside for the application of chemicals and subsequent monitoring of downward leaching through the soil profile. The ideal conditions for the field plots to satisfy included: (1) locations within the proposed development sites which would include a representative range of the existing soil conditions; (2) homogeneous soil properties, both laterally and with depth, within each plot to isolate the temporal effects upon chemical leaching; (3) relatively level topography to minimize the potential for surface runoff and erosion; (4) easily accessible areas which would minimize the efforts in plot preparation, monitoring, and maintenance. Due to problems encountered in obtaining access to key locations on Waiawa Ridge and constraints in resources, only two test plots were established. The first was located in Waiawa Valley and the second at Poamoho (see Chapter III). Each plot is a square, 10.6 m on each side, with an area of 0.011 ha.

The Waiawa plot is located within the proposed Navy development site, on one of the more permeable soils found in the valley. Guinea grass and koa haole were cleared from an area extending at least 5 m beyond the plot boundaries. The vegetation was cut down to the soil surface with little disturbance of the soil. The Poamoho plot was first cleared of its corn residue and then tilled to loosen the soil. The plot was then raked to level the gently sloping topography. This leveling procedure was unnecessary at the Waiawa plot. Vegetation cover at both plots was almost nonexistent at the time of their first chemical applications and was kept at a relatively short and uniform length thereafter.

Trenches, approximately 0.15 m deep and 0.4 m wide, were dug around the perimeter of each plot to prevent surface runoff and eroded soil of surrounding areas from entering the plot. Using soil from the trenches, berms were built between the trenches and plot boundaries to insure that runoff and eroded soil from within the plot remained within its boundaries. Both of the field plots were divided into quadrants of equal area. Three of the quadrants were used to measure leaching while the fourth was used as a hydraulic quadrant where infiltration tests were performed and samples to determine soil water contents were collected.

A portable irrigation system was designed and used to induce chemical leaching at the Waiawa site (see Figure 22). Due to the relatively remote location of the Waiawa plot, water was trucked in using a 1.04 m^3 water bag and pumped into the irrigation system with a gas powered centrifugal pump. Figures 23 and 24 show the set-up and sampling locations at the two field sites.

b. Chemical application. The chemicals applied to the field plots were: bromide (as NaBr); chlorpyrifos (trade name Dursban), a termiticide; and fenamiphos (trade name Nemacur), a nematicide. Bromide served as a conservative tracer while the two pesticides provided a relatively wide range in sorption and transformation properties to evaluate PRZM. The fenamiphos metabolite f. sulfoxide is a persistent chemical which is relatively mobile while chlorpyrifos is sorbed very strongly and is less persistent in soil. The AF rankings in Table 2 (Chapter I) reveal the wide range in leaching potential between fenamiphos and chlorpyrifos. Fenamiphos was also selected as one of the pesticides to apply on the plots because of its documented analysis in Hawaiian soils (Lee *et al.*, 1986; and Lee, 1987) while chlorpyrifos is distinguished as being the most popular termiticide used by local pest control operators.

Each of the quadrants set aside for leaching experiments received 0.164 kg of NaBr, 0.114 l of Dursban 2E, and 0.027 l of Nemacur 3E which were mixed into 7.6 l of water and evenly applied to the soil surface with a manual sprayer (note: the first application at Waiawa received only 0.82 kg of NaBr). The respective application rates for the active ingredients bromide, chlorpyrifos, and fenamiphos were 45.7, 9.80, and

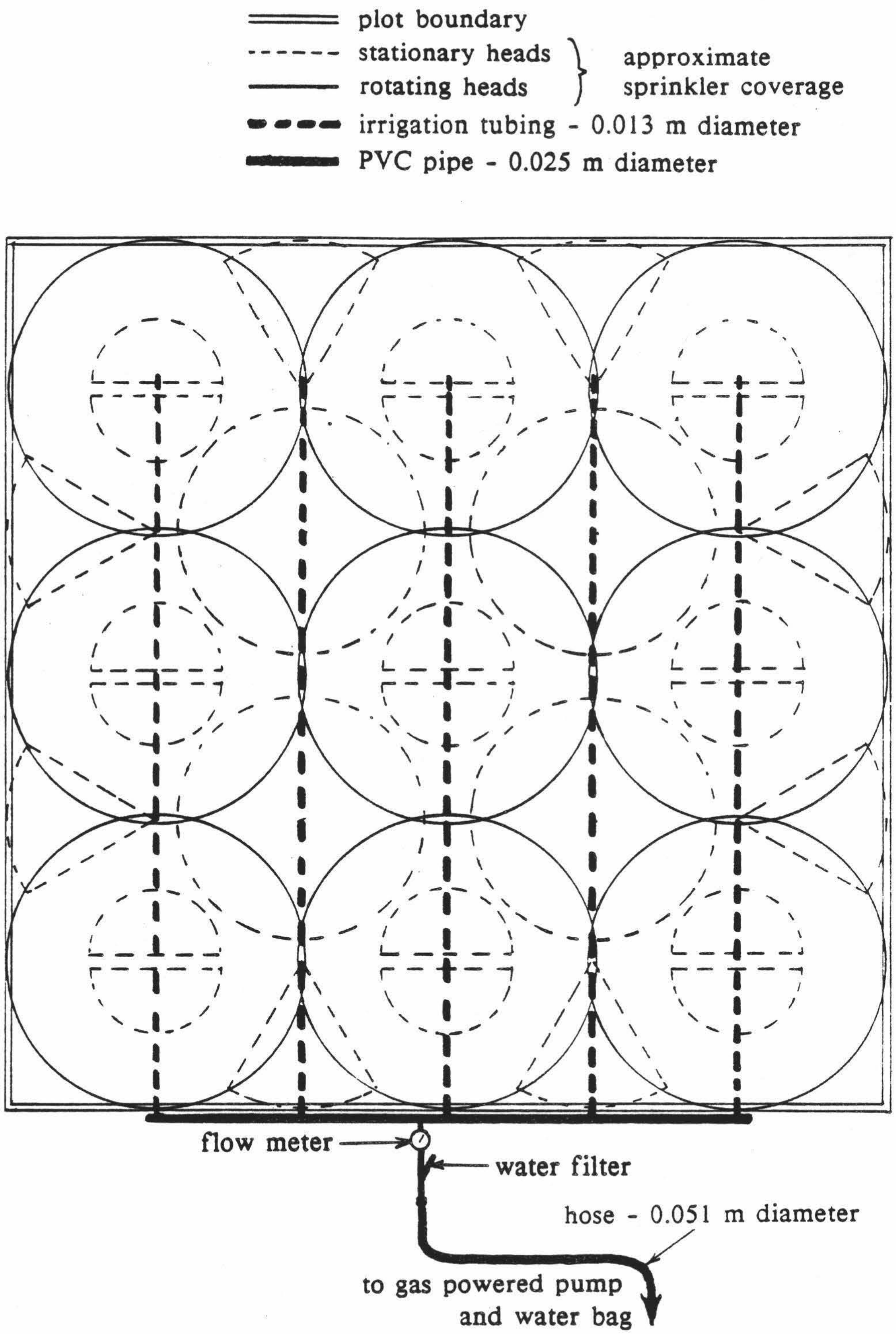


Figure 22. Portable irrigation system used on field plots

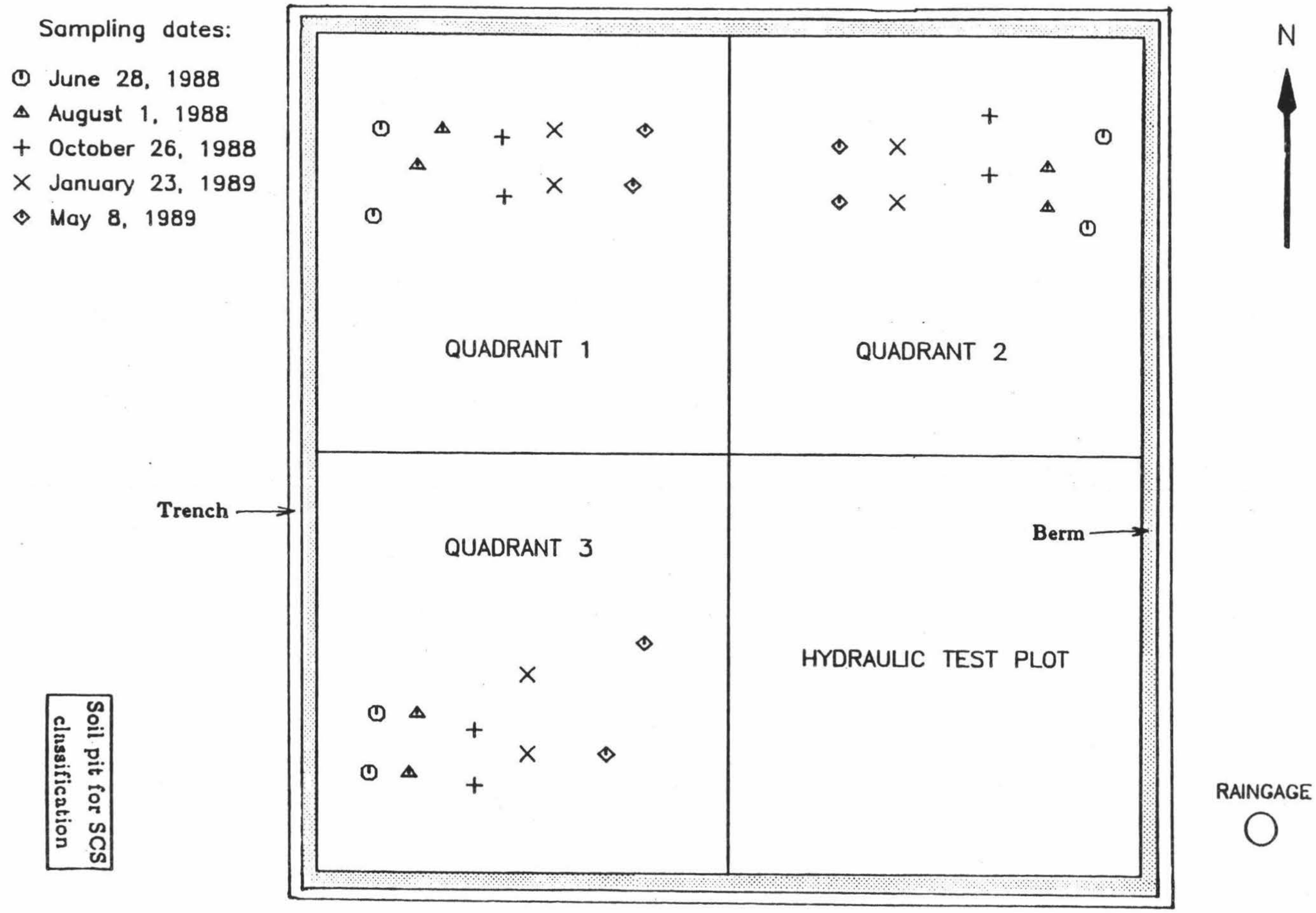


Figure 23. Waiawa plot layout and sample locations (after Oki *et al.*, 1990)

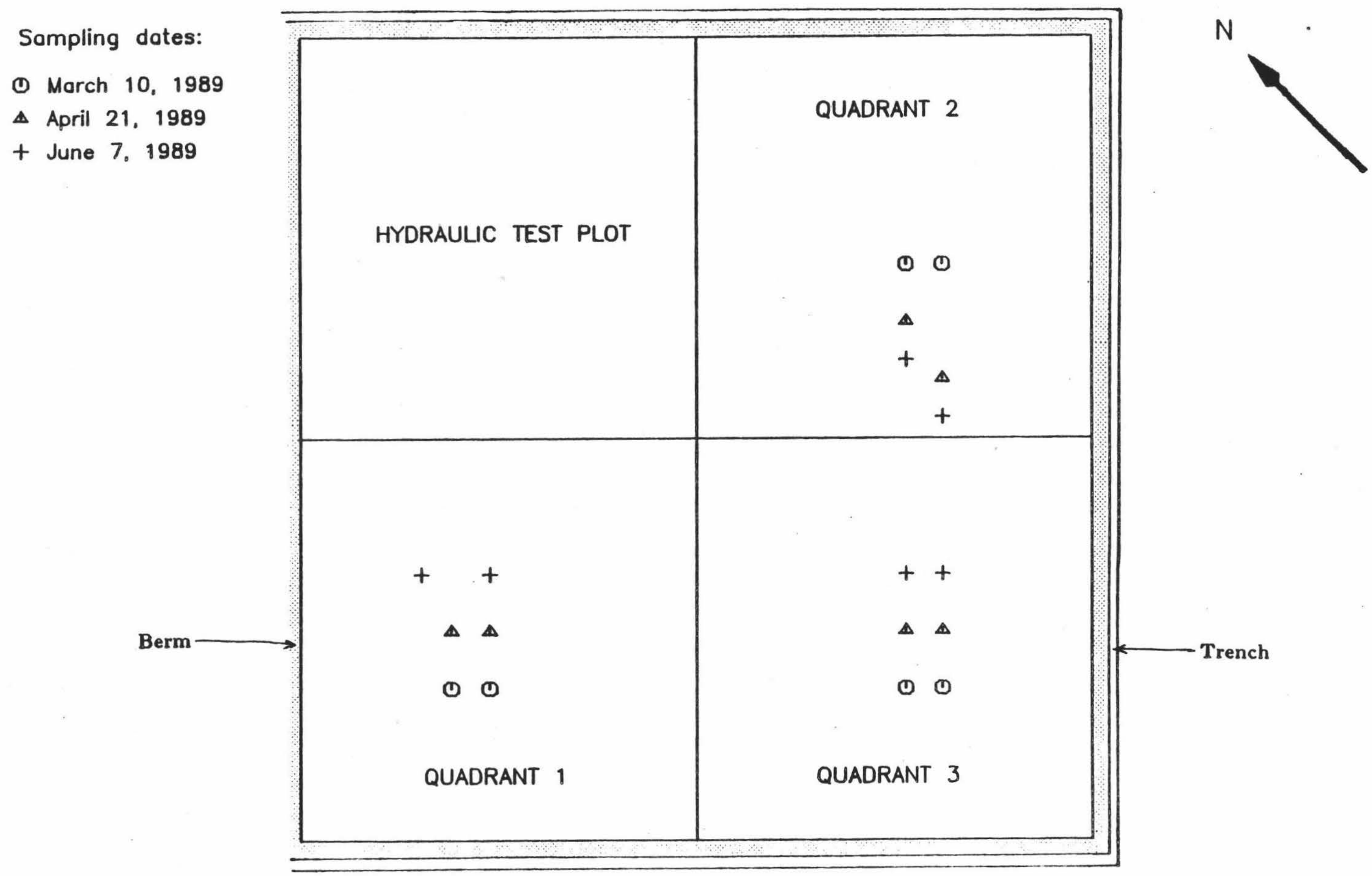


Figure 24. Poamoho plot layout and sample locations (after Oki *et al.*, 1990)

3.48 kg/ha (see Table 15, Chapter V for adjusted pesticide application rates which account for laboratory extraction efficiencies).

The uniformity of chemical applications within each quadrant was assured by adhering to the following procedures: (1) maintaining a constant flow rate from the sprayer by regulating the application pressure, (2) calibration of the applicator's walking pace, (3) application along guidelines which were uniformly spaced over the quadrants, and (4) spraying only when the wind velocity was low enough so as not to affect dispersal of the chemicals. To insure that the chemicals were taken in by the soil, the antecedent soil water content was kept high and the plots were irrigated following the application. The high soil water content prior to application was achieved with irrigation or by applying the chemicals shortly after a rainfall event. The second application to the Waiawa plot was performed after the pesticide concentrations from the first application diminished below the detection limit of the laboratory analyses. Figure 29 (Chapter V) juxtaposes the rainfall/irrigation events with the chemical application dates.

c. Soil sampling. Soil samples used for chemical analyses were collected on several occasions after the applications to define the temporal characteristics of the leaching process. To obtain better representations of the concentration profiles, duplicate samples were collected from each of the three quadrants which received chemicals.

On each sampling date, the six sampled profiles were collected with hand augers using a methodology similar to that described by Schneider *et al.* (1990). All samples weighed at least 0.5 kg and were placed in moisture tight polymer bags and stored in the shade while in the field. The first augered hole from each quadrant was usually located about 1 m from the plot boundary with a duplicate hole about 0.75 m further from the boundary. The locations of sampled holes at the Waiawa and Poamoho plots are shown in Figures 23 and 24.

The first three samples, each about 0.1 m in depth, were usually collected with a 0.1 m diameter auger before the first PVC casing was installed (see Figure 25). Exceptions to this procedure occurred during initial samplings after applications, when samples were collected at 0.05 m increments to a depth of 0.2 m using a tube auger. The tube auger provided a more precise and accurate method of collecting the 0.05 m samples while minimizing disturbance to the deeper samples. Smaller sample increments at the surface provided better resolution of the concentration profiles at the early times when leaching depths were the smallest.

After the first PVC casing was inserted, a smaller auger (0.075 m diameter) was used to collect samples to a depth of about 0.7 m before the second PVC casing was inserted. The PVC casings were installed to minimize cross-contamination of the various depths while sampling. Two other procedures used to minimize contamination included cleaning the augers prior to collection of subsequent samples, and removal of about 0.01 m of soil between samples.

The last samples from each hole were then collected with a smaller auger (0.05 m diameter). The sample increment generally increased (to about 0.2 m) with the decreasing auger size to obtain a consistent amount of soil. The depth to which samples were collected usually increased with time as leaching progressed. The exact depth increments (within 0.05 m) of all collected samples are listed in Tables 23 and 24 of Appendix D. With the exception of soil removed to minimize cross-contamination, the samples from each hole comprise a complete core of soil which was used to determine chemical mass balances at both field plots.

Prior to chemical applications, soil samples were collected at various depths from around the field plots to determine the background concentrations, if any, of the

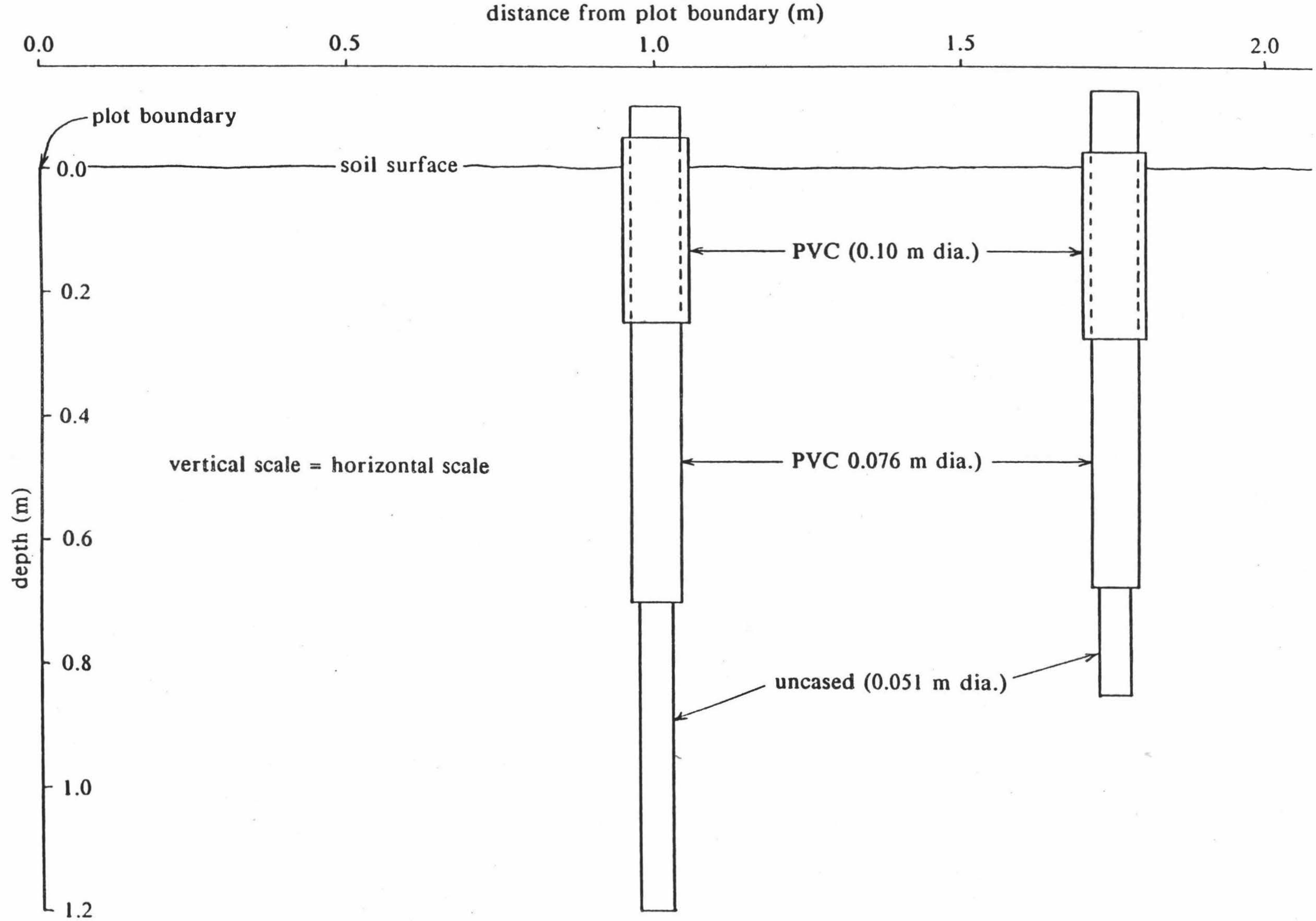


Figure 25. Typical soil sample profile at field plots

three chemicals that were applied. Soil samples used to determine soil water contents were collected with an auger and stored in moisture tight cans while in the field.

2. Water Balance

Rainfall at the Waiawa plot was recorded digitally on an hourly basis and summed to provide daily values. There were several gaps in the rainfall record due to data logger malfunctions. These gaps were filled using data from a manually read back-up rain gage installed at the plot. When necessary, the back-up data were disaggregated to a daily basis by comparison with U.S. National Weather Service data from a rain gage in the Pacific Palisades area. Rainfall at Poamoho was recorded daily by UHPRS (University of Hawai'i Poamoho Research Station) personnel at a weather station located about 100 m from the test plot. The back-up rain gage installed at the Poamoho plot was not needed because there were no data gaps.

Potential evapotranspiration at Waiawa was estimated by the Priestly-Taylor equation (Priestley and Taylor, 1972) using net radiation data recorded at the plot. Data gaps in the net radiation were either interpolated or filled with monthly average values. A standard Class A evaporation pan was installed beside the UHPRS weather station, which also houses a solar radiometer and an additional evaporimeter. Despite the instrumentation to obtain estimates of evaporation, there were 15 days of missing data from the months of February, March, and April due to overflows of the Class A pan. These gaps were filled in by assuming a pan evaporation rate of 1.78 m per year (from Ekern and Chang, 1985).

This annual pan evaporation rate was then disaggregated into monthly values by using historical data from the two nearest sources. The stations selected have six years of continuous data between them (Ekern and Chang, 1985). Stations 851.00 and 856.10 are located approximately 2.4 and 4.3 km from the test plot at elevations of 87 and 213 m, respectively. The two data sets were then normalized and averaged to obtain the monthly variation. Pan evaporation for each of the three months was then equally distributed to accommodate PRZM's daily time step. These daily pan values were then input with a pan factor of 0.33 (Ekern, 1966) to estimate potential evapotranspiration at the Poamoho plot. The pan factor of 0.33 corresponds to a bare soil in Hawai'i, thus approximating the very sparse vegetative cover of the Poamoho plot.

3. Soil Organic Carbon

Four soil transects were established in Waiawa to determine the spatial structure with respect to f_{oc}. Three straight line transects aligned with the prevailing slope were established on Waiawa Ridge. Each of these three transects were located within one of the three dominant soil series on the ridge: Moloka'i, Lahaina, and Wahiawa. The lengths and locations of the transects on Waiawa Ridge were constrained by the extent of areas that were made available by the landowner. The fourth transect, which actually includes a two-dimensional grid, was located in the Waiawa Valley within the Kawaihapai soil series. The locations of these four transects are shown in Figure 26 (and Figures 40 and 41 of Appendix E).

Soils from the transects were collected at the surface with a spade and then with a hand auger at 0.3 m depth intervals to a typical depth of 1.2 m. Procedures to minimize cross-contamination with depth along the transects did not include the use of PVC casings, and the cleaning of the auger between samples was kept to a minimum. These procedures reduced the time required to collect the samples and were justified because of the relatively low variation in f_{oc} with depth (when compared with the high concentration variations observed with depth for the applied pesticides).

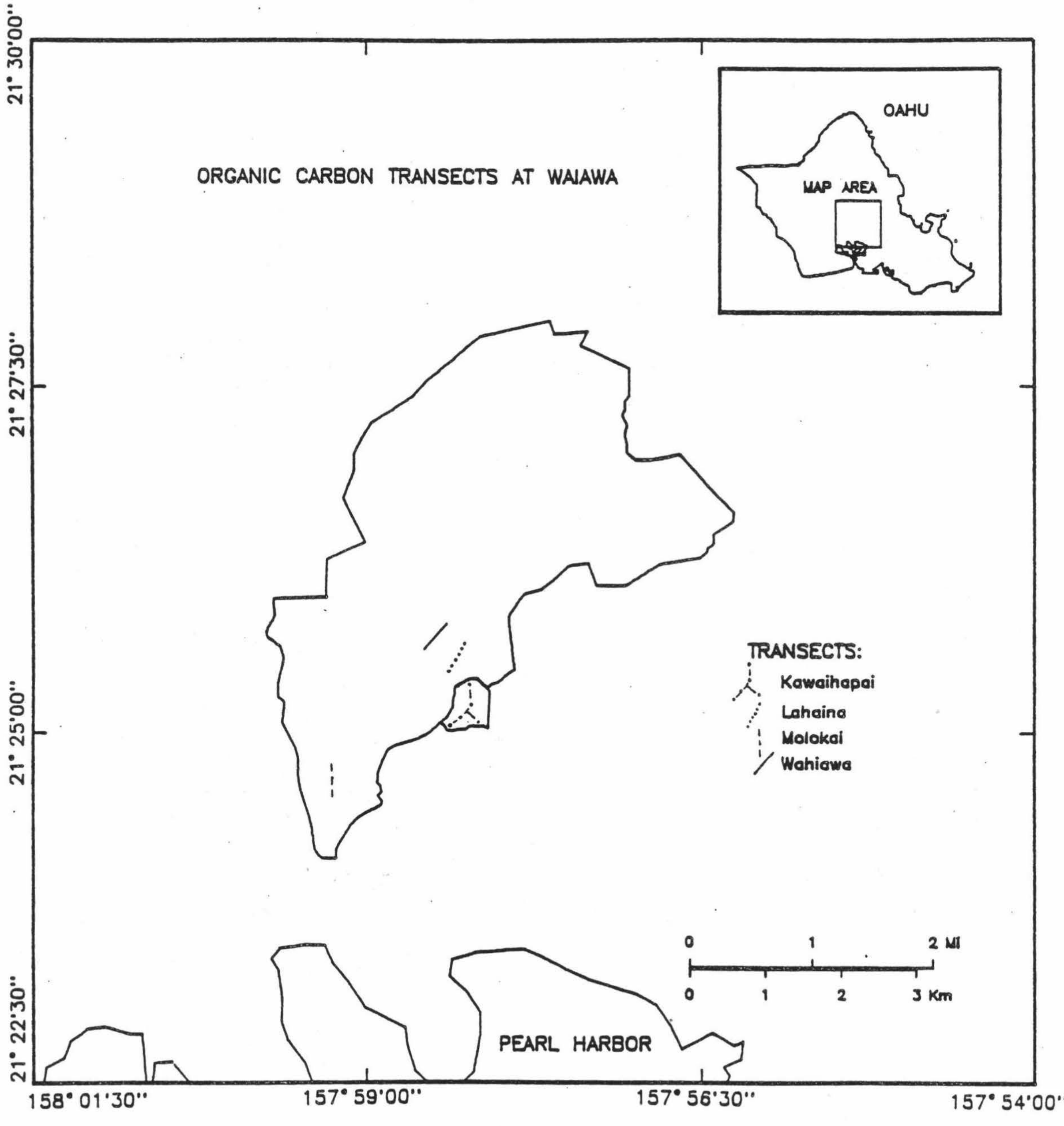


Figure 26. Location of organic carbon transects at Waiawa (after Oki *et al.*, 1990)

C. LABORATORY ANALYSES

1. Chemical Concentrations

Gas chromatography was used to determine the field concentrations of chlorpyrifos, fenamiphos, fenamiphos sulfoxide, and fenamiphos sulfone. As soon as the soil samples were brought in from the field they were stored in a refrigerator at 4°C to minimize additional pesticide transformations. Prior to the determination of pesticide concentrations with a Hewlett-Packard 5890A gas chromatograph, the samples were: (1) homogenized by manual mixing and by passing the collected soils through a 4 mm sieve; (2) extracted from the soils with ethyl acetate; (3) mixed with anhydrous sodium sulfate to remove water and then dried with an evaporator; and (4) mixed with acetone to produce a solution ready for analysis. The homogenization of each soil sample assured that the measured chemical concentrations were representative of its sampled depth interval.

Bromide was extracted from the soil samples with deionized distilled water. Concentrations were then determined with an Orion 94-35 bromide electrode which was calibrated with known concentrations. Recovery tests were performed with predetermined concentrations of bromide and the pesticides to quantify any discrepancies with the concentrations measured in the laboratory. All chemical concentration determinations were performed on duplicate samples to verify the consistency in analytic techniques.

2. Chemical Sorption and Transformation

The sorption (K_{oc}) and transformation (k) of fenamiphos and chlorpyrifos were determined for surface and subsurface soils from both field plots and from the Lahaina, Moloka'i, and Wahiawa soil series on Waiawa Ridge. The methodology summarized here to determine K_{oc} and k is similar to that used by Lee (1987).

Soil samples from the two field plots received 3 and 4 different concentrations of carbon-14 labelled chlorpyrifos and f. sulfoxide, respectively, and were allowed to equilibrate before measuring the amounts of sorbed pesticides. The relatively nonpersistent chlorpyrifos was allowed to equilibrate for only 4 hours while f. sulfoxide was allotted a 24 hour period. Varying concentrations were applied to determine the shape of sorption isotherms. The metabolite f. sulfoxide was used instead of its parent (fenamiphos) because it is the more persistent constituent. Use of carbon-14 labelled pesticides permitted their concentrations to be readily determined with a Packard Tricarb liquid scintillation counter. The sorption of pesticides on soils from Waiawa Ridge were determined in a similar manner except that only chlorpyrifos was used and only one concentration was applied. However, this was performed on soils of varying f_{oc} values to determine the relationship between sorption of chlorpyrifos and f_{oc}. The sorption of f. sulfoxide to Moloka'i, Lahaina, and Wahiawa soil series was taken from existing data (see Table 13, Chapter V). Calculated K_d values were then converted to K_{oc} according to equation 1-1. The assumed high mobility of bromide was verified by demonstrating its lack of sorption in a laboratory equilibration with soil.

Laboratory pesticide transformation rates were determined under aerobic conditions at 30°C in the dark to simulate conditions at the field plots. The soil samples received chlorpyrifos and f. sulfoxide concentrations of 5 mg/kg and were extracted and analyzed by gas chromatography on four separate occasions (7 for the Waiawa plot) over a period of about one month. The observed concentration vs. time data were then used to obtain pseudo first-order decay rates, k. Methods used to determine transformation rates with soil from the Waiawa field plot differed slightly from the others as the parent compound fenamiphos was used instead of its metabolite.

3. Soil Water and Soil Cores

Gravimetric soil water contents (ratio of soil water mass to dry soil mass) were determined by weighing the samples at field conditions and then drying them in an oven at 105°C for at least 24 hours before determining the dry weights.

Soil bulk density (ratio of dry soil mass to soil bulk volume) was determined using the core method as described by Blake and Hartge (1986). This procedure involved the insertion of brass cylinders (0.076 m diameter x 0.076 m height) to collect an undisturbed volume of soil. The soil core was then oven dried to determine its dry mass. Once bulk density was known, the volumetric water content (ratio of soil water volume to soil bulk volume) was readily determined by the following relation:

$$\theta = \theta_g \rho_b / \rho_m \tag{4-2}$$

where, θ = volumetric soil water content (m^3/m^3)
θ_g = gravimetric soil water content (kg/kg)
ρ_b = soil bulk density (kg/m^3)
ρ_m = soil water density (kg/m^3)

and ρ_m is assumed to be 1000 (kg/m^3).

4. Soil Organic Carbon

Soil samples from the two field plots and the four transects were oven dried and powderized prior to measuring their f_{oc} with a Leco WR-112 Carbon Determinator. In addition, several soil samples from the valley plot were mixed with hydrochloric acid to remove significant concentrations of inorganic carbonate-carbon (*e.g.* coral and concrete) which were introduced during previous construction activities.

CHAPTER V. RESULTS AND DISCUSSION

A. FIELD AND LABORATORY RESULTS

1. Chemical Leaching Experiments

a. Water balance. Daily rainfall and irrigation events at the Waiawa and Poamoho field plots are shown in Figures 27 and 28. The Waiawa plot was irrigated on several occasions during the summer months to supplement the lower rainfall and to induce leaching. However, due to an oversight in field monitoring, the Poamoho plot received very little water throughout the entire experimental period. Table 11 summarizes the measured water input as well as the evapotranspiration and recharge as estimated by PRZM. The low water input to the Poamoho plot is reflected by the very low simulated recharge. Although surface runoff was always assumed to be zero, there was an undetermined amount of runoff (upper boundary as high as 100 mm) at the Poamoho plot in early March of 1989 as evidenced by a breach in one of the berms. Figure 29 juxtaposes chemical application and sampling events with water inputs to the two field plots. Daily meteorologic files from both field sites which were input to PRZM are listed in Tables 21 and 22 of Appendix C.

b. Bromide. The raw bromide concentration data from each of the six sampled holes collected on each of the eight collection dates are presented in Tables 23 and 24 of Appendix D. Bromide concentration profiles which summarize the data in Tables 23 and 24 are illustrated in Figure 30. The method used to derive summarized field concentration profiles is described in Appendix D.

Bromide profiles at the Waiawa plot show a considerable amount of variation between quadrants and even between profiles of the same quadrant (see quadrant #1 of the second sampling in Table 23, Appendix D). On the fourth (238 and 17 days after the first and second applications, respectively) and fifth (318 and 122 days after the

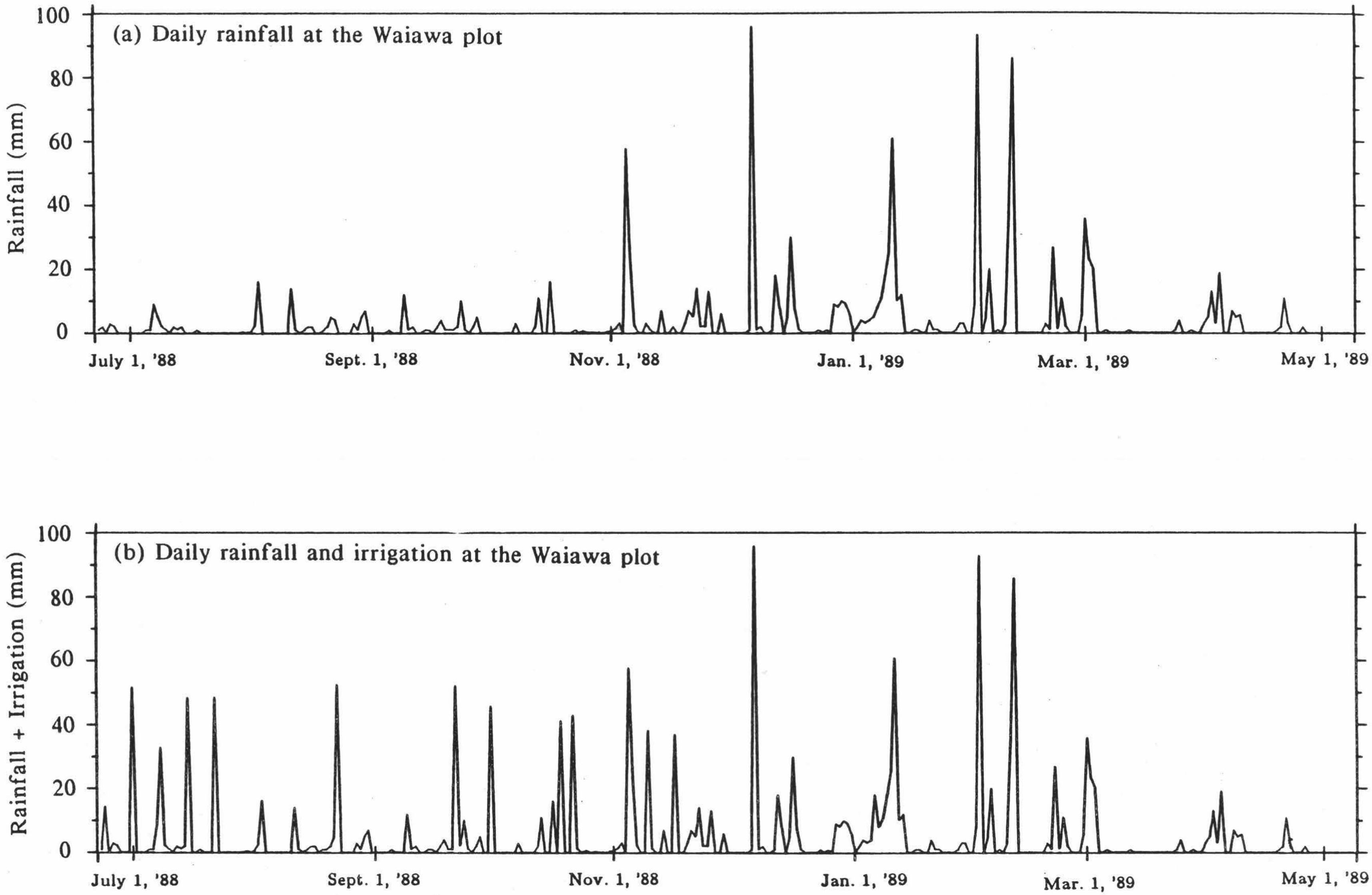


Figure 27. Daily water input at the Waiawa field site

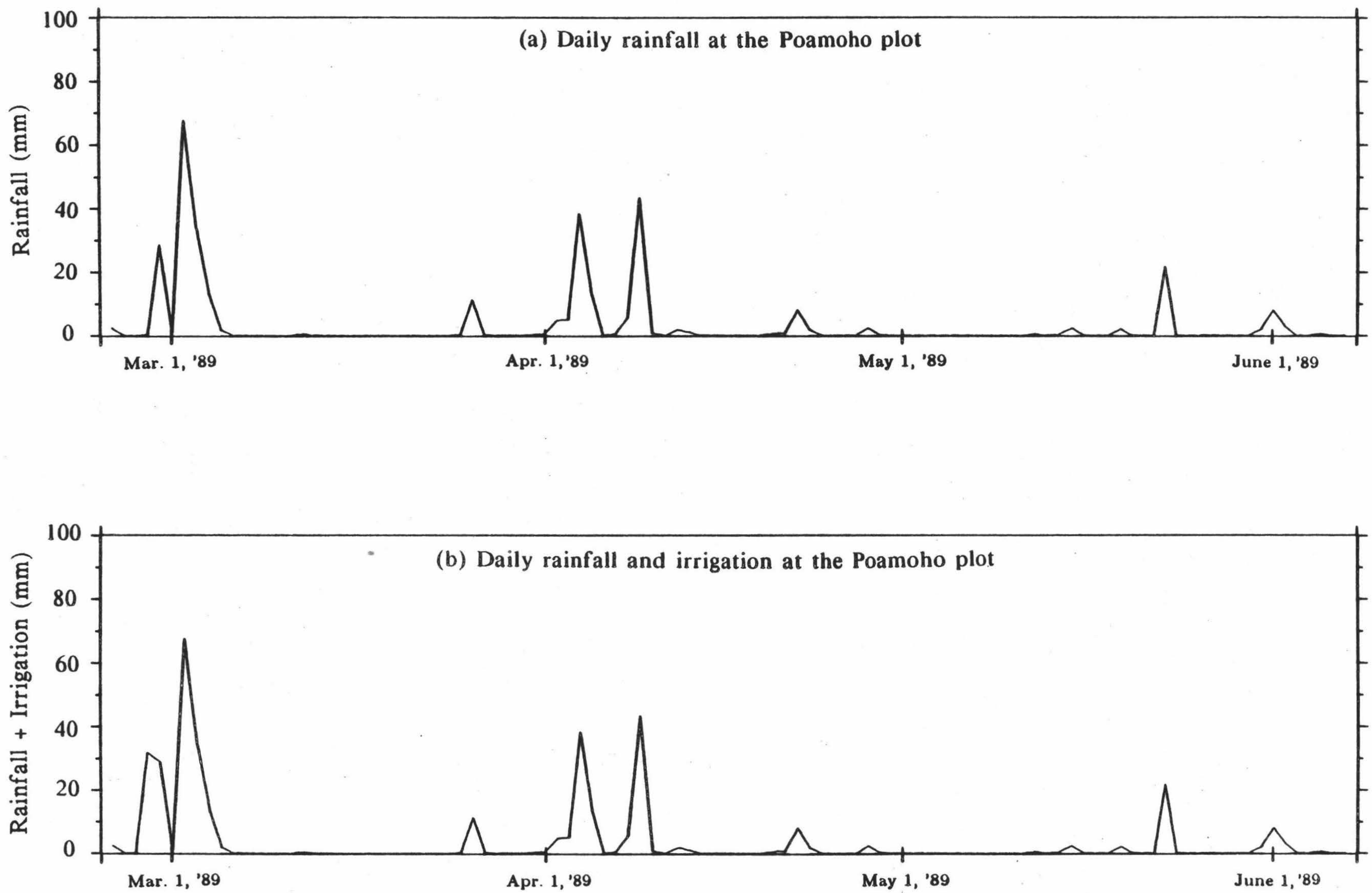


Figure 28. Daily water input at the Poamoho field site

Table 11

Summary of Water Balance at Field Sites

Field plot and sample number[1]	Cumulative[2] rainfall and irrigation (mm)	Cumulative recharge[3] (mm) below 0.3 m	Cumulative evapotrans-piration[3] (mm)	Cumulative surface runoff[4] (mm)
Waiawa 1	20	2	26	0
Waiawa 2	223	75	166	0
Waiawa 3	602	156	406	0
Waiawa 4	1225	511	630	0
Waiawa 5	1703	768	852	0
Poamoho 1	181	166	18	0
Poamoho 2	314	251	68	0
Poamoho 3	370	251	120	0

[1] sample numbers and rainfall/irrigation events are shown in Figure 29
[2] cumulative time since first chemical application
[3] values estimated by PRZM
[4] estimated

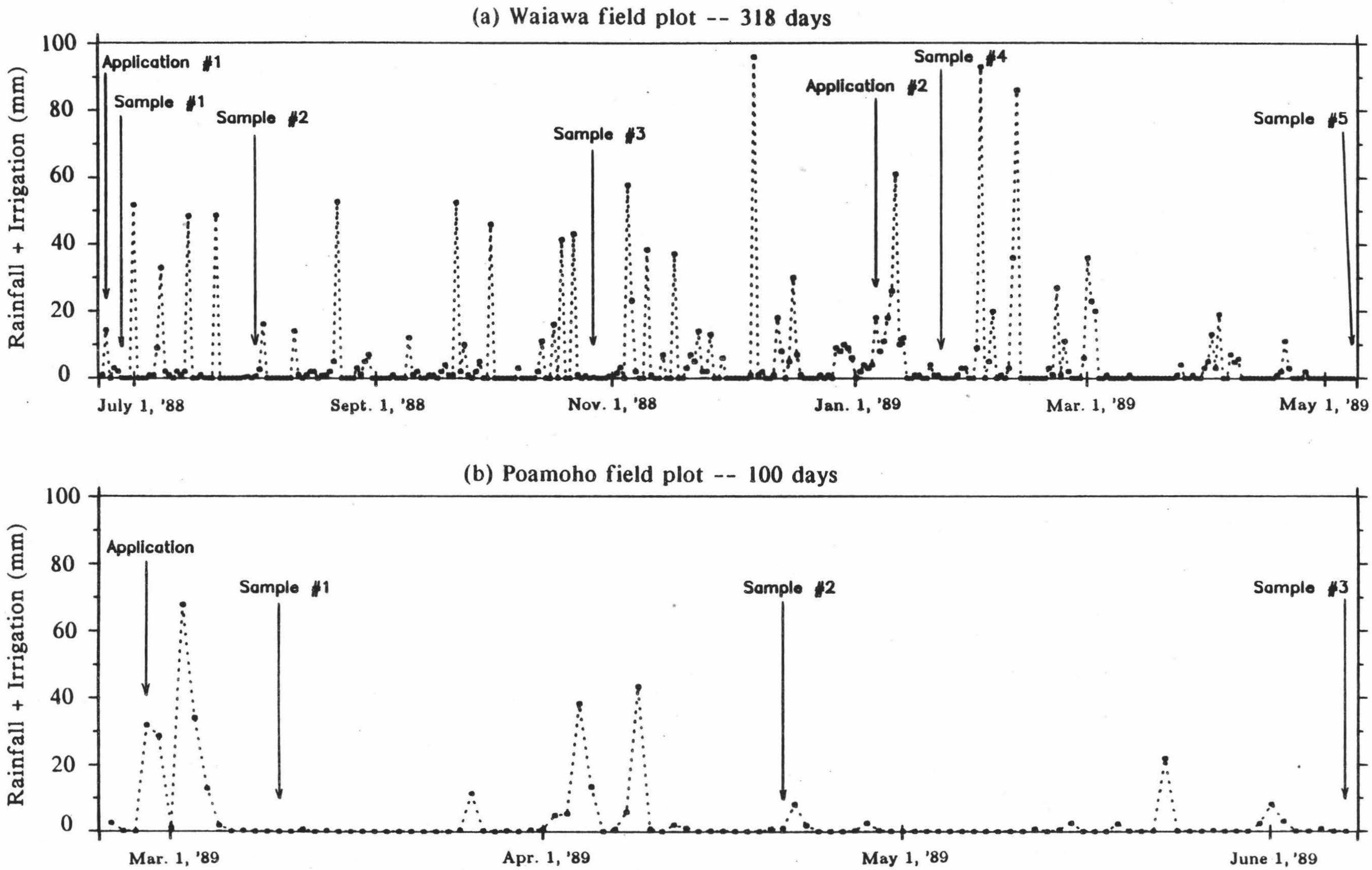
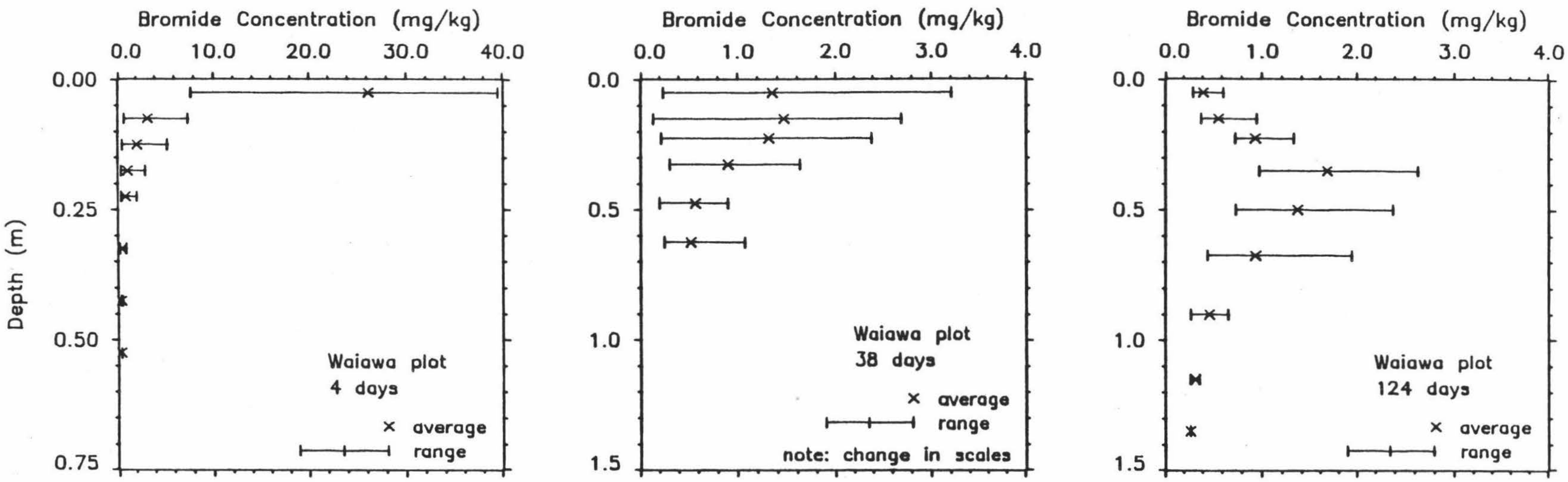


Figure 29. Time series of events at field sites



Note: Compiled from data presented in Appendix D

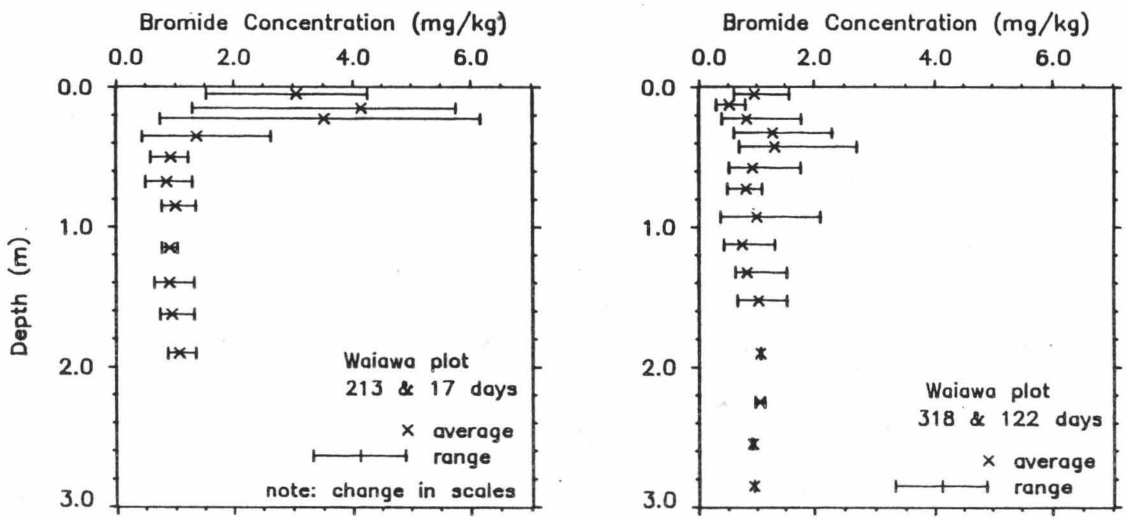
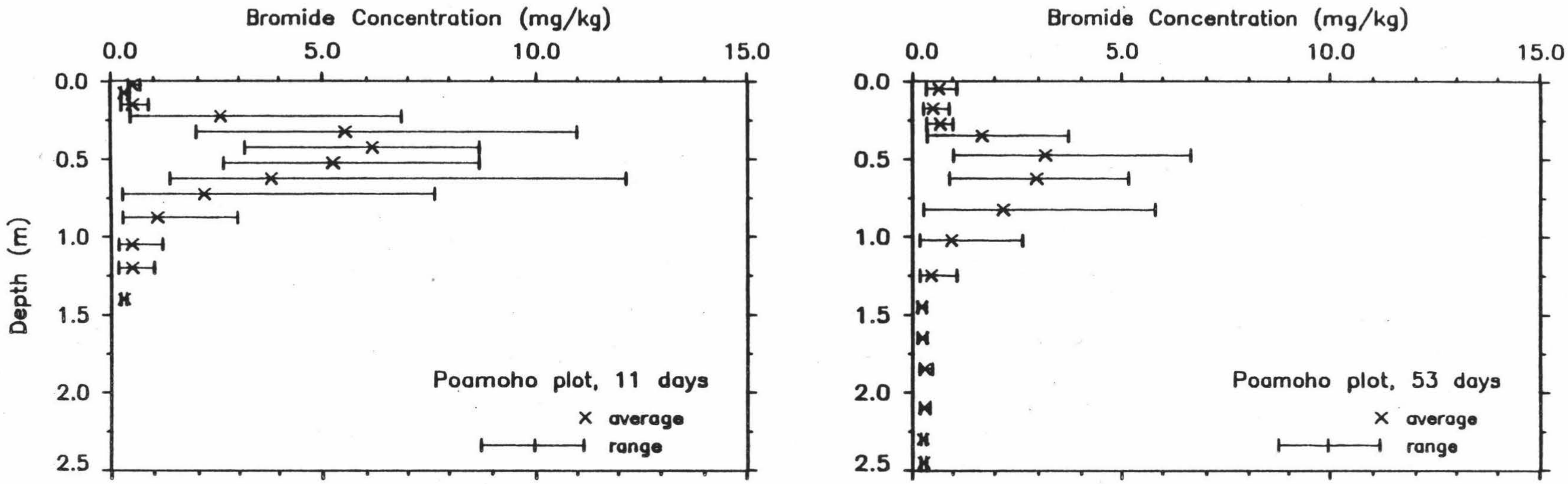


Figure 30. Summary of observed bromide concentration profiles, (a) Waiawa field plot



Note: Compiled from data presented in Appendix D

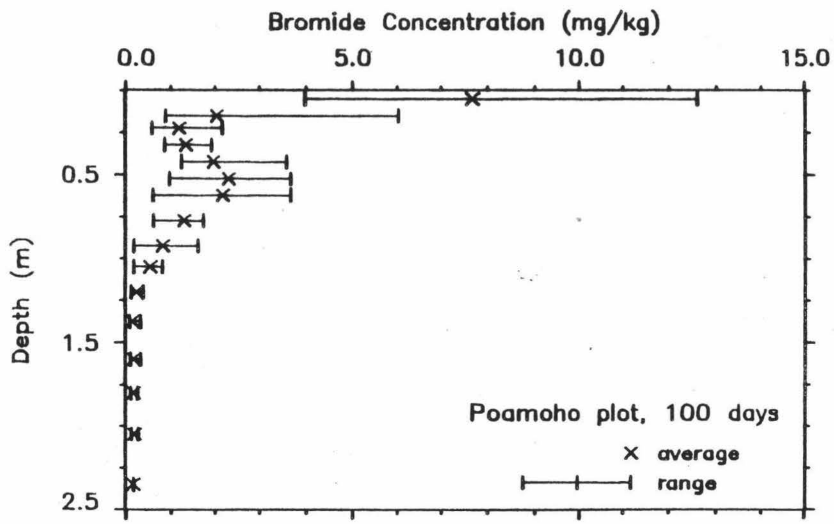


Figure 30. (Continued) Summary of observed bromide concentration profiles, (b) Poamoho field plot

first and second applications, respectively) sampling dates at Waiawa, background concentrations of about 0.5 mg/kg make it difficult to identify the bromide peak from the initial application (Figure 30a). It appears that the first peak may have moved below the maximum sampling depth on these two occasions.

The mass balance of bromide at the Waiawa plot reveals low recoveries versus the amount applied for each of the five sampling dates, with an increase in lost mass with time (method of mass balance determinations and tabular results are presented in Appendix D). Bromide profiles at Poamoho (Figure 30b) also reveal similar mass balance discrepancies. Another complication is observed during the third sampling at Poamoho where bromide has moved upward toward the surface. This was apparently caused by a capillary transport mechanism. The plot received very little rainfall and no irrigation between the second and third sampling dates, allowing the soil to become very dry near the surface.

The time series of Figure 31 plots the approximate fractions of bromide recovered in the field versus the amounts applied. These findings may suggest one or more of the following: mass loss due to lateral dispersion; preferential flow which transported the unaccountable mass of bromide below the maximum sampling depths; nonrepresentative sampling within the plot; nonuniform chemical application. Errors introduced by the application and sampling methods are probably the least significant since they were performed under controlled conditions and because all of the samples, which were collected from distributed locations, revealed the observed trend.

Lower background concentrations at Poamoho (typically 0.2 mg/kg) allow the observation of a more discernable bromide peak. This increased sensitivity in detecting the applied bromide suggests that unless there is a very tenuous and extended tailing of the concentration profile with depth, preferential flow is not evident. However, upon closer examination of Figure 29 it appears that shortly after each of the three chemical

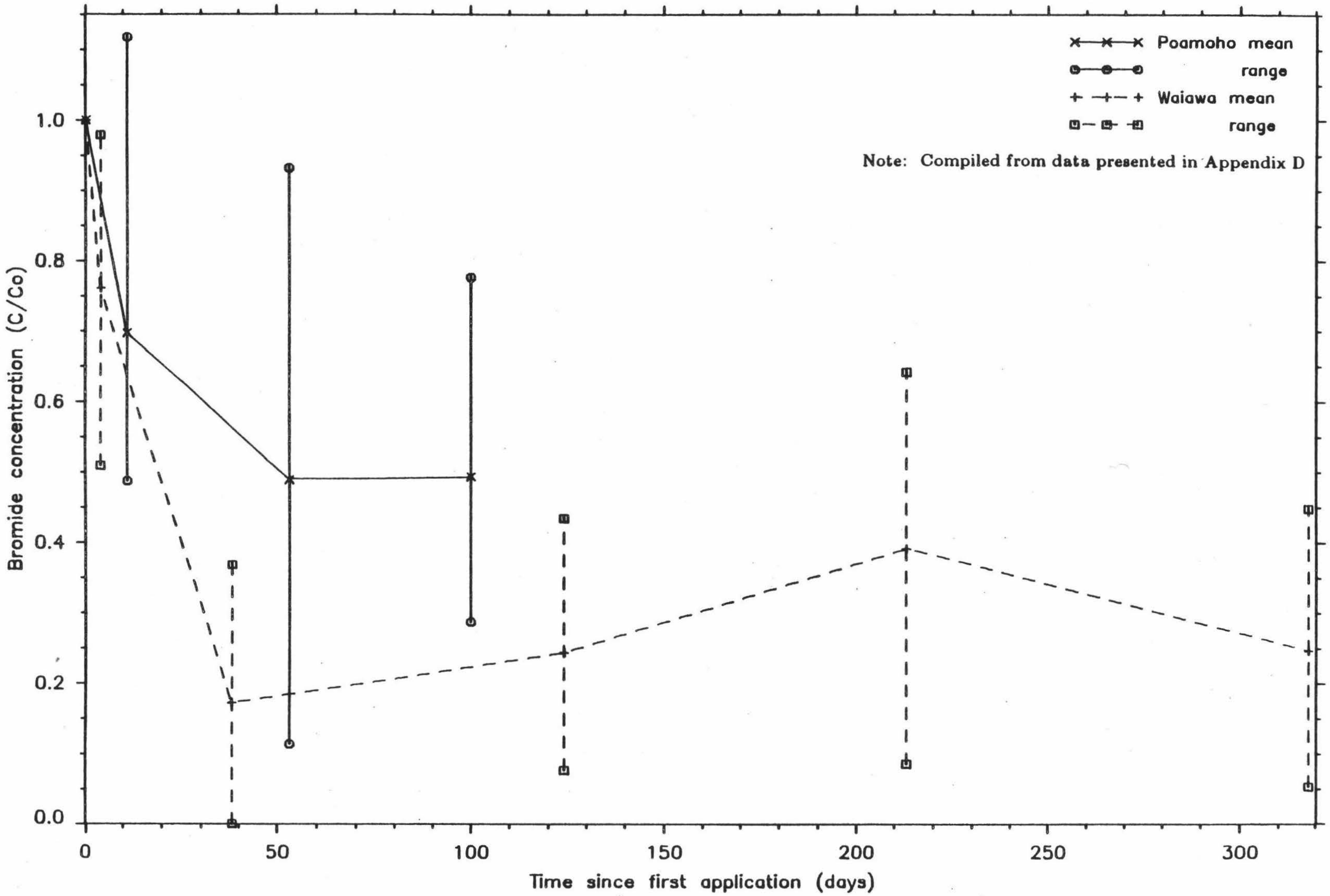


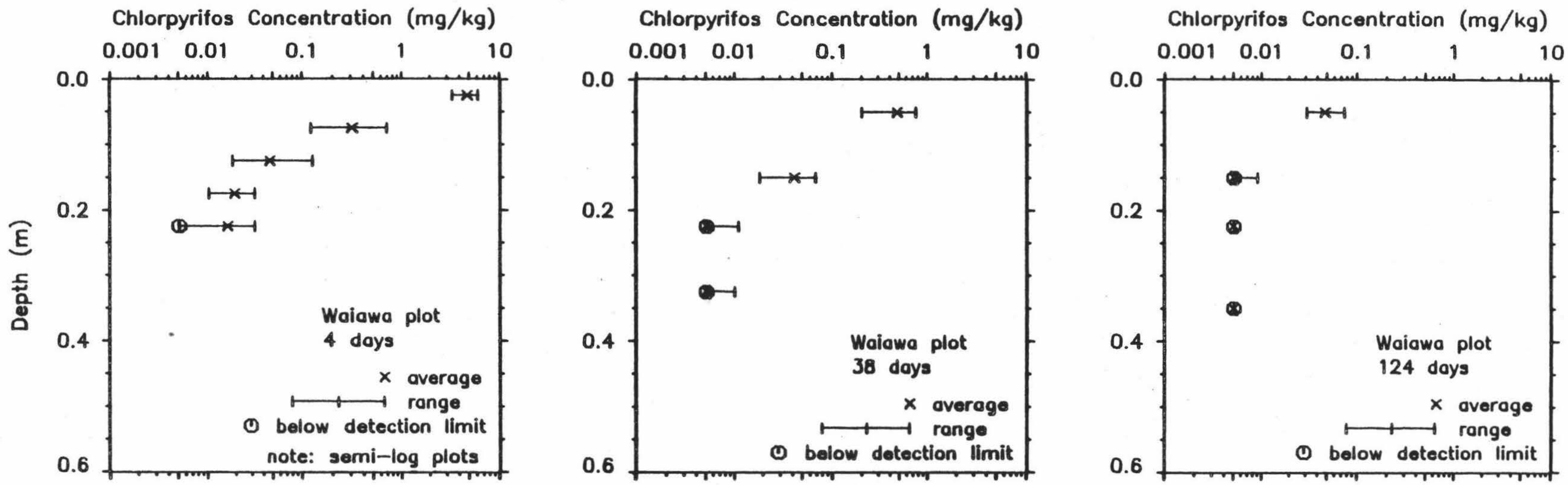
Figure 31. Bromide recovery at field sites

applications, and prior to their most immediate sample collections, relatively large water input events occurred. These recharge events may have provided a suitable condition for preferential flow and therefore account for the steep rates of bromide loss observed at the respective sampling dates (Figure 31).

Lateral dispersion is another pathway which can account for the lost bromide mass. Augered soil samples were taken relatively close to the plot boundaries and the effects of dispersion were probably magnified at later dates when samples were collected at greater depths (see Figures 23, 24, and 25 of Chapter IV).

c. Chlorpyrifos and fenamiphos. The concentrations of fenamiphos measured from the field plots and simulated by PRZM are presented as the total toxic residue of fenamiphos (Fen.TTR), which includes the parent compound, fenamiphos, and its metabolites, fenamiphos sulfoxide (f. sulfoxide) and fenamiphos sulfone (f. sulfone). Reported field pesticide concentrations do not directly account for laboratory recovery rates of 0.90 and 0.95 for chlorpyrifos and fenamiphos, respectively. Instead, their simulated application rates have been reduced accordingly (see Table 15, Chapter V). Raw pesticide concentration data are presented in Tables 25 and 26 of Appendix D and summarized in Figures 32 and 33. Summarized data used to plot Figures 32 and 33 are also listed in Appendix D (Tables 25 and 26).

The amount of chlorpyrifos leaching below 0.5 m was negligible at both plots, with the great majority of mass remaining within the top 0.2 m for all sampling dates (Figure 32). Fenamiphos showed greater variability than chlorpyrifos in its concentration profiles and was even less persistent. Fenamiphos also showed minimal leaching, although the first sampling at Poamoho (Figure 33b) showed detectable levels down to about 0.7 m. In either case, both chlorpyrifos and fenamiphos behaved as relatively immobile and nonpersistent pesticides. The extended tailing in some of the observed pesticide profiles indicate that preferential flow may have occurred.



Note: Compiled from data presented in Appendix D

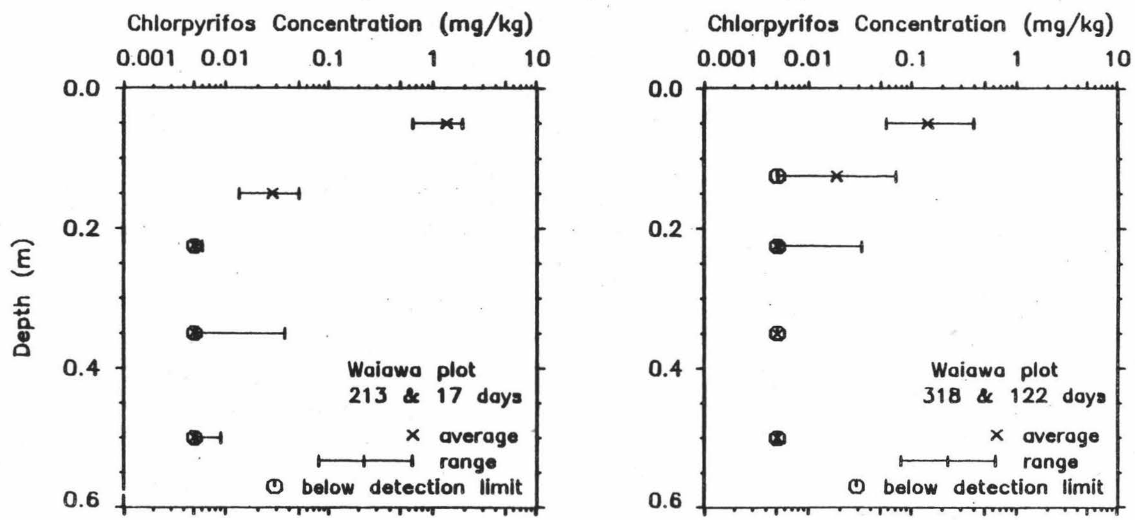
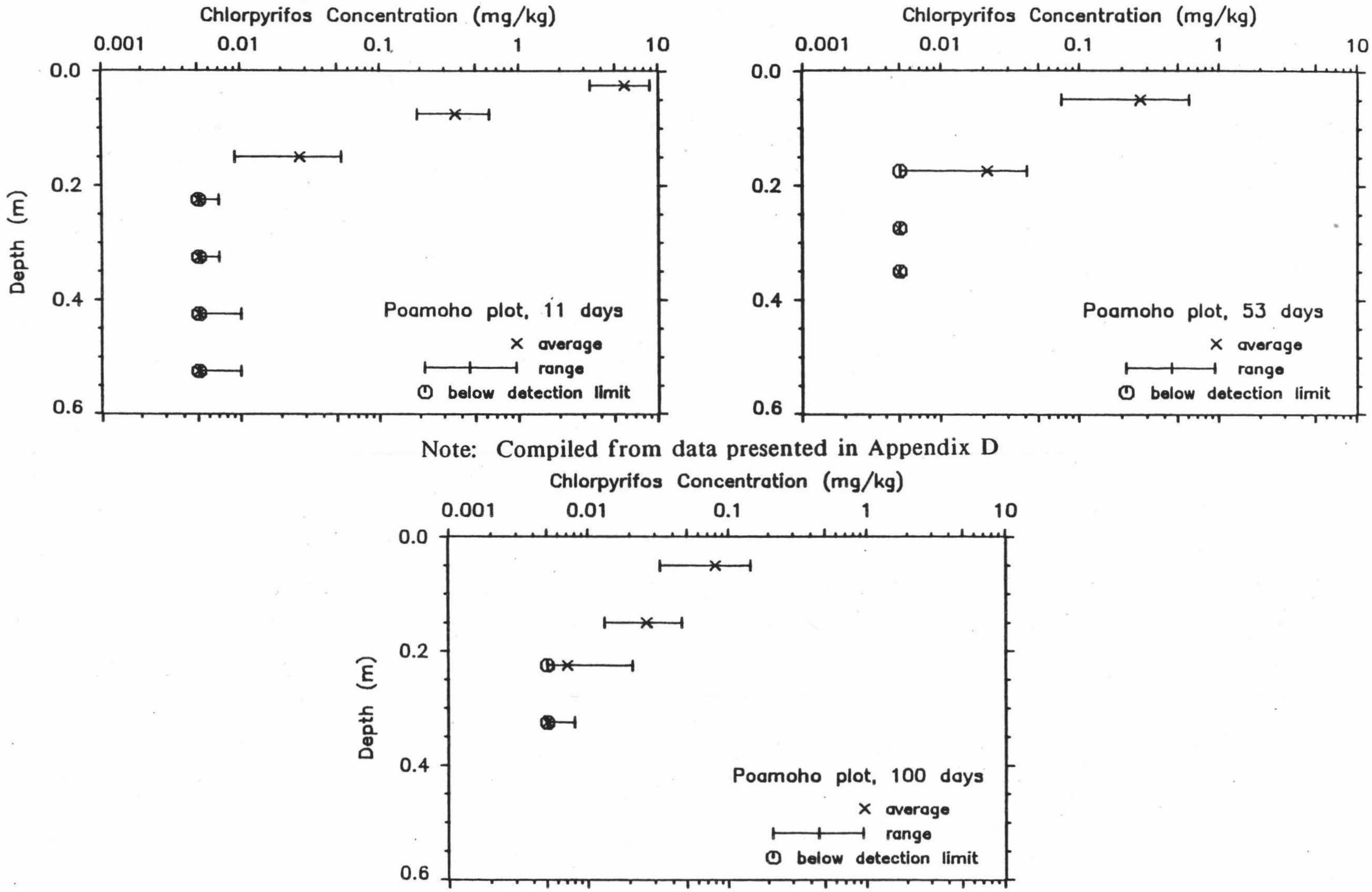


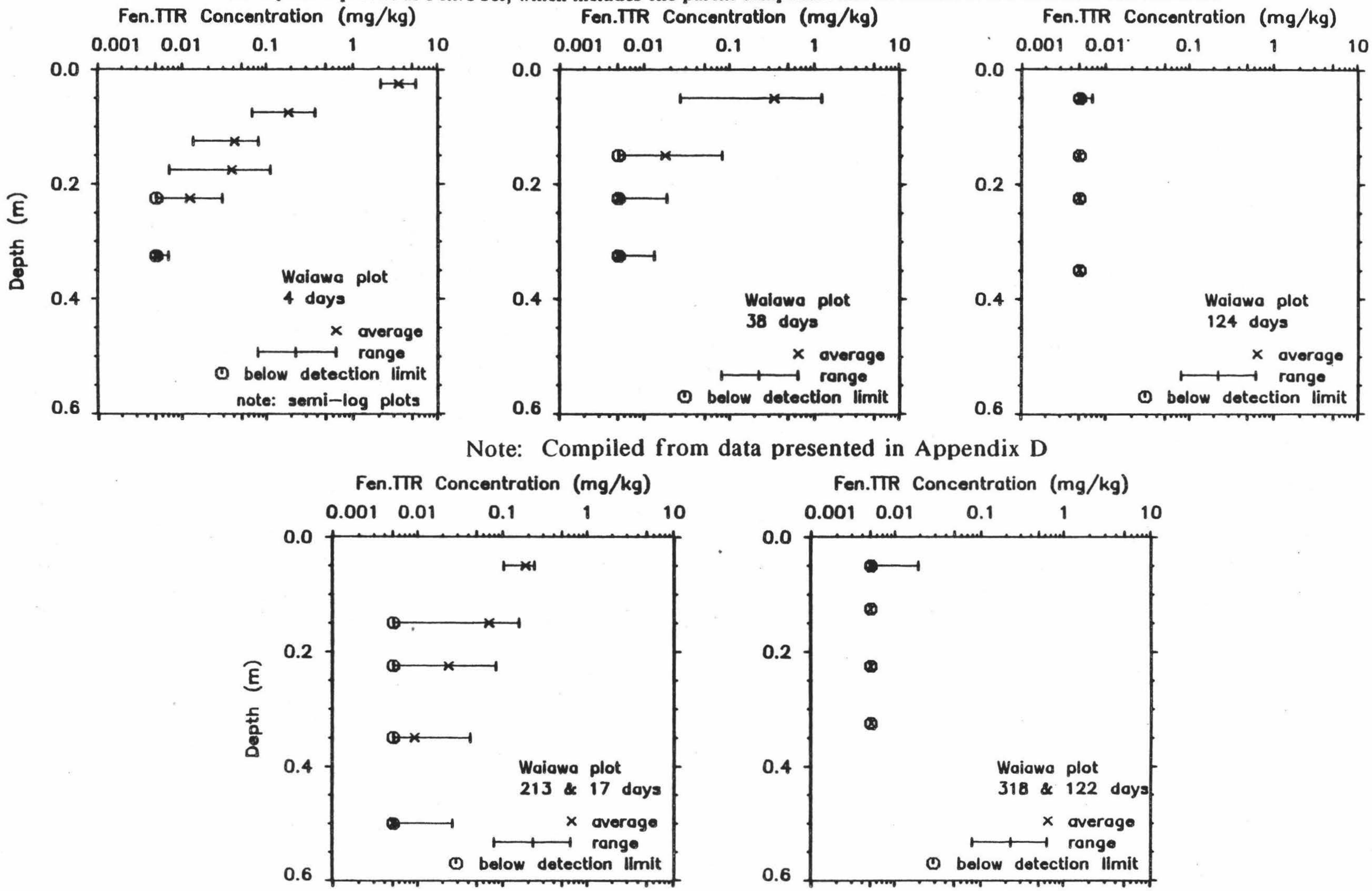
Figure 32. Summary of observed chlorpyrifos concentration profiles, (a) Waiawa field plot



Note: Compiled from data presented in Appendix D

Figure 32. (Continued) Summary of observed chlorpyrifos concentration profiles, (b) Poamoho field plot

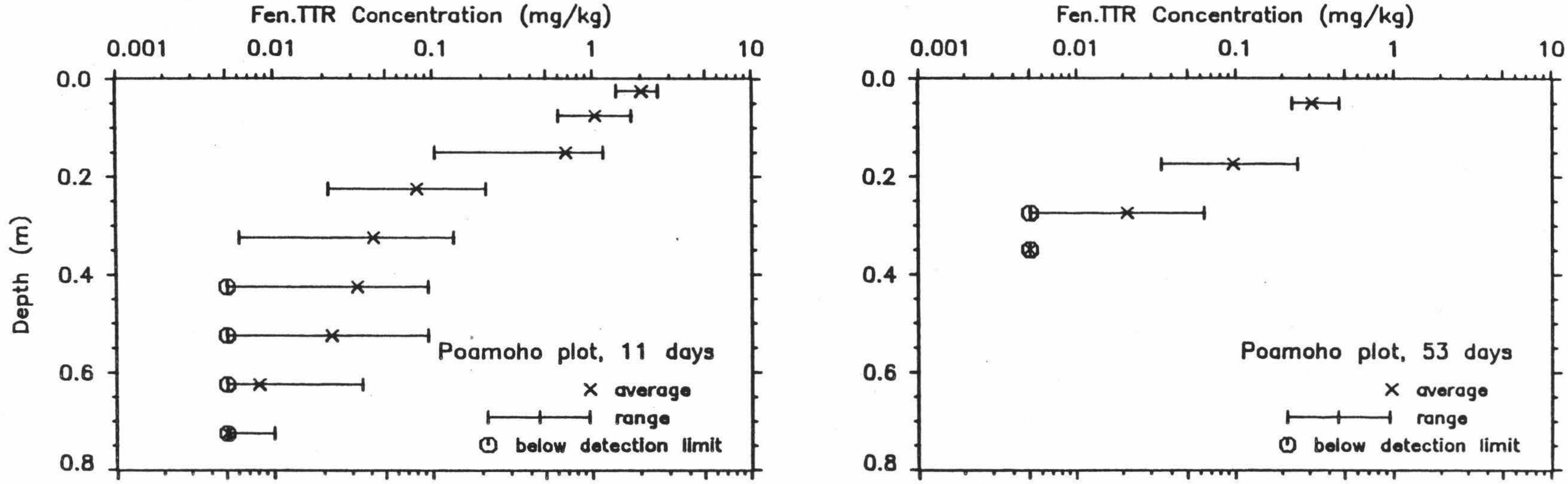
Note: Fenamiphos reported as Fen.TTR, which includes the parent compound and its metabolites f. sulfoxide and f. sulfone



Note: Compiled from data presented in Appendix D

Figure 33. Summary of observed fenamiphos concentration profiles, (a) Waiawa field plot

Note: Fenamiphos reported as Fen.TTR, which includes the parent compound and its metabolites f. sulfoxide and f. sulfone



Note: Compiled from data presented in Appendix D

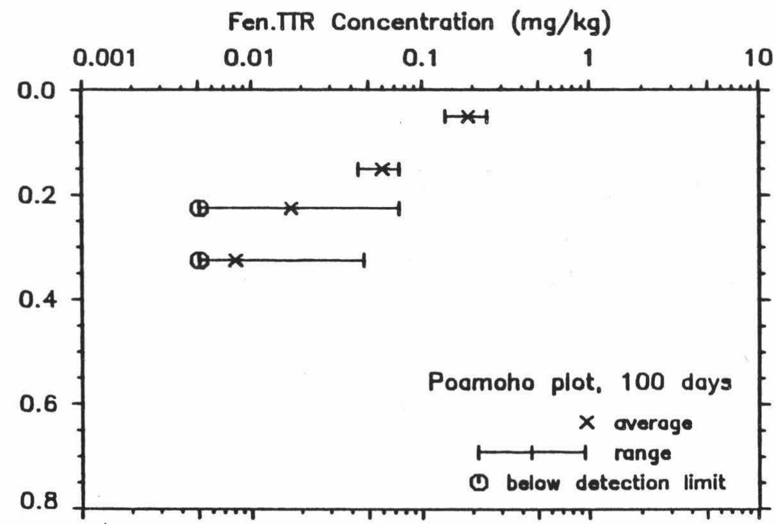


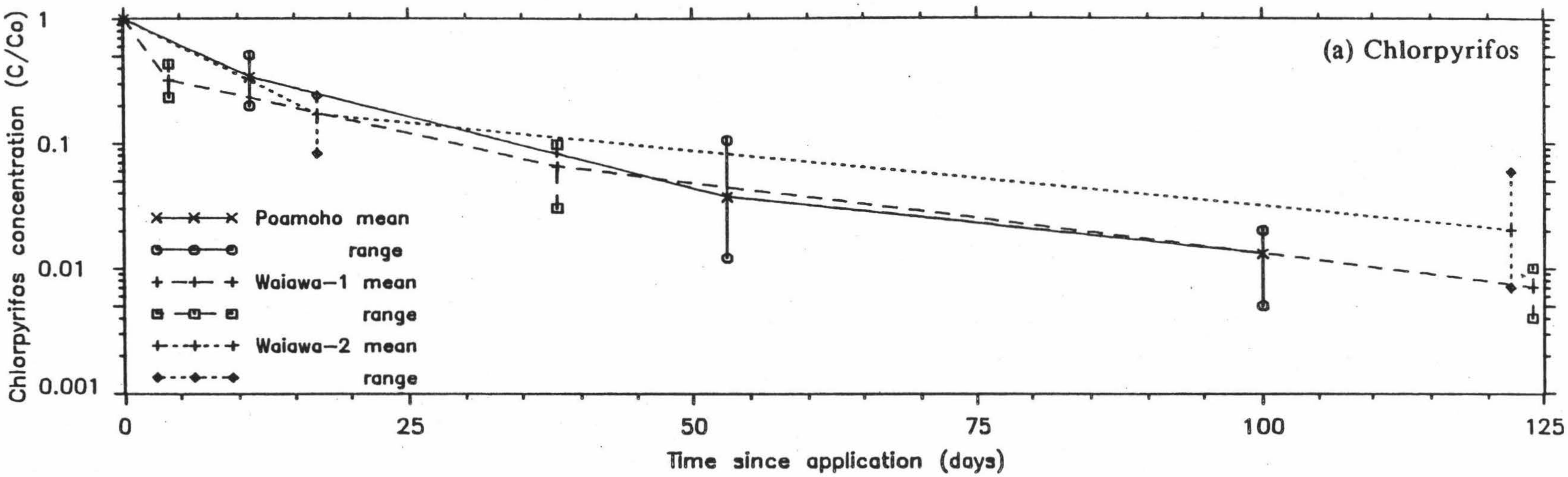
Figure 33. (Continued) Summary of observed fenamiphos concentration profiles, (b) Poamoho field plot

Mass balances of the pesticides were used to calculate their degradation rates in the field. Figure 34 reveals that unless disproportionate amounts of pesticide masses were lost just after applications (*i.e.* preferential flow or lateral dispersion), the degradation rates decrease with time and therefore do not follow the assumed first-order kinetics.

2. <u>Pesticide Transformation and Sorption</u>

Summaries of laboratory measured transformation and sorption of chlorpyrifos and f. sulfoxide are shown in Tables 12 and 13, respectively. Approximate first-order field degradation rates of chlorpyrifos and fenamiphos are presented in Table 28 (Appendix D). Field degradation rates reveal that chlorpyrifos was more persistent than fenamiphos (Fen.TTR). They also indicate that chlorpyrifos was more persistent at the field plots than in the laboratory and more persistent at the Waiawa plot than the Poamoho plot. However, the reverse is observed for fenamiphos (Fen.TTR) which was less persistent at the field than in the laboratory (compare k for Waiawa plot from Tables 12 and 28) and less persistent at the Waiawa plot than the Poamoho plot.

The laboratory measured transformation rates of chlorpyrifos were slightly higher than expected while the rates of f. sulfoxide fell within the expected range. Measured sorption values of chlorpyrifos at the Poamoho plot and on Waiawa Ridge were several times lower than expected and even lower on soils from the Waiawa field plot. Measured sorption of f. sulfoxide was higher at the Waiawa plot than at the Poamoho plot, but both values were within the expected range. The laboratory results suggest that in Hawaiian soils, chlorpyrifos may be less persistent and more mobile than expected. However, these results do not address the chlorpyrifos metabolite 3,5,6-trichloro-2-pyridinol which may be of concern.



Note: Compiled from data presented in Appendix D

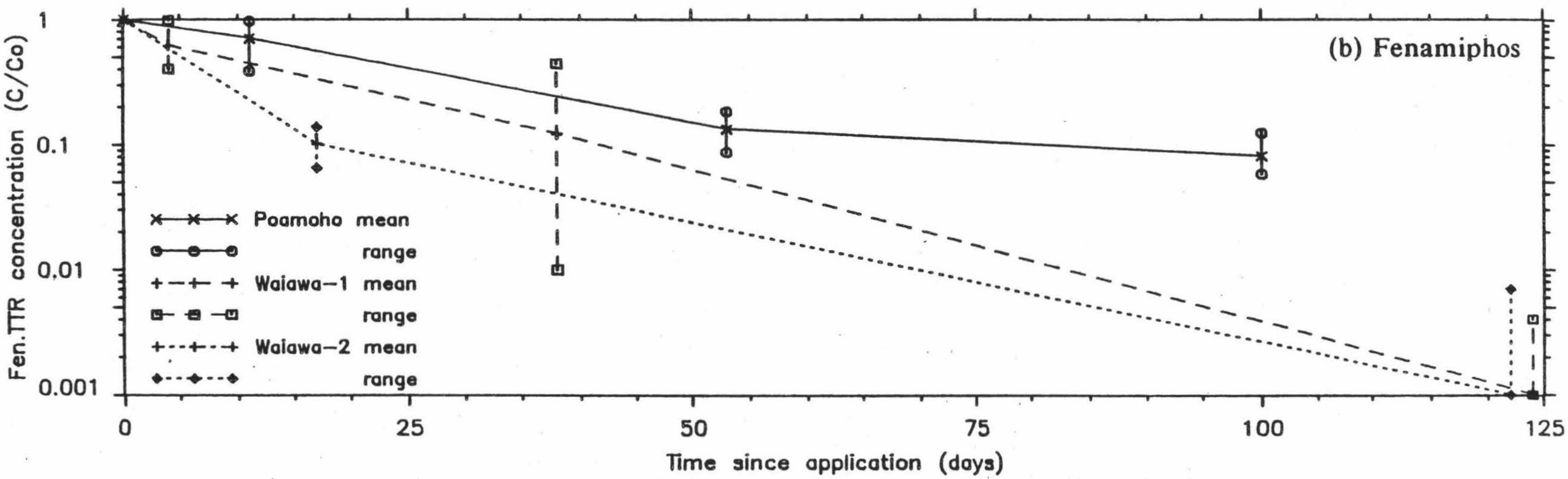


Figure 34. Pesticide degradation at field sites: (a) chlorpyrifos (b) fenamiphos

Table 12

Summary of Laboratory Pesticide Transformation Data (after Oki *et al.*, 1990)

Site	Soil series	Depth (m)	Chlorpyrifos k (day^{-1})	F. sulfoxide k (day^{-1})
Waiawa	Kawaihapai	0.0 - 0.10	0.083	0.187*
plot		0.2 - 0.30	0.067	0.086*
Poamoho	Wahiawa	0.05 - 0.20	0.091	0.025
plot		0.35 - 0.55	0.103	0.031
Waiawa	Lahaina	0.05 - 0.20	0.064	0.030
Ridge		0.70 - 0.85	0.099	0.037
Waiawa	Moloka'i	0.05 - 0.25	0.065	0.026
Ridge		0.75 - 0.90	0.098	0.029
Waiawa	Wahiawa	0.05 - 0.20	0.051	0.024
Ridge		0.65 - 0.80	0.102	0.027

*the parent compound fenamiphos was used instead of f. sulfoxide

Table 13

Summary of Laboratory Pesticide Sorption Data (after Oki *et al.*, 1990)

Site	Soil series	Depth	Chlorpyrifos K_{oc} (m^3/kg)	Chlorpyrifos r^2	F. sulfoxide K_{oc} (m^3/kg)	F. sulfoxide r^2
Waiawa						
field	Kawaihapai	surface	1.18	0.988	0.071	0.989
plot	Kawaihapai	subsoil	1.51	0.975	0.378	0.977
Poamoho						
field	Wahiawa	surface	1.67	0.997	0.072	0.990
plot	Wahiawa	subsoil	1.27	0.988	0.035	0.956
Waiawa	Lahaina	- - -	1.22	0.958	na	- - -
Ridge	Moloka'i	- - -	1.27	0.967	na	- - -
	Wahiawa	- - -	1.41	0.981	na	- - -
O'ahu*	Lahaina	- - -	- - -	- - -	0.033	0.927
	Wahiawa	- - -	- - -	- - -	0.027	0.974

*Unpublished data from various pineapple fields on O'ahu by R.E. Green and C.C. Lee, University of Hawai'i, Department of Agronomy and Soil Science

r^2 = coefficient of determination

na = not analyzed

3. Soil Organic Carbon

Figure 35 summarizes the soil organic carbon contents from the transects and Table 14 lists the measured f_{oc} (mass fraction of organic carbon to dry soil) profiles from the two field plots. The complete listing of organic carbon data from the transects is presented in Tables 29 and 30 of Appendix E (Table 31 lists the summary plotted in Figure 35). Soils from the Poamoho plot had a slightly lower surface f_{oc} value than the Wahiawa soil transect on Waiawa Ridge, just as surface soils from the Waiawa plot had a lower f_{oc} value than the Kawaihapai transect within Waiawa Valley. Thus, in this respect the field plots were conservative representatives of their respective soil series from the standpoint of groundwater quality protection. No lateral spatial structure was observed along any of the transects and f_{oc} was quite uniform along the Waiawa Ridge transects (Table 29, Appendix E). Surface soils of the Kawaihapai series in Waiawa Valley had higher f_{oc} values, but nearly all of the sampled profiles were under 0.01 kg/kg below a depth of 0.5 m (Table 30).

B. PRZM SIMULATIONS

1. Evaluation of PRZM in the Near-surface

a. Daily vs. hourly time step. The effect of reducing PRZM's time step to an hourly basis for the transport of bromide at the Waiawa plot was simulated. Continuous hourly meteorologic data over a period of approximately 35 days after the initial chemical application was recorded at the Waiawa plot. Comparisons of the simulated bromide profiles revealed minimal differences in the hourly versus daily time step. The simulated recharge using an hourly time step was only about 3% greater than that from a daily time step. This slight increase in estimated recharge advanced the simulated bromide peak from 0.025 m for the daily time step to 0.0275 m for the hourly time step. Thus, on a scale as small as one month, the use of a daily time step

Note: Compiled from data presented in Appendix E

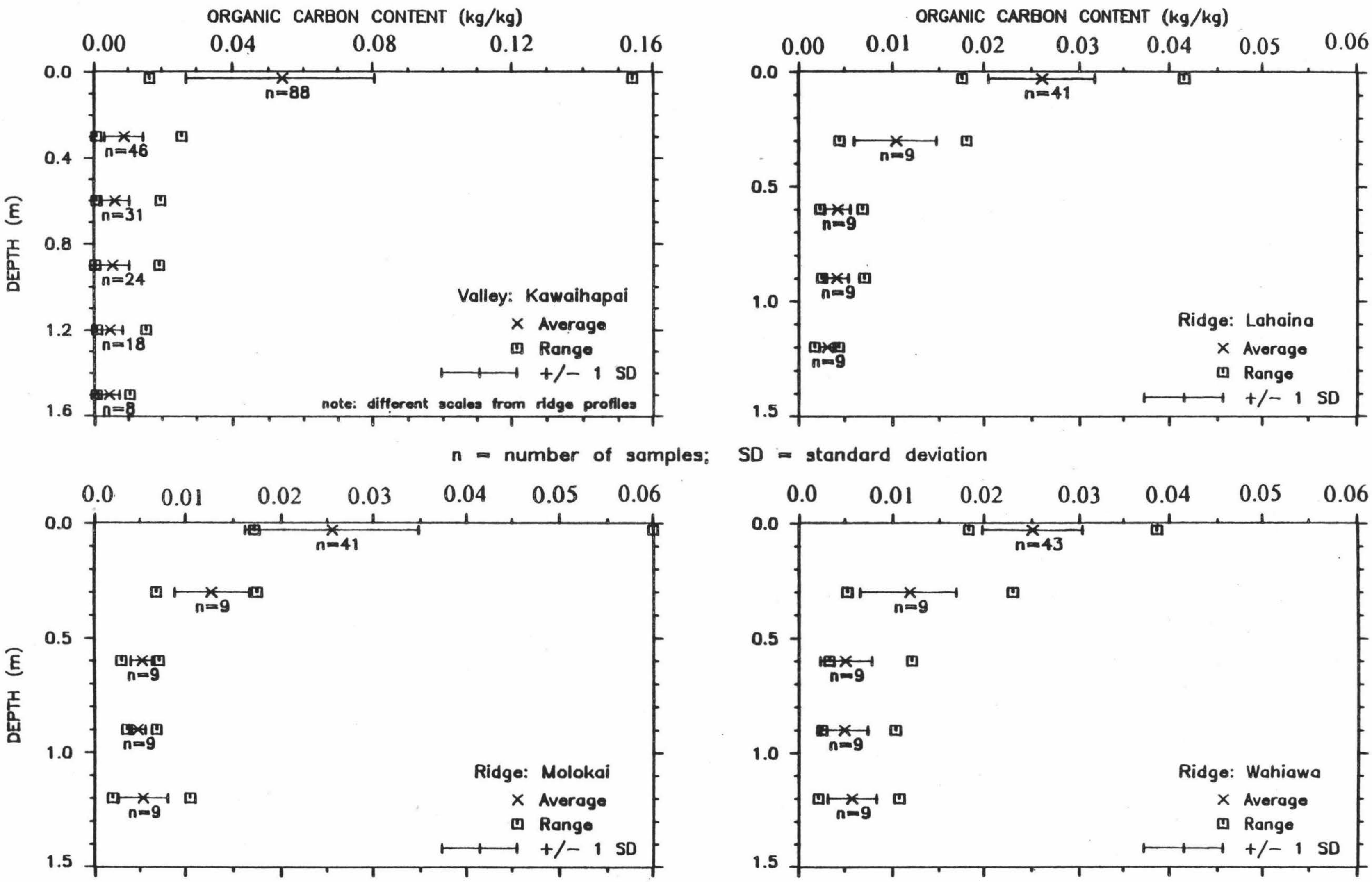


Figure 35. Summary of organic carbon profiles at Waiawa

appears to be adequate for the simulation of transport processes at the Waiawa field plot (when compared to an hourly time step).

b. Chemical transport. PRZM accurately simulated the locations of peak bromide concentrations at the Waiawa field plot for profiles sampled closest to the application dates (Figure 36a). In general, the shapes of the observed and simulated bromide concentration profiles are also similar. PRZM also accurately simulated the observed bromide profiles of the first two Poamoho samplings, especially when viewed with respect to the ranges in observed concentrations. The unquantifiable amount of surface runoff observed at the plot does not appear to have affected the simulated results. By isolating the first two Poamoho sampling dates it appears that PRZM has been successfully calibrated and validated. However, with the exception of these two samplings, PRZM significantly over predicted most of the observed mean concentrations. Another discrepancy with the field data is observed at the third Poamoho sampling where PRZM was unable to simulate the observed upward capillary transport of bromide because its water flow algorithm handles only downward vertical flow. Despite these discrepancies and with the possible exception of preferential flow, the empirical drainage algorithm employed by PRZM appears to be at least marginally adequate for simulating bromide transport in the tested soils. However, in view of the differences in mass balance, it does not seem appropriate to claim that PRZM has been validated with respect to bromide transport through the soils of this study.

While evaluating PRZM with graphical comparisons of the observed chlorpyrifos and fenamiphos concentration profiles, it became apparent that PRZM could not be definitively validated for each of the sampling dates. With this in mind, the chemical parameters input to PRZM to simulate the field data were selected such that they would result in a simulation which would best describe pesticide leaching over the entire test period. This modified approach to simulating the field data

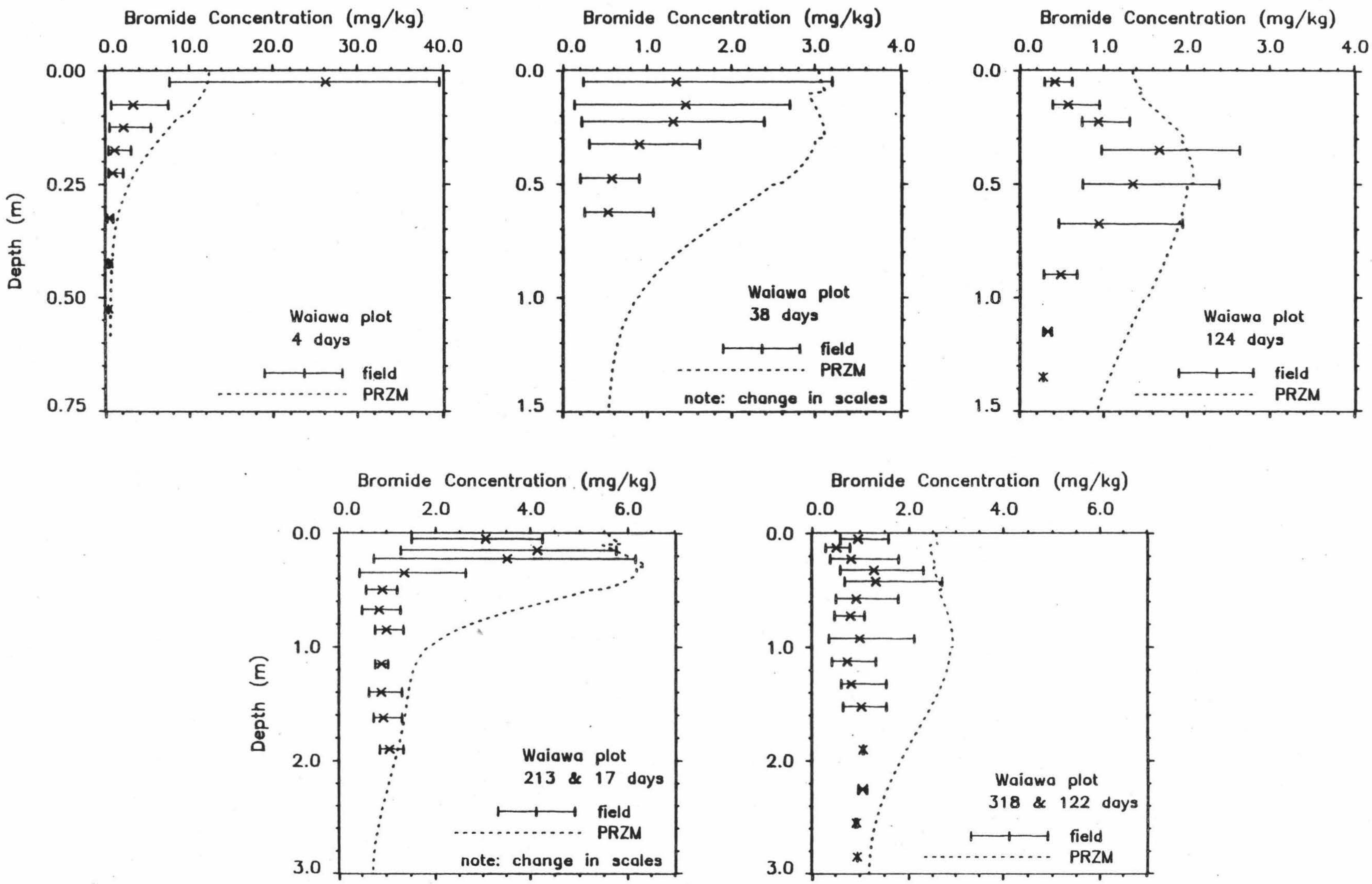


Figure 36. PRZM vs. field data for bromide, (a) Waiawa plot

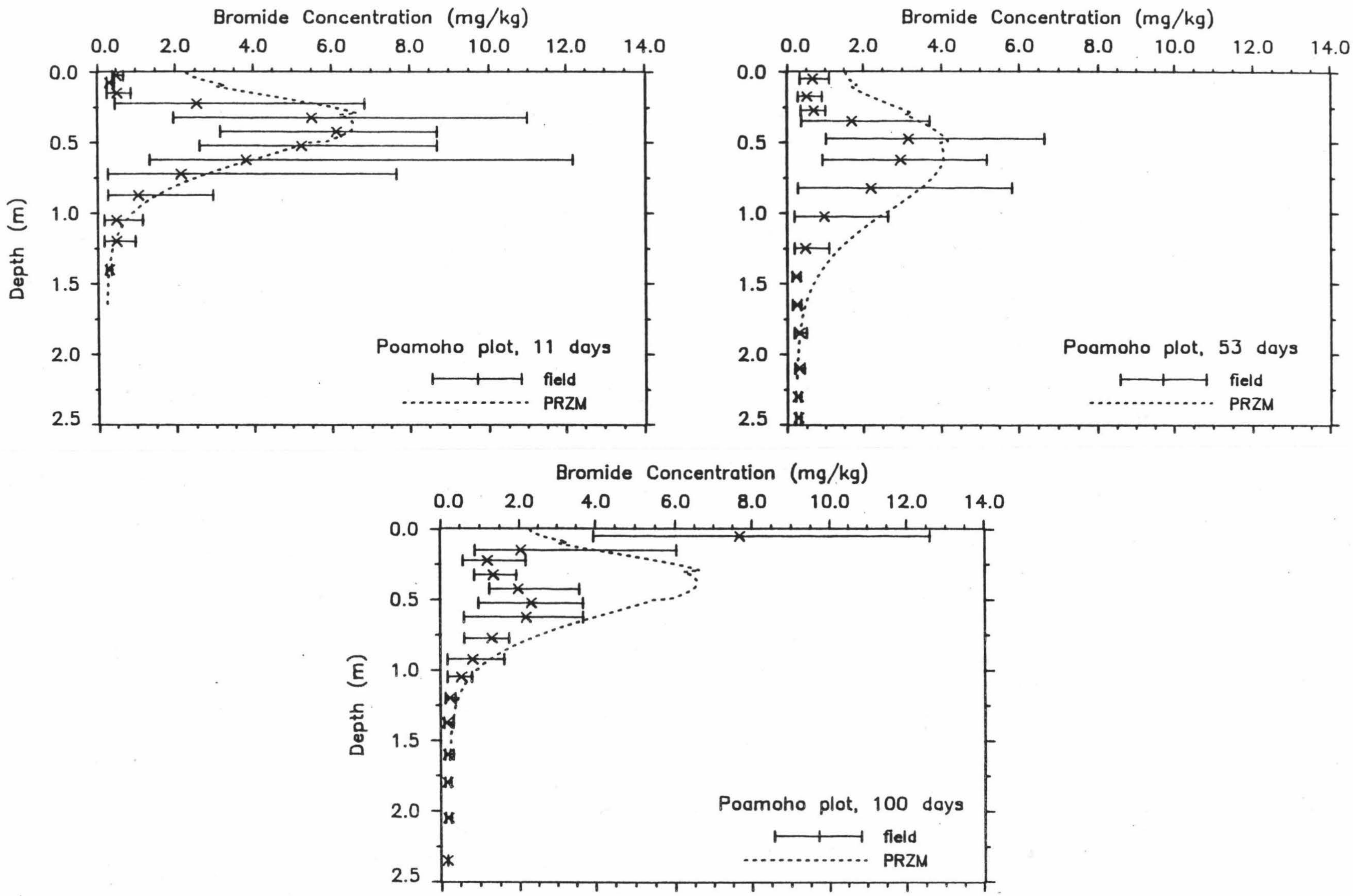


Figure 36. (Continued) PRZM vs. field data for bromide, (b) Poamoho plot

resulted in a single "best estimate" set of parameters at each of the sites (Tables 14 and 15). The values for ρ_b, f_{oc}, θ_{fc}, θ_{wp}, and the pan factor were predetermined from field data and the literature. Thus, the primary parameters which were adjusted to simulate the field data were D, K_{oc}, and k. The selected values for D were relatively close to those reported by Khan (1979) and provided an adequate simulation of the shapes of the bromide concentration profiles. The higher D value used at the Waiawa plot can be attributed to the more disturbed and heterogeneous nature of its soil as well as its larger and more frequent water input events.

PRZM simulations for chlorpyrifos and fenamiphos are shown in Figures 37 and 38. When compared with field data collected shortly after a pesticide application, PRZM tended to over predict near-surface concentrations, but as time progressed it underestimated the concentrations. This trend is probably caused by nonlinear, variable sorption, and non-first-order, variable transformation of pesticides. The greater persistence of observed pesticide concentrations with time may also suggest that desorption is occurring at a lower rate and/or the pesticides are being trapped in "dead end" pores or within soil aggregates. Findings of nonreversible sorption would be consistent with those of Buxton (1987). PRZM assumes constant, first-order, and linear pesticide relationships. Thus, it is not surprising that fenamiphos (Fen.TTR) was not accurately simulated by PRZM because it has metabolites of varying characteristics. The parameters used to simulate chlorpyrifos movement (Table 15) indicate that it is more mobile in soils from the two field plots and slightly more persistent in both soils than was indicated by laboratory determinations (Tables 12 and 13).

Statistical evaluation methods described by Loague and Green (1989a) were performed for all three chemical simulations using average field concentration profiles. These results are summarized in Table 16. Maximum error (ME) values for the pesticides decrease with time after applications and generally appear to be low for

Table 14

Soil and Hydrologic Parameters Used to Evaluate PRZM

Depth (m)	ρ_b (kg/m^3)	f_{oc} (kg/kg)	θ_{fc} (m^3/m^3)	D (m^2/day)
		WAIAWA FIELD PLOT		
0.0 - 0.05	1100	0.040	0.45	0.002
0.05 - 0.1	1100	0.015	0.45	0.002
0.1 - 0.2	1200	0.005	0.45	0.002
0.2 - 0.3	1200	0.004	0.45	0.002
0.3 - 0.5	1250	0.004	0.50	0.002
0.5 - 0.6	1250	0.003	0.50	0.002
0.6 - 0.8	1300	0.003	0.50	0.002
0.8 - 1.0	1350	0.003	0.50	0.002
1.0 - 3.0	1350	0.001	0.50	0.002
		POAMOHO FIELD PLOT		
0.0 - 0.1	950	0.017	0.35	0.001
0.1 - 0.2	1050	0.015	0.37	0.001
0.2 - 0.3	1150	0.010	0.37	0.001
0.3 - 0.4	1200	0.010	0.40	0.001
0.4 - 0.5	1200	0.008	0.40	0.001
0.5 - 0.7	1250	0.008	0.40	0.001
0.7 - 2.5	1300	0.005	0.42	0.001

ρ_b = bulk density
f_{oc} = mass fraction of organic carbon to dry soil
θ_{fc} = water content at field capacity
D = hydrodynamic dispersion coefficient
θ_{wp} = water content at wilting point = 0.25 m^3/m^3
pan factor = 1.0 for Waiawa plot since potential evapotranspiration was input
pan factor = 0.33 for Poamoho plot

Table 15

Chemical Parameters Derived from Modified Calibration of PRZM†

Depth (m)	Bromide K_{oc} m^3/kg	Bromide k day^{-1}	Chlorpyrifos K_{oc} m^3/kg	Chlorpyrifos k day^{-1}	Fen.TTR* K_{oc} m^3/kg	Fen.TTR* k day^{-1}
WAIAWA PLOT						
0.0 - 0.05	0.0	0.0	0.60	0.055	0.20	0.060
0.05 - 0.1	0.0	0.0	0.60	0.050	0.20	0.055
0.1 - 0.6	0.0	0.0	0.60	0.040	0.20	0.050
0.6 - 3.0	0.0	0.0	- - -	- - -	- - -	- - -
Application Rate (kg/ha)	22.85 & 45.7		8.82**		3.31**	
POAMOHO PLOT						
0.0 - 0.1	0.0	0.0	0.65	0.055	0.20	0.040
0.1 - 0.6	0.0	0.0	0.65	0.040	0.20	0.035
0.6 - 0.8	0.0	0.0	0.65	- - -	0.20	0.035
0.8 - 2.5	0.0	0.0	- - -	- - -	- - -	- - -
Application Rate (kg/ha)	45.7		8.82**		3.31**	

†Calibration consisted of an approximate best fit to all field data

*Fen.TTR includes the parent compound, f. sulfoxide, and f. sulfone

**These values were reduced to account for laboratory recoveries of 0.90 and 0.95 for chlorpyrifos and fenamiphos, respectively

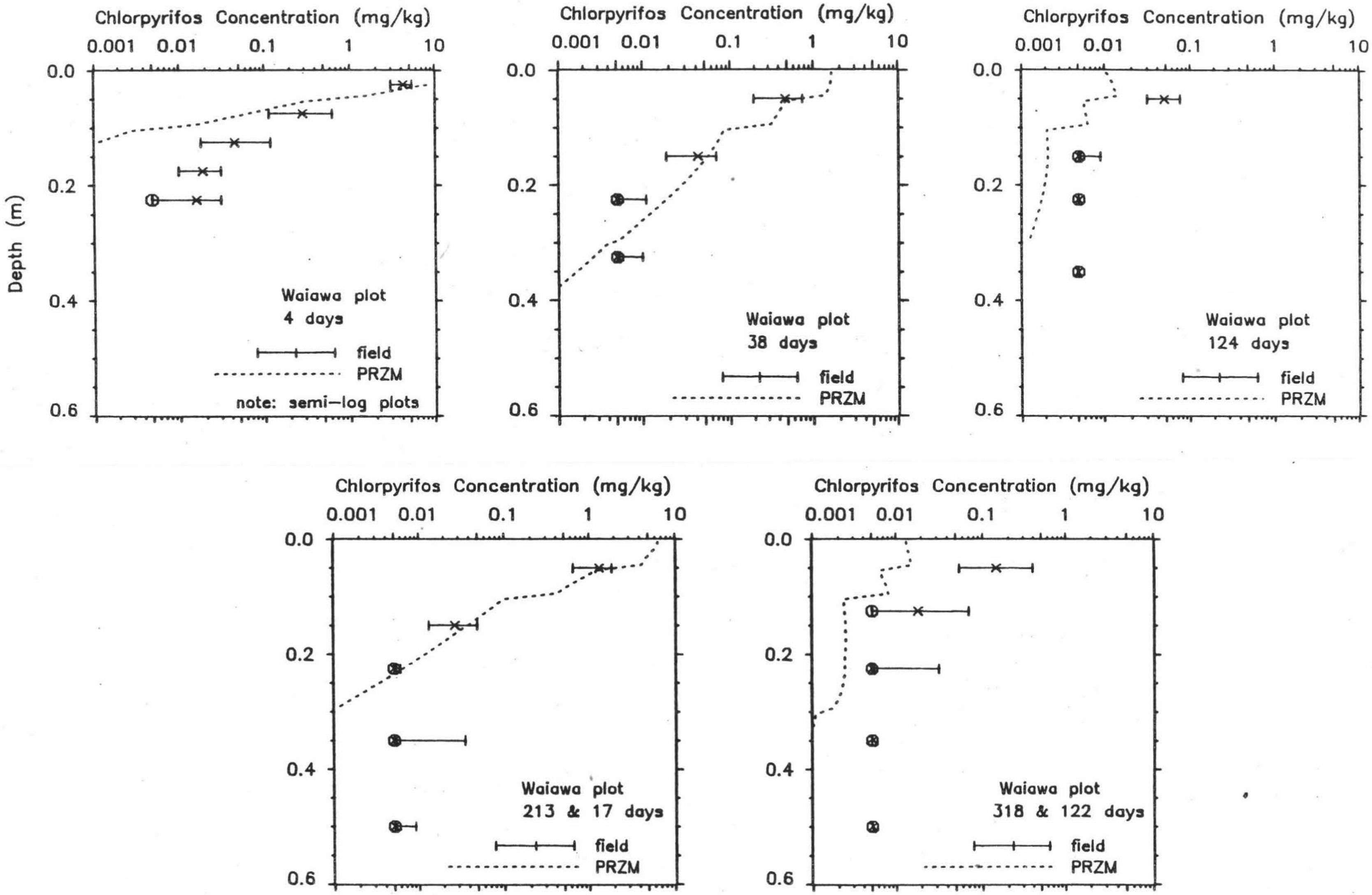


Figure 37. PRZM vs. field data for chlorpyrifos, (a) Waiawa plot

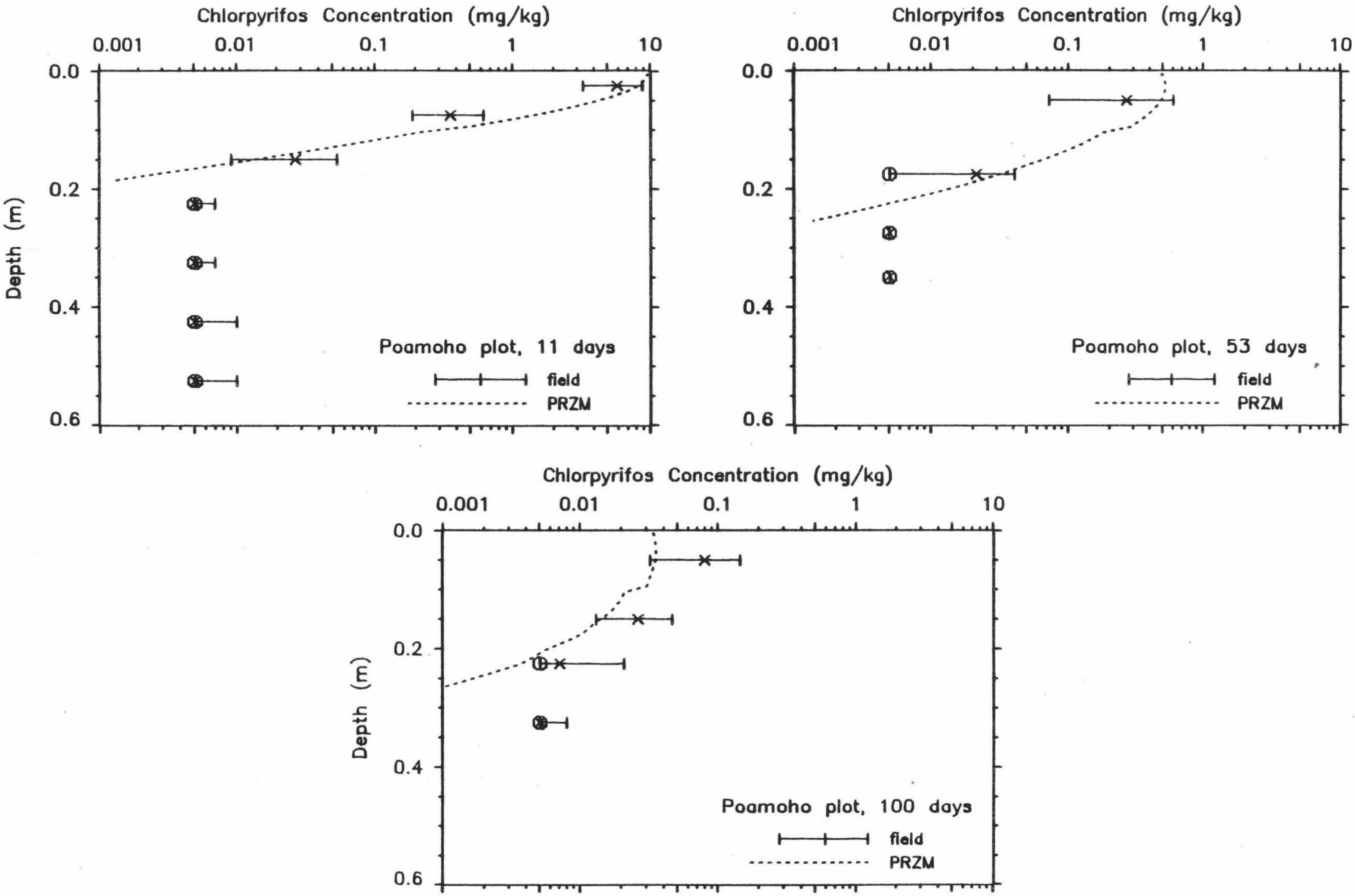


Figure 37. (Continued) PRZM vs. field data for chlorpyrifos, (b) Poamoho plot

Note: Fenamiphos reported as Fen.TTR, which includes the parent compound and its metabolites f. sulfoxide and f. sulfone

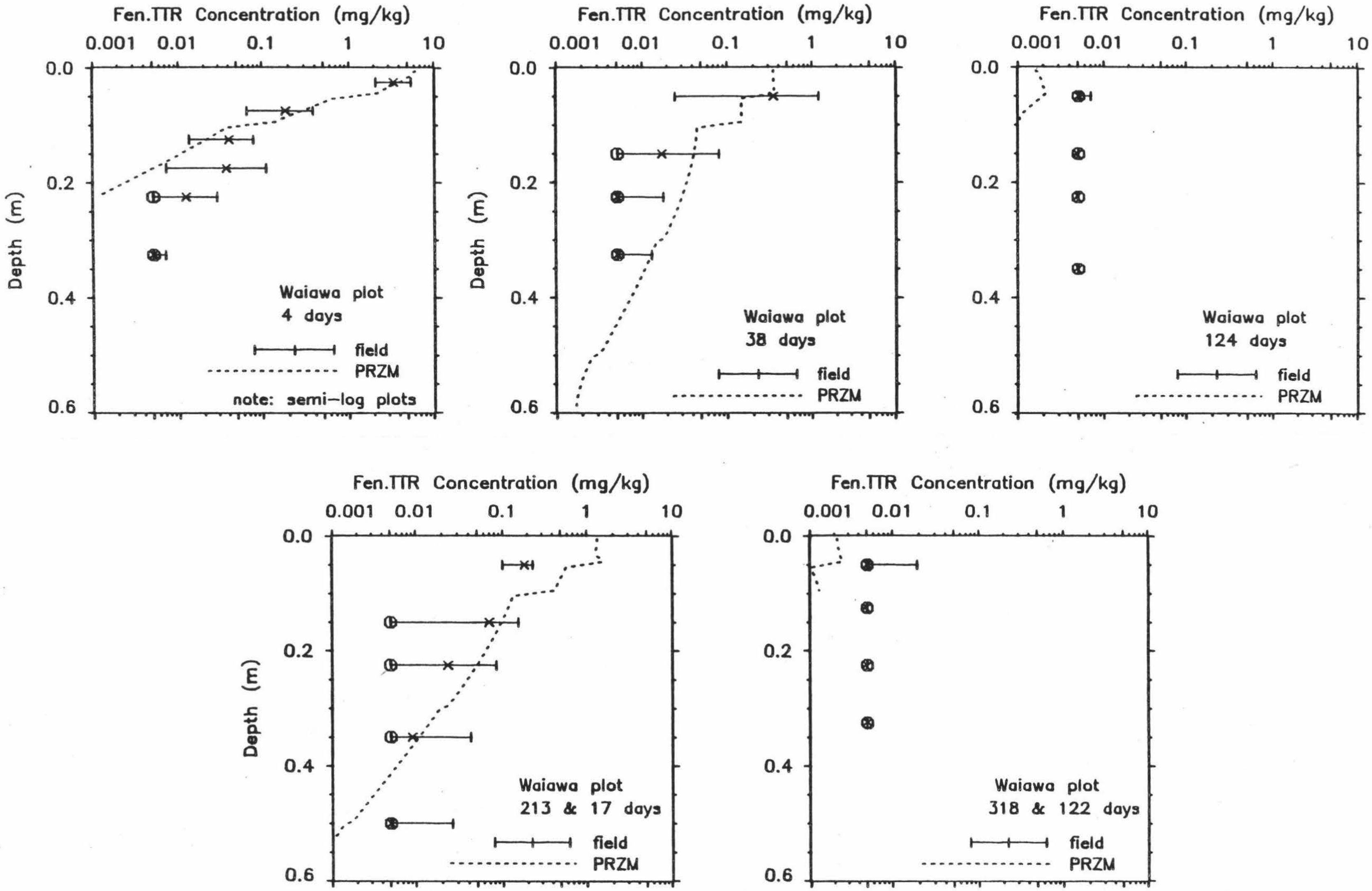


Figure 38. PRZM vs. field data for fenamiphos, (a) Waiawa plot

Note: Fenamiphos reported as Fen.TTR, which includes the parent compound and its metabolites f. sulfoxide and f. sulfone

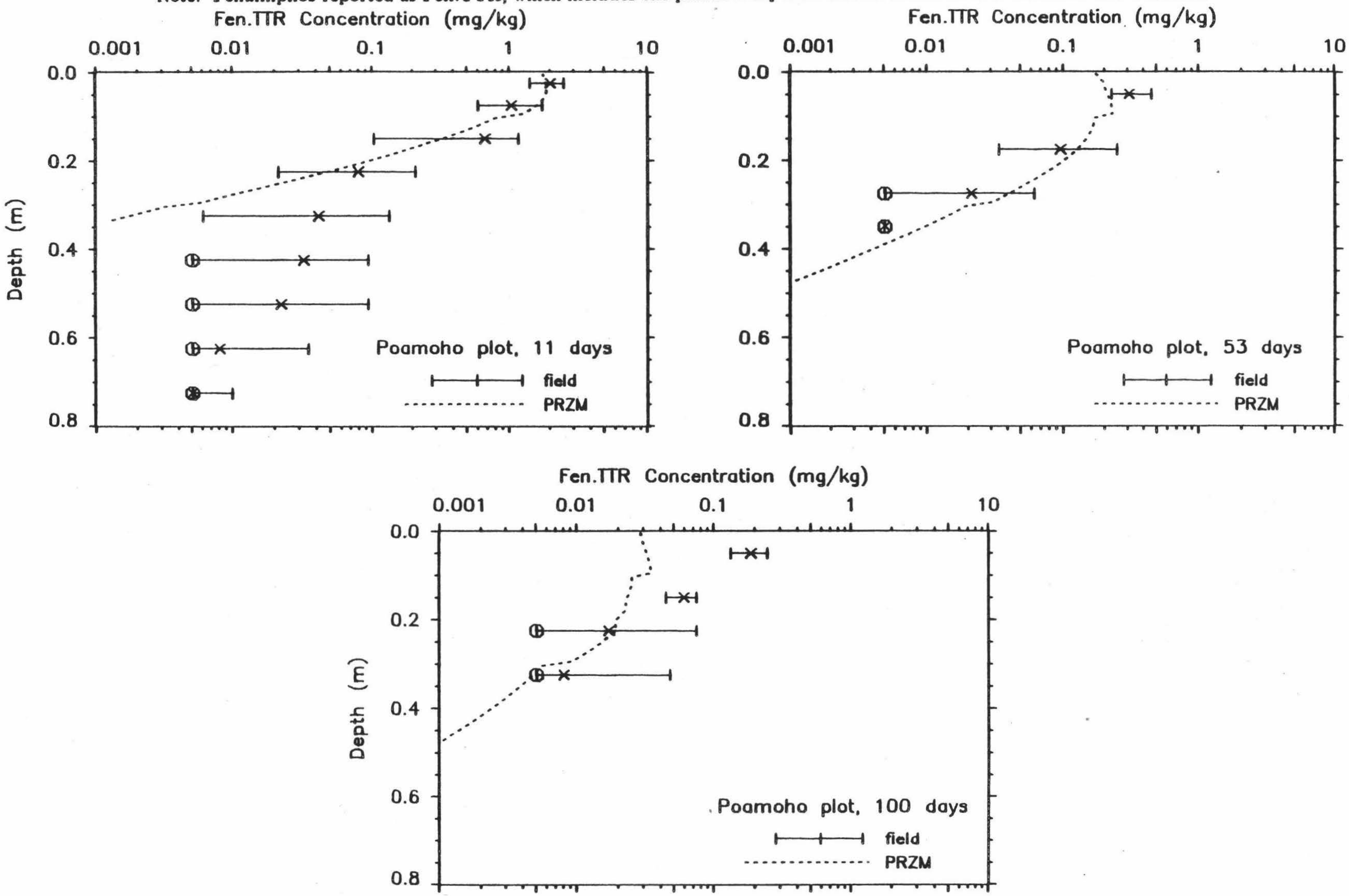


Figure 38. (Continued) PRZM vs. field data for fenamiphos, (b) Poamoho plot

Table 16

Statistical Summary of PRZM Evaluation

Sample†	ME	RMSE	CD	EF	CRM	N
wb1	13.79	143	3.63	0.45	-0.22	8
wb2	2.10	178	0.04	-21.74	-1.77	6
wb3	1.18	117	0.25	-2.73	-1.13	9
wb4	4.82	150	0.17	-3.59	-1.20	11
wb5	2.11	164	0.02	-60.16	-1.50	15
wc1	4.47	195	0.24	-0.16	-0.81	5
wc2	0.44	170	0.24	-0.25	-0.90	4^{*2}
wc3	0.04	135	3.11	0.05	0.74	4^{*3}
wc4	1.36	224	0.23	-0.34	-1.00	5^{*3}
wc5	0.13	156	2.27	-0.30	0.90	4^{*1}
wf1	0.66	45	0.69	0.95	-0.19	6^{*1}
wf2	0.09	53	2.18	0.89	0.09	4^{*2}
wf3	0.00	169	3.20	-0.60	0.22	4^{*4}
wf4	0.87	672	0.02	-33.84	-3.17	5^{*1}
wf5	0.00	84	4.97	-0.63	0.18	4^{*4}
pb1	3.41	71	0.82	0.44	-0.47	13
pb2	2.38	116	0.34	-0.35	-0.89	15
pb3	4.84	125	1.78	0.07	-0.54	16
pc1	2.51	116	0.48	0.74	-0.57	7^{*4}
pc2	0.22	152	0.27	0.03	-0.79	4^{*2}
pc3	0.04	80	2.13	0.41	0.55	4^{*1}
pf1	0.56	52	0.86	0.88	0.01	9^{*1}
pf2	0.10	48	2.37	0.82	0.10	4^{*1}
pf3	0.15	116	2.02	-0.27	0.71	4

ME = maximum error (mg/kg) **RMSE** = root mean square error
CD = coefficient of determination **EF** = modeling efficiency
CRM = coefficient of residual mass **N** = number of samples

A perfect match between observed and predicted concentration profiles would yield ME, RMSE, and CRM values of zero; and CD and EF values of one. These statistical criteria are defined in Table 5 and described by Loague and Green (1989a,b).

†Samples: w = Waiawa, p = Poamoho, b = bromide, c = chlorpyrifos, f = fenamiphos (Fen.TTR), numbers refer to sampling dates.

*At least one average concentration was below the limit of detection (LD), thus, an estimated field value equal to 0.5 LD was used for the first sample below LD and a field value of 0 was used for any deeper samples (see Appendix D). The numeral superscript after the asterisk indicates number of samples below LD.

fenamiphos. This may give the impression that PRZM performed better with time and that it accurately simulated fenamiphos transport, but these are not valid arguments if ME values are normalized with the observed concentrations.

Coefficient of variation (CD) values less than one indicate over predicted concentrations while CD values greater than one indicate under prediction. The CD results verify PRZM's general tendency to: (1) under predict bromide concentrations in general and (2) under predict pesticide concentrations at earlier times and over predict them at later times. A modeling efficiency (EF) value less than zero indicates that the predicted concentration profile is worse than that approximated by simply using the observed mean. Table 16 reveals that only the modeled results for chlorpyrifos at Poamoho have all EF values above zero. It should be recognized that the statistical analysis used mean concentrations from the field data to evaluate PRZM. When the ranges of observed concentrations are considered, the simulated results do not appear to be as dismal. Although PRZM simulated some of the pesticide profiles to a reasonable extent, it would again be inappropriate to claim that PRZM has been validated for pesticide transport through soil. This was particularly evident when PRZM was evaluated with the statistical criteria (*e.g.* modeling efficiencies generally less than zero).

2. PRZM Modification

In an attempt to approximate preferential flow, the modification of PRZM as discussed in Chapter IV was tested by varying MPM (macropore multiplier, the threshold determinant) and FCM (field capacity multiplier). Figure 39 (Appendix B) illustrates four different bromide simulations for the Waiawa plot at two times. Variations in MPM and FCM and their effects upon the simulated bromide concentration profiles are depicted in Figure 39. The first case uses a low MPM value and the third case uses a high FCM value. The second case is intermediate of the first and third while the fourth case simulates preferential flow only in the root zone. As expected, the modified version of PRZM is capable of transporting the bromide to much greater depths than the unmodified version. Case #4 is capable of reducing the simulated concentrations to levels close to those observed in the field without introducing an unrealistic advance in the bromide peak location. The statistical evaluation of case #4 for bromide at Waiawa is compared with results from unmodified PRZM in Table 20 (Appendix B). Despite the remaining discrepancy with bromide masses in the field, the modified PRZM results are better for almost every statistical value calculated. Although yielding some positive results, this altered version of PRZM requires additional testing due to its highly empirical and sensitive nature. It may also require additional modifications to differentiate and simultaneously simulate macropore flow as well as matrix flow. Therefore, it was not incorporated into the long-term PRZM simulations.

Another, unrelated modification to PRZM involved the use of a variable compartment thickness (∂z of equation 2-3). This modification was introduced to minimize the required amount of computer time for the long-term simulations of deep profiles. The use of thicker compartments at greater depths would increase the numerical dispersion of the results, but this was assumed to be tolerable when compared with the increased uncertainty in parameter estimates with depth. However, this modification was not implemented with the long-term simulations because the availability of computer services did not turn out to be a limiting factor.

3. Long-term PRZM Simulations

The maximum annual loading rates of diazinon, metribuzin, and nitrate to the water table for various scenarios are summarized in Table 17. The complete listing of

Table 17

Summary of Long-term PRZM Simulations

Simulated chemical	Land use	Profile†	Waiawa Ridge Max. Conc.*	Waiawa Valley Max. Conc.*
nitrate	lawn, no runoff	3	1.4 mg/l	1.2 mg/l
nitrate	apartment	2	0.76 mg/l	
nitrate	comm./indus.	2	0.34 mg/l	
nitrate	residential	2	0.80 mg/l	0.76 mg/l
nitrate	golf course	2	1.3 mg/l	
nitrate	apartment	2d	0.67 mg/l	
nitrate	comm./indus.	2d	0.28 mg/l	
nitrate	residential	2d	0.75 mg/l	0.64 mg/l
diazinon	apartment	3	2.2 μg/l	
diazinon	comm./indus.	3	8.5 μg/l	
diazinon	residential	3	2.2 μg/l	6.3 μg/l
diazinon	apartment	2	0.091 μg/l	
diazinon	comm./indus.	2	1.7 μg/l	
diazinon	residential	2	0.070 μg/l	2.8 μg/l
diazinon	apartment	3d	0.008 μg/l	
diazinon	comm./indus.	3d	LC	
diazinon	residential	3d	0.078 μg/l	0.81 μg/l
diazinon	apartment	2d	LC**	
diazinon	comm./indus.	2d	LC	
diazinon	residential	2d	LC	0.33 μg/l
diazinon	apartment	1d	LC	
diazinon	comm./indus.	1d	LC	
diazinon	residential	1d	LC	0.20 μg/l
metribuzin	lawn, no runoff	3	41 μg/l	
metribuzin	golf course	3	40 μg/l	
metribuzin	golf course	2	32 μg/l	
metribuzin	golf course	b2	31 μg/l	
metribuzin	golf course	1	23 μg/l	
metribuzin	lawn, no runoff	3h	0.21 μg/l	
metribuzin	golf course	3h	0.15 μg/l	
metribuzin	golf course	2h	0.003 μg/l	
metribuzin	golf course	b2h	0.003 μg/l	
metribuzin	golf course	1h	0.002 μg/l	

†1, 2, and 3 = increasing levels of surface grading; d = distributed at top of saprolite (default is advection dominated, see Figure 18; b = staggered metribuzin application dates; h = metribuzin hydrolysis included (default is without metribuzin hydrolysis); refer to Table 32 (Appendix F).

*concentrations are maximum annual averages at the water table

**LC = less than 0.001 μg/l

annual PRZM output from the unsaturated zone is presented in Tables 33 through 36 of Appendix F.

Long-term loading rates of chlorpyrifos to the water table are not presented in tabular format because there were no significant concentrations even at the shallow depth of 5 m. The maximum average annual dissolved concentration at 5 m, when distributed at the saprolite, is below 0.011 μg/l. This maximum average annual leaching of chlorpyrifos below 5 m is about 10 orders of magnitude lower than the application rate. In view of this, chlorpyrifos is not expected to be a threat to groundwater. The immobile and nonpersistent behavior of chlorpyrifos can be directly attributed to its very high K_{oc} value and high soil degradation and hydrolysis decay rates. However, consideration must be given to the toxic metabolite of chlorpyrifos. No information on decay or sorption was found in the literature for the metabolite 3,5,6-trichloro-2-pyridinol. If this metabolite is mobile and persistent, then chlorpyrifos may pose a threat to groundwater in a less direct but equally significant manner.

Based on application rates presented in Table 6 (Chapter IV), the maximum diazinon concentrations being leached to the water table are below 10 μg/l. The method of distributing the water and pesticide in the profile can decrease this maximum level by a few orders of magnitude by increasing the travel time through the vadose zone. Simulations of profiles representing higher elevations of the Waiawa Ridge have annual average diazinon concentrations nearly an order of magnitude lower than those at lower elevations on the ridge. The amount of organic carbon in the surface soil also has a significant effect on these concentrations (*i.e.* greater than one order of magnitude).

Simulation cases 635.d3 and 635.d2 (see Table 32 for description of case identifiers) which represent a land use with large fractions of impermeable surfaces and advection dominated flow illustrate the bias of the water distribution scheme shown in Figure 18 (Chapter IV). The travel times to groundwater are significantly shorter than if water had been distributed at the saprolite. These shorter travel times may be viewed as a very crude approximation of the possible consequence of preferential flow.

Metribuzin concentrations to the water table are most significantly affected by the hydrolysis rate used. The assumption of no hydrolysis increases the concentrations at the water table by several orders of magnitude. This observation underlines the importance of determining pesticide decay rates below the soil. Staggering the metribuzin application dates by three months had no significant impact on travel times or concentrations reaching the water table. This is not surprising when considering the relatively minimal seasonal variations in rainfall and the large time scale (37 years) which were used for the long-term simulations.

Nitrate concentrations introduced to the water table are near 1 mg/l (as nitrogen) for the assumed 3% leaching rate. The nitrate simulations also illustrate that the method used to distribute water within the profile can significantly affect travel time through the vadose zone. Longer travel times provide a reduction buffer for those chemicals which decay below the soil. However, for chemicals with negligible or very low decay rates (like nitrate), longer travel times merely result in longer residence times within the profile for any particular application. Thus, a longer period would be required to "flush out" the profile even after all chemical applications have ceased.

Simulated pesticide leachate concentrations input to the water table from the proposed Navy development site (Waiawa Valley concentrations listed in Table 17) are higher than those from the proposed Gentry developments on Waiawa Ridge. This is a result of the simulated depth to the water table as there is an inverse relationship between the profile thickness (and travel time) and concentrations of degradable chemicals arriving at the water table. However, the actual mass of chemicals introduced to the water table by the proposed Gentry developments are be expected to be higher due to its larger areal extent. There is also a great deal of uncertainty concerning the hydrologic properties of the alluvium in Waiawa Valley and the relationship between its alluvial aquifer and the underlying basal water table.

The long-term results discussed above are presented on an annual average basis. Significant variations from these annual averages can be expected on a smaller time scale. A comparison of PRZM's daily time series vs. annual values for recharge and loading rates of a particular nitrate simulation on selected years is shown in Figure 42 (Appendix F). These time series also illustrate the "piston displacement" nature of PRZM's drainage algorithm, where near-surface recharge events produce an immediate response at the water table. This may result in PRZM's over prediction of chemical concentrations at the water table, particularly on time scales as small as one day.

CHAPTER VI. CONCLUSIONS

The two field plots which were set aside for chemical leaching experiments provided a data base for preliminary evaluations of the near surface modeling effort. The protocol to conduct similar experiments has been established, fulfilling one of the objectives of this study. However, the utility of these experiments in determining long-term, deep leaching is limited due to scale restrictions in both time and space. Suggested mechanisms to account for the observed bromide mass balance deficiencies include lateral dispersion near plot boundaries and the by-passing of sampled profiles via preferential flow. Laboratory and field observations indicated greater mobility of chlorpyrifos than commonly reported in the literature. The distribution of soil organic carbon collected along four transects did not show any obvious spatial structure in the variance of this property.

PRZM occasionally simulated near surface solute transport with some degree of accuracy, but with a cursory analysis of residual errors coupled with qualitative graphical comparisons, it was evident that PRZM could not be validated with the collected field data. The comparison of PRZM simulations with field data revealed several of its limitations. In particular, its inability to incorporate complex pesticide transformation characteristics and its omission of algorithms to account for preferential flow and lateral dispersion. A highly simplistic empirical modification introduced to PRZM yielded some encouraging results but still requires extensive testing and may necessitate additional modifications. Modifications to account for PRZM's shortcomings may not be difficult to introduce but would require extensive site specific characterizations of these processes.

The inadequacies and inaccuracies of PRZM revealed during the near surface evaluation phase were then propagated into the predictive long-term simulations of transport through the deep unsaturated profiles. Despite the limited success of reported solute transport simulations, the approach of using a process oriented model is appropriate as it helps to identify those processes which require further understanding and improved mathematical descriptions.

Bearing in mind the large degree of uncertainty associated with the results, the long-term modeling effort presented in this thesis has shown that chemicals with properties similar to diazinon, metribuzin, and nitrate can reach the groundwater in detectable quantities. This finding is supported by the recent history of contamination at Waiawa Shaft. Specifically, the long-term simulations revealed that variations in the method of distributing water through the profile, and the wide range in estimated pesticide decay rates can produce differences in leachate concentrations spanning several orders of magnitude. Due to the large difference in elevations within the proposed development sites, and therefore the variation in profile thickness and travel time, the concentrations of pesticides varied by nearly an order of magnitude. The extent of surface grading practices may also affect the resultant concentrations of sorbed chemicals by more than an order of magnitude. The long-term PRZM simulations did provide the required input to the MOC groundwater model, but because of the large uncertainties involved, the primary objective of estimating chemical loading rates to the water table, as introduced by the proposed developments, was met with only limited success.

By considering the inherent uncertainties involved with modeling deep unsaturated profiles of Hawai'i, the simulated results are about as good as can be expected of a deterministic empirical modeling approach. The validity of PRZM for use on deep profiles in Hawaii is still not known. To test the validity of PRZM's drainage algorithm in deep profiles the extent and nature of preferential flow must be characterized, and to test the validity of PRZM's simulation of chemical transformations, the nature and rate of transformation processes require more attention.

A stochastic modeling approach may be more appropriate but it will also produce limited results until data which better characterize chemical movement and transformation in deep unsaturated profiles of Hawai'i are made available.

Thorough characterizations of chemical behavior and the exact nature of flow through the deep unsaturated Hawaiian profiles are difficult to obtain and unavailable at this time. Thus, an accurate and reliable estimate of the quantities of chemicals reaching the water table is not possible. A cumulative compilation of the specific chemicals which may be introduced by the proposed developments and their applied quantities is also difficult to assess, because in addition to the use of readily available and regulated pesticides and fertilizers, there may also exist the improper use and disposal of a multitude of other chemicals. Therefore, a comprehensive evaluation of the quantities and types of chemicals which may be introduced to groundwater by the proposed developments is beyond the scope of this study. This thesis does not address these issues of environmental concern, nor does it address numerous other relevant issues, including alternative land uses and land use practices, human overpopulation, and military expansionism.

Finally, this work emphasizes the need to reduce uncertainties in the parameters used to simulate solute transport through the deep unsaturated profiles of Hawai'i; the effects of preferential flow within the profile need to be characterized further, and as mentioned by Loague *et al.* (1989b), the characterization of chemical transformation rates at greater depths requires immediate attention. Obtaining believable long-term predictions of chemical fate in this study was most hampered by these deficiencies in data.

APPENDICES

APPENDIX A. Soil Descriptions

Descriptions of soil profiles from pits located near the Waiawa and Poamoho field plots are presented in Tables 18 and 19. The actual distributions of soil series in the Waiawa and Poamoho areas are documented by Foote *et al.* (1972). The location of the pit used to describe the soil profile at the Waiawa site (Table 18) is shown in Figure 23 (Chapter IV). The soil profile description at Poamoho (Table 19) was taken from a pit located within approximately 100 m to the west of the field plot.

Table 18

Waiawa Soil Profile (Oki *et al.*, 1990)

Soil Classification: Fine, mixed, ishohyperthermic Typic Troporthents

Location: Island of Oahu, Hawaii. University of Hawaii Water Resources Research Center study plot in Waiawa Valley on Navy land

Elevation: 40 m (130 feet)

Annual Rainfall: 102 cm (40 inches)

Vegetation: Guineagrass, koa haole

Parent Material: Colluvium or possibly fill, consisting of highly weathered basaltic rock fragments

Physiography: Nearly level gulch bottom and at the base of the gulch side

Slope: 2 percent (0 to 3 percent)

Drainage: Well drained

Ground water: Deep

Erosion: None

Permeability: Moderate

Stoniness: Nonstony (few rock fragments in places)

Described by: S. Nakamura, 2/16/89

Sampled by: S. Nakamura, Delwyn Oki, Robert Miyahira, Ed Murabayashi

Remarks: This soil is mapped as an inclusion with Kawaihapai stony clay loam, 2 to 6 percent slopes. It lacks stratified alluvial layers typical of the Kawaihapai soils. This soil is along the bottom of the gulch but at a higher level than the existing stream. The site was probably filled by material cut from the base of the gulch side.

Table 18. (Continued) Waiawa Soil Profile (Oki *et al.*, 1990)

A1 -- 0 to 10 cm (0-4"); fill layer of oyster shells and coral rock fragments; common fine and very fine roots; abrupt smooth boundary.

A2 -- 10 to 18 cm (4-7"); dark brown (10YR 3/3) clay loam; weak fine and medium subangular blocky structure; firm, sticky, and plastic; common fine and very fine roots; common very fine pores; clear smooth boundary.

C1 -- 18 to 75 cm (7-30"); variegated dark yellowish brown (10YR 4/4) yellowish brown (10YR 5/6) and dark brown (10YR 3/3) clay loam; weak fine and medium subangular blocky structure; friable, very sticky, and plastic; common very fine roots; common very fine pores; 10 percent weathered gravel and 3% weathered cobbles; gradual smooth boundary.

C2 -- 75-126 cm (30-50"); variegated yellowish brown (10YR 5/6), dark brown (10YR 4/4), and dark yellowish brown (10YR 4/6) gravelly clay loam; weak fine and medium subangular blocky structure; friable, very sticky, and plastic; few very fine roots; common very fine pores; 15% weathered gravel and 5% weathered cobbles; gradual smooth boundary.

C3 -- 126-190 cm (50-75"); variegated yellowish brown (10YR 5/6), dark brown (10YR 4/4), and dark yellowish brown (10YR 4/6) very gravelly clay loam; weak fine and medium subangular blocky structure; friable, very sticky, and plastic; few very fine roots; common very fine pores; 25% weathered gravel and 10% weathered cobbles.

Table 19

Poamoho Soil Profile (Green *et al.*, 1982)

Site:	W1
Soil:	Wahiawa silty clay, Tropeptic Eutrustox; clayey, kaolinitic, isohyperthermic family
Location:	O'ahu UH Poamoho Experimental Farm; Poamoho II site, about 15 m (50 ft) SW of Kaukonahua Rd. and 46 m (150 ft) NW of reservoir
Date:	5 July 1977
Description by:	S. Nakamura, Soil Conservation Service
Topography:	Gently sloping upland; 7% slope
Parent Material:	Residuum from basic igneous rock
Elevation:	213 m (700 ft)
Annual Rainfall:	1 016 mm (40 in.)
Drainage and Permeability:	Well drained; moderately rapid permeability (low end of moderately rapid)
Erosion:	None
Stoniness:	None
Vegetation:	Guineagrass, natal redtop, lantana, koa-haole
Remarks:	Representative of Wahiawa series

Profile Description: (Colors for moist soil unless otherwise noted; all textures "apparent field textures")

Ap 0-30 cm (0-12 in.)—Very dusky red (2.5 YR 2/2) silty clay; weak, very fine granular structure; friable, very sticky and plastic; many pores; many roots; many very fine manganese concretions; clear, smooth boundary

B21 30-96 cm (12-38 in.)—Dark reddish brown (2.5 YR 2/4) silty clay; gritty due to earthy lumps; strong, fine and very fine subangular blocky structure; few roots; common very fine pores; common manganese concretions and stains; nearly continuous pressure faces; compact in place; diffuse, smooth boundary

B22 96-112 cm (38-44 in.)—Dark reddish brown (2.5 YR 2/4) silty clay; moderate, fine and medium subangular blocky structure; friable, stocky and plastic; few roots, many very fine pores; common pressure faces; common manganese stains and concretions; firm in place

APPENDIX B. Modified PRZM

Minor modifications to the HYDR1 subroutine (option #1 -- free draining profile, discussed in Chapter II) are as follows (** denotes a modified line):

```
         DO 20 I=1,NCOM2
            THETO(I) = SW(I)/DELX
            THETN(I) = (SW(I)+AINF(I)-ET(I))/DELX
            AINF(I+1) = 0.0
            IF(THETN(I).LE.THEFC(I)) GO TO 10
**             MPTMP(I) = MPM(I)*THETAS(I)
**             IF(THETN(I).GE.MPTMP(I)) THEN
**                FCTMP(I) = THEFC(I)
**                THEFC(I) = FCM(I)*THEFC(I)
**                AINF(I+1) = (THETN(I)-THEFC(I))*DELX
**                THETN(I) = THEFC(I)
**                THEFC(I) = FCTMP(I)
**                GO TO 10
**             ENDIF
            AINF(I+1) = (THETN(I)-THEFC(I))*DELX
            THETN(I) = THEFC(I)
      10    CONTINUE
            VEL(I) = AINF(I+1)/THETN(I)
         SW(I) = THETN(I)*DELX
      20 CONTINUE
```

Where, († denotes new variable)

AINF = amount of infiltration
DELX = thickness of each compartment (unit of discretization)
ET = amount of evapotranspired water
NCOM2 = number of compartments in the profile
SW = amount of soil water
THEFC = field capacity (also assumed = specific yield)
THETAS = saturated water content
THETN = new water content
THETO = initial water content
VEL = velocity of water movement

† MPM = macropore multiplier; this variable determines the "macropore trigger" for its respective compartment; THEFC will be reduced when the new water content meets or exceeds the desired number of pore volumes (saturated moisture content = one pore volume)

† MPTMP = temporary "trigger value" to set off macropore flow

† FCM = field capacity multiplier for its representative soil compartment; reduces THEFC to approximate macropore dominated drainage

† FCTMP = temporary variable to allow resetting of field capacity

Figure 39 compares modified PRZM and unmodified PRZM with observed bromide concentrations for two sample collection dates at the Waiawa field plot. Case #1 has MPM and FCM values of 1.0 and 0.5, respectively. This means that the field capacity is reduced by 0.5 whenever the amount of water available for infiltration is equal to the soil pore volume (of the compartment). Case #2 has the same FCM value, but a higher MPM value than case #1. This larger MPM value results in fewer instances (due to a higher threshold value) of "macropore flow", as evidenced by a slower advance of the bromide peak (Figure 39). Case #3 has a larger FCM value, thus reducing the amount of additional water which can be drained from the profile and resulting in a much slower advance of the bromide peak than the previous two cases. Case #4 uses the same values as case #3, but they are applied only to the top 0.3 m of the profile. This results in bromide profiles close to those of unmodified PRZM but with a slightly reduced peak at a slightly greater depth. Table 20 presents the statistical criteria of unmodified PRZM and modified PRZM (case #4) versus the field data for bromide at the Waiawa field plot for two of the sample collection dates.

Table 20

Statistical Summary of Modified PRZM Simulation

PRZM version	Sample	ME	RMSE	CD	EF	CRM	N
unmodified	wb2	2.10	178.14	0.04	-21.74	-1.77	6
unmodified	wb3	1.18	116.95	0.25	-2.73	-1.13	9
modified	wb2m	2.09	142.11	0.08	-13.47	-1.32	6
modified	wb3m	1.22	99.36	0.49	-1.69	-0.78	9

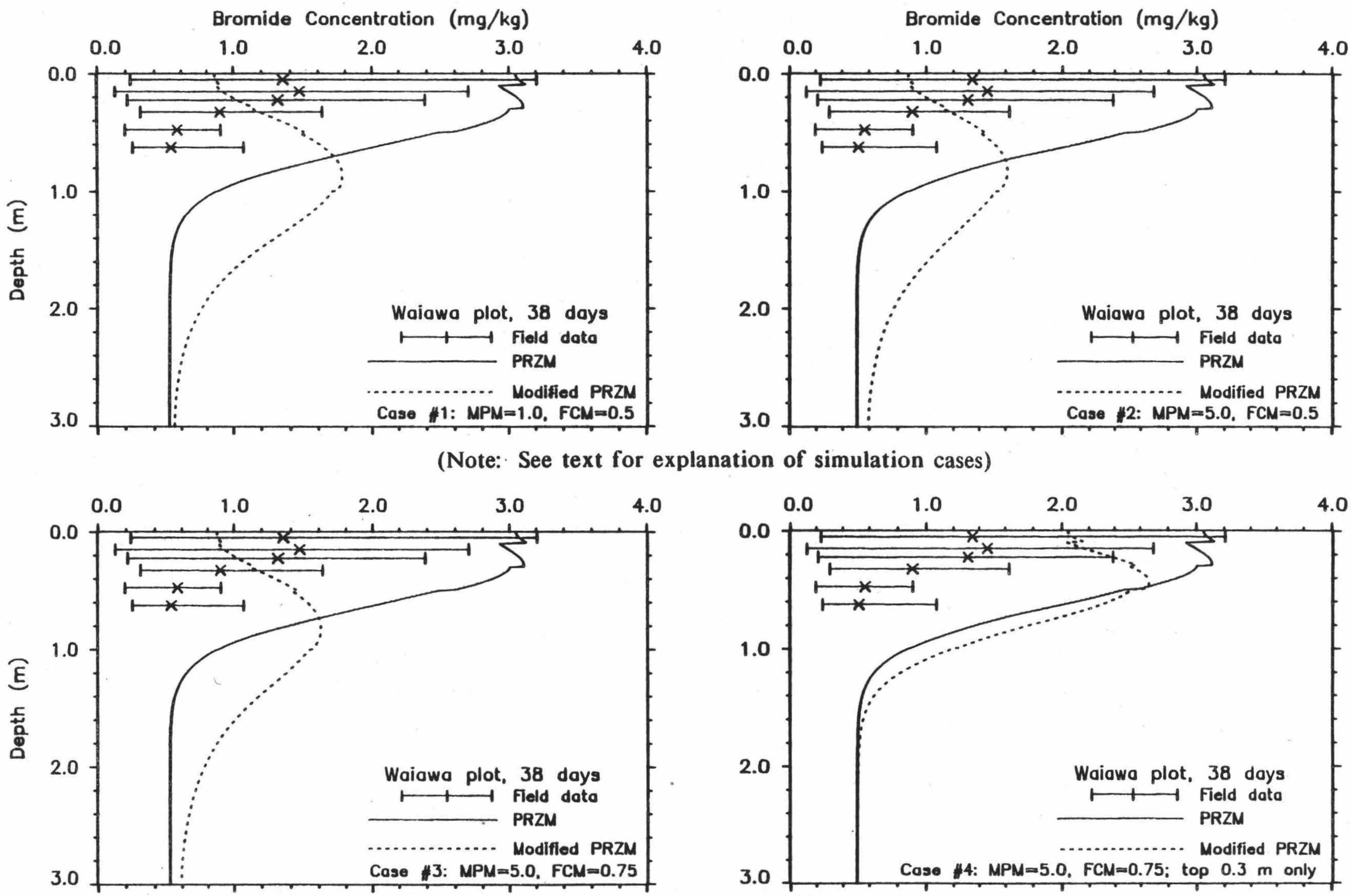


Figure 39. Modified and unmodified PRZM vs. Waiawa field plot data for bromide, (a) 38 days post-application

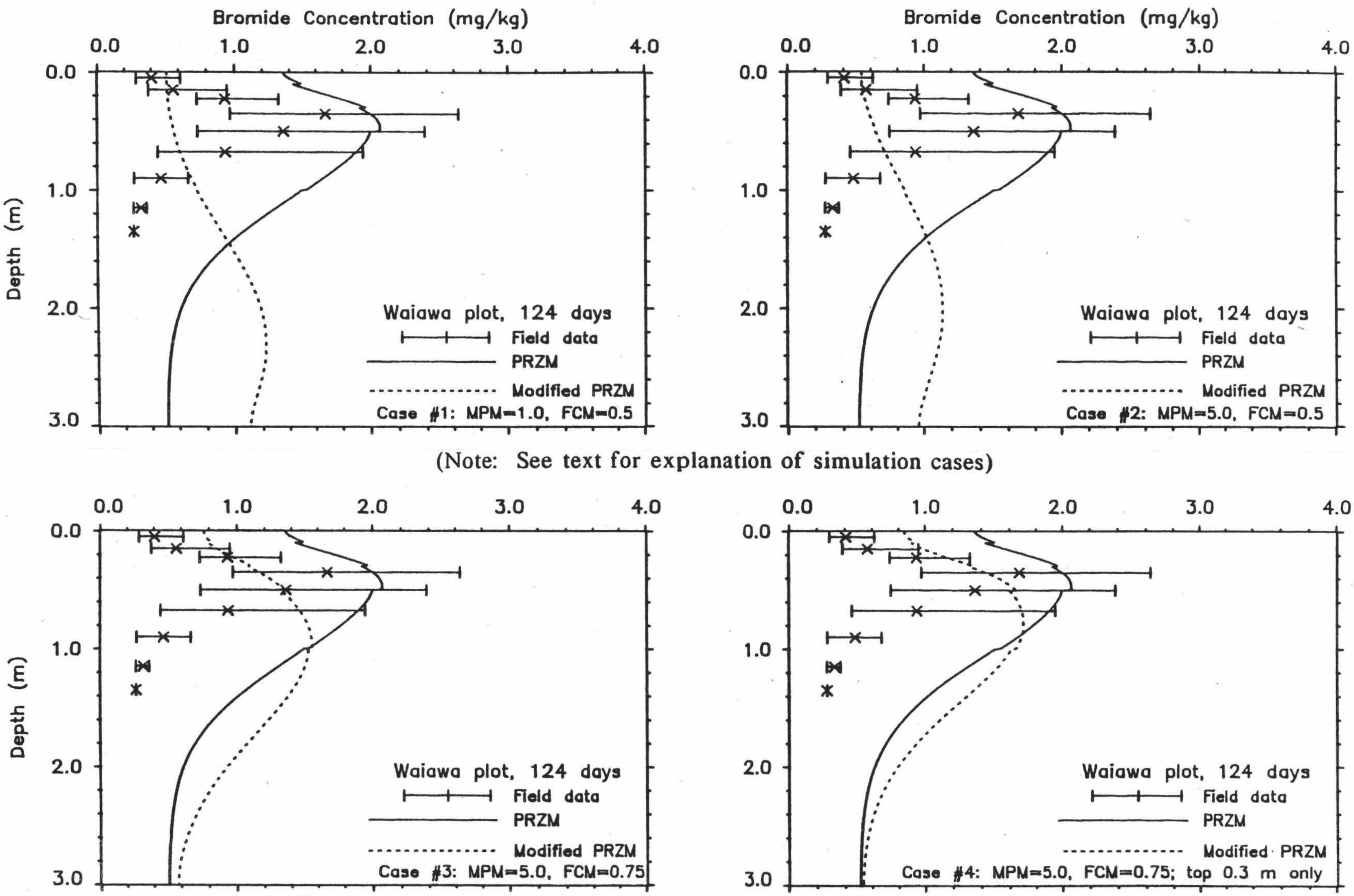


Figure 39. (Continued) Modified and unmodified PRZM vs. Waiawa field plot data for bromide, (b) 124 days post-application

APPENDIX C. Field Meteorologic Data

Daily meteorologic data from both of the field sites are listed in Tables 21 and 22. The rainfall and irrigation values are also presented in Figures 27 through 29 of Chapter V.

Table 21

Daily Meteorologic Data from the Waiawa Site

Date (MDY)	RIR (mm)	PE (mm)	Date (MDY)	RIR (mm)	PE (mm)	Date (MDY)	RIR (mm)	PE (mm)
62388	1.00	3.34	80188	0.60	4.54	90988	12.00	2.21
62488	14.30	5.48	80288	2.60	4.54	91088	1.00	4.76
62588	0.00	4.57	80388	16.10	4.54	91188	2.00	2.62
62688	3.00	5.10	80488	0.00	2.83	91288	0.00	5.04
62788	2.00	5.22	80588	0.00	3.89	91388	0.00	4.81
62888	0.00	4.17	80688	0.00	5.21	91488	1.00	4.27
62988	0.00	5.02	80788	0.00	4.36	91588	1.00	4.30
63088	0.00	4.98	80888	0.00	4.03	91688	0.00	5.02
70188	51.70	5.09	80988	0.00	4.29	91788	2.00	4.91
70288	0.00	5.46	81088	0.00	3.74	91888	4.00	4.38
70388	0.00	5.15	81188	14.00	5.38	91988	1.00	4.38
70488	0.00	2.86	81288	1.00	5.47	92088	1.00	4.38
70588	1.00	4.78	81388	0.00	5.37	92188	52.40	4.38
70688	1.00	4.73	81488	1.00	4.31	92288	2.00	2.67
70788	9.00	3.34	81588	2.00	5.45	92388	10.00	3.58
70888	32.90	5.35	81688	2.00	5.31	92488	1.00	4.16
70988	2.00	5.13	81788	0.00	2.69	92588	0.00	5.20
71088	1.00	5.33	81888	0.95	4.73	92688	2.00	4.82
71188	0.00	3.20	81988	1.00	3.48	92788	5.00	4.00
71288	2.00	3.63	82088	2.00	3.09	92888	0.00	4.47
71388	1.00	4.48	82188	5.00	5.32	92988	0.00	3.43
71488	2.00	4.40	82288	52.70	5.46	93088	45.90	4.43
71588	48.40	5.13	82388	0.00	5.31	100188	0.00	4.19
71688	0.00	5.41	82488	0.00	3.21	100288	0.00	2.66
71788	0.00	5.56	82588	0.00	3.81	100388	0.00	4.47
71888	1.00	5.57	82688	0.00	5.54	100488	0.00	3.20
71988	0.00	4.72	82788	3.00	5.43	100588	0.00	4.32
72088	0.00	5.28	82888	1.00	4.90	100688	0.00	3.12
72188	0.00	5.14	82988	5.00	4.64	100788	3.00	3.63
72288	48.60	5.20	83088	7.00	4.49	100888	0.00	3.63
72388	0.00	4.85	83188	0.00	4.50	100988	0.00	3.63
72488	0.00	3.72	90188	0.00	3.86	101088	0.00	3.63
72588	0.00	2.44	90288	0.00	5.30	101188	0.00	3.63
72688	0.00	2.54	90388	0.00	4.62	101288	2.00	3.63
72788	0.00	4.54	90488	0.00	5.22	101388	11.00	3.63
72888	0.00	4.54	90588	1.00	4.25	101488	0.00	3.63
72988	0.20	4.54	90688	0.00	5.33	101588	0.00	3.63
73088	0.50	4.54	90788	0.00	5.27	101688	16.00	3.63
73188	0.00	4.54	90888	0.00	5.22	101788	0.00	3.63

Note: Date expressed in month-day-year format
RIR = rainfall + irrigation
PE = potential evapotranspiration

Table 21. (Continued) Daily Meteorologic Data from the Waiawa Site

Date (MDY)	RIR (mm)	PE (mm)	Date (MDY)	RIR (mm)	PE (mm)	Date (MDY)	RIR (mm)	PE (mm)
101888	41.30	3.63	120288	0.00	3.02	11689	1.00	3.35
101988	0.00	3.63	120388	0.00	3.02	11789	1.00	2.93
102088	0.00	3.63	120488	0.00	3.02	11889	0.00	3.08
102188	43.10	3.63	120588	1.00	3.02	11989	0.00	2.93
102288	1.05	3.63	120688	96.00	3.02	12089	4.00	3.63
102388	0.00	3.63	120788	1.00	3.02	12189	1.00	3.48
102488	0.75	3.63	120888	2.00	3.02	12289	1.00	2.63
102588	0.00	3.63	120988	0.00	3.02	12389	0.00	1.68
102688	0.30	3.63	121088	0.00	3.02	12489	0.00	3.31
102788	0.00	3.63	121188	1.00	3.02	12589	0.00	4.08
102888	0.00	3.63	121288	18.00	3.02	12689	0.00	4.17
102988	0.00	3.63	121388	8.00	3.02	12789	1.00	3.46
103088	0.60	3.63	121488	0.00	3.02	12889	3.00	3.10
103188	0.60	3.63	121588	5.00	3.02	12989	3.00	4.24
110188	1.50	3.33	121688	30.00	3.02	13089	0.00	2.97
110288	3.20	3.33	121788	7.00	3.02	13189	0.00	3.37
110388	0.00	3.33	121888	1.00	3.02	20189	9.00	2.75
110488	57.70	3.33	121988	0.00	3.02	20289	93.00	1.20
110588	23.10	3.33	122088	0.00	3.02	20389	0.00	3.06
110688	2.00	3.33	122188	0.00	3.02	20489	5.00	2.87
110788	0.00	3.33	122288	0.00	3.02	20589	20.00	3.37
110888	0.00	3.33	122388	1.00	3.02	20689	0.00	2.86
110988	38.30	3.33	122488	0.00	3.02	20789	1.00	2.56
111088	1.00	3.33	122588	1.00	3.02	20889	0.00	4.31
111188	0.00	3.33	122688	0.00	3.02	20989	3.00	3.54
111288	0.00	3.33	122788	9.00	3.02	21089	36.00	2.25
111388	7.00	3.33	122888	8.00	3.02	21189	86.00	1.26
111488	0.00	3.33	122988	10.00	3.02	21289	0.00	3.62
111588	0.00	3.33	123088	9.00	3.02	21389	0.00	3.70
111688	37.10	3.33	123188	6.00	4.68	21489	0.00	2.43
111788	0.00	3.33	10189	0.00	3.69	21589	0.00	3.52
111888	0.00	3.33	10289	2.00	2.83	21689	0.00	3.10
111988	3.00	3.33	10389	4.00	3.02	21789	0.00	3.53
112088	7.00	3.33	10489	3.00	3.01	21889	0.00	3.22
112188	5.00	3.33	10589	4.00	2.82	21989	3.00	3.29
112288	14.00	3.33	10689	18.00	2.83	22089	1.00	3.63
112388	2.00	3.33	10789	8.00	3.11	22189	27.00	2.62
112488	2.00	3.33	10889	11.00	2.49	22289	1.00	2.27
112588	13.00	3.33	10989	18.00	2.62	22389	11.00	2.87
112688	0.00	3.33	11089	26.00	2.93	22489	2.00	1.60
112788	0.00	3.33	11189	61.00	1.48	22589	0.00	3.66
112888	6.00	3.33	11289	10.00	2.03	22689	0.00	4.08
112988	0.00	3.33	11389	12.00	0.58	22789	0.00	1.34
113088	0.00	3.33	11489	0.00	2.20	22889	6.00	2.20
120188	0.00	3.02	11589	0.00	2.91	30189	36.00	1.71

Table 21. (Continued) Daily Meteorologic Data from the Waiawa Site

Date (MDY)	RIR (mm)	PE (mm)	Date (MDY)	RIR (mm)	PE (mm)	Date (MDY)	RIR (mm)	PE (mm)
30289	23.00	3.09	32589	4.00	3.14	41789	0.00	3.93
30389	20.00	3.88	32689	0.00	3.65	50889	0.00	5.00
30489	0.00	3.21	32789	0.00	5.27	41889	0.00	3.93
30589	0.00	4.74	32889	1.00	5.02	41989	1.00	3.93
30689	1.00	4.33	32989	0.00	4.86	42089	2.00	2.17
30789	0.00	4.30	33089	0.00	4.40	42189	11.00	5.18
30889	0.00	4.00	33189	3.00	3.04	42289	3.00	5.32
30989	0.00	3.29	40189	5.00	4.98	42389	0.00	3.77
31089	0.00	3.54	40289	13.00	3.32	42489	0.00	4.26
31189	0.00	3.00	40389	3.00	3.57	42589	0.00	3.86
31289	1.00	2.75	40489	19.00	2.72	42689	2.00	3.56
31389	0.00	5.17	40589	0.00	3.90	42789	0.00	5.22
31489	0.00	3.51	40689	0.00	4.41	42889	0.00	3.30
31589	0.00	4.03	40789	7.00	3.95	42989	0.00	4.26
31689	0.00	3.71	40889	4.80	3.93	43089	0.00	2.90
31789	0.00	4.30	40989	5.70	3.93	50189	0.00	3.08
31889	0.00	3.74	41089	0.00	3.93	50289	0.00	3.39
31989	0.00	4.17	41189	0.00	3.93	50389	0.00	5.12
32089	0.00	4.61	41289	0.00	3.93	50489	0.00	5.13
32189	0.00	5.02	41389	0.00	3.93	50589	0.00	2.61
32289	0.00	4.85	41489	0.00	3.93	50689	0.00	5.52
32389	0.00	3.89	41589	0.00	3.93	50789	0.00	5.00
32489	1.00	3.98	41689	0.00	3.93			

Table 22

Daily Meteorologic Data from the Poamoho Site

Date (MDY)	RIR (mm)	Pan (mm)	Date (MDY)	RIR (mm)	Pan (mm)	Date (MDY)	RIR (mm)	Pan (mm)
22489	2.50	3.73	33189	0.50	5.70	50589	0.00	2.80
22589	0.10	3.73	40189	0.80	3.50	50689	0.00	4.00
22689	0.00	3.73	40289	4.80	5.40	50789	0.00	1.40
22789	31.90	3.73	40389	5.30	2.20	50889	0.00	2.90
22889	28.70	3.73	40489	38.40	4.43	50989	0.00	5.70
30189	1.00	4.49	40589	13.50	4.43	51089	0.00	4.50
30289	67.80	4.49	40689	0.00	3.10	51189	0.00	5.60
30389	34.00	3.70	40789	0.80	4.43	51289	0.80	4.10
30489	13.00	3.90	40889	5.80	4.43	51389	0.00	5.50
30589	1.80	4.49	40989	43.40	4.43	51489	0.50	3.10
30689	0.00	1.80	41089	0.80	3.20	51589	2.50	4.10
30789	0.30	4.49	41189	0.00	3.70	51689	0.00	6.80
30889	0.00	2.90	41289	2.00	3.10	51789	0.00	4.90
30989	0.00	3.40	41389	1.00	4.43	51889	0.00	6.50
31089	0.00	2.40	41489	0.00	4.00	51989	2.30	6.20
31189	0.00	1.40	41589	0.10	4.00	52089	0.10	5.60
31289	0.80	2.30	41689	0.10	5.80	52189	0.00	6.30
31389	0.00	2.80	41789	0.00	3.10	52289	0.10	6.00
31489	0.30	3.90	41889	0.00	3.50	52389	21.80	4.20
31589	0.00	3.50	41989	0.00	5.60	52489	0.10	5.10
31689	0.00	3.80	42089	0.80	3.20	52589	0.00	4.20
31789	0.00	3.30	42189	1.00	6.30	52689	0.00	3.70
31889	0.00	2.50	42289	8.10	4.70	52789	0.30	6.70
31989	0.00	4.50	42389	1.80	6.80	52889	0.00	6.40
32089	0.00	3.70	42489	0.00	3.50	52989	0.00	7.40
32189	0.00	4.10	42589	0.00	5.80	53089	0.00	6.50
32289	0.00	6.10	42689	0.00	4.80	53189	2.30	5.60
32389	0.00	6.00	42789	0.30	3.70	60189	8.10	4.40
32489	0.00	4.10	42889	2.50	2.00	60289	3.00	2.60
32589	0.50	3.70	42989	0.30	2.60	60389	0.00	3.80
32689	11.40	3.80	43089	0.00	2.80	60489	0.00	5.80
32789	0.30	5.50	50189	0.00	2.00	60589	0.80	4.90
32889	0.00	3.50	50289	0.00	3.20	60689	0.00	1.50
32989	0.30	4.30	50389	0.00	4.90	60789	0.00	8.10
33089	0.00	4.80	50489	0.00	3.10			

Note: Date expressed in month-day-year format
RIR = rainfall + irrigation
Pan = pan evaporation

APPENDIX D. Field Chemical Concentrations

Tables 23 and 24 list the depth intervals (to the nearest 0.05 m) and chemical concentrations of all samples collected at the two field sites.

Since the depth and number of sampled intervals varied with each of the six cores collected on each of the collection dates, representative sample midpoints were assigned to approximate the sample midpoints typified by the 6 cores. Once these representative sample depths were assigned, the measured chemical concentrations within each sampled depth interval were assumed to be constant and then accordingly assigned to the selected representative depths. For example, whether a selected representative depth corresponded to the upper or lower portion of a particular sample made no difference in its assigned concentration. In other words, no attempt was made at characterizing the variation in concentrations within sampled depth intervals. If the representative depth was located on the boundary between two samples, then the arithmetic means of the concentrations were assigned. The summarized field concentrations used in Figures 30, 32, 33, 36, 37, and 38 (Chapter V) are listed in Tables 25 and 26.

While summarizing the pesticide concentration profiles of Tables 25 and 26 to be used for the statistical analysis, those values below the limit of detection (LD) were averaged in a slightly different manner. Rather than equating all concentrations that were below LD to zero, the first sample with a pesticide concentration below LD was assigned a concentration equal to half of the LD, or 0.0035 mg/kg (0.5 x 0.007 mg/kg). Only the samples which were deeper than this were assigned a concentration value of zero. This procedure attempts to account for concentrations of pesticides which are present but not quantifiable due to the detection limitations in the laboratory. This explains why some of the summarized concentrations in Tables 25 and 26 are below LD.

Mass balance calculations also used the method described above to quantify pesticide concentrations throughout each profile. The remaining mass fraction was calculated as: M/M_o

where, M = current chemical mass within field plot (kg/m²)
M_o = original chemical mass applied to field plot (kg/m²)

and M is calculated by:

$$M = \sum_{i=1}^{n} C_i \rho_{b_i} d_i A$$

where, C_i = measured chemical concentration (mg/kg)
ρ_{b_i} = bulk density (kg/m³)
d_i = sample depth interval (m)
A = area of field plot (m²)
n = number of samples in profile where $C > 0$

Background bromide concentrations of 0.5 and 0.2 mg/kg were subtracted from measured values at the Waiawa and Poamoho field plots, respectively. M_o values for chlorpyrifos and fenamiphos (Fen.TTR) were reduced by 0.90 and 0.95, respectively, to account for laboratory extraction efficiencies (recoveries). The mass fraction can also be expressed as C/C_o (current concentration over original concentration) as presented in Figures 31 and 34 of Chapter V.

Table 23

Chemical Concentration Profiles at the Waiawa Plot, a) First Sampling (June 28, 1988; 4 Days Post-application)

Profile W11A depth (m)	Bromide mg/kg	Chlorp. mg/kg	Fen.TTR mg/kg	Profile W11B depth (m)	Bromide mg/kg	Chlorp. mg/kg	Fen.TTR mg/kg
0.00 - 0.05	39.10	6.103	3.146	0.00 - 0.05	39.55	5.459	3.274
0.05 - 0.10	2.57	0.696	0.381	0.05 - 0.10	0.62	0.144	0.065
0.10 - 0.15	0.51	0.064	0.035	0.10 - 0.20	0.47	0.021	0.013
0.15 - 0.25	0.29	0.032	0.014	0.20 - 0.25	0.59	0.018	0.010
0.25 - 0.30	0.10	LLD	LLD	0.25 - 0.35	0.35	LLD	0.007
0.30 - 0.40	0.16	NM	NM	0.35 - 0.45	0.32	NM	NM
0.40 - 0.50	0.28	NM	NM	0.45 - 0.55	0.31	NM	NM

Profile W11A depth (m)	Bromide mg/kg	Chlorp. mg/kg	Fen.TTR mg/kg	Profile W11B depth (m)	Bromide mg/kg	Chlorp. mg/kg	Fen.TTR mg/kg
0.00 - 0.05	18.16	6.122	5.559	0.00 - 0.05	7.62	3.736	3.762
0.05 - 0.10	7.02	0.519	0.332	0.05 - 0.10	7.43	0.120	0.119
0.10 - 0.15	5.34	0.019	0.033	0.10 - 0.15	5.04	0.018	0.015
0.15 - 0.20	3.01	0.010	0.014	0.15 - 0.20	1.39	0.012	0.007
0.20 - 0.30	2.08	0.008	0.011	0.20 - 0.30	1.03	LLD	0.007
0.30 - 0.40	0.90	NM	NM	0.30 - 0.40	0.27	NM	NM
0.40 - 0.45	0.49	NM	NM	0.40 - 0.50	0.22	NM	NM

Profile W13A depth (m)	Bromide mg/kg	Chlorp. mg/kg	Fen.TTR mg/kg	Profile W13B depth (m)	Bromide mg/kg	Chlorp. mg/kg	Fen.TTR mg/kg
0.00 - 0.05	26.89	3.616	2.115	0.00 - 0.05	24.98	3.389	2.555
0.05 - 0.10	0.83	0.184	0.101	0.05 - 0.10	0.76	0.171	0.095
0.10 - 0.20	0.42	0.026	0.063	0.10 - 0.15	0.54	0.128	0.080
0.20 - 0.25	0.33	0.026	0.005	0.15 - 0.25	0.64	0.012	0.112
0.25 - 0.30	0.68	LLD	0.050	0.25 - 0.30	0.36	0.009	0.029
0.30 - 0.40	0.52	NM	NM	0.30 - 0.40	0.22	NM	NM
0.40 - 0.50	0.33	NM	NM	0.40 - 0.45	0.34	NM	NM

Notes for Tables 23 and 24:

1) Profile identification (see Figures 23 and 24):
   - First letter identifies the field plot: W = Waiawa, P = Poamoho
   - First numeral designates the sampling date: 1 = 1st, 2 = 2nd, 3 = 3rd, 4 = 4th, 5 = 5th
   - Second numeral locates the plot quadrant: 1 = 1st quadrant, 2 = 2nd quadrant, 3 = 3rd quadrant
   - Second letter specifies one of the two profiles sampled from the quadrant: A = sampled closer to plot boundary, B = sampled more toward plot interior

2) Chemical concentrations (expressed as chemical mass to dry soil mass):
   - Chlorp. = chlorpyrifos
   - Fen.TTR = fenamiphos total toxic residue, which includes the parent compund and its two metabolites f. sulfoxide and f. sulfone
   - LLD = less than the limit of detection, ~0.007 mg/kg
   - NM = not measured

Table 23. (Continued) Chemical Concentration Profiles at the Waiawa Plot, b) Second Sampling (August 1, 1988; 38 Days Post-application)

Profile W21A depth (m)	Bromide mg/kg	Chlorp. mg/kg	Fen.TTR mg/kg	Profile W21B depth (m)	Bromide mg/kg	Chlorp. mg/kg	Fen.TTR mg/kg
0.00 - 0.10	3.21	0.441	1.207	0.00 - 0.10	0.23	0.325	0.045
0.10 - 0.20	2.38	0.034	0.081	0.10 - 0.20	0.12	0.054	LLD
0.20 - 0.30	1.18	0.011	0.018	0.20 - 0.30	0.20	LLD	LLD
0.30 - 0.40	0.83	0.010	0.013	0.30 - 0.40	0.29	LLD	LLD
0.40 - 0.55	0.41	LLD	LLD	0.40 - 0.55	0.19	LLD	LLD
0.55 - 0.75	0.38	LLD	LLD	0.55 - 0.75	0.24	LLD	LLD

Profile W22A depth (m)	Bromide mg/kg	Chlorp. mg/kg	Fen.TTR mg/kg	Profile W22B depth (m)	Bromide mg/kg	Chlorp. mg/kg	Fen.TTR mg/kg
0.00 - 0.10	2.50	0.759	0.462	0.00 - 0.10	1.20	0.689	0.251
0.10 - 0.20	2.70	0.018	0.011	0.10 - 0.20	2.03	0.037	0.009
0.20 - 0.30	1.56	LLD	LLD	0.20 - 0.25	2.39	LLD	LLD
0.30 - 0.45	0.87	LLD	LLD	0.25 - 0.35	1.63	LLD	LLD
0.45 - 0.55	0.90	LLD	LLD	0.35 - 0.50	0.65	LLD	LLD
0.55 - 0.70	1.07	LLD	LLD	0.50 - 0.65	0.51	LLD	LLD

Profile W23A depth (m)	Bromide mg/kg	Chlorp. mg/kg	Fen.TTR mg/kg	Profile W23B depth (m)	Bromide mg/kg	Chlorp. mg/kg	Fen.TTR mg/kg
0.00 - 0.10	0.49	0.197	0.025	0.00 - 0.10	0.42	0.418	0.049
0.10 - 0.20	0.78	0.037	LLD	0.10 - 0.20	0.74	0.068	LLD
0.20 - 0.25	1.63	LLD	LLD	0.20 - 0.30	0.88	LLD	LLD
0.25 - 0.40	0.98	LLD	LLD	0.30 - 0.40	0.76	LLD	LLD
0.40 - 0.60	0.49	LLD	LLD	0.40 - 0.50	0.73	LLD	LLD
0.60 - 0.80	0.38	LLD	LLD				

Table 23. (Continued) Chemical Concentration Profiles at the Waiawa Plot, c) Third Sampling (October 26, 1988; 124 Days Post-application)

Profile W31A depth (m)	Bromide mg/kg	Chlorp. mg/kg	Fen.TTR mg/kg	Profile W31B depth (m)	Bromide mg/kg	Chlorp. mg/kg	Fen.TTR mg/kg
0.00 - 0.10	0.29	0.075	0.007	0.00 - 0.10	0.29	0.052	0.007
0.10 - 0.20	0.67	LLD	LLD	0.10 - 0.20	0.47	0.009	LLD
0.20 - 0.25	0.95	LLD	LLD	0.20 - 0.25	0.74	LLD	LLD
0.25 - 0.40	0.96	LLD	LLD	0.25 - 0.40	1.62	LLD	LLD
0.40 - 0.55	0.73	NM	NM	0.40 - 0.60	1.43	NM	NM
0.55 - 0.75	0.49	NM	NM	0.60 - 0.80	0.63	NM	NM
0.75 - 1.00	0.41	NM	NM	0.80 - 1.10	0.26	NM	NM
1.00 - 1.25	0.34	NM	NM	1.10 - 1.35	0.27	NM	NM
1.25 - 1.45	0.26	NM	NM				

Profile W32A depth (m)	Bromide mg/kg	Chlorp. mg/kg	Fen.TTR mg/kg	Profile W32B depth (m)	Bromide mg/kg	Chlorp. mg/kg	Fen.TTR mg/kg
0.00 - 0.10	0.62	0.031	LLD	0.00 - 0.10	0.40	0.030	LLD
0.10 - 0.20	0.95	LLD	LLD	0.10 - 0.20	0.51	0.007	LLD
0.20 - 0.30	1.32	LLD	LLD	0.20 - 0.30	1.03	LLD	LLD
0.30 - 0.45	1.80	LLD	LLD	0.30 - 0.45	2.63	LLD	LLD
0.45 - 0.60	1.02	NM	NM	0.45 - 0.60	1.03	NM	NM
0.60 - 0.75	0.68	NM	NM	0.60 - 0.75	0.44	NM	NM
				0.75 - 1.00	0.37	NM	NM
				1.00 - 1.20	0.36	NM	NM

Profile W33A depth (m)	Bromide mg/kg	Chlorp. mg/kg	Fen.TTR mg/kg	Profile W33B depth (m)	Bromide mg/kg	Chlorp. mg/kg	Fen.TTR mg/kg
0.00 - 0.10	0.34	0.064	LLD	0.00 - 0.10	0.46	0.031	LLD
0.10 - 0.20	0.37	0.007	LLD	0.10 - 0.20	0.39	0.007	LLD
0.20 - 0.30	0.73	LLD	LLD	0.20 - 0.25	0.80	LLD	LLD
0.30 - 0.45	1.96	LLD	LLD	0.25 - 0.40	1.04	LLD	LLD
0.45 - 0.60	2.38	LLD	LLD	0.40 - 0.55	1.52	LLD	LLD
0.60 - 0.75	1.95	LLD	LLD	0.55 - 0.75	1.40	LLD	LLD
0.75 - 1.00	0.67	LLD	LLD	0.75 - 1.05	0.62	LLD	LLD
1.00 - 1.25	0.26	LLD	LLD	1.05 - 1.25	0.36	LLD	LLD

Table 23. (Continued) Chemical Concentration Profiles at the Waiawa Plot, d) Fourth Sampling (January 23, 1989; 213 & 17 Days Post-application)

Profile W41A depth (m)	Bromide mg/kg	Chlorp. mg/kg	Fen.TTR mg/kg
0.00 - 0.10	2.78	1.086	0.228
0.10 - 0.20	2.47	0.032	0.041
0.20 - 0.30	1.73	LLD	LLD
0.30 - 0.45	0.42	LLD	LLD
0.45 - 0.60	0.56	LLD	LLD
0.60 - 0.75	0.48	LLD	LLD
0.75 - 1.00	0.75	LLD	LLD
1.00 - 1.25	0.75	NM	NM
1.25 - 1.55	0.70	NM	NM
1.55 - 1.85	0.74	NM	NM
1.85 - 2.20	0.96	NM	NM

Profile W41B depth (m)	Bromide mg/kg	Chlorp. mg/kg	Fen.TTR mg/kg
0.00 - 0.10	3.59	1.905	0.167
0.10 - 0.20	5.11	0.015	0.026
0.20 - 0.25	2.73	LLD	LLD
0.25 - 0.40	0.71	LLD	LLD
0.40 - 0.55	1.22	LLD	LLD
0.55 - 0.70	1.28	LLD	LLD
0.70 - 0.95	1.34	LLD	LLD
0.95 - 1.25	1.03	NM	NM
1.25 - 1.45	0.62	NM	NM
1.45 - 1.70	0.72	NM	NM
1.70 - 2.00	0.85	NM	NM

Profile W42A depth (m)	Bromide mg/kg	Chlorp. mg/kg	Fen.TTR mg/kg
0.00 - 0.10	4.25	1.438	0.149
0.10 - 0.20	5.10	0.027	0.142
0.20 - 0.30	6.16	LLD	0.034
0.30 - 0.45	0.79	LLD	LLD
0.45 - 0.65	0.69	LLD	LLD
0.65 - 0.85	0.84	LLD	LLD

Profile W42B depth (m)	Bromide mg/kg	Chlorp. mg/kg	Fen.TTR mg/kg
0.00 - 0.10	1.51	1.461	0.211
0.10 - 0.20	1.27	0.050	LLD
0.20 - 0.25	0.72	LLD	LLD
0.25 - 0.45	0.92	LLD	LLD
0.45 - 0.55	1.07	LLD	LLD

Profile W43A depth (m)	Bromide mg/kg	Chlorp. mg/kg	Fen.TTR mg/kg
0.00 - 0.10	2.47	0.648	0.100
0.10 - 0.20	5.75	0.013	0.155
0.20 - 0.30	5.50	LLD	0.084
0.30 - 0.40	2.63	LLD	0.042
0.40 - 0.55	0.82	LLD	LLD
0.55 - 0.70	0.73	LLD	LLD
0.70 - 0.95	0.98	LLD	LLD
0.95 - 1.30	0.86	NM	NM
1.30 - 1.65	1.32	NM	NM
1.65 - 2.00	1.34	NM	NM

Profile W43B depth (m)	Bromide mg/kg	Chlorp. mg/kg	Fen.TTR mg/kg
0.00 - 0.10	3.64	1.365	0.234
0.10 - 0.20	5.09	0.028	0.046
0.20 - 0.30	4.16	0.006	0.023
0.30 - 0.45	2.59	0.036	0.010
0.45 - 0.60	1.06	0.009	0.026
0.60 - 0.75	0.84	LLD	LLD
0.75 - 1.05	1.02	LLD	LLD
1.05 - 1.35	0.91	NM	NM

Table 23. (Continued) Chemical Concentration Profiles at the Waiawa Plot, e) Fifth Sampling (May 8, 1989; 318 & 122 Days Post-application)

Profile W51A depth (m)	Bromide mg/kg	Chlorp. mg/kg	Fen.TTR mg/kg
0.00 - 0.10	0.94	0.113	LLD
0.10 - 0.20	0.39	0.016	LLD
0.20 - 0.30	0.42	LLD	LLD
0.30 - 0.40	0.57	LLD	LLD
0.40 - 0.60	0.67	NM	NM
0.60 - 0.75	0.91	LLD	LLD
0.75 - 0.95	2.11	NM	NM
0.95 - 1.10	1.73	NM	NM
1.10 - 1.25	0.70	NM	NM
1.25 - 1.50	0.69	NM	NM

Profile W51B depth (m)	Bromide mg/kg	Chlorp. mg/kg	Fen.TTR mg/kg
0.00 - 0.10	0.57	0.109	LLD
0.10 - 0.20	0.39	0.008	LLD
0.20 - 0.30	0.65	LLD	LLD
0.30 - 0.40	1.47	LLD	LLD
0.40 - 0.50	1.91	LLD	LLD
0.50 - 0.65	1.01	LLD	LLD
0.65 - 0.80	0.65	NM	NM
0.80 - 1.00	0.71	NM	NM
1.00 - 1.20	0.83	NM	NM
1.20 - 1.40	0.73	NM	NM
1.40 - 1.55	1.01	NM	NM
1.55 - 1.80	1.19	NM	NM
1.80 - 2.10	1.06	NM	NM
2.10 - 2.45	1.13	NM	NM
2.45 - 2.65	0.94	NM	NM
2.65 - 3.00	0.93	NM	NM

Profile W52A depth (m)	Bromide mg/kg	Chlorp. mg/kg	Fen.TTR mg/kg
0.00 - 0.10	1.09	0.070	LLD
0.10 - 0.20	0.71	LLD	LLD
0.20 - 0.30	1.78	LLD	LLD
0.30 - 0.35	2.30	LLD	LLD
0.35 - 0.50	1.19	LLD	LLD
0.50 - 0.65	0.49	NM	NM
0.65 - 0.85	0.46	NM	NM
0.85 - 1.00	0.41	NM	NM
1.00 - 1.25	0.56	NM	NM
1.25 - 1.45	0.67	NM	NM
1.45 - 1.50	0.91	NM	NM

Profile W52B depth (m)	Bromide mg/kg	Chlorp. mg/kg	Fen.TTR mg/kg
0.00 - 0.10	0.90	0.393	0.019
0.10 - 0.15	0.45	0.070	LLD
0.15 - 0.25	0.37	0.032	LLD
0.25 - 0.35	0.63	LLD	LLD
0.35 - 0.45	0.69	LLD	LLD
0.45 - 0.55	0.60	LLD	LLD
0.55 - 0.75	0.70	NM	NM
0.75 - 1.00	0.34	NM	NM
1.00 - 1.20	0.40	NM	NM
1.20 - 1.40	0.64	NM	NM
1.40 - 1.70	0.63	NM	NM

Profile W53A depth (m)	Bromide mg/kg	Chlorp. mg/kg	Fen.TTR mg/kg
0.00 - 0.10	0.59	0.055	LLD
0.10 - 0.20	0.27	LLD	LLD
0.20 - 0.25	0.47	LLD	LLD
0.25 - 0.35	0.59	LLD	LLD
0.35 - 0.50	0.69	LLD	LLD
0.50 - 0.65	0.81	LLD	LLD
0.65 - 0.85	0.92	NM	NM
0.85 - 1.00	1.00	NM	NM
1.00 - 1.15	0.52	NM	NM
1.15 - 1.45	0.60	NM	NM
1.45 - 1.75	0.89	NM	NM
1.75 - 2.10	1.04	NM	NM
2.10 - 2.45	0.94	NM	NM
2.45 - 2.60	0.88	NM	NM

Profile W53B depth (m)	Bromide mg/kg	Chlorp. mg/kg	Fen.TTR mg/kg
0.00 - 0.10	1.57	0.106	LLD
0.10 - 0.20	0.80	0.017	LLD
0.20 - 0.30	1.13	LLD	LLD
0.30 - 0.40	2.06	LLD	LLD
0.40 - 0.50	2.70	LLD	LLD
0.50 - 0.60	1.78	LLD	LLD
0.60 - 0.70	1.67	NM	NM
0.70 - 0.85	1.09	NM	NM
0.85 - 1.05	1.33	NM	NM
1.05 - 1.30	1.32	NM	NM
1.30 - 1.60	1.53	NM	NM

Table 24

Chemical Concentration Profiles at the Poamoho Plot, a) First Sampling (March 10, 1989; 11 Days Post-application)

Profile P11A depth (m)	Bromide mg/kg	Chlorp. mg/kg	Fen.TTR mg/kg	Profile P11B depth (m)	Bromide mg/kg	Chlorp. mg/kg	Fen.TTR mg/kg
0.00 - 0.05	0.41	4.800	1.944	0.00 - 0.05	0.53	8.861	2.552
0.05 - 0.10	0.38	0.275	1.040	0.05 - 0.10	0.45	0.539	1.402
0.10 - 0.20	0.35	0.009	0.277	0.10 - 0.20	0.89	0.021	1.168
0.20 - 0.25	1.95	LLD	0.040	0.20 - 0.25	4.17	LLD	0.084
0.25 - 0.35	6.21	LLD	0.034	0.25 - 0.35	10.98	LLD	0.025
0.35 - 0.40	5.21	LLD	LLD	0.35 - 0.45	6.99	LLD	0.018
0.40 - 0.50	4.00	LLD	LLD	0.45 - 0.55	4.76	LLD	0.020
0.50 - 0.55	2.58	LLD	LLD	0.55 - 0.65	1.73	LLD	LLD
0.55 - 0.70	1.33	LLD	LLD	0.65 - 0.75	1.07	LLD	LLD
0.70 - 0.85	0.78	NM	NM	0.75 - 0.95	0.68	NM	NM
0.85 - 1.00	0.55	NM	NM				
1.00 - 1.15	0.37	NM	NM				
1.15 - 1.30	0.31	NM	NM				
1.30 - 1.45	0.36	NM	NM				

Profile P12A depth (m)	Bromide mg/kg	Chlorp. mg/kg	Fen.TTR mg/kg	Profile P12B depth (m)	Bromide mg/kg	Chlorp. mg/kg	Fen.TTR mg/kg
0.00 - 0.05	0.41	6.641	2.216	0.00 - 0.05	0.51	5.158	1.802
0.05 - 0.10	0.29	0.188	0.745	0.05 - 0.10	0.29	0.231	0.660
0.10 - 0.20	0.31	0.042	1.138	0.10 - 0.20	0.54	0.009	0.102
0.20 - 0.30	0.45	0.007	0.212	0.20 - 0.25	0.64	LLD	0.046
0.30 - 0.40	1.93	0.007	0.135	0.25 - 0.35	3.83	LLD	0.033
0.40 - 0.55	8.71	0.010	0.094	0.35 - 0.45	7.61	LLD	LLD
0.55 - 0.65	12.19	LLD	0.035	0.45 - 0.55	6.00	LLD	LLD
0.65 - 0.80	7.66	LLD	LLD	0.55 - 0.70	1.71	LLD	LLD
0.80 - 0.90	2.95	LLD	LLD	0.70 - 0.90	0.26	LLD	LLD
0.90 - 1.10	0.21	NM	NM	0.90 - 1.15	0.16	NM	NM
1.10 - 1.25	0.15	NM	NM				
1.25 - 1.50	0.21	NM	NM				

Profile P13A depth (m)	Bromide mg/kg	Chlorp. mg/kg	Fen.TTR mg/kg	Profile P13B depth (m)	Bromide mg/kg	Chlorp. mg/kg	Fen.TTR mg/kg
0.00 - 0.05	0.41	3.335	1.423	0.00 - 0.05	0.69	6.372	2.062
0.05 - 0.10	0.24	0.297	0.595	0.05 - 0.10	0.25	0.626	1.762
0.10 - 0.20	0.24	0.027	0.154	0.10 - 0.20	0.78	0.054	1.178
0.20 - 0.25	1.12	LLD	0.021	0.20 - 0.25	6.84	LLD	0.070
0.25 - 0.35	2.58	LLD	0.006	0.25 - 0.40	7.45	LLD	0.012
0.35 - 0.45	3.12	LLD	0.069	0.40 - 0.50	6.31	LLD	0.010
0.45 - 0.55	4.20	LLD	0.020	0.50 - 0.60	5.11	LLD	LLD
0.55 - 0.65	2.70	LLD	0.011	0.60 - 0.65	3.12	LLD	LLD
0.65 - 0.80	1.90	LLD	0.010	0.65 - 0.80	1.08	LLD	LLD
0.80 - 0.95	1.46	NM	NM	0.80 - 0.90	0.40	NM	NM
0.95 - 1.10	1.18	NM	NM				
1.10 - 1.30	0.99	NM	NM				
1.30 - 1.45	0.29	NM	NM				

See notes from Table 23

Table 24. (Continued) Chemical Concentration Profiles at the Poamoho Plot, b) Second Sampling (April 21, 1989; 53 Days Post-application)

Profile P21A depth (m)	Bromide mg/kg	Chlorp. mg/kg	Fen.TTR mg/kg	Profile P21B depth (m)	Bromide mg/kg	Chlorp. mg/kg	Fen.TTR mg/kg
0.00 - 0.10	0.61	0.073	0.251	0.00 - 0.10	1.01	0.378	0.271
0.10 - 0.20	0.91	0.034	0.043	0.10 - 0.20	0.25	0.028	0.250
0.20 - 0.30	0.97	LLD	LLD	0.20 - 0.30	0.59	LLD	0.063
0.30 - 0.40	2.87	LLD	LLD	0.30 - 0.40	1.68	LLD	LLD
0.40 - 0.55	4.58	LLD	LLD	0.40 - 0.55	3.85	LLD	LLD
0.55 - 0.70	4.71	LLD	LLD	0.55 - 0.70	5.17	LLD	LLD
0.70 - 0.90	3.82	LLD	LLD	0.70 - 0.90	5.82	LLD	LLD
0.90 - 1.10	1.59	LLD	LLD	0.90 - 1.10	2.63	LLD	LLD
1.10 - 1.30	0.66	LLD	LLD	1.10 - 1.30	1.10	LLD	LLD
1.30 - 1.55	0.33	NM	NM	1.30 - 1.50	0.32	NM	NM
1.55 - 1.75	0.35	NM	NM				
1.75 - 2.00	0.49	NM	NM				
2.00 - 2.20	0.43	NM	NM				
2.20 - 2.45	0.34	NM	NM				

Profile P22A depth (m)	Bromide mg/kg	Chlorp. mg/kg	Fen.TTR mg/kg	Profile P22B depth (m)	Bromide mg/kg	Chlorp. mg/kg	Fen.TTR mg/kg
0.00 - 0.10	0.33	0.288	0.460	0.00 - 0.15	0.40	0.605	0.226
0.10 - 0.20	0.31	LLD	0.138	0.15 - 0.25	0.39	0.041	0.069
0.20 - 0.30	0.33	LLD	0.020	0.25 - 0.30	0.70	LLD	0.024
0.30 - 0.40	0.35	LLD	LLD	0.30 - 0.40	0.73	LLD	LLD
0.40 - 0.55	1.48	LLD	LLD	0.40 - 0.55	0.99	LLD	LLD
0.55 - 0.75	2.78	LLD	LLD	0.55 - 0.75	1.08	LLD	LLD
0.75 - 0.95	1.68	LLD	LLD	0.75 - 0.95	0.25	LLD	LLD
0.95 - 1.15	0.72	LLD	LLD	0.95 - 1.20	0.16	LLD	LLD
1.15 - 1.40	0.22	LLD	LLD	1.20 - 1.50	0.16	LLD	LLD
1.40 - 1.60	0.11	NM	NM	1.50 - 1.70	0.11	NM	NM
				1.70 - 1.95	0.15	NM	NM
				1.95 - 2.15	0.17	NM	NM
				2.15 - 2.40	0.19	NM	NM
				2.40 - 2.50	0.19	NM	NM

Profile P23A depth (m)	Bromide mg/kg	Chlorp. mg/kg	Fen.TTR mg/kg	Profile P23B depth (m)	Bromide mg/kg	Chlorp. mg/kg	Fen.TTR mg/kg
0.00 - 0.10	1.10	0.110	0.318	0.00 - 0.10	0.44	0.134	0.313
0.10 - 0.20	0.60	0.022	0.034	0.10 - 0.25	0.52	LLD	0.038
0.20 - 0.30	1.00	LLD	LLD	0.25 - 0.30	0.48	LLD	0.018
0.30 - 0.40	3.69	LLD	LLD	0.30 - 0.40	0.83	LLD	LLD
0.40 - 0.55	6.64	LLD	LLD	0.40 - 0.60	1.31	LLD	LLD
0.55 - 0.70	3.00	LLD	LLD	0.60 - 0.70	0.89	LLD	LLD
0.70 - 0.90	1.15	LLD	LLD	0.70 - 0.90	0.37	LLD	LLD
0.90 - 1.10	0.36	LLD	LLD	0.90 - 1.10	0.24	LLD	LLD
1.10 - 1.30	0.33	LLD	LLD	1.10 - 1.30	0.23	LLD	LLD
1.30 - 1.50	0.16	NM	NM	1.30 - 1.55	0.19	NM	NM
				1.55 - 1.75	0.25	NM	NM
				1.75 - 2.00	0.25	NM	NM
				2.00 - 2.20	0.24	NM	NM
				2.20 - 2.40	0.21	NM	NM

Table 24. (Continued) Chemical Concentration Profiles at the Poamoho Plot, c) Third Sampling (June 7, 1989; 100 Days Post-application)

Profile P31A depth (m)	Bromide mg/kg	Chlorp. mg/kg	Fen.TTR mg/kg
0.00 - 0.10	3.95	0.032	0.185
0.10 - 0.20	1.05	0.013	0.068
0.20 - 0.25	0.73	LLD	LLD
0.25 - 0.35	1.69	LLD	LLD
0.35 - 0.45	1.37	LLD	LLD
0.45 - 0.55	0.94	LLD	LLD
0.55 - 0.70	0.58	NM	NM
0.70 - 0.85	0.63	NM	NM
0.85 - 1.10	0.80	NM	NM
1.10 - 1.25	0.38	NM	NM
1.25 - 1.40	0.18	NM	NM
1.40 - 1.65	0.22	NM	NM
1.65 - 1.90	0.26	NM	NM
1.90 - 2.15	0.27	NM	NM

Profile P31B depth (m)	Bromide mg/kg	Chlorp. mg/kg	Fen.TTR mg/kg
0.00 - 0.10	4.97	0.064	0.171
0.10 - 0.25	1.15	0.017	0.049
0.25 - 0.35	1.16	LLD	LLD
0.35 - 0.45	1.83	LLD	LLD
0.45 - 0.50	2.36	LLD	LLD
0.50 - 0.65	2.91	LLD	LLD
0.65 - 0.80	1.73	NM	NM
0.80 - 0.95	0.66	NM	NM
0.95 - 1.15	0.47	NM	NM
1.15 - 1.35	0.35	NM	NM
1.35 - 1.65	0.33	NM	NM
1.65 - 1.90	0.21	NM	NM
1.90 - 2.10	0.22	NM	NM

Profile P32A depth (m)	Bromide mg/kg	Chlorp. mg/kg	Fen.TTR mg/kg
0.00 - 0.10	7.50	0.068	0.134
0.10 - 0.20	0.85	0.027	0.053
0.20 - 0.30	0.55	0.007	0.007
0.30 - 0.40	0.84	LLD	LLD
0.40 - 0.50	1.93	LLD	LLD
0.50 - 0.55	2.00	LLD	LLD
0.55 - 0.75	0.85	NM	NM
0.75 - 0.90	1.54	NM	NM
0.90 - 1.10	0.16	NM	NM
1.10 - 1.25	0.11	NM	NM
1.25 - 1.50	0.08	NM	NM
1.50 - 1.75	0.10	NM	NM
1.75 - 2.00	0.10	NM	NM

Profile P32B depth (m)	Bromide mg/kg	Chlorp. mg/kg	Fen.TTR mg/kg
0.00 - 0.10	4.43	0.147	0.137
0.10 - 0.20	0.90	0.029	0.043
0.20 - 0.30	0.60	LLD	0.010
0.30 - 0.40	0.95	LLD	LLD
0.40 - 0.45	1.21	LLD	LLD
0.45 - 0.55	1.55	LLD	LLD
0.55 - 0.75	2.23	NM	NM
0.75 - 0.90	1.59	NM	NM
0.90 - 1.10	0.49	NM	NM
1.10 - 1.25	0.15	NM	NM
1.25 - 1.40	0.08	NM	NM
1.40 - 1.65	0.09	NM	NM
1.65 - 1.90	0.15	NM	NM
1.90 - 2.15	0.11	NM	NM

Profile P33A depth (m)	Bromide mg/kg	Chlorp. mg/kg	Fen.TTR mg/kg
0.00 - 0.10	12.60	0.084	0.245
0.10 - 0.25	2.17	0.021	0.074
0.25 - 0.35	1.92	0.008	0.047
0.35 - 0.40	3.29	LLD	LLD
0.40 - 0.50	3.59	LLD	LLD
0.50 - 0.65	3.68	LLD	LLD
0.65 - 0.80	0.58	NM	NM
0.80 - 0.95	1.06	NM	NM
0.95 - 1.10	0.56	NM	NM
1.10 - 1.30	0.19	NM	NM
1.30 - 1.45	0.12	NM	NM
1.45 - 1.70	0.11	NM	NM
1.70 - 2.00	0.12	NM	NM
2.00 - 2.20	0.12	NM	NM
2.20 - 2.50	0.16	NM	NM

Profile P33B depth (m)	Bromide mg/kg	Chlorp. mg/kg	Fen.TTR mg/kg
0.00 - 0.10	12.55	0.080	0.242
0.10 - 0.20	6.03	0.046	0.069
0.20 - 0.30	1.82	0.011	0.009
0.30 - 0.35	1.37	LLD	LLD
0.35 - 0.45	1.80	LLD	LLD
0.45 - 0.50	2.47	LLD	LLD
0.50 - 0.70	2.73	NM	NM
0.70 - 0.95	1.61	NM	NM
0.95 - 1.10	0.63	NM	NM
1.10 - 1.35	0.22	NM	NM
1.35 - 1.55	0.09	NM	NM
1.55 - 1.75	0.21	NM	NM
1.75 - 2.00	0.14	NM	NM

Table 25

Summary of Chemical Concentration Profiles at the Waiawa Plot, a) First Three Sampling Dates

Repr.	W B 1				W C 1			W F 1		
depth	Mean	Min.	Max.	N	Mean	Min.	Max.	Mean	Min.	Max.
0.025	26.05	7.62	39.55	6	4.737	3.389	6.122	3.402	2.115	5.559
0.075	3.21	0.62	7.43	6	0.306	0.120	0.696	0.182	0.065	0.381
0.125	2.05	0.42	5.34	6	0.046	0.018	0.128	0.040	0.013	0.080
0.175	1.04	0.29	3.01	6	0.019	0.010	0.032	0.037	0.007	0.112
0.225	0.83	0.29	2.08	6	0.017	0.004	0.032	0.012	0.005	0.029
0.325	0.40	0.16	0.90	6				0.004	0.004	0.007
0.425	0.33	0.22	0.49	6						
0.525	0.31	0.31	0.31	1						

Repr.	W B 2				W C 2			W F 2		
depth	Mean	Min.	Max.	N	Mean	Min.	Max.	Mean	Min.	Max.
0.050	1.34	0.23	3.21	6	0.471	0.197	0.759	0.340	0.025	1.207
0.150	1.46	0.12	2.70	6	0.041	0.018	0.068	0.019	0.004	0.081
0.225	1.31	0.20	2.39	6	0.005	0.004	0.011	0.004	0.000	0.018
0.325	0.90	0.29	1.63	6	0.002	0.000	0.010	0.002	0.000	0.013
0.475	0.56	0.19	0.90	6						
0.625	0.51	0.24	1.07	5						

Repr.	W B 3				W C 3			W F 3		
depth	Mean	Min.	Max.	N	Mean	Min.	Max.	Mean	Min.	Max.
0.050	0.40	0.29	0.62	6	0.047	0.030	0.075	0.002	0.000	0.007
0.150	0.56	0.37	0.95	6	0.006	0.004	0.009	0.001	0.000	0.004
0.225	0.93	0.73	1.32	6	0.002	0.000	0.004	0.000	0.000	0.000
0.350	1.67	0.96	2.63	6	0.000	0.000	0.000	0.000	0.000	0.000
0.500	1.35	0.73	2.38	6						
0.675	0.93	0.44	1.95	6						
0.900	0.47	0.26	0.67	5						
1.150	0.32	0.26	0.36	5						
1.350	0.26	0.26	0.26	1						

Notes for Tables 25 and 26:

1) Profile identification:
   First letter identifies the field plot: **W** = Waiawa, **P** = Poamoho
   Second letter designates the chemical: **B** = bromide, **C** = chlorpyrifos, **F** = fenamiphos (expressed as total toxic residue, see note 2 under Table 12)
   Numeral specifies the sampling date: 1 = 1st, 2 = 2nd, 3 = 3rd, 4 = 4th, 5 = 5th
2) Explanation of subheadinigs:
   Repr. depth = representative sample depth, m
   Mean = arithmetic mean concentration, mg/kg
   Min. = minimum concentration, mg/kg
   Max. = maximum concentration, mg/kg
   N = number of bromide samples used to determine Mean, Min., and Max.

Table 25. (Continued) Summary of Chemical Concentration Profiles at the Waiawa Plot
b) Fourth and Fifth Sampling Dates

Repr.	---- W B 4 ----				--- W C 4 ---			--- W F 4 ---		
depth	Mean	Min.	Max.	N	Mean	Min.	Max.	Mean	Min.	Max.
0.050	3.04	1.51	4.25	6	1.317	0.648	1.905	0.181	0.100	0.234
0.150	4.13	1.27	5.75	6	0.027	0.013	0.050	0.069	0.004	0.155
0.225	3.50	0.72	6.16	6	0.004	0.004	0.006	0.025	0.000	0.084
0.350	1.35	0.42	2.63	6	0.006	0.000	0.036	0.009	0.000	0.042
0.500	0.90	0.56	1.22	6	0.001	0.000	0.009	0.005	0.000	0.026
0.675	0.83	0.48	1.28	5						
0.850	0.99	0.75	1.34	5						
1.150	0.89	0.75	1.03	4						
1.400	0.88	0.62	1.32	3						
1.625	0.93	0.72	1.32	3						
1.900	1.05	0.85	1.34	3						

Repr.	---- W B 5 ----				--- W C 5 ---			--- W F 5 ---		
depth	Mean	Min.	Max.	N	Mean	Min.	Max.	Mean	Min.	Max.
0.050	0.94	0.57	1.57	6	0.141	0.055	0.393	0.003	0.000	0.019
0.125	0.50	0.27	0.80	6	0.020	0.004	0.070	0.001	0.000	0.004
0.225	0.80	0.37	1.78	6	0.007	0.000	0.032	0.000	0.000	0.000
0.325	1.27	0.57	2.30	6	0.001	0.000	0.004	0.000	0.000	0.000
0.425	1.31	0.67	2.70	6						
0.575	0.91	0.49	1.78	6						
0.725	0.79	0.46	1.09	6						
0.925	0.98	0.34	2.11	6						
1.125	0.72	0.40	1.32	6						
1.325	0.81	0.60	1.53	6						
1.525	1.02	0.63	1.53	4						
1.900	1.05	1.04	1.06	2						
2.250	1.04	0.94	1.13	2						
2.550	0.91	0.88	0.94	2						
2.850	0.93	0.93	0.93	1						

Table 26
Summary of Chemical Concentration Profiles at the Poamoho Plot

Repr.	---- P B 1 ----				--- P C 1 ---			--- P F 1 ---		
depth	Mean	Min.	Max.	N	Mean	Min.	Max.	Mean	Min.	Max.
0.025	0.50	0.41	0.69	6	5.861	3.335	8.861	2.000	1.423	2.552
0.075	0.32	0.24	0.45	6	0.359	0.188	0.626	1.034	0.595	1.762
0.150	0.52	0.24	0.89	6	0.027	0.009	0.054	0.669	0.102	1.178
0.225	2.53	0.45	6.84	6	0.004	0.004	0.007	0.079	0.021	0.212
0.325	5.50	1.93	10.98	6	0.001	0.000	0.007	0.041	0.006	0.135
0.425	6.12	3.12	8.71	6	0.002	0.000	0.010	0.033	0.004	0.094
0.525	5.23	2.58	8.71	6	0.002	0.000	0.010	0.023	0.000	0.094
0.625	3.80	1.33	12.19	6				0.008	0.000	0.035
0.725	2.12	0.26	7.66	6				0.002	0.000	0.010
0.875	1.05	0.26	2.95	6						
1.050	0.48	0.16	1.18	4						
1.200	0.49	0.15	0.99	3						
1.400	0.29	0.21	0.36	3						

Repr.	---- P B 2 ----				--- P C 2 ---			--- P F 2 ---		
depth	Mean	Min.	Max.	N	Mean	Min.	Max.	Mean	Min.	Max.
0.050	0.65	0.33	1.10	6	0.265	0.073	0.605	0.306	0.226	0.460
0.175	0.50	0.25	0.91	6	0.022	0.004	0.041	0.095	0.034	0.250
0.275	0.68	0.33	1.00	6	0.002	0.000	0.004	0.022	0.004	0.063
0.350	1.69	0.35	3.69	6	0.000	0.000	0.000	0.002	0.000	0.004
0.475	3.14	0.99	6.64	6						
0.625	2.94	0.89	5.17	6						
0.825	2.18	0.25	5.82	6						
1.025	0.95	0.16	2.63	6						
1.250	0.45	0.16	1.10	6						
1.450	0.21	0.11	0.33	6						
1.650	0.24	0.11	0.35	3						
1.850	0.30	0.15	0.49	3						
2.100	0.28	0.17	0.43	3						
2.300	0.24	0.19	0.34	3						
2.450	0.26	0.19	0.34	2						

Repr.	---- P B 3 ----				--- P C 3 ---			--- P F 3 ---		
depth	Mean	Min.	Max.	N	Mean	Min.	Max.	Mean	Min.	Max.
0.050	7.67	3.95	12.60	6	0.079	0.032	0.147	0.186	0.134	0.245
0.150	2.02	0.85	6.03	6	0.026	0.013	0.046	0.059	0.043	0.074
0.225	1.17	0.55	2.17	6	0.008	0.004	0.021	0.018	0.004	0.074
0.325	1.32	0.84	1.92	6	0.002	0.000	0.008	0.010	0.000	0.047
0.425	1.96	1.21	3.59	6						
0.525	2.30	0.94	3.68	6						
0.625	2.16	0.58	3.68	6						
0.775	1.28	0.58	1.73	6						
0.925	0.80	0.16	1.61	6						
1.050	0.52	0.16	0.80	6						
1.200	0.24	0.11	0.38	6						
1.375	0.15	0.08	0.33	6						
1.600	0.18	0.09	0.33	6						
1.800	0.16	0.10	0.26	6						
2.050	0.18	0.11	0.27	4						
2.350	0.16	0.16	0.16	1						

See notes from Table 25

Table 27

Bromide Mass Balance at Field Sites

Sample date	Waiawa plot AVG	MIN	MAX	σ	N	Poamoho plot AVG	MIN	MAX	σ	N
1	0.76	0.51	0.98	0.20	6	0.70	0.49	1.12	0.24	6
2	0.17	0.00	0.37	0.14	6	0.49	0.11	0.93	0.35	6
3	0.24	0.08	0.43	0.11	6	0.49	0.29	0.78	0.20	6
4	0.39	0.09	0.64	0.19	6					
5	0.25	0.05	0.45	0.15	6					

Mass balance recoveries expressed as fraction of amount applied; 1.0 would indicate 100% recovery

Table 28

Pesticide Degradation at Field Sites

Sample date	Concentration (M/M_0) AVG	MIN	MAX	σ	N	per application k	per application r^2	overall k	overall r^2
Chlorpyrifos									
W1	0.32	0.23	0.43	0.09	6				
W2	0.07	0.03	0.10	0.03	6	0.036	0.924		
W3	0.01	0.00	0.01	0.00	6				
W4	0.17	0.08	0.24	0.05	6	0.028	0.887	0.034	0.883
W5	0.02	0.01	0.06	0.02	6				
P1	0.34	0.20	0.51	0.11	6				
P2	0.04	0.01	0.11	0.04	6	0.042	0.942		
P3	0.01	0.01	0.02	0.00	6				
Fenamiphos (Fen.TTR)									
W1	0.62	0.40	0.99	0.20	6				
W2	0.12	0.01	0.44	0.17	6	0.053	0.999		
W3	0.00	0.00	0.00	0.00	6				
W4	0.10	0.07	0.14	0.03	6	0.051	0.956	0.046	0.853
W5	0.00	0.00	0.01	0.00	6				
P1	0.70	0.39	0.98	0.29	6				
P2	0.13	0.09	0.18	0.04	6	0.026	0.928		
P3	0.08	0.06	0.12	0.03	6				

W = Waiawa plot
P = Poamoho plot
numeral = sample collection date
AVG = average
MIN = minimum
MAX = maximum
σ = standard deviation
N = number of profiles
k = first-order decay rate (day^{-1})
r^2 = coefficient of determination

APPENDIX E. Soil Organic Carbon Data

Figures 40 and 41 identify the locations of organic carbon sampling points with a higher resolution than depicted in Figure 26 (Chapter IV). Table 31 lists the summarized data which were used to plot Figure 35 (Chapter V). The zero X coordinates of the three Waiawa Ridge transects shown in Figure 40 are located at the highest (most northern) end of each transect.

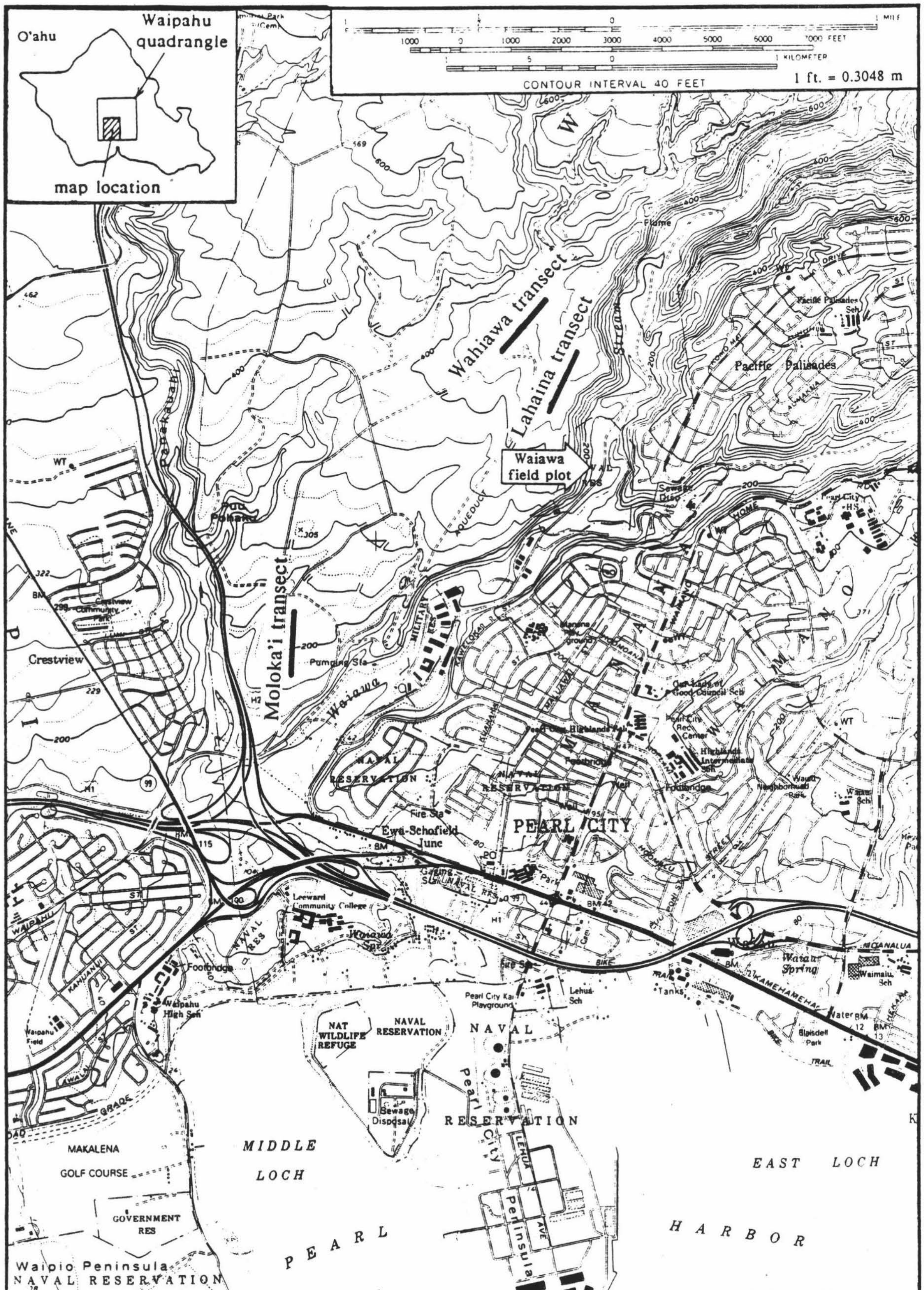
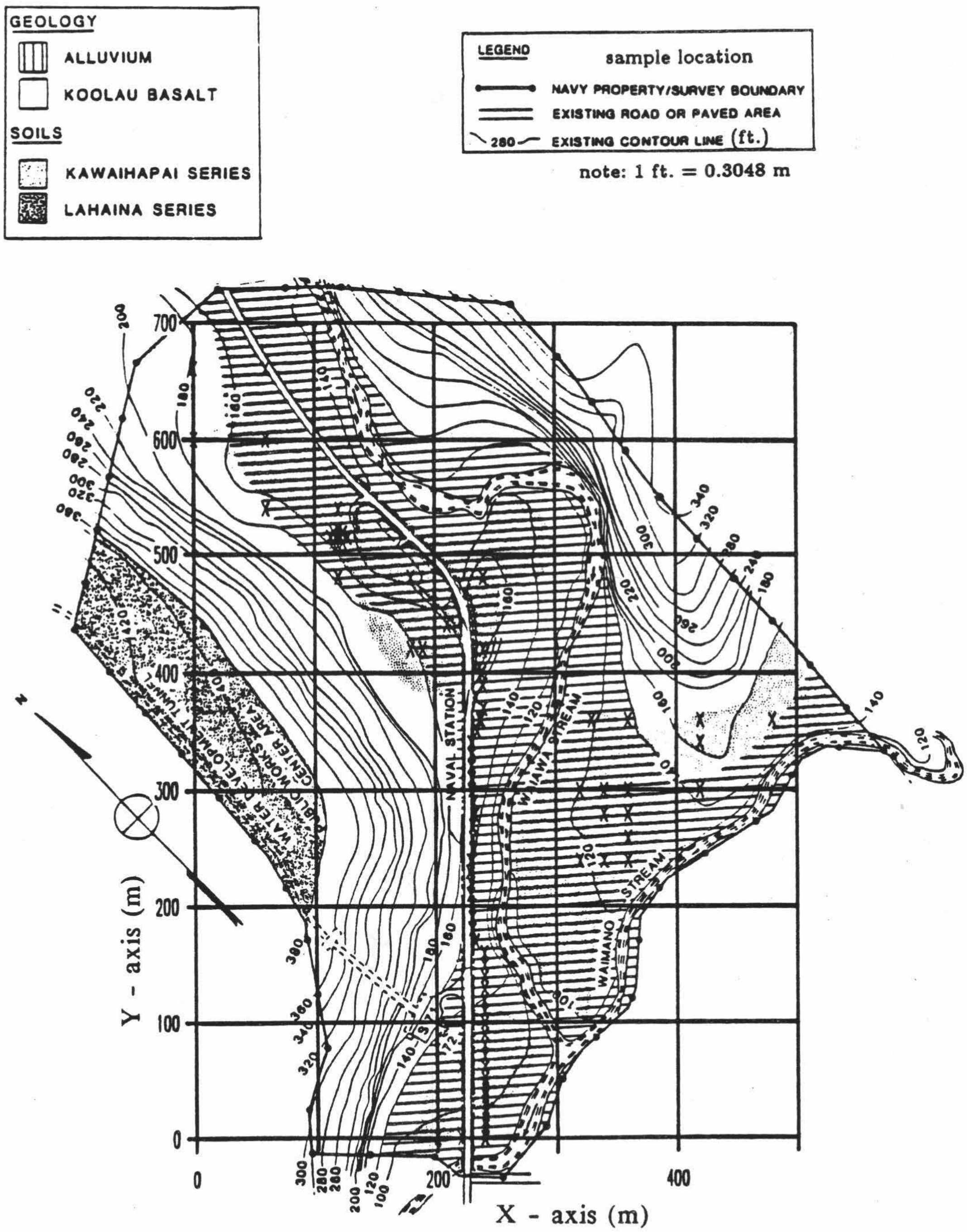


Figure 40. Location of Waiawa Ridge organic carbon transects (after U.S. Geological Survey, 1983a)



Note: map area corresponds to the Navy development site shown in Figure 2 (Chapter I)

Figure 41. Location of Waiawa Valley organic carbon grid (after Mink, 1985)

Table 29

Soil Organic Carbon Content from Waiawa Ridge

Lahaina			Moloka'i			Wahiawa		
X (m)	Depth (m)	f_{oc} (kg/kg)	X (m)	Depth (m)	f_{oc} (kg/kg)	X (m)	Depth (m)	f_{oc} (kg/kg)
0	0.0	0.0343	0	0.0	0.0182	0	0.0	0.0293
10	0.0	0.0312	10	0.0	0.0243	10	0.0	0.0267
20	0.0	0.0296	20	0.0	0.0265	20	0.0	0.0321
30	0.0	0.0230	30	0.0	0.0252	30	0.0	0.0318
40	0.0	0.0297	40	0.0	0.0366	40	0.0	0.0244
50	0.0	0.0300	50	0.0	0.0438	50	0.0	0.0369
60	0.0	0.0235	60	0.0	0.0301	60	0.0	0.0312
70	0.0	0.0311	70	0.0	0.0196	70	0.0	0.0280
80	0.0	0.0298	80	0.0	0.0318	80	0.0	0.0283
90	0.0	0.0257	90	0.0	0.0250	90	0.0	0.0283
100	0.0	0.0216	100	0.0	0.0192	100	0.0	0.0188
110	0.0	0.0256	110	0.0	0.0214	110	0.0	0.0182
120	0.0	0.0220	120	0.0	0.0259	120	0.0	0.0227
130	0.0	0.0193	130	0.0	0.0261	130	0.0	0.0195
140	0.0	0.0210	140	0.0	0.0229	140	0.0	0.0217
150	0.0	0.0175	150	0.0	0.0226	150	0.0	0.0209
160	0.0	0.0192	160	0.0	0.0201	160	0.0	0.0387
170	0.0	0.0401	170	0.0	0.0276	170	0.0	0.0294
180	0.0	0.0203	180	0.0	0.0199	180	0.0	0.0299
190	0.0	0.0295	190	0.0	0.0209	190	0.0	0.0185
200	0.0	0.0264	200	0.0	0.0253	200	0.0	0.0300
210	0.0	0.0240	210	0.0	0.0207	210	0.0	0.0223
220	0.0	0.0281	220	0.0	0.0208	220	0.0	0.0297
230	0.0	0.0352	230	0.0	0.0239	230	0.0	0.0268
240	0.0	0.0263	240	0.0	0.0201	240	0.0	0.0258
250	0.0	0.0243	250	0.0	0.0585	250	0.0	0.0228
260	0.0	0.0254	260	0.0	0.0206	260	0.0	0.0220
270	0.0	0.0197	270	0.0	0.0214	270	0.0	0.0214
280	0.0	0.0234	280	0.0	0.0288	280	0.0	0.0193
290	0.0	0.0267	290	0.0	0.0197	290	0.0	0.0279
300	0.0	0.0359	300	0.0	0.0600	300	0.0	0.0216
310	0.0	0.0195	310	0.0	0.0215	310	0.0	0.0237
320	0.0	0.0228	320	0.0	0.0259	320	0.0	0.0358
330	0.0	0.0220	330	0.0	0.0241	330	0.0	0.0203
340	0.0	0.0244	340	0.0	0.0213	340	0.0	0.0220
350	0.0	0.0205	350	0.0	0.0248	350	0.0	0.0252
360	0.0	0.0282	360	0.0	0.0181	360	0.0	0.0194
370	0.0	0.0415	370	0.0	0.0174	370	0.0	0.0190
380	0.0	0.0257	380	0.0	0.0279	380	0.0	0.0211
390	0.0	0.0217	390	0.0	0.0171	390	0.0	0.0223
400	0.0	0.0216	400	0.0	0.0185	400	0.0	0.0209
						410	0.0	0.0200
						420	0.0	0.0217

Table 29. (Continued) Soil Organic Carbon Content from Waiawa Ridge

	Lahaina			Moloka'i			Wahiawa	
X (m)	Depth (m)	f_{oc} (kg/kg)	X (m)	Depth (m)	f_{oc} (kg/kg)	X (m)	Depth (m)	f_{oc} (kg/kg)
0	0.3	0.0147	0	0.3	0.0157	0	0.3	0.0230
50	0.3	0.0068	50	0.3	0.0160	50	0.3	0.0165
100	0.3	0.0180	100	0.3	0.0116	100	0.3	0.0105
150	0.3	0.0086	150	0.3	0.0125	150	0.3	0.0122
200	0.3	0.0081	200	0.3	0.0174	200	0.3	0.0103
250	0.3	0.0044	250	0.3	0.0068	250	0.3	0.0104
300	0.3	0.0137	300	0.3	0.0078	300	0.3	0.0090
350	0.3	0.0109	350	0.3	0.0104	350	0.3	0.0052
400	0.3	0.0074	400	0.3	0.0166	400	0.3	0.0084
0	0.6	0.0068	0	0.6	0.0037	0	0.6	0.0119
50	0.6	0.0054	50	0.6	0.0062	50	0.6	0.0051
100	0.6	0.0044	100	0.6	0.0056	100	0.6	0.0034
150	0.6	0.0031	150	0.6	0.0048	150	0.6	0.0041
200	0.6	0.0023	200	0.6	0.0056	200	0.6	0.0062
250	0.6	0.0027	250	0.6	0.0029	250	0.6	0.0033
300	0.6	0.0040	300	0.6	0.0049	300	0.6	0.0039
350	0.6	0.0036	350	0.6	0.0071	350	0.6	0.0041
400	0.6	0.0052	400	0.6	0.0057	400	0.6	0.0033
	0.0000							
0	0.9	0.0048	0	0.9	0.0047	0	0.9	0.0102
50	0.9	0.0028	50	0.9	0.0035	50	0.9	0.0060
100	0.9	0.0044	100	0.9	0.0040	100	0.9	0.0025
150	0.9	0.0045	150	0.9	0.0051	150	0.9	0.0064
200	0.9	0.0033	200	0.9	0.0068	200	0.9	0.0061
250	0.9	0.0041	250	0.9	0.0046	250	0.9	0.0030
300	0.9	0.0070	300	0.9	0.0045	300	0.9	0.0030
350	0.9	0.0025	350	0.9	0.0038	350	0.9	0.0025
400	0.9	0.0033	400	0.9	0.0050	400	0.9	0.0041
	0	.0000						
0	1.2	0.0032	0	1.2	0.0043	0	1.2	0.0090
50	1.2	0.0022	50	1.2	0.0089	50	1.2	0.0062
100	1.2	0.0029	100	1.2	0.0038	100	1.2	0.0021
150	1.2	0.0029	150	1.2	0.0046	150	1.2	0.0106
200	1.2	0.0025	200	1.2	0.0050	200	1.2	0.0059
250	1.2	0.0017	250	1.2	0.0105	250	1.2	0.0040
300	1.2	0.0042	300	1.2	0.0060	300	1.2	0.0051
350	1.2	0.0043	350	1.2	0.0026	350	1.2	0.0046
400	1.2	0.0041	400	1.2	0.0019	400	1.2	0.0040

Table 30

Soil Organic Carbon Content from Waiawa Valley

X (m)	Y (m)	Depth (m)	f_{oc} (kg/kg)	X (m)	Y (m)	Depth (m)	f_{oc} (kg/kg)	X (m)	Y (m)	Depth (m)	f_{oc} (kg/kg)
0	600	0.00	0.0380	237	360	0.00	0.0355	420	360	0.00	0.0395
0	660	0.00	0.0279	238	360	0.00	0.0494	480	360	0.00	0.0660
60	540	0.00	0.154	239	0	0.00	0.0244				
60	600	0.00	0.0300	239	400	0.00	0.0660	0	600	0.30	0.0052
60	660	0.00	0.0532	240	0	0.00	0.0444	0	660	0.30	0.0040
113	515	0.00	0.0781	240	5	0.00	0.118	60	540	0.30	0.0200
116	511	0.00	0.0525	240	10	0.00	0.0808	60	600	0.30	0.0158
116	519	0.00	0.0483	240	15	0.00	0.0333	60	660	0.30	0.0128
120	480	0.00	0.0423	240	20	0.00	0.0202	113	515	0.30	0.0032
120	508	0.00	0.102	240	25	0.00	0.0185	116	511	0.30	0.0024
120	515	0.00	0.0516	240	30	0.00	0.0307	116	519	0.30	0.0017
120	522	0.00	0.0551	240	35	0.00	0.0287	120	480	0.30	0.0048
120	540	0.00	0.0682	240	40	0.00	0.0244	120	508	0.30	0.0012
124	511	0.00	0.0478	240	45	0.00	0.0325	120	515	0.30	0.0017
124	519	0.00	0.0614	240	50	0.00	0.0382	120	522	0.30	0.0065
128	515	0.00	0.134	240	60	0.00	0.103	120	540	0.30	0.0256
180	420	0.00	0.0343	240	70	0.00	0.0333	124	511	0.30	0.0026
180	480	0.00	0.0896	240	80	0.00	0.119	124	519	0.30	0.0031
190	420	0.00	0.0359	240	90	0.00	0.103	128	515	0.30	0.0044
200	0	0.00	0.0600	240	100	0.00	0.0529	180	420	0.30	0.0159
210	440	0.00	0.0338	240	110	0.00	0.0313	180	480	0.30	0.0048
220	0	0.00	0.0370	240	120	0.00	0.0949	200	0	0.30	0.0080
220	60	0.00	0.0409	240	130	0.00	0.0274	210	440	0.30	0.0005
228	230	0.00	0.0474	240	140	0.00	0.0437	220	0	0.30	0.0130
229	210	0.00	0.0396	240	150	0.00	0.0162	220	60	0.30	0.0060
229	220	0.00	0.0449	240	160	0.00	0.0428	229	240	0.30	0.0047
229	240	0.00	0.0536	240	370	0.00	0.0265	230	180	0.30	0.0034
230	180	0.00	0.0382	240	390	0.00	0.0405	230	300	0.30	0.0091
230	190	0.00	0.0796	240	420	0.00	0.0625	235	155	0.30	0.0206
230	200	0.00	0.0637	240	480	0.00	0.0443	238	360	0.30	0.0098
230	300	0.00	0.0308	320	240	0.00	0.0539	239	0	0.30	0.0103
230	310	0.00	0.0312	320	300	0.00	0.0786	240	0	0.30	0.0081
230	320	0.00	0.0305	330	360	0.00	0.105	240	60	0.30	0.0053
230	330	0.00	0.0480	340	240	0.00	0.0705	240	120	0.30	0.0143
230	340	0.00	0.0717	340	280	0.00	0.0433	240	420	0.30	0.0113
231	250	0.00	0.0550	340	300	0.00	0.0240	240	480	0.30	0.0031
231	260	0.00	0.0489	360	240	0.00	0.0565	320	240	0.30	0.0190
231	270	0.00	0.0616	360	260	0.00	0.0469	320	300	0.30	0.0083
232	290	0.00	0.0597	360	280	0.00	0.0433	330	360	0.30	0.0123
233	170	0.00	0.0696	360	300	0.00	0.0331	340	240	0.30	0.0042
233	280	0.00	0.0334	360	360	0.00	0.0823	340	280	0.30	0.0161
234	380	0.00	0.0337	420	300	0.00	0.0711	340	300	0.30	0.0065
235	350	0.00	0.0328	420	340	0.00	0.0717	360	240	0.30	0.0098

Table 30. (Continued) Soil Organic Carbon Content from Waiawa Valley

X (m)	Y (m)	Depth (m)	f_{oc} (kg/kg)
360	260	0.30	0.0051
360	300	0.30	0.0076
360	360	0.30	0.0106
420	300	0.30	0.0134
420	340	0.30	0.0047
480	360	0.30	0.0113
180	420	0.40	0.0045
200	0	0.40	0.0071
220	60	0.50	0.0094
0	600	0.60	0.0020
0	660	0.60	0.0071
60	540	0.60	0.0030
60	600	0.60	0.0031
60	660	0.60	0.0104
113	515	0.60	0.0008
116	519	0.60	0.0015
120	508	0.60	0.0019
120	515	0.60	0.0010
120	522	0.60	0.0079
120	540	0.60	0.0077
124	511	0.60	0.0025
124	519	0.60	0.0058
128	515	0.60	0.0022
229	240	0.60	0.0085
230	180	0.60	0.0161
230	300	0.60	0.0105
235	155	0.60	0.0047
238	360	0.60	0.0083
239	0	0.60	0.0038
240	60	0.60	0.0040
240	120	0.60	0.0050
240	420	0.60	0.0076
240	480	0.60	0.0007
340	240	0.60	0.0034
340	280	0.60	0.0195
340	300	0.60	0.0040
360	240	0.60	0.0061
360	300	0.60	0.0054
420	300	0.60	0.0117
480	360	0.60	0.0074
0	660	0.75	0.0021
360	240	0.80	0.0061
229	240	0.85	0.0036
0	600	0.90	0.0022
60	540	0.90	0.0027
60	600	0.90	0.0024
60	660	0.90	0.0158
113	515	0.90	0.0010
116	511	0.90	0.0009
116	519	0.90	0.0045
120	508	0.90	0.0008
120	515	0.90	0.0024
120	540	0.90	0.0088
124	511	0.90	0.0003
124	519	0.90	0.0042
235	155	0.90	0.0044
239	0	0.90	0.0113
240	60	0.90	0.0123
240	120	0.90	0.0026
240	420	0.90	0.0074
240	480	0.90	0.0009
340	240	0.90	0.0022
340	280	0.90	0.0191
340	300	0.90	0.0018
360	300	0.90	0.0024
420	300	0.90	0.0096
480	360	0.90	0.0059
229	240	0.95	0.0045
60	540	1.20	0.0009
60	600	1.20	0.0027
60	660	1.20	0.0151
116	511	1.20	0.0017
116	519	1.20	0.0102
120	508	1.20	0.0029
120	515	1.20	0.0095
120	540	1.20	0.0079
124	511	1.20	0.0015
240	60	1.20	0.0039
240	120	1.20	0.0026
240	420	1.20	0.0032
240	480	1.20	0.0007
340	240	1.20	0.0017
340	300	1.20	0.0022
360	300	1.20	0.0022
420	300	1.20	0.0060
480	360	1.20	0.0049
60	540	1.50	0.0005
60	600	1.50	0.0023
60	660	1.50	0.0102
116	511	1.50	0.0064
120	515	1.50	0.0030
240	60	1.50	0.0063
240	120	1.50	0.0023
360	300	1.50	0.0020
116	511	1.80	0.0033

Table 31

Summary of Soil Organic Carbon at Waiawa

Soil series	Depth (m)	N	Minimum (kg/kg)	Maximum (kg/kg)	Average (kg/kg)	σ (kg/kg)
Lahaina	0.03	41	0.0175	0.0415	0.0260	0.0057
Lahaina	0.30	9	0.0044	0.0180	0.0103	0.0044
Lahaina	0.60	9	0.0023	0.0068	0.0042	0.0015
Lahaina	0.90	9	0.0025	0.0070	0.0041	0.0014
Lahaina	1.20	9	0.0017	0.0043	0.0031	0.0009
Molokai	0.03	41	0.0171	0.0600	0.0255	0.0093
Molokai	0.30	9	0.0068	0.0174	0.0127	0.0039
Molokai	0.60	9	0.0029	0.0071	0.0052	0.0013
Molokai	0.90	9	0.0035	0.0068	0.0047	0.0010
Molokai	1.20	9	0.0019	0.0105	0.0053	0.0028
Wahiawa	0.03	43	0.0182	0.0387	0.0250	0.0053
Wahiawa	0.30	9	0.0052	0.0230	0.0117	0.0052
Wahiawa	0.60	9	0.0033	0.0119	0.0050	0.0028
Wahiawa	0.90	9	0.0025	0.0102	0.0049	0.0026
Wahiawa	1.20	9	0.0021	0.0106	0.0057	0.0026
L, M, & W	0.03	125	0.0171	0.0600	0.0255	0.0069
L, M, & W	0.30	27	0.0044	0.0230	0.0116	0.0045
L, M, & W	0.60	27	0.0023	0.0119	0.0048	0.0019
L, M, & W	0.90	27	0.0025	0.0102	0.0045	0.0017
L, M, & W	1.20	27	0.0017	0.0106	0.0047	0.0025
Kawaihapai	0.03	88	0.0162	0.154	0.0537	0.0269
Kawaihapai	0.30	46	0.0005	0.0256	0.0085	0.0059
Kawaihapai	0.60	31	0.0007	0.0195	0.0059	0.0044
Kawaihapai	0.90	24	0.0003	0.0191	0.0052	0.0051
Kawaihapai	1.20	18	0.0007	0.0151	0.0044	0.0039
Kawaihapai	1.50	8	0.0005	0.0102	0.0041	0.0032

N = number of samples; σ = standard deviation
L, M, & W = inclusion of all 3 Waiawa Ridge transects

APPENDIX F. Long-term PRZM Simulations

Table 32 describes the simulation case identifiers used for the long-term simulations of diazinon, metribuzin, and nitrate (as nitrogen) which are tabulated on an annual average basis in Tables 33 through 36. The parameters used to generate these data are summarized in Tables 6 through 10 (Chapter IV). Figure 42 compares daily time series with their annual averages for selected years of simulation case 454.n2.

Table 32

Legend for Long-term PRZM Simulations (Tables 33 through 36)

Sample case identification: 257b.m2h

- 2 — land use
- 57 — cell I.D. (x,y)
- b — option #1
- m — chemical
- 2 — profile
- h — option #2

land use

1	irrigated lawn, no runoff
2	golf course
4	residential
5	apartment
6	commercial/industrial

chemical

d	diazinon
m	metribuzin
n	nitrate (as nitrogen)

cell I.D.*

X	Y
---	---
3	3
4	4
5	5
6	6
7	7

profile

1	no loss of surface f_{oc}
2	0.2 m loss of surface f_{oc}
3	0.5 m loss of f_{oc}, lower θ_{fc}, thinner saprolite

option #1

b	chemical application dates are offset
v	valley profile (default = ridge)

option #2

d	distributed at top of saprolite (default = at top of water table)
h	includes hydrolysis rate for metribuzin (default = no metribuzin hydrolysis rate)

* Refer to Figure 19 (water balance grid)

Table 33

Long-term PRZM Simulations for Diazinon

YEAR	Case: 533.d3 LOAD (kg/ha)	Case: 533.d3 CONC. (µg/l)	Case: 534.d3 LOAD (kg/ha)	Case: 534.d3 CONC. (µg/l)	Case: 635.d3 LOAD (kg/ha)	Case: 635.d3 CONC. (µg/l)	Case: 443.d3 LOAD (kg/ha)	Case: 443.d3 CONC. (µg/l)	Case: 444.d3 LOAD (kg/ha)	Case: 444.d3 CONC. (µg/l)	Case: 446.d3 LOAD (kg/ha)	Case: 446.d3 CONC. (µg/l)	Case: 453.d3 LOAD (kg/ha)	Case: 453.d3 CONC. (µg/l)	Case: 454.d3 LOAD (kg/ha)	Case: 454.d3 CONC. (µg/l)
1	LL	LC	LL	LC	LL	LC	LL	LC	LL	LC	LL	LC	LL	LC	LL	LC
2	LL	LC	LL	LC	0.00293	0.371	LL	LC	LL	LC	LL	LC	LL	LC	LL	LC
3	LL	LC	0.00001	0.001	0.04344	5.247	0.00005	0.005	LL	LC	LL	LC	0.00023	0.021	LL	LC
4	0.00031	0.043	0.00114	0.137	0.04618	6.314	0.00185	0.223	0.00027	0.031	LL	LC	0.00530	0.548	0.00017	0.019
5	0.00288	0.338	0.00516	0.577	0.04710	5.879	0.00769	0.803	0.00270	0.269	0.00082	0.062	0.01682	1.521	0.00269	0.244
6	0.00761	0.756	0.00999	0.924	0.05290	5.995	0.01396	1.301	0.00641	0.566	0.00376	0.268	0.02869	2.196	0.00645	0.538
7	0.00383	0.697	0.00456	0.762	0.03532	6.108	0.00782	1.182	0.00365	0.519	0.00317	0.318	0.02168	2.356	0.00440	0.553
8	0.00209	0.427	0.00257	0.458	0.02043	3.502	0.00429	0.811	0.00186	0.327	0.00199	0.231	0.01190	1.813	0.00224	0.350
9	0.00294	0.356	0.00348	0.386	0.02638	3.125	0.00547	0.570	0.00227	0.230	0.00244	0.186	0.01195	1.112	0.00277	0.264
10	0.00318	0.350	0.00424	0.419	0.05743	6.504	0.00547	0.564	0.00294	0.278	0.00291	0.223	0.01179	1.099	0.00324	0.300
11	0.00335	0.407	0.00442	0.510	0.05901	7.764	0.00709	0.808	0.00237	0.256	0.00196	0.180	0.01071	1.268	0.00228	0.249
12	0.00583	0.753	0.00702	0.849	0.03438	4.935	0.01097	1.302	0.00370	0.395	0.00194	0.182	0.01372	1.519	0.00305	0.316
13	0.00653	0.779	0.00716	0.808	0.03103	4.187	0.00923	1.029	0.00578	0.558	0.00256	0.224	0.01130	1.139	0.00475	0.450
14	0.00363	0.575	0.00361	0.549	0.02644	4.444	0.00494	0.787	0.00310	0.423	0.00186	0.210	0.00576	0.856	0.00258	0.355
15	0.00317	0.433	0.00265	0.373	0.02056	3.235	0.00363	0.560	0.00230	0.285	0.00092	0.111	0.00584	0.736	0.00196	0.225
16	0.00253	0.413	0.00240	0.355	0.02307	3.396	0.00263	0.433	0.00202	0.274	0.00064	0.072	0.00503	0.649	0.00192	0.232
17	0.00274	0.361	0.00244	0.316	0.03138	4.400	0.00294	0.368	0.00194	0.237	0.00071	0.074	0.00547	0.613	0.00193	0.222
18	0.00459	0.481	0.00373	0.382	0.04647	5.688	0.00476	0.468	0.00237	0.231	0.00091	0.076	0.00900	0.844	0.00240	0.223
19	0.00352	0.497	0.00352	0.439	0.03816	5.097	0.00482	0.608	0.00217	0.244	0.00080	0.072	0.00875	0.998	0.00260	0.261
20	0.00664	0.640	0.00661	0.603	0.05115	5.654	0.01012	0.918	0.00394	0.331	0.00123	0.095	0.01661	1.317	0.00486	0.373
21	0.00763	0.896	0.00834	0.883	0.05131	6.791	0.01031	1.172	0.00502	0.508	0.00160	0.153	0.01462	1.596	0.00571	0.559
22	0.01488	1.313	0.01829	1.428	0.08068	7.750	0.01923	1.626	0.01073	0.786	0.00340	0.228	0.02164	1.961	0.01039	0.771
23	0.01984	1.908	0.02521	2.188	0.07545	8.507	0.02337	2.172	0.01475	1.246	0.00380	0.306	0.02101	2.043	0.01238	1.046
24	0.01366	1.824	0.01995	2.237	0.05751	7.421	0.01726	2.114	0.01210	1.333	0.00407	0.377	0.01444	1.719	0.01021	1.055
25	0.00691	1.010	0.00963	1.244	0.03204	4.955	0.00890	1.263	0.00534	0.731	0.00216	0.240	0.00750	1.043	0.00449	0.605
26	0.00881	0.932	0.01205	1.148	0.04573	5.125	0.01081	1.125	0.00588	0.604	0.00236	0.228	0.00952	0.979	0.00473	0.495
27	0.00735	0.819	0.00929	0.979	0.06768	8.493	0.00912	0.973	0.00408	0.428	0.00155	0.154	0.00832	0.877	0.00328	0.339
28	0.00218	0.529	0.00473	0.742	0.03748	5.292	0.00413	0.788	0.00189	0.277	0.00082	0.097	0.00479	0.783	0.00182	0.238
29	0.00548	0.623	0.01013	0.967	0.05407	5.985	0.00989	0.924	0.00459	0.387	0.00135	0.100	0.01284	1.054	0.00435	0.331
30	0.00388	0.534	0.00616	0.769	0.04866	7.143	0.00757	0.896	0.00382	0.443	0.00102	0.123	0.01099	1.182	0.00422	0.442
31	0.00222	0.402	0.00455	0.670	0.03586	5.619	0.00578	0.892	0.00299	0.407	0.00088	0.107	0.00916	1.303	0.00370	0.458
32	0.00136	0.246	0.00318	0.478	0.02052	3.363	0.00411	0.673	0.00197	0.285	0.00046	0.062	0.00593	0.932	0.00253	0.338
33	0.00183	0.242	0.00347	0.396	0.01983	2.750	0.00449	0.514	0.00232	0.248	0.00045	0.047	0.00600	0.640	0.00285	0.288
34	0.00218	0.298	0.00359	0.431	0.03157	4.243	0.00427	0.523	0.00229	0.266	0.00051	0.057	0.00531	0.612	0.00255	0.282
35	0.00280	0.297	0.00494	0.471	0.05146	5.985	0.00694	0.652	0.00285	0.250	0.00065	0.052	0.00934	0.810	0.00310	0.253
36	0.00323	0.442	0.00669	0.737	0.05232	6.027	0.00919	1.055	0.00357	0.359	0.00074	0.059	0.01295	1.343	0.00401	0.367
37	0.01230	1.001	0.01692	1.325	0.08286	8.274	0.02364	1.736	0.01134	0.816	0.00240	0.168	0.03114	2.132	0.01256	0.835

NOTE: LL = less than 0.00001 kg/ha; LC = less than 0.001 µg/l.

Table 33. (Continued) Long-term PRZM Simulations for Diazinon

YEAR	Case: 455.d3 LOAD (kg/ha)	CONC. (µg/l)	Case: 456.d3 LOAD (kg/ha)	CONC. (µg/l)	Case: 463.d3 LOAD (kg/ha)	CONC. (µg/l)	Case: 465.d3 LOAD (kg/ha)	CONC. (µg/l)	Case: 473.d3 LOAD (kg/ha)	CONC. (µg/l)	Case: 475.d3 LOAD (kg/ha)	CONC. (µg/l)	Case: 533.d2 LOAD (kg/ha)	CONC. (µg/l)	Case: 534.d2 LOAD (kg/ha)	CONC. (µg/l)
1	LL	LC	LL	LC	LL	LC	LL	LC	LL	LC	LL	LC	LL	LC	LL	LC
2	LL	LC	LL	LC	LL	LC	LL	LC	LL	LC	LL	LC	LL	LC	LL	LC
3	LL	LC	LL	LC	0.00002	0.002	LL	LC	0.00007	0.007	LL	LC	LL	LC	LL	LC
4	0.00028	0.030	LL	LC	0.00198	0.202	0.00069	0.062	0.00345	0.343	0.00006	0.005	LL	LC	LL	LC
5	0.00325	0.291	0.00029	0.020	0.00911	0.814	0.00796	0.575	0.01179	1.017	0.00353	0.236	LL	LC	LL	LC
6	0.00655	0.538	0.00257	0.176	0.01509	1.221	0.01560	1.141	0.01672	1.355	0.01028	0.710	0.00001	0.001	0.00005	0.004
7	0.00401	0.518	0.00303	0.275	0.00963	1.126	0.01255	1.214	0.01052	1.197	0.01092	0.880	0.00003	0.005	0.00008	0.013
8	0.00222	0.351	0.00220	0.236	0.00535	0.780	0.00868	0.989	0.00594	0.857	0.00784	0.787	0.00003	0.007	0.00007	0.013
9	0.00263	0.260	0.00269	0.197	0.00711	0.621	0.00952	0.710	0.00805	0.671	0.00906	0.605	0.00006	0.008	0.00010	0.012
10	0.00314	0.285	0.00298	0.223	0.00711	0.636	0.00982	0.777	0.00832	0.725	0.00890	0.659	0.00010	0.011	0.00016	0.016
11	0.00232	0.241	0.00224	0.183	0.00709	0.752	0.01090	0.917	0.00988	0.947	0.00899	0.693	0.00010	0.012	0.00014	0.016
12	0.00325	0.335	0.00208	0.187	0.00969	0.995	0.01386	1.250	0.01361	1.334	0.00950	0.844	0.00009	0.011	0.00012	0.014
13	0.00547	0.496	0.00284	0.225	0.00931	0.890	0.01205	0.970	0.01208	1.083	0.00958	0.716	0.00008	0.010	0.00011	0.013
14	0.00328	0.415	0.00203	0.216	0.00459	0.634	0.00631	0.745	0.00642	0.847	0.00492	0.525	0.00008	0.012	0.00011	0.016
15	0.00246	0.278	0.00108	0.118	0.00403	0.469	0.00559	0.548	0.00553	0.620	0.00410	0.357	0.00009	0.013	0.00010	0.015
16	0.00254	0.291	0.00078	0.082	0.00397	0.464	0.00534	0.534	0.00542	0.585	0.00425	0.375	0.00007	0.012	0.00008	0.012
17	0.00230	0.265	0.00076	0.078	0.00367	0.417	0.00475	0.478	0.00462	0.525	0.00390	0.371	0.00007	0.010	0.00007	0.010
18	0.00300	0.276	0.00096	0.077	0.00534	0.493	0.00666	0.541	0.00651	0.599	0.00508	0.384	0.00010	0.011	0.00009	0.010
19	0.00389	0.334	0.00095	0.076	0.00511	0.546	0.00825	0.654	0.00646	0.652	0.00615	0.463	0.00006	0.009	0.00007	0.009
20	0.00742	0.527	0.00141	0.102	0.00990	0.749	0.01232	0.881	0.01114	0.837	0.00784	0.550	0.00011	0.010	0.00010	0.010
21	0.00924	0.836	0.00168	0.154	0.00981	1.014	0.01130	1.086	0.01018	1.083	0.00602	0.607	0.00014	0.016	0.00016	0.017
22	0.01961	1.273	0.00380	0.240	0.01426	1.206	0.01811	1.242	0.01501	1.238	0.00872	0.634	0.00034	0.030	0.00045	0.035
23	0.02148	1.675	0.00418	0.324	0.01692	1.472	0.01759	1.411	0.01834	1.533	0.00911	0.697	0.00047	0.045	0.00070	0.061
24	0.01791	1.631	0.00438	0.371	0.01190	1.317	0.01597	1.421	0.01391	1.453	0.00817	0.698	0.00046	0.061	0.00081	0.091
25	0.00843	0.952	0.00245	0.246	0.00639	0.817	0.00860	0.924	0.00800	0.974	0.00467	0.490	0.00032	0.047	0.00057	0.073
26	0.00877	0.802	0.00293	0.247	0.00847	0.787	0.01020	0.851	0.01126	0.968	0.00673	0.513	0.00049	0.052	0.00083	0.079
27	0.00572	0.560	0.00181	0.174	0.00618	0.638	0.00645	0.642	0.00752	0.781	0.00423	0.415	0.00038	0.042	0.00060	0.063
28	0.00373	0.418	0.00102	0.109	0.00321	0.475	0.00497	0.523	0.00500	0.641	0.00301	0.295	0.00009	0.023	0.00023	0.036
29	0.00905	0.649	0.00160	0.114	0.00948	0.731	0.01128	0.796	0.01297	0.965	0.00614	0.437	0.00015	0.017	0.00032	0.031
30	0.00652	0.674	0.00137	0.144	0.00802	0.804	0.00785	0.777	0.00994	0.991	0.00485	0.462	0.00010	0.014	0.00022	0.027
31	0.00612	0.688	0.00109	0.122	0.00593	0.808	0.00740	0.813	0.00776	1.014	0.00358	0.397	0.00007	0.012	0.00019	0.028
32	0.00440	0.524	0.00062	0.072	0.00345	0.535	0.00548	0.628	0.00445	0.662	0.00249	0.283	0.00004	0.008	0.00011	0.017
33	0.00406	0.392	0.00061	0.059	0.00432	0.444	0.00467	0.449	0.00466	0.482	0.00244	0.229	0.00004	0.005	0.00010	0.011
34	0.00343	0.369	0.00066	0.072	0.00363	0.404	0.00375	0.407	0.00371	0.426	0.00209	0.225	0.00004	0.005	0.00011	0.013
35	0.00467	0.364	0.00085	0.064	0.00523	0.427	0.00539	0.405	0.00519	0.427	0.00251	0.187	0.00006	0.006	0.00015	0.015
36	0.00658	0.545	0.00083	0.065	0.00769	0.747	0.00710	0.590	0.00719	0.702	0.00276	0.230	0.00005	0.006	0.00012	0.014
37	0.01647	1.089	0.00240	0.158	0.02129	1.414	0.01843	1.175	0.01997	1.337	0.00842	0.529	0.00014	0.011	0.00032	0.025

NOTE: LL = less than 0.00001 kg/ha; LC = less than 0.001 µg/l.

Table 33. (Continued) Long-term PRZM Simulations for Diazinon

YEAR	Case: 635.d2 LOAD (kg/ha)	CONC. (μg/l)	Case: 443.d2 LOAD (kg/ha)	CONC. (μg/l)	Case: 444.d2 LOAD (kg/ha)	CONC. (μg/l)	Case: 446.d2 LOAD (kg/ha)	CONC. (μg/l)	Case: 453.d2 LOAD (kg/ha)	CONC. (μg/l)	Case: 454.d2 LOAD (kg/ha)	CONC. (μg/l)	Case: 455.d2 LOAD (kg/ha)	CONC. (μg/l)	Case: 456.d2 LOAD (kg/ha)	CONC. (μg/l)
1	LL	LC	LL	LC	LL	LC	LL	LC	LL	LC	LL	LC	LL	LC	LL	LC
2	LL	LC	LL	LC	LL	LC	LL	LC	LL	LC	LL	LC	LL	LC	LL	LC
3	0.00024	0.029	LL	LC	LL	LC	LL	LC	LL	LC	LL	LC	LL	LC	LL	LC
4	0.00506	0.691	LL	LC	LL	LC	LL	LC	LL	LC	LL	LC	LL	LC	LL	LC
5	0.00794	0.990	LL	LC	LL	LC	LL	LC	0.00002	0.001	LL	LC	LL	LC	LL	LC
6	0.00943	1.068	0.00005	0.005	0.00001	0.001	0.00000	0.000	0.00033	0.025	0.00001	0.001	0.00001	0.001	LL	LC
7	0.00493	0.852	0.00010	0.015	0.00002	0.003	0.00001	0.001	0.00062	0.067	0.00003	0.004	0.00004	0.005	0.00001	0.001
8	0.00370	0.634	0.00008	0.016	0.00003	0.005	0.00003	0.003	0.00041	0.062	0.00004	0.006	0.00004	0.006	0.00002	0.002
9	0.00445	0.527	0.00014	0.014	0.00005	0.005	0.00006	0.005	0.00053	0.049	0.00006	0.006	0.00006	0.006	0.00005	0.004
10	0.00524	0.594	0.00018	0.018	0.00008	0.007	0.00010	0.007	0.00062	0.058	0.00010	0.009	0.00009	0.008	0.00010	0.007
11	0.00717	0.944	0.00016	0.019	0.00007	0.007	0.00008	0.007	0.00040	0.048	0.00008	0.008	0.00008	0.008	0.00010	0.008
12	0.00833	1.196	0.00013	0.016	0.00006	0.007	0.00007	0.006	0.00030	0.034	0.00007	0.007	0.00008	0.008	0.00008	0.007
13	0.00572	0.771	0.00014	0.016	0.00006	0.006	0.00005	0.005	0.00030	0.031	0.00006	0.006	0.00007	0.006	0.00007	0.005
14	0.00350	0.588	0.00012	0.019	0.00005	0.007	0.00003	0.004	0.00021	0.032	0.00004	0.006	0.00005	0.007	0.00004	0.004
15	0.00287	0.452	0.00010	0.016	0.00005	0.007	0.00002	0.003	0.00020	0.025	0.00005	0.005	0.00006	0.007	0.00003	0.003
16	0.00290	0.428	0.00007	0.011	0.00005	0.007	0.00002	0.002	0.00014	0.017	0.00005	0.006	0.00007	0.008	0.00003	0.003
17	0.00344	0.483	0.00007	0.009	0.00005	0.006	0.00002	0.002	0.00014	0.016	0.00004	0.005	0.00006	0.007	0.00003	0.003
18	0.00507	0.621	0.00009	0.009	0.00005	0.005	0.00002	0.002	0.00019	0.018	0.00005	0.005	0.00007	0.007	0.00003	0.002
19	0.00548	0.731	0.00007	0.008	0.00004	0.005	0.00002	0.002	0.00015	0.017	0.00005	0.005	0.00008	0.007	0.00002	0.002
20	0.00732	0.809	0.00010	0.009	0.00005	0.005	0.00002	0.002	0.00028	0.022	0.00007	0.005	0.00012	0.009	0.00003	0.002
21	0.00749	0.992	0.00014	0.016	0.00006	0.007	0.00002	0.002	0.00033	0.036	0.00008	0.008	0.00016	0.015	0.00002	0.002
22	0.01395	1.340	0.00036	0.031	0.00017	0.013	0.00004	0.003	0.00056	0.050	0.00019	0.014	0.00044	0.028	0.00005	0.003
23	0.01512	1.706	0.00052	0.049	0.00027	0.023	0.00007	0.005	0.00062	0.060	0.00027	0.023	0.00065	0.051	0.00008	0.006
24	0.01313	1.695	0.00049	0.059	0.00029	0.032	0.00008	0.008	0.00055	0.065	0.00029	0.030	0.00076	0.070	0.00011	0.009
25	0.00670	1.036	0.00035	0.049	0.00017	0.023	0.00005	0.006	0.00034	0.048	0.00016	0.021	0.00045	0.051	0.00007	0.007
26	0.00817	0.915	0.00047	0.049	0.00026	0.027	0.00007	0.006	0.00043	0.044	0.00021	0.022	0.00054	0.050	0.00010	0.008
27	0.00735	0.923	0.00038	0.041	0.00020	0.021	0.00006	0.005	0.00032	0.034	0.00016	0.016	0.00036	0.035	0.00007	0.007
28	0.00726	1.024	0.00013	0.025	0.00009	0.013	0.00003	0.004	0.00014	0.022	0.00008	0.011	0.00021	0.023	0.00005	0.005
29	0.01014	1.123	0.00022	0.020	0.00013	0.011	0.00005	0.004	0.00026	0.021	0.00013	0.010	0.00028	0.020	0.00006	0.005
30	0.00672	0.986	0.00017	0.020	0.00008	0.009	0.00002	0.003	0.00025	0.026	0.00008	0.009	0.00018	0.018	0.00003	0.004
31	0.00623	0.976	0.00014	0.021	0.00006	0.008	0.00002	0.002	0.00022	0.031	0.00006	0.008	0.00016	0.018	0.00002	0.003
32	0.00403	0.660	0.00008	0.014	0.00004	0.005	0.00001	0.001	0.00012	0.019	0.00004	0.006	0.00011	0.013	0.00001	0.002
33	0.00319	0.443	0.00008	0.010	0.00004	0.004	0.00001	0.001	0.00014	0.015	0.00005	0.005	0.00011	0.010	0.00001	0.001
34	0.00350	0.471	0.00010	0.012	0.00005	0.005	0.00001	0.001	0.00017	0.020	0.00006	0.007	0.00012	0.013	0.00001	0.001
35	0.00506	0.588	0.00015	0.014	0.00007	0.006	0.00001	0.001	0.00025	0.022	0.00010	0.008	0.00017	0.013	0.00002	0.001
36	0.00813	0.937	0.00012	0.013	0.00006	0.006	0.00001	0.001	0.00019	0.020	0.00009	0.008	0.00015	0.012	0.00002	0.002
37	0.01436	1.434	0.00034	0.025	0.00013	0.010	0.00003	0.002	0.00058	0.040	0.00018	0.012	0.00030	0.020	0.00004	0.002

NOTE: LL - less than 0.00001 kg/ha; LC - less than 0.001 μg/l.

Table 33. (Continued) Long-term PRZM Simulations for Diazinon

YEAR	Case: 463.d2 LOAD (kg/ha)	Case: 463.d2 CONC. (µg/l)	Case: 465.d2 LOAD (kg/ha)	Case: 465.d2 CONC. (µg/l)	Case: 473.d2 LOAD (kg/ha)	Case: 473.d2 CONC. (µg/l)	Case: 475.d2 LOAD (kg/ha)	Case: 475.d2 CONC. (µg/l)	Case: 533.d3d LOAD (kg/ha)	Case: 533.d3d CONC. (µg/l)	Case: 534.d3d LOAD (kg/ha)	Case: 534.d3d CONC. (µg/l)	Case: 635.d3d LOAD (kg/ha)	Case: 635.d3d CONC. (µg/l)	Case: 443.d3d LOAD (kg/ha)	Case: 443.d3d CONC. (µg/l)
1	LL	LC	LL	LC	LL	LC	LL	LC	LL	LC	LL	LC	LL	LC	LL	LC
2	LL	LC	LL	LC	LL	LC	LL	LC	LL	LC	LL	LC	LL	LC	LL	LC
3	LL	LC	LL	LC	LL	LC	LL	LC	LL	LC	LL	LC	LL	LC	LL	LC
4	LL	LC	LL	LC	LL	LC	LL	LC	LL	LC	LL	LC	LL	LC	LL	LC
5	LL	LC	LL	LC	0.00001	0.001	LL	LC	LL	LC	LL	LC	LL	LC	0.00001	0.001
6	0.00009	0.007	0.00008	0.006	0.00015	0.012	0.00002	0.001	LL	LC	LL	LC	LL	LC	0.00015	0.014
7	0.00020	0.023	0.00025	0.024	0.00028	0.032	0.00015	0.012	LL	LC	LL	LC	LL	LC	0.00016	0.024
8	0.00016	0.023	0.00026	0.030	0.00020	0.029	0.00021	0.021	LL	LC	LL	LC	LL	LC	0.00011	0.021
9	0.00025	0.022	0.00042	0.031	0.00031	0.026	0.00039	0.026	0.00001	0.001	0.00001	0.001	LL	LC	0.00019	0.020
10	0.00030	0.026	0.00057	0.045	0.00037	0.032	0.00053	0.039	0.00001	0.001	0.00001	0.001	LL	LC	0.00029	0.030
11	0.00024	0.025	0.00047	0.039	0.00032	0.031	0.00046	0.036	0.00002	0.002	0.00002	0.002	LL	LC	0.00020	0.023
12	0.00019	0.020	0.00036	0.033	0.00026	0.026	0.00033	0.029	0.00002	0.002	0.00002	0.002	LL	LC	0.00019	0.022
13	0.00019	0.019	0.00040	0.032	0.00031	0.028	0.00033	0.025	0.00001	0.002	0.00001	0.001	LL	LC	0.00022	0.024
14	0.00015	0.021	0.00032	0.038	0.00026	0.034	0.00024	0.026	0.00001	0.001	0.00001	0.001	LL	LC	0.00020	0.031
15	0.00015	0.017	0.00029	0.029	0.00023	0.026	0.00025	0.022	0.00001	0.001	0.00001	0.001	LL	LC	0.00013	0.020
16	0.00012	0.014	0.00022	0.022	0.00019	0.020	0.00019	0.017	0.00001	0.002	0.00001	0.001	LL	LC	0.00009	0.015
17	0.00010	0.012	0.00018	0.018	0.00015	0.017	0.00014	0.014	0.00001	0.002	0.00001	0.001	LL	LC	0.00011	0.014
18	0.00013	0.012	0.00022	0.018	0.00018	0.017	0.00017	0.013	0.00002	0.002	0.00001	0.001	LL	LC	0.00015	0.015
19	0.00010	0.010	0.00022	0.017	0.00014	0.014	0.00018	0.013	0.00001	0.002	0.00001	0.001	LL	LC	0.00010	0.013
20	0.00017	0.013	0.00030	0.022	0.00023	0.017	0.00022	0.015	0.00002	0.002	0.00001	0.001	LL	LC	0.00017	0.016
21	0.00019	0.020	0.00030	0.029	0.00023	0.024	0.00017	0.017	0.00002	0.002	0.00001	0.001	LL	LC	0.00024	0.027
22	0.00034	0.028	0.00059	0.041	0.00038	0.032	0.00027	0.020	0.00005	0.004	0.00004	0.003	LL	LC	0.00054	0.045
23	0.00044	0.038	0.00071	0.057	0.00052	0.043	0.00034	0.026	0.00007	0.007	0.00006	0.005	LL	LC	0.00064	0.059
24	0.00042	0.046	0.00074	0.066	0.00052	0.054	0.00035	0.030	0.00006	0.008	0.00007	0.008	LL	LC	0.00064	0.078
25	0.00026	0.033	0.00042	0.045	0.00033	0.040	0.00020	0.021	0.00004	0.006	0.00005	0.006	LL	LC	0.00036	0.052
26	0.00038	0.036	0.00056	0.046	0.00050	0.043	0.00027	0.021	0.00007	0.007	0.00008	0.008	LL	LC	0.00060	0.063
27	0.00026	0.027	0.00037	0.037	0.00035	0.036	0.00019	0.019	0.00007	0.008	0.00008	0.008	LL	LC	0.00044	0.047
28	0.00012	0.018	0.00024	0.026	0.00019	0.025	0.00014	0.014	0.00002	0.005	0.00004	0.006	LL	LC	0.00017	0.032
29	0.00022	0.017	0.00034	0.024	0.00033	0.025	0.00019	0.014	0.00003	0.003	0.00005	0.005	LL	LC	0.00030	0.028
30	0.00018	0.018	0.00024	0.024	0.00028	0.028	0.00013	0.013	0.00002	0.003	0.00003	0.004	LL	LC	0.00026	0.031
31	0.00015	0.020	0.00023	0.026	0.00023	0.031	0.00011	0.012	0.00001	0.002	0.00002	0.003	LL	LC	0.00019	0.029
32	0.00008	0.013	0.00015	0.018	0.00012	0.018	0.00008	0.009	0.00001	0.001	0.00001	0.002	LL	LC	0.00011	0.018
33	0.00009	0.010	0.00014	0.013	0.00012	0.013	0.00007	0.006	0.00001	0.001	0.00001	0.001	LL	LC	0.00013	0.014
34	0.00011	0.012	0.00015	0.016	0.00013	0.015	0.00006	0.007	0.00001	0.001	0.00001	0.001	LL	LC	0.00018	0.022
35	0.00017	0.014	0.00022	0.016	0.00019	0.016	0.00009	0.007	0.00001	0.001	0.00002	0.002	LL	LC	0.00022	0.020
36	0.00013	0.012	0.00017	0.014	0.00013	0.013	0.00008	0.007	0.00001	0.001	0.00002	0.002	LL	LC	0.00016	0.018
37	0.00032	0.021	0.00036	0.023	0.00031	0.020	0.00014	0.009	0.00002	0.002	0.00003	0.002	LL	LC	0.00056	0.041

NOTE: LL = less than 0.00001 kg/ha; LC = less than 0.001 µg/l.

Table 33. (Continued) Long-term PRZM Simulations for Diazinon

YEAR	Case: 444.d3d		Case: 446.d3d		Case: 453.d3d		Case: 454.d3d		Case: 455.d3d		Case: 456.d3d		Case: 463.d3d		Case: 465.d3d	
	LOAD (kg/ha)	CONC. (µg/l)	LOAD (kg/ha)	CONC. (µg/l)	LOAD (kg/ha)	CONC. (µg/l)	LOAD (kg/ha)	CONC. (µg/l)	LOAD (kg/ha)	CONC. (µg/l)	LOAD (kg/ha)	CONC. (µg/l)	LOAD (kg/ha)	CONC. (µg/l)	LOAD (kg/ha)	CONC. (µg/l)
1	LL	LC	LL	LC	LL	LC	LL	LC	LL	LC	LL	LC	LL	LC	LL	LC
2	LL	LC	LL	LC	LL	LC	LL	LC	LL	LC	LL	LC	LL	LC	LL	LC
3	LL	LC	LL	LC	LL	LC	LL	LC	LL	LC	LL	LC	LL	LC	LL	LC
4	LL	LC	LL	LC	LL	LC	LL	LC	LL	LC	LL	LC	LL	LC	LL	LC
5	LL	LC	LL	LC	0.00004	0.004	LL	LC	LL	LC	LL	LC	LL	LC	LL	LC
6	LL	LC	LL	LC	0.00045	0.034	LL	LC	LL	LC	LL	LC	0.00003	0.002	0.00001	0.000
7	LL	LC	LL	LC	0.00065	0.071	LL	LC	LL	LC	LL	LC	0.00008	0.009	0.00003	0.003
8	0.00001	0.001	LL	LC	0.00038	0.058	0.00000	0.001	0.00001	0.001	LL	LC	0.00007	0.010	0.00005	0.005
9	0.00001	0.001	LL	LC	0.00054	0.050	0.00001	0.001	0.00001	0.001	LL	LC	0.00012	0.010	0.00010	0.007
10	0.00003	0.002	LL	LC	0.00071	0.066	0.00002	0.002	0.00002	0.002	LL	LC	0.00017	0.015	0.00016	0.012
11	0.00003	0.003	LL	LC	0.00039	0.046	0.00002	0.002	0.00002	0.002	LL	LC	0.00015	0.015	0.00016	0.014
12	0.00003	0.003	LL	LC	0.00033	0.036	0.00002	0.002	0.00002	0.002	LL	LC	0.00011	0.011	0.00013	0.012
13	0.00003	0.002	LL	LC	0.00036	0.036	0.00002	0.002	0.00002	0.002	LL	LC	0.00010	0.010	0.00011	0.009
14	0.00002	0.002	LL	LC	0.00026	0.039	0.00001	0.002	0.00001	0.002	LL	LC	0.00007	0.010	0.00007	0.009
15	0.00002	0.002	LL	LC	0.00020	0.025	0.00001	0.001	0.00001	0.001	LL	LC	0.00008	0.009	0.00008	0.008
16	0.00002	0.002	LL	LC	0.00016	0.021	0.00001	0.001	0.00001	0.002	LL	LC	0.00006	0.008	0.00007	0.007
17	0.00002	0.002	LL	LC	0.00018	0.021	0.00001	0.001	0.00002	0.002	LL	LC	0.00006	0.007	0.00006	0.006
18	0.00002	0.002	LL	LC	0.00024	0.023	0.00001	0.001	0.00002	0.002	LL	LC	0.00008	0.007	0.00007	0.005
19	0.00002	0.002	LL	LC	0.00018	0.020	0.00001	0.001	0.00002	0.002	LL	LC	0.00006	0.006	0.00007	0.005
20	0.00002	0.002	LL	LC	0.00036	0.029	0.00002	0.002	0.00004	0.002	LL	LC	0.00009	0.007	0.00009	0.006
21	0.00002	0.002	LL	LC	0.00041	0.045	0.00002	0.002	0.00004	0.004	LL	LC	0.00011	0.011	0.00008	0.007
22	0.00006	0.005	LL	LC	0.00061	0.056	0.00005	0.003	0.00011	0.007	LL	LC	0.00018	0.015	0.00016	0.011
23	0.00009	0.008	LL	LC	0.00064	0.062	0.00007	0.006	0.00016	0.012	LL	LC	0.00022	0.020	0.00019	0.015
24	0.00010	0.011	LL	LC	0.00059	0.070	0.00007	0.008	0.00020	0.018	LL	LC	0.00021	0.023	0.00022	0.020
25	0.00006	0.008	LL	LC	0.00034	0.047	0.00004	0.005	0.00012	0.013	LL	LC	0.00013	0.017	0.00013	0.014
26	0.00008	0.009	LL	LC	0.00047	0.048	0.00005	0.005	0.00015	0.014	LL	LC	0.00019	0.018	0.00017	0.014
27	0.00007	0.008	LL	LC	0.00034	0.036	0.00004	0.005	0.00011	0.011	LL	LC	0.00015	0.016	0.00011	0.011
28	0.00004	0.006	LL	LC	0.00016	0.026	0.00002	0.003	0.00007	0.008	LL	LC	0.00007	0.011	0.00008	0.009
29	0.00006	0.005	LL	LC	0.00032	0.026	0.00004	0.003	0.00010	0.007	LL	LC	0.00012	0.010	0.00012	0.008
30	0.00003	0.004	LL	LC	0.00032	0.034	0.00003	0.003	0.00006	0.006	LL	LC	0.00011	0.011	0.00008	0.008
31	0.00002	0.003	LL	LC	0.00024	0.034	0.00002	0.002	0.00005	0.005	LL	LC	0.00008	0.011	0.00007	0.007
32	0.00001	0.002	LL	LC	0.00014	0.021	0.00001	0.002	0.00003	0.004	LL	LC	0.00004	0.007	0.00004	0.005
33	0.00001	0.002	LL	LC	0.00017	0.018	0.00001	0.001	0.00003	0.003	LL	LC	0.00005	0.005	0.00004	0.004
34	0.00002	0.002	LL	LC	0.00025	0.029	0.00001	0.002	0.00003	0.003	LL	LC	0.00006	0.006	0.00004	0.004
35	0.00003	0.002	LL	LC	0.00029	0.025	0.00002	0.002	0.00005	0.004	LL	LC	0.00011	0.009	0.00006	0.005
36	0.00003	0.003	LL	LC	0.00022	0.023	0.00003	0.003	0.00005	0.004	LL	LC	0.00008	0.007	0.00006	0.005
37	0.00005	0.004	LL	LC	0.00075	0.051	0.00005	0.004	0.00009	0.006	LL	LC	0.00017	0.011	0.00010	0.007

NOTE: LL = less than 0.00001 kg/ha; LC = less than 0.001 µg/I.

Table 33. (Continued) Long-term PRZM Simulations for Diazinon

YEAR	Case: 473.d3d LOAD (kg/ha)	CONC. (µg/l)	Case: 475.d3d LOAD (kg/ha)	CONC. (µg/l)	Case: 533.d2d LOAD (kg/ha)	CONC. (µg/l)	Case: 534.d2d LOAD (kg/ha)	CONC. (µg/l)	Case: 635.d2d LOAD (kg/ha)	CONC. (µg/l)	Case: 443.d2d LOAD (kg/ha)	CONC. (µg/l)	Case: 444.d2d LOAD (kg/ha)	CONC. (µg/l)	Case: 446.d2d LOAD (kg/ha)	CONC. (µg/l)
1	LL	LC	LL	LC	LL	LC	LL	LC	LL	LC	LL	LC	LL	LC	LL	LC
2	LL	LC	LL	LC	LL	LC	LL	LC	LL	LC	LL	LC	LL	LC	LL	LC
3	LL	LC	LL	LC	LL	LC	LL	LC	LL	LC	LL	LC	LL	LC	LL	LC
4	LL	LC	LL	LC	LL	LC	LL	LC	LL	LC	LL	LC	LL	LC	LL	LC
5	LL	LC	LL	LC	LL	LC	LL	LC	LL	LC	LL	LC	LL	LC	LL	LC
6	0.00005	0.004	LL	LC	LL	LC	LL	LC	LL	LC	LL	LC	LL	LC	LL	LC
7	0.00011	0.013	LL	LC	LL	LC	LL	LC	LL	LC	LL	LC	LL	LC	LL	LC
8	0.00009	0.013	0.00001	0.001	LL	LC	LL	LC	LL	LC	LL	LC	LL	LC	LL	LC
9	0.00015	0.012	0.00003	0.002	LL	LC	LL	LC	LL	LC	LL	LC	LL	LC	LL	LC
10	0.00021	0.018	0.00006	0.005	LL	LC	LL	LC	LL	LC	LL	LC	LL	LC	LL	LC
11	0.00019	0.019	0.00008	0.006	LL	LC	LL	LC	LL	LC	LL	LC	LL	LC	LL	LC
12	0.00015	0.015	0.00007	0.006	LL	LC	LL	LC	LL	LC	LL	LC	LL	LC	LL	LC
13	0.00016	0.014	0.00006	0.004	LL	LC	LL	LC	LL	LC	LL	LC	LL	LC	LL	LC
14	0.00012	0.016	0.00003	0.003	LL	LC	LL	LC	LL	LC	LL	LC	LL	LC	LL	LC
15	0.00012	0.014	0.00003	0.003	LL	LC	LL	LC	LL	LC	LL	LC	LL	LC	LL	LC
16	0.00010	0.011	0.00003	0.003	LL	LC	LL	LC	LL	LC	LL	LC	LL	LC	LL	LC
17	0.00009	0.010	0.00003	0.003	LL	LC	LL	LC	LL	LC	LL	LC	LL	LC	LL	LC
18	0.00011	0.010	0.00003	0.002	LL	LC	LL	LC	LL	LC	LL	LC	LL	LC	LL	LC
19	0.00008	0.008	0.00003	0.002	LL	LC	LL	LC	LL	LC	LL	LC	LL	LC	LL	LC
20	0.00012	0.009	0.00003	0.002	LL	LC	LL	LC	LL	LC	LL	LC	LL	LC	LL	LC
21	0.00013	0.013	0.00002	0.002	LL	LC	LL	LC	LL	LC	LL	LC	LL	LC	LL	LC
22	0.00020	0.017	0.00003	0.002	LL	LC	LL	LC	LL	LC	LL	LC	LL	LC	LL	LC
23	0.00027	0.022	0.00004	0.003	LL	LC	LL	LC	LL	LC	LL	LC	LL	LC	LL	LC
24	0.00026	0.028	0.00005	0.004	LL	LC	LL	LC	LL	LC	LL	LC	LL	LC	LL	LC
25	0.00017	0.020	0.00003	0.003	LL	LC	LL	LC	LL	LC	LL	LC	LL	LC	LL	LC
26	0.00026	0.022	0.00004	0.003	LL	LC	LL	LC	LL	LC	LL	LC	LL	LC	LL	LC
27	0.00020	0.021	0.00003	0.003	LL	LC	LL	LC	LL	LC	LL	LC	LL	LC	LL	LC
28	0.00011	0.014	0.00002	0.002	LL	LC	LL	LC	LL	LC	LL	LC	LL	LC	LL	LC
29	0.00019	0.014	0.00003	0.002	LL	LC	LL	LC	LL	LC	LL	LC	LL	LC	LL	LC
30	0.00016	0.016	0.00002	0.002	LL	LC	LL	LC	LL	LC	LL	LC	LL	LC	LL	LC
31	0.00012	0.016	0.00002	0.002	LL	LC	LL	LC	LL	LC	LL	LC	LL	LC	LL	LC
32	0.00006	0.009	0.00001	0.001	LL	LC	LL	LC	LL	LC	LL	LC	LL	LC	LL	LC
33	0.00006	0.007	0.00001	0.001	LL	LC	LL	LC	LL	LC	LL	LC	LL	LC	LL	LC
34	0.00007	0.008	0.00001	0.001	LL	LC	LL	LC	LL	LC	LL	LC	LL	LC	LL	LC
35	0.00012	0.010	0.00001	0.001	LL	LC	LL	LC	LL	LC	LL	LC	LL	LC	LL	LC
36	0.00008	0.008	0.00001	0.001	LL	LC	LL	LC	LL	LC	LL	LC	LL	LC	LL	LC
37	0.00017	0.011	0.00002	0.001	LL	LC	LL	LC	LL	LC	LL	LC	LL	LC	LL	LC

NOTE: LL = less than 0.00001 kg/ha; LC = less than 0.001 µg/l.

Table 33. (Continued) Long-term PRZM Simulations for Diazinon

YEAR	Case: 453.d2d		Case: 454.d2d		Case: 455.d2d		Case: 456.d2d		Case: 463.d2d		Case: 465.d2d		Case: 473.d2d		Case: 475.d2d	
	LOAD (kg/ha)	CONC. (µg/l)	LOAD (kg/ha)	CONC. (µg/l)	LOAD (kg/ha)	CONC. (µg/l)	LOAD (kg/ha)	CONC. (µg/l)	LOAD (kg/ha)	CONC. (µg/l)	LOAD (kg/ha)	CONC. (µg/l)	LOAD (kg/ha)	CONC. (µg/l)	LOAD (kg/ha)	CONC. (µg/l)
1	LL	LC	LL	LC	LL	LC	LL	LC	LL	LC	LL	LC	LL	LC	LL	LC
2	LL	LC	LL	LC	LL	LC	LL	LC	LL	LC	LL	LC	LL	LC	LL	LC
3	LL	LC	LL	LC	LL	LC	LL	LC	LL	LC	LL	LC	LL	LC	LL	LC
4	LL	LC	LL	LC	LL	LC	LL	LC	LL	LC	LL	LC	LL	LC	LL	LC
5	LL	LC	LL	LC	LL	LC	LL	LC	LL	LC	LL	LC	LL	LC	LL	LC
6	LL	LC	LL	LC	LL	LC	LL	LC	LL	LC	LL	LC	LL	LC	LL	LC
7	LL	LC	LL	LC	LL	LC	LL	LC	LL	LC	LL	LC	LL	LC	LL	LC
8	LL	LC	LL	LC	LL	LC	LL	LC	LL	LC	LL	LC	LL	LC	LL	LC
9	LL	LC	LL	LC	LL	LC	LL	LC	LL	LC	LL	LC	LL	LC	LL	LC
10	LL	LC	LL	LC	LL	LC	LL	LC	LL	LC	LL	LC	LL	LC	LL	LC
11	LL	LC	LL	LC	LL	LC	LL	LC	LL	LC	LL	LC	LL	LC	LL	LC
12	LL	LC	LL	LC	LL	LC	LL	LC	LL	LC	LL	LC	LL	LC	LL	LC
13	LL	LC	LL	LC	LL	LC	LL	LC	LL	LC	LL	LC	LL	LC	LL	LC
14	LL	LC	LL	LC	LL	LC	LL	LC	LL	LC	LL	LC	LL	LC	LL	LC
15	LL	LC	LL	LC	LL	LC	LL	LC	LL	LC	LL	LC	LL	LC	LL	LC
16	LL	LC	LL	LC	LL	LC	LL	LC	LL	LC	LL	LC	LL	LC	LL	LC
17	LL	LC	LL	LC	LL	LC	LL	LC	LL	LC	LL	LC	LL	LC	LL	LC
18	LL	LC	LL	LC	LL	LC	LL	LC	LL	LC	LL	LC	LL	LC	LL	LC
19	LL	LC	LL	LC	LL	LC	LL	LC	LL	LC	LL	LC	LL	LC	LL	LC
20	LL	LC	LL	LC	LL	LC	LL	LC	LL	LC	LL	LC	LL	LC	LL	LC
21	LL	LC	LL	LC	LL	LC	LL	LC	LL	LC	LL	LC	LL	LC	LL	LC
22	LL	LC	LL	LC	LL	LC	LL	LC	LL	LC	LL	LC	LL	LC	LL	LC
23	LL	LC	LL	LC	LL	LC	LL	LC	LL	LC	LL	LC	LL	LC	LL	LC
24	LL	LC	LL	LC	LL	LC	LL	LC	LL	LC	LL	LC	LL	LC	LL	LC
25	LL	LC	LL	LC	LL	LC	LL	LC	LL	LC	LL	LC	LL	LC	LL	LC
26	LL	LC	LL	LC	LL	LC	LL	LC	LL	LC	LL	LC	LL	LC	LL	LC
27	LL	LC	LL	LC	LL	LC	LL	LC	LL	LC	LL	LC	LL	LC	LL	LC
28	LL	LC	LL	LC	LL	LC	LL	LC	LL	LC	LL	LC	LL	LC	LL	LC
29	LL	LC	LL	LC	LL	LC	LL	LC	LL	LC	LL	LC	LL	LC	LL	LC
30	LL	LC	LL	LC	LL	LC	LL	LC	LL	LC	LL	LC	LL	LC	LL	LC
31	LL	LC	LL	LC	LL	LC	LL	LC	LL	LC	LL	LC	LL	LC	LL	LC
32	LL	LC	LL	LC	LL	LC	LL	LC	LL	LC	LL	LC	LL	LC	LL	LC
33	LL	LC	LL	LC	LL	LC	LL	LC	LL	LC	LL	LC	LL	LC	LL	LC
34	LL	LC	LL	LC	LL	LC	LL	LC	LL	LC	LL	LC	LL	LC	LL	LC
35	LL	LC	LL	LC	LL	LC	LL	LC	LL	LC	LL	LC	LL	LC	LL	LC
36	LL	LC	LL	LC	LL	LC	LL	LC	LL	LC	LL	LC	LL	LC	LL	LC
37	LL	LC	LL	LC	LL	LC	LL	LC	LL	LC	LL	LC	LL	LC	LL	LC

NOTE: LL = less than 0.00001 kg/ha; LC = less than 0.001 µg/l.

Table 33. (Continued) Long-term PRZM Simulations for Diazinon

YEAR	Case: 533.dld LOAD (kg/ha)	Case: 533.dld CONC. (µg/l)	Case: 534.dld LOAD (kg/ha)	Case: 534.dld CONC. (µg/l)	Case: 635.dld LOAD (kg/ha)	Case: 635.dld CONC. (µg/l)	Case: 443.dld LOAD (kg/ha)	Case: 443.dld CONC. (µg/l)	Case: 444.dld LOAD (kg/ha)	Case: 444.dld CONC. (µg/l)	Case: 446.dld LOAD (kg/ha)	Case: 446.dld CONC. (µg/l)	Case: 453.dld LOAD (kg/ha)	Case: 453.dld CONC. (µg/l)	Case: 454.dld LOAD (kg/ha)	Case: 454.dld CONC. (µg/l)
1	LL	LC	LL	LC	LL	LC	LL	LC	LL	LC	LL	LC	LL	LC	LL	LC
2	LL	LC	LL	LC	LL	LC	LL	LC	LL	LC	LL	LC	LL	LC	LL	LC
3	LL	LC	LL	LC	LL	LC	LL	LC	LL	LC	LL	LC	LL	LC	LL	LC
4	LL	LC	LL	LC	LL	LC	LL	LC	LL	LC	LL	LC	LL	LC	LL	LC
5	LL	LC	LL	LC	LL	LC	LL	LC	LL	LC	LL	LC	LL	LC	LL	LC
6	LL	LC	LL	LC	LL	LC	LL	LC	LL	LC	LL	LC	LL	LC	LL	LC
7	LL	LC	LL	LC	LL	LC	LL	LC	LL	LC	LL	LC	LL	LC	LL	LC
8	LL	LC	LL	LC	LL	LC	LL	LC	LL	LC	LL	LC	LL	LC	LL	LC
9	LL	LC	LL	LC	LL	LC	LL	LC	LL	LC	LL	LC	LL	LC	LL	LC
10	LL	LC	LL	LC	LL	LC	LL	LC	LL	LC	LL	LC	LL	LC	LL	LC
11	LL	LC	LL	LC	LL	LC	LL	LC	LL	LC	LL	LC	LL	LC	LL	LC
12	LL	LC	LL	LC	LL	LC	LL	LC	LL	LC	LL	LC	LL	LC	LL	LC
13	LL	LC	LL	LC	LL	LC	LL	LC	LL	LC	LL	LC	LL	LC	LL	LC
14	LL	LC	LL	LC	LL	LC	LL	LC	LL	LC	LL	LC	LL	LC	LL	LC
15	LL	LC	LL	LC	LL	LC	LL	LC	LL	LC	LL	LC	LL	LC	LL	LC
16	LL	LC	LL	LC	LL	LC	LL	LC	LL	LC	LL	LC	LL	LC	LL	LC
17	LL	LC	LL	LC	LL	LC	LL	LC	LL	LC	LL	LC	LL	LC	LL	LC
18	LL	LC	LL	LC	LL	LC	LL	LC	LL	LC	LL	LC	LL	LC	LL	LC
19	LL	LC	LL	LC	LL	LC	LL	LC	LL	LC	LL	LC	LL	LC	LL	LC
20	LL	LC	LL	LC	LL	LC	LL	LC	LL	LC	LL	LC	LL	LC	LL	LC
21	LL	LC	LL	LC	LL	LC	LL	LC	LL	LC	LL	LC	LL	LC	LL	LC
22	LL	LC	LL	LC	LL	LC	LL	LC	LL	LC	LL	LC	LL	LC	LL	LC
23	LL	LC	LL	LC	LL	LC	LL	LC	LL	LC	LL	LC	LL	LC	LL	LC
24	LL	LC	LL	LC	LL	LC	LL	LC	LL	LC	LL	LC	LL	LC	LL	LC
25	LL	LC	LL	LC	LL	LC	LL	LC	LL	LC	LL	LC	LL	LC	LL	LC
26	LL	LC	LL	LC	LL	LC	LL	LC	LL	LC	LL	LC	LL	LC	LL	LC
27	LL	LC	LL	LC	LL	LC	LL	LC	LL	LC	LL	LC	LL	LC	LL	LC
28	LL	LC	LL	LC	LL	LC	LL	LC	LL	LC	LL	LC	LL	LC	LL	LC
29	LL	LC	LL	LC	LL	LC	LL	LC	LL	LC	LL	LC	LL	LC	LL	LC
30	LL	LC	LL	LC	LL	LC	LL	LC	LL	LC	LL	LC	LL	LC	LL	LC
31	LL	LC	LL	LC	LL	LC	LL	LC	LL	LC	LL	LC	LL	LC	LL	LC
32	LL	LC	LL	LC	LL	LC	LL	LC	LL	LC	LL	LC	LL	LC	LL	LC
33	LL	LC	LL	LC	LL	LC	LL	LC	LL	LC	LL	LC	LL	LC	LL	LC
34	LL	LC	LL	LC	LL	LC	LL	LC	LL	LC	LL	LC	LL	LC	LL	LC
35	LL	LC	LL	LC	LL	LC	LL	LC	LL	LC	LL	LC	LL	LC	LL	LC
36	LL	LC	LL	LC	LL	LC	LL	LC	LL	LC	LL	LC	LL	LC	LL	LC
37	LL	LC	LL	LC	LL	LC	LL	LC	LL	LC	LL	LC	LL	LC	LL	LC

NOTE: LL = less than 0.00001 kg/ha; LC = less than 0.001 µg/l.

Table 33. (Continued) Long-term PRZM Simulations for Diazinon

YEAR	Case: 455.dld LOAD (kg/ha)	CONC. (µg/l)	Case: 456.dld LOAD (kg/ha)	CONC. (µg/l)	Case: 463.dld LOAD (kg/ha)	CONC. (µg/l)	Case: 465.dld LOAD (kg/ha)	CONC. (µg/l)	Case: 473.dld LOAD (kg/ha)	CONC. (µg/l)	Case: 475.dld LOAD (kg/ha)	CONC. (µg/l)
1	LL	LC	LL	LC	LL	LC	LL	LC	LL	LC	LL	LC
2	LL	LC	LL	LC	LL	LC	LL	LC	LL	LC	LL	LC
3	LL	LC	LL	LC	LL	LC	LL	LC	LL	LC	LL	LC
4	LL	LC	LL	LC	LL	LC	LL	LC	LL	LC	LL	LC
5	LL	LC	LL	LC	LL	LC	LL	LC	LL	LC	LL	LC
6	LL	LC	LL	LC	LL	LC	LL	LC	LL	LC	LL	LC
7	LL	LC	LL	LC	LL	LC	LL	LC	LL	LC	LL	LC
8	LL	LC	LL	LC	LL	LC	LL	LC	LL	LC	LL	LC
9	LL	LC	LL	LC	LL	LC	LL	LC	LL	LC	LL	LC
10	LL	LC	LL	LC	LL	LC	LL	LC	LL	LC	LL	LC
11	LL	LC	LL	LC	LL	LC	LL	LC	LL	LC	LL	LC
12	LL	LC	LL	LC	LL	LC	LL	LC	LL	LC	LL	LC
13	LL	LC	LL	LC	LL	LC	LL	LC	LL	LC	LL	LC
14	LL	LC	LL	LC	LL	LC	LL	LC	LL	LC	LL	LC
15	LL	LC	LL	LC	LL	LC	LL	LC	LL	LC	LL	LC
16	LL	LC	LL	LC	LL	LC	LL	LC	LL	LC	LL	LC
17	LL	LC	LL	LC	LL	LC	LL	LC	LL	LC	LL	LC
18	LL	LC	LL	LC	LL	LC	LL	LC	LL	LC	LL	LC
19	LL	LC	LL	LC	LL	LC	LL	LC	LL	LC	LL	LC
20	LL	LC	LL	LC	LL	LC	LL	LC	LL	LC	LL	LC
21	LL	LC	LL	LC	LL	LC	LL	LC	LL	LC	LL	LC
22	LL	LC	LL	LC	LL	LC	LL	LC	LL	LC	LL	LC
23	LL	LC	LL	LC	LL	LC	LL	LC	LL	LC	LL	LC
24	LL	LC	LL	LC	LL	LC	LL	LC	LL	LC	LL	LC
25	LL	LC	LL	LC	LL	LC	LL	LC	LL	LC	LL	LC
26	LL	LC	LL	LC	LL	LC	LL	LC	LL	LC	LL	LC
27	LL	LC	LL	LC	LL	LC	LL	LC	LL	LC	LL	LC
28	LL	LC	LL	LC	LL	LC	LL	LC	LL	LC	LL	LC
29	LL	LC	LL	LC	LL	LC	LL	LC	LL	LC	LL	LC
30	LL	LC	LL	LC	LL	LC	LL	LC	LL	LC	LL	LC
31	LL	LC	LL	LC	LL	LC	LL	LC	LL	LC	LL	LC
32	LL	LC	LL	LC	LL	LC	LL	LC	LL	LC	LL	LC
33	LL	LC	LL	LC	LL	LC	LL	LC	LL	LC	LL	LC
34	LL	LC	LL	LC	LL	LC	LL	LC	LL	LC	LL	LC
35	LL	LC	LL	LC	LL	LC	LL	LC	LL	LC	LL	LC
36	LL	LC	LL	LC	LL	LC	LL	LC	LL	LC	LL	LC
37	LL	LC	LL	LC	LL	LC	LL	LC	LL	LC	LL	LC

NOTE: LL = less than 0.00001 kg/ha; LC = less than 0.001 µg/l.

Table 34

Long-term PRZM Simulations for Metribuzin

YEAR	Case: 145.m3		Case: 157.m3		Case: 166.m3		Case: 245.m3		Case: 257.m3		Case: 266.m3		Case: 245.m2		Case: 257.m2	
	LOAD (kg/ha)	CONC. (μg/l)	LOAD (kg/ha)	CONC. (μg/l)	LOAD (kg/ha)	CONC. (μg/l)	LOAD (kg/ha)	CONC. (μg/l)	LOAD (kg/ha)	CONC. (μg/l)	LOAD (kg/ha)	CONC. (μg/l)	LOAD (kg/ha)	CONC. (μg/l)	LOAD (kg/ha)	CONC. (μg/l)
1	LL	LC	LL	LC	LL	LC	LL	LC	LL	LC	LL	LC	LL	LC	LL	LC
2	LL	LC	LL	LC	LL	LC	LL	LC	LL	LC	LL	LC	LL	LC	LL	LC
3	LL	LC	LL	LC	LL	LC	LL	LC	LL	LC	LL	LC	LL	LC	LL	LC
4	LL	LC	LL	LC	LL	LC	LL	LC	LL	LC	LL	LC	LL	LC	LL	LC
5	LL	LC	LL	LC	LL	LC	LL	LC	LL	LC	LL	LC	LL	LC	LL	LC
6	0.00079	0.043	LL	LC	LL	LC	0.00016	0.010	LL	LC	LL	LC	LL	LC	LL	LC
7	0.00812	0.879	0.00001	0.001	0.00003	0.003	0.00280	0.306	LL	LC	LL	LC	LL	LC	LL	LC
8	0.0308	3.74	0.00025	0.026	0.00046	0.051	0.0161	1.96	0.00001	0.001	0.00002	0.002	LL	LC	LL	LC
9	0.1903	12.64	0.0193	1.02	0.0255	1.34	0.1212	8.62	0.00225	0.132	0.00301	0.182	LL	LC	LL	LC
10	0.4345	26.75	0.1730	9.31	0.1937	10.51	0.3132	21.10	0.0456	2.80	0.0439	2.88	0.00012	0.008	LL	LC
11	0.4175	37.35	0.3491	23.03	0.4157	25.93	0.3531	32.06	0.1768	12.34	0.1866	12.55	0.00150	0.136	LL	LC
12	0.4866	40.28	0.4607	33.18	0.5628	38.20	0.4282	37.78	0.2894	23.31	0.3272	25.52	0.0101	0.891	0.00004	0.003
13	0.4849	38.14	0.6528	40.45	0.6634	41.01	0.4565	37.87	0.4983	32.90	0.5523	36.90	0.0364	3.02	0.00102	0.067
14	0.3222	38.36	0.4424	40.64	0.3257	36.25	0.3303	39.38	0.4210	39.46	0.3487	40.24	0.0494	5.89	0.00528	0.495
15	0.3109	34.77	0.3322	36.57	0.2976	33.24	0.3254	37.61	0.3555	39.87	0.3404	38.35	0.0856	9.89	0.0148	1.66
16	0.2909	32.83	0.3129	33.52	0.3403	31.08	0.3138	35.45	0.3498	37.92	0.3896	37.03	0.1287	14.54	0.0355	3.85
17	0.3055	32.24	0.2703	31.65	0.2807	30.01	0.3186	33.70	0.3116	36.74	0.3249	35.18	0.1841	19.47	0.0575	6.78
18	0.4887	31.74	0.5817	30.64	0.5335	31.64	0.4541	32.65	0.5482	34.38	0.4932	33.47	0.3409	24.51	0.1940	12.16
19	0.3943	32.96	0.4379	31.83	0.5080	32.02	0.3904	34.01	0.4243	33.15	0.4728	33.17	0.3301	28.75	0.2521	19.69
20	0.6646	34.75	0.5891	31.63	0.6382	32.72	0.5721	34.37	0.5185	32.66	0.5341	33.37	0.4982	29.94	0.4165	26.24
21	0.5681	36.41	0.5282	33.61	0.4902	34.84	0.4869	35.58	0.4472	33.57	0.4131	35.10	0.3855	28.17	0.3962	29.74
22	0.6998	37.19	0.6575	36.22	0.6433	37.47	0.6796	37.60	0.6052	35.22	0.5798	35.97	0.4963	27.46	0.5209	30.32
23	0.6087	35.10	0.5840	36.97	0.5977	39.04	0.5505	35.10	0.5238	36.46	0.5046	37.70	0.4249	27.09	0.4247	29.57
24	0.4518	35.65	0.5117	38.28	0.4923	38.85	0.4174	36.19	0.4669	37.16	0.4612	39.42	0.3133	27.17	0.3484	27.73
25	0.3526	35.49	0.4685	36.75	0.4580	38.13	0.3297	35.11	0.4542	38.33	0.4177	39.10	0.2684	28.58	0.3162	26.68
26	0.4208	33.40	0.5364	36.42	0.5357	38.47	0.4153	35.56	0.4955	36.67	0.4920	38.23	0.3355	28.73	0.3727	27.58
27	0.3359	29.83	0.3764	36.22	0.3544	38.03	0.3790	34.43	0.3697	36.51	0.3477	38.52	0.3206	29.12	0.2836	28.01
28	0.2248	25.99	0.3149	35.08	0.3257	37.48	0.2642	30.56	0.3266	36.49	0.3292	38.23	0.2552	29.51	0.2519	28.14
29	0.4164	24.85	0.5810	32.67	0.5838	34.48	0.4578	29.00	0.5735	36.00	0.5810	37.94	0.4665	29.56	0.4676	29.35
30	0.2636	25.87	0.3329	28.41	0.2990	29.47	0.2665	26.68	0.3768	34.51	0.3488	36.61	0.2826	28.29	0.3288	30.12
31	0.2720	28.79	0.2588	25.86	0.2571	26.48	0.2624	28.40	0.2992	31.72	0.3072	34.05	0.2585	27.98	0.2866	30.39
32	0.2563	31.22	0.2244	24.53	0.2054	24.49	0.2435	29.90	0.2611	29.85	0.2561	31.44	0.2275	27.93	0.2665	30.47
33	0.3825	32.65	0.2968	24.77	0.2932	25.80	0.3518	30.89	0.3201	27.64	0.3119	28.71	0.3020	26.52	0.3510	30.31
34	0.3910	37.45	0.2950	27.85	0.2495	29.16	0.3590	35.16	0.2739	27.86	0.2374	29.16	0.2462	24.11	0.2937	29.87
35	0.6300	39.70	0.5773	31.78	0.5447	32.44	0.5699	38.23	0.4946	29.98	0.4704	30.88	0.3609	24.21	0.4753	28.81
36	0.5086	39.66	0.5070	35.83	0.4164	35.93	0.4921	39.07	0.4523	32.67	0.3738	33.16	0.3018	23.96	0.3910	28.24
37	0.7011	36.75	0.8037	38.23	0.7297	37.54	0.6189	35.73	0.6725	36.38	0.6253	36.46	0.4205	24.28	0.4690	25.38

NOTE: LL - less than 0.00001 kg/ha; LC - less than 0.001 μg/l.

Table 34. (Continued) Long-term PRZM Simulations for Metribuzin

YEAR	Case: 266.m2 LOAD (kg/ha)	Case: 266.m2 CONC. (µg/l)	Case: 245.ml LOAD (kg/ha)	Case: 245.ml CONC. (µg/l)	Case: 257.ml LOAD (kg/ha)	Case: 257.ml CONC. (µg/l)	Case: 266.ml LOAD (kg/ha)	Case: 266.ml CONC. (µg/l)	Case: 145.m3h LOAD (kg/ha)	Case: 145.m3h CONC. (µg/l)	Case: 157.m3h LOAD (kg/ha)	Case: 157.m3h CONC. (µg/l)	Case: 166.m3h LOAD (kg/ha)	Case: 166.m3h CONC. (µg/l)	Case: 245.m3h LOAD (kg/ha)	Case: 245.m3h CONC. (µg/l)
1	LL	LC	LL	LC	LL	LC	LL	LC	LL	LC	LL	LC	LL	LC	LL	LC
2	LL	LC	LL	LC	LL	LC	LL	LC	LL	LC	LL	LC	LL	LC	LL	LC
3	LL	LC	LL	LC	LL	LC	LL	LC	LL	LC	LL	LC	LL	LC	LL	LC
4	LL	LC	LL	LC	LL	LC	LL	LC	LL	LC	LL	LC	LL	LC	LL	LC
5	LL	LC	LL	LC	LL	LC	LL	LC	LL	LC	LL	LC	LL	LC	LL	LC
6	LL	LC	LL	LC	LL	LC	LL	LC	0.00001	0.001	LL	LC	LL	LC	LL	LC
7	LL	LC	LL	LC	LL	LC	LL	LC	0.00009	0.010	LL	LC	LL	LC	0.00003	0.003
8	LL	LC	LL	LC	LL	LC	LL	LC	0.00021	0.025	LL	LC	LL	LC	0.00010	0.012
9	LL	LC	LL	LC	LL	LC	LL	LC	0.00081	0.054	0.00005	0.003	0.00008	0.004	0.00045	0.032
10	LL	LC	0.00006	0.004	LL	LC	LL	LC	0.00201	0.124	0.00041	0.022	0.00063	0.034	0.00111	0.075
11	LL	LC	0.00078	0.071	LL	LC	LL	LC	0.00180	0.161	0.00073	0.048	0.00134	0.084	0.00115	0.104
12	0.00009	0.007	0.00570	0.503	0.00002	0.001	0.00004	0.003	0.00178	0.147	0.00086	0.062	0.00171	0.116	0.00121	0.107
13	0.00191	0.128	0.0217	1.80	0.00053	0.035	0.00100	0.067	0.00133	0.105	0.00105	0.065	0.00160	0.099	0.00101	0.084
14	0.00610	0.703	0.0305	3.64	0.00292	0.274	0.00335	0.387	0.00066	0.079	0.00059	0.054	0.00062	0.069	0.00055	0.065
15	0.0173	1.94	0.0543	6.28	0.00860	0.965	0.00985	1.11	0.00048	0.053	0.00030	0.032	0.00036	0.040	0.00038	0.044
16	0.0454	4.32	0.0839	9.48	0.0213	2.31	0.0270	2.56	0.00041	0.046	0.00019	0.020	0.00032	0.030	0.00032	0.036
17	0.0735	7.96	0.1235	13.06	0.0357	4.21	0.0452	4.90	0.00045	0.047	0.00013	0.015	0.00025	0.026	0.00034	0.036
18	0.2128	14.44	0.2365	17.01	0.1253	7.86	0.1373	9.32	0.00076	0.050	0.00032	0.017	0.00051	0.030	0.00054	0.039
19	0.3196	22.42	0.2360	20.56	0.1699	13.27	0.2173	15.25	0.00055	0.046	0.00023	0.017	0.00043	0.027	0.00043	0.037
20	0.4497	28.09	0.3635	21.84	0.2928	18.45	0.3205	20.03	0.00098	0.051	0.00028	0.015	0.00050	0.026	0.00064	0.038
21	0.3518	29.89	0.2820	20.61	0.2886	21.67	0.2586	21.97	0.00106	0.068	0.00027	0.017	0.00041	0.029	0.00064	0.047
22	0.4845	30.06	0.3599	19.92	0.3877	22.57	0.3602	22.35	0.00210	0.112	0.00038	0.021	0.00056	0.033	0.00125	0.069
23	0.3745	27.98	0.3065	19.54	0.3170	22.07	0.2772	20.71	0.00339	0.195	0.00037	0.023	0.00061	0.040	0.00168	0.107
24	0.3178	27.16	0.2255	19.56	0.2578	20.51	0.2337	19.98	0.00341	0.269	0.00037	0.027	0.00063	0.050	0.00178	0.154
25	0.2913	27.27	0.1927	20.52	0.2328	19.65	0.2143	20.06	0.00207	0.209	0.00034	0.027	0.00055	0.046	0.00116	0.124
26	0.3610	28.05	0.2398	20.54	0.2750	20.35	0.2666	20.72	0.00265	0.210	0.00056	0.038	0.00081	0.058	0.00157	0.134
27	0.2566	28.43	0.2276	20.67	0.2098	20.72	0.1900	21.05	0.00176	0.157	0.00037	0.035	0.00048	0.051	0.00126	0.114
28	0.2521	29.27	0.1797	20.79	0.1863	20.81	0.1867	21.68	0.00090	0.104	0.00023	0.026	0.00032	0.037	0.00070	0.081
29	0.4673	30.52	0.3256	20.63	0.3447	21.63	0.3450	22.53	0.00170	0.101	0.00044	0.025	0.00055	0.033	0.00129	0.082
30	0.2963	31.10	0.1966	19.69	0.2410	22.08	0.2174	22.82	0.00090	0.089	0.00024	0.020	0.00024	0.024	0.00068	0.068
31	0.2846	31.55	0.1804	19.52	0.2089	22.15	0.2073	22.98	0.00073	0.077	0.00018	0.018	0.00019	0.019	0.00055	0.059
32	0.2582	31.70	0.1594	19.57	0.1928	22.05	0.1864	22.89	0.00045	0.055	0.00011	0.012	0.00011	0.013	0.00034	0.042
33	0.3452	31.77	0.2128	18.68	0.2517	21.73	0.2468	22.72	0.00049	0.042	0.00010	0.008	0.00011	0.009	0.00037	0.032
34	0.2518	30.93	0.1746	17.10	0.2090	21.26	0.1787	21.95	0.00051	0.049	0.00009	0.009	0.00009	0.010	0.00039	0.038
35	0.4642	30.47	0.2579	17.30	0.3374	20.46	0.3284	21.56	0.00084	0.053	0.00018	0.010	0.00016	0.010	0.00062	0.042
36	0.3381	30.00	0.2172	17.25	0.2784	20.11	0.2398	21.28	0.00073	0.057	0.00014	0.010	0.00010	0.009	0.00057	0.045
37	0.4702	27.42	0.3027	17.47	0.3354	18.15	0.3353	19.55	0.00144	0.076	0.00028	0.013	0.00022	0.011	0.00104	0.060

NOTE: LL = less than 0.00001 kg/ha; LC = less than 0.001 µg/l.

Table 34. (Continued) Long-term PRZM Simulations for Metribuzin

YEAR	Case: 257.m3h LOAD (kg/ha)	Case: 257.m3h CONC. (µg/l)	Case: 266.m3h LOAD (kg/ha)	Case: 266.m3h CONC. (µg/l)	Case: 245.m2h LOAD (kg/ha)	Case: 245.m2h CONC. (µg/l)	Case: 257.m2h LOAD (kg/ha)	Case: 257.m2h CONC. (µg/l)	Case: 266.m2h LOAD (kg/ha)	Case: 266.m2h CONC. (µg/l)	Case: 245.mlh LOAD (kg/ha)	Case: 245.mlh CONC. (µg/l)	Case: 257.mlh LOAD (kg/ha)	Case: 257.mlh CONC. (µg/l)	Case: 266.mlh LOAD (kg/ha)	Case: 266.mlh CONC. (µg/l)
1	LL	LC	LL	LC	LL	LC	LL	LC	LL	LC	LL	LC	LL	LC	LL	LC
2	LL	LC	LL	LC	LL	LC	LL	LC	LL	LC	LL	LC	LL	LC	LL	LC
3	LL	LC	LL	LC	LL	LC	LL	LC	LL	LC	LL	LC	LL	LC	LL	LC
4	LL	LC	LL	LC	LL	LC	LL	LC	LL	LC	LL	LC	LL	LC	LL	LC
5	LL	LC	LL	LC	LL	LC	LL	LC	LL	LC	LL	LC	LL	LC	LL	LC
6	LL	LC	LL	LC	LL	LC	LL	LC	LL	LC	LL	LC	LL	LC	LL	LC
7	LL	LC	LL	LC	LL	LC	LL	LC	LL	LC	LL	LC	LL	LC	LL	LC
8	LL	LC	LL	LC	LL	LC	LL	LC	LL	LC	LL	LC	LL	LC	LL	LC
9	0.00001	LC	0.00001	LC	LL	LC	LL	LC	LL	LC	LL	LC	LL	LC	LL	LC
10	0.00008	0.005	0.00009	0.006	LL	LC	LL	LC	LL	LC	LL	LC	LL	LC	LL	LC
11	0.00023	0.016	0.00032	0.022	LL	LC	LL	LC	LL	LC	LL	LC	LL	LC	LL	LC
12	0.00031	0.025	0.00052	0.041	LL	LC	LL	LC	LL	LC	LL	LC	LL	LC	LL	LC
13	0.00047	0.031	0.00075	0.050	0.00001	0.001	LL	LC	LL	LC	0.00001	0.001	LL	LC	LL	LC
14	0.00036	0.033	0.00039	0.045	0.00001	0.001	LL	LC	LL	LC	0.00001	0.001	LL	LC	LL	LC
15	0.00021	0.023	0.00025	0.028	0.00001	0.001	LL	LC	LL	LC	0.00001	0.001	LL	LC	LL	LC
16	0.00014	0.015	0.00021	0.020	0.00001	0.001	LL	LC	LL	LC	0.00001	0.001	LL	LC	LL	LC
17	0.00010	0.011	0.00014	0.015	0.00001	0.001	LL	LC	LL	LC	0.00001	0.001	LL	LC	LL	LC
18	0.00016	0.010	0.00022	0.015	0.00002	0.001	LL	LC	0.00001	LC	0.00001	0.001	LL	LC	LL	LC
19	0.00012	0.009	0.00022	0.015	0.00001	0.001	LL	LC	0.00001	LC	0.00001	0.001	LL	LC	LL	LC
20	0.00015	0.009	0.00025	0.015	0.00002	0.001	LL	LC	0.00001	LC	0.00001	0.001	LL	LC	0.00001	LC
21	0.00013	0.010	0.00019	0.016	0.00002	0.001	LL	LC	LL	LC	0.00001	0.001	LL	LC	LL	LC
22	0.00019	0.011	0.00027	0.017	0.00003	0.002	LL	LC	0.00001	LC	0.00002	0.001	LL	LC	LL	LC
23	0.00018	0.013	0.00025	0.019	0.00003	0.002	LL	LC	0.00001	LC	0.00002	0.001	LL	LC	LL	LC
24	0.00016	0.013	0.00024	0.020	0.00003	0.002	LL	LC	0.00001	LC	0.00002	0.002	LL	LC	LL	LC
25	0.00014	0.012	0.00019	0.018	0.00002	0.002	LL	LC	LL	LC	0.00001	0.001	LL	LC	LL	LC
26	0.00020	0.015	0.00028	0.022	0.00002	0.002	LL	LC	LL	LC	0.00002	0.001	LL	LC	LL	LC
27	0.00016	0.016	0.00020	0.022	0.00002	0.002	LL	LC	LL	LC	0.00001	0.001	LL	LC	LL	LC
28	0.00012	0.013	0.00015	0.018	0.00002	0.002	LL	LC	LL	LC	0.00001	0.001	LL	LC	LL	LC
29	0.00022	0.014	0.00028	0.018	0.00004	0.003	LL	LC	LL	LC	0.00003	0.002	LL	LC	LL	LC
30	0.00015	0.013	0.00015	0.016	0.00003	0.003	LL	LC	LL	LC	0.00002	0.002	LL	LC	LL	LC
31	0.00011	0.012	0.00012	0.013	0.00002	0.003	LL	LC	LL	LC	0.00002	0.002	LL	LC	LL	LC
32	0.00007	0.008	0.00007	0.009	0.00002	0.002	LL	LC	LL	LC	0.00001	0.001	LL	LC	LL	LC
33	0.00007	0.006	0.00006	0.006	0.00002	0.001	LL	LC	LL	LC	0.00001	0.001	LL	LC	LL	LC
34	0.00005	0.006	0.00005	0.006	0.00001	0.001	LL	LC	LL	LC	0.00001	0.001	LL	LC	LL	LC
35	0.00009	0.006	0.00009	0.006	0.00002	0.001	LL	LC	LL	LC	0.00001	0.001	LL	LC	LL	LC
36	0.00008	0.006	0.00006	0.005	0.00001	0.001	LL	LC	LL	LC	0.00001	0.001	LL	LC	LL	LC
37	0.00014	0.008	0.00012	0.007	0.00002	0.001	LL	LC	LL	LC	0.00002	0.001	LL	LC	LL	LC

NOTE: LL = less than 0.00001 kg/ha; LC = less than 0.001 µg/l.

Table 34. (Continued) Long-term PRZM Simulations for Metribuzin

YEAR	Case: 245b.m2 LOAD (kg/ha)	Case: 245b.m2 CONC. (µg/l)	Case: 257b.m2 LOAD (kg/ha)	Case: 257b.m2 CONC. (µg/l)	Case: 266b.m2 LOAD (kg/ha)	Case: 266b.m2 CONC. (µg/l)	Case: 245b.m2h LOAD (kg/ha)	Case: 245b.m2h CONC. (µg/l)	Case: 257b.m2h LOAD (kg/ha)	Case: 257b.m2h CONC. (µg/l)	Case: 266b.m2h LOAD (kg/ha)	Case: 266b.m2h CONC. (µg/l)
1	LL	LC	LL	LC	LL	LC	LL	LC	LL	LC	LL	LC
2	LL	LC	LL	LC	LL	LC	LL	LC	LL	LC	LL	LC
3	LL	LC	LL	LC	LL	LC	LL	LC	LL	LC	LL	LC
4	LL	LC	LL	LC	LL	LC	LL	LC	LL	LC	LL	LC
5	LL	LC	LL	LC	LL	LC	LL	LC	LL	LC	LL	LC
6	LL	LC	LL	LC	LL	LC	LL	LC	LL	LC	LL	LC
7	LL	LC	LL	LC	LL	LC	LL	LC	LL	LC	LL	LC
8	LL	LC	LL	LC	LL	LC	LL	LC	LL	LC	LL	LC
9	LL	LC	LL	LC	LL	LC	LL	LC	LL	LC	LL	LC
10	0.00004	0.002	LL	LC	LL	LC	LL	LC	LL	LC	LL	LC
11	0.00067	0.061	LL	LC	LL	LC	LL	LC	LL	LC	LL	LC
12	0.00601	0.530	0.00001	0.001	0.00004	0.003	LL	LC	LL	LC	LL	LC
13	0.0262	2.17	0.00047	0.031	0.00114	0.076	0.00001	0.001	LL	LC	LL	LC
14	0.0392	4.68	0.00307	0.287	0.00426	0.492	0.00001	0.001	LL	LC	LL	LC
15	0.0712	8.23	0.0101	1.14	0.0133	1.50	0.00001	0.001	LL	LC	LL	LC
16	0.1083	12.23	0.0271	2.94	0.0372	3.53	0.00001	0.001	LL	LC	LL	LC
17	0.1518	16.06	0.0473	5.58	0.0612	6.63	0.00001	0.001	LL	LC	LL	LC
18	0.2688	19.33	0.1664	10.44	0.1725	11.71	0.00001	0.001	LL	LC	0.00001	LC
19	0.2541	22.13	0.2107	16.46	0.2455	17.23	0.00001	0.001	LL	LC	0.00001	LC
20	0.4027	24.20	0.3257	20.52	0.3367	21.04	0.00002	0.001	LL	LC	0.00001	LC
21	0.3477	25.41	0.2986	22.42	0.2723	23.13	0.00002	0.001	LL	LC	LL	LC
22	0.4857	26.87	0.4090	23.80	0.4091	25.38	0.00003	0.002	LL	LC	0.00001	LC
23	0.4158	26.51	0.3708	25.81	0.3501	26.16	0.00003	0.002	LL	LC	0.00001	LC
24	0.2914	25.27	0.3312	26.36	0.3105	26.54	0.00002	0.002	LL	LC	0.00001	LC
25	0.2388	25.42	0.3091	26.08	0.2831	26.50	0.00001	0.002	LL	LC	LL	LC
26	0.2896	24.80	0.3570	26.42	0.3371	26.19	0.00002	0.002	LL	LC	LL	LC
27	0.2769	25.15	0.2599	25.67	0.2273	25.19	0.00002	0.002	LL	LC	LL	LC
28	0.2263	26.18	0.2213	24.72	0.2137	24.81	0.00002	0.002	LL	LC	LL	LC
29	0.4362	27.64	0.3905	24.51	0.3768	24.61	0.00004	0.003	LL	LC	LL	LC
30	0.2794	27.97	0.2652	24.29	0.2327	24.43	0.00003	0.003	LL	LC	LL	LC
31	0.2672	28.92	0.2316	24.56	0.2248	24.92	0.00003	0.003	LL	LC	LL	LC
32	0.2464	30.26	0.2209	25.26	0.2084	25.59	0.00002	0.002	LL	LC	LL	LC
33	0.3476	30.52	0.3048	26.31	0.2884	26.54	0.00002	0.002	LL	LC	LL	LC
34	0.3009	29.46	0.2694	27.41	0.2180	26.78	0.00002	0.002	LL	LC	LL	LC
35	0.4577	30.70	0.4674	28.34	0.4213	27.66	0.00002	0.002	LL	LC	LL	LC
36	0.3778	30.00	0.4204	30.36	0.3274	29.05	0.00002	0.001	LL	LC	LL	LC
37	0.4897	28.27	0.5585	30.22	0.5003	29.17	0.00002	0.001	LL	LC	LL	LC

NOTE: LL = less than 0.00001 kg/ha; LC = less than 0.001 µg/l.

Table 35

Long-term PRZM Simulations for Nitrate (as Nitrogen)

YEAR	Case: 133.n3		Case: 134.n3		Case: 135.n3		Case: 143.n3		Case: 144.n3		Case: 145.n3		Case: 146.n3		Case: 153.n3	
	LOAD (kg/ha)	CONC. (mg/l)	LOAD (kg/ha)	CONC. (mg/l)	LOAD (kg/ha)	CONC. (mg/l)	LOAD (kg/ha)	CONC. (mg/l)	LOAD (kg/ha)	CONC. (mg/l)	LOAD (kg/ha)	CONC. (mg/l)	LOAD (kg/ha)	CONC. (mg/l)	LOAD (kg/ha)	CONC. (mg/l)
1	LL	LC	LL	LC	LL	LC	LL	LC	LL	LC	LL	LC	LL	LC	LL	LC
2	LL	LC	LL	LC	LL	LC	LL	LC	LL	LC	LL	LC	LL	LC	LL	LC
3	LL	LC	LL	LC	LL	LC	LL	LC	LL	LC	LL	LC	LL	LC	LL	LC
4	LL	LC	LL	LC	LL	LC	0.0026	LC	LL	LC	LL	LC	LL	LC	0.0119	0.001
5	0.0005	LC	0.0004	LC	LL	LC	0.355	0.026	0.0012	LC	LL	LC	LL	LC	0.944	0.062
6	0.233	0.015	0.232	0.014	0.0224	0.001	5.05	0.310	0.376	0.023	0.0268	0.002	0.0007	LC	10.07	0.508
7	0.972	0.128	0.926	0.119	0.202	0.025	6.35	0.745	1.41	0.167	0.283	0.031	0.0261	0.002	10.73	0.921
8	2.16	0.320	2.40	0.329	0.963	0.117	6.81	0.974	2.79	0.412	1.13	0.137	0.249	0.026	8.22	0.978
9	7.83	0.672	8.19	0.648	6.28	0.427	15.26	1.111	9.61	0.728	7.20	0.478	3.59	0.217	14.09	0.980
10	16.10	1.084	15.81	1.019	13.64	0.849	14.47	0.960	16.65	1.024	14.72	0.906	11.93	0.679	14.24	0.838
11	12.46	1.055	11.71	1.016	11.87	1.007	12.39	1.027	11.39	0.975	11.28	1.009	11.67	0.909	9.95	0.848
12	13.06	1.082	11.92	0.953	12.04	0.929	13.64	1.070	12.13	0.920	11.11	0.920	12.75	0.897	12.11	0.900
13	13.85	1.110	13.20	1.020	11.61	0.896	16.46	1.290	14.51	1.003	10.51	0.827	11.60	0.825	15.30	1.098
14	10.08	1.216	9.51	1.126	8.31	0.955	10.12	1.244	9.89	1.136	7.39	0.879	7.34	0.760	9.13	1.052
15	13.42	1.396	12.04	1.300	9.63	1.050	9.62	1.163	13.09	1.314	8.31	0.930	7.36	0.783	10.28	0.983
16	10.82	1.347	10.92	1.291	10.97	1.182	8.35	1.079	10.48	1.226	9.54	1.076	8.03	0.843	8.74	0.905
17	12.26	1.269	11.78	1.228	12.24	1.245	9.90	0.993	10.87	1.141	11.33	1.196	10.12	0.979	10.37	0.934
18	16.03	1.083	15.84	1.070	16.78	1.081	14.40	0.981	14.56	1.000	16.89	1.097	18.08	1.066	15.09	0.971
19	10.20	1.044	10.97	1.013	11.57	0.954	10.90	1.008	11.28	0.988	11.53	0.964	12.23	0.910	11.68	0.998
20	18.09	1.078	17.44	1.014	16.44	0.962	20.72	1.236	17.16	0.975	18.51	0.968	15.19	0.849	22.35	1.197
21	16.96	1.257	18.07	1.211	15.65	1.023	17.84	1.346	16.70	1.147	16.41	1.052	13.35	0.894	16.66	1.204
22	19.83	1.304	22.12	1.281	21.65	1.228	20.84	1.370	21.05	1.227	23.67	1.258	17.34	0.949	16.54	1.176
23	19.74	1.309	21.94	1.298	22.64	1.288	19.49	1.209	21.35	1.270	22.91	1.321	18.93	1.148	16.07	1.093
24	13.74	1.242	15.53	1.210	15.48	1.192	13.63	1.168	14.87	1.197	15.58	1.230	16.12	1.229	13.04	1.074
25	12.07	1.237	12.57	1.173	12.51	1.131	10.21	1.067	10.96	1.153	11.46	1.154	13.88	1.205	8.91	0.934
26	14.56	1.103	14.68	1.020	16.51	1.095	11.99	0.925	13.26	1.044	13.90	1.104	14.21	1.071	11.86	0.896
27	11.53	0.975	11.33	0.917	11.81	0.956	10.34	0.867	11.11	0.956	11.18	0.993	12.02	1.034	10.13	0.834
28	4.80	0.814	6.03	0.746	8.90	0.907	5.71	0.824	6.45	0.806	7.35	0.850	9.22	1.014	6.87	0.862
29	10.62	0.878	11.39	0.766	12.59	0.747	12.62	0.895	11.96	0.768	12.99	0.775	16.13	0.915	15.24	0.925
30	9.73	0.904	9.03	0.795	8.62	0.742	11.18	0.954	8.78	0.782	7.18	0.704	8.14	0.834	12.83	1.006
31	7.37	0.940	7.94	0.850	8.24	0.783	9.37	1.078	7.63	0.821	6.75	0.714	7.16	0.737	10.29	1.092
32	7.53	0.985	8.13	0.937	7.95	0.843	8.43	1.043	7.78	0.931	6.17	0.752	6.25	0.746	8.99	1.064
33	11.67	1.066	12.00	1.001	11.94	0.943	14.40	1.210	12.69	1.054	9.62	0.821	8.99	0.762	15.50	1.204
34	11.86	1.130	11.59	1.019	11.68	0.981	12.75	1.152	12.14	1.108	10.33	0.990	8.62	0.817	12.73	1.096
35	15.69	1.167	16.86	1.111	17.10	1.035	17.36	1.188	18.31	1.189	17.24	1.086	15.49	0.919	16.73	1.057
36	11.39	1.225	12.17	1.069	13.68	1.036	12.41	1.164	12.89	1.094	15.24	1.188	14.68	1.016	12.52	1.043
37	23.22	1.314	20.97	1.123	19.03	0.982	24.16	1.281	21.47	1.124	20.55	1.077	21.96	1.104	24.41	1.216

NOTE: LL = less than 0.0001 kg/ha; LC = less than 0.001 mg/l.

Table 35. (Continued) Long-term PRZM Simulations for Nitrate (as Nitrogen)

YEAR	Case: 154.n3 LOAD (kg/ha)	Case: 154.n3 CONC. (mg/l)	Case: 155.n3 LOAD (kg/ha)	Case: 155.n3 CONC. (mg/l)	Case: 156.n3 LOAD (kg/ha)	Case: 156.n3 CONC. (mg/l)	Case: 157.n3 LOAD (kg/ha)	Case: 157.n3 CONC. (mg/l)	Case: 163.n3 LOAD (kg/ha)	Case: 163.n3 CONC. (mg/l)	Case: 165.n3 LOAD (kg/ha)	Case: 165.n3 CONC. (mg/l)	Case: 166.n3 LOAD (kg/ha)	Case: 166.n3 CONC. (mg/l)	Case: 173.n3 LOAD (kg/ha)	Case: 173.n3 CONC. (mg/l)
1	LL	LC	LL	LC	LL	LC	LL	LC	LL	LC	LL	LC	LL	LC	LL	LC
2	LL	LC	LL	LC	LL	LC	LL	LC	LL	LC	LL	LC	LL	LC	LL	LC
3	LL	LC	LL	LC	LL	LC	LL	LC	LL	LC	LL	LC	LL	LC	LL	LC
4	LL	LC	LL	LC	LL	LC	LL	LC	0.0001	LC	LL	LC	LL	LC	0.0001	LC
5	0.0003	LC	0.0001	LC	LL	LC	LL	LC	0.0748	0.005	0.0004	LC	LL	LC	0.0564	0.004
6	0.271	0.015	0.148	0.008	LL	LC	LL	LC	3.65	0.192	0.360	0.018	LL	LC	3.09	0.166
7	1.40	0.146	0.764	0.090	0.0006	LC	0.0003	LC	6.71	0.630	1.82	0.174	0.0014	LC	5.79	0.576
8	2.99	0.388	1.69	0.248	0.0114	0.001	0.0090	LC	7.26	0.843	3.77	0.460	0.0208	0.002	6.19	0.789
9	9.87	0.712	6.68	0.539	0.629	0.038	0.722	0.038	14.52	0.951	13.68	0.843	1.23	0.065	14.73	0.954
10	16.54	0.978	15.05	0.925	6.01	0.341	6.57	0.354	15.65	0.911	18.37	1.046	9.15	0.496	16.18	0.935
11	11.21	0.969	11.86	1.047	10.84	0.796	12.20	0.805	10.04	0.825	12.39	0.918	15.87	0.990	10.66	0.845
12	11.85	0.870	12.20	0.937	13.84	0.998	13.00	0.936	12.23	0.871	11.54	0.816	15.13	1.027	12.52	0.898
13	13.17	0.918	13.76	0.958	14.26	0.950	13.91	0.862	14.17	0.991	12.98	0.870	13.68	0.846	14.96	1.031
14	8.90	1.011	8.82	1.012	7.65	0.829	8.35	0.768	10.59	1.151	8.80	1.036	6.39	0.711	10.54	1.193
15	12.80	1.153	12.37	1.158	6.87	0.770	6.40	0.705	11.91	1.052	11.79	1.129	6.18	0.690	11.87	1.083
16	11.52	1.182	12.09	1.270	7.45	0.788	6.51	0.698	9.78	0.936	10.95	1.063	8.13	0.743	9.88	0.941
17	11.02	1.068	11.32	1.194	7.90	0.847	6.36	0.745	9.53	0.878	8.68	0.894	8.04	0.860	8.85	0.884
18	14.70	0.958	16.14	1.072	17.02	1.029	17.10	0.901	14.40	0.922	13.44	0.852	16.83	0.998	13.34	0.900
19	12.38	0.964	14.73	1.013	15.10	1.035	13.42	0.976	11.88	0.956	12.99	0.878	13.65	0.860	11.66	0.948
20	18.86	0.972	20.61	1.007	16.60	0.867	14.72	0.790	20.47	1.051	18.37	0.933	14.48	0.742	19.54	1.026
21	17.15	1.132	18.50	1.153	13.13	0.859	11.97	0.762	16.60	1.158	15.84	1.118	10.98	0.780	15.22	1.159
22	19.98	1.186	23.16	1.217	16.65	0.906	15.25	0.840	16.98	1.151	20.03	1.204	14.54	0.847	17.00	1.175
23	19.78	1.191	20.90	1.189	16.88	1.049	13.90	0.880	17.24	1.087	19.13	1.192	14.92	0.975	18.40	1.158
24	14.18	1.077	15.05	1.083	15.94	1.207	13.70	1.025	13.12	1.051	13.67	1.066	14.53	1.146	13.03	1.096
25	9.98	1.065	11.00	0.986	15.01	1.256	14.87	1.166	10.74	1.035	11.06	1.011	14.58	1.214	11.13	1.090
26	12.72	1.005	11.67	0.856	16.21	1.190	17.90	1.215	12.72	0.886	13.06	0.939	16.33	1.173	13.97	0.945
27	10.09	0.852	9.22	0.773	11.48	1.076	11.68	1.124	10.05	0.816	8.99	0.841	9.95	1.067	9.96	0.865
28	7.60	0.835	7.10	0.724	9.21	1.030	9.31	1.037	6.86	0.798	7.72	0.820	8.76	1.008	7.42	0.828
29	13.24	0.751	12.58	0.684	16.47	0.936	17.69	0.995	15.51	0.851	13.69	0.763	15.83	0.935	16.00	0.878
30	9.49	0.768	8.32	0.719	8.43	0.827	10.61	0.906	12.14	0.902	8.96	0.791	8.64	0.852	11.84	0.913
31	8.36	0.815	8.51	0.796	7.53	0.776	8.28	0.827	9.65	0.998	8.55	0.842	7.97	0.821	9.38	1.005
32	8.25	0.903	8.43	0.893	6.16	0.716	7.01	0.767	8.58	1.018	8.17	0.915	6.48	0.772	8.24	1.030
33	13.82	1.049	12.83	0.990	8.62	0.734	8.68	0.725	13.81	1.039	12.54	1.016	8.63	0.759	12.81	1.040
34	12.82	1.106	11.37	1.025	7.53	0.768	7.99	0.754	13.61	1.161	10.28	1.035	6.73	0.787	12.27	1.164
35	19.71	1.172	19.17	1.100	14.43	0.850	14.95	0.823	16.37	0.991	19.40	1.134	14.14	0.842	16.36	1.034
36	13.05	0.995	13.16	0.947	12.94	0.966	12.79	0.904	12.29	0.968	12.95	1.015	10.97	0.947	11.73	0.985
37	20.74	1.005	20.61	0.989	21.17	1.059	20.44	0.972	22.68	1.091	20.54	1.005	19.98	1.028	21.16	1.051

NOTE: LL = less than 0.0001 kg/ha; LC = less than 0.001 mg/l.

Table 35. (Continued) Long-term PRZM Simulations for Nitrate (as Nitrogen)

YEAR	Case: 175.n3 LOAD (kg/ha)	Case: 175.n3 CONC. (mg/l)	Case: 533.n2 LOAD (kg/ha)	Case: 533.n2 CONC. (mg/l)	Case: 534.n2 LOAD (kg/ha)	Case: 534.n2 CONC. (mg/l)	Case: 635.n2 LOAD (kg/ha)	Case: 635.n2 CONC. (mg/l)	Case: 443.n2 LOAD (kg/ha)	Case: 443.n2 CONC. (mg/l)	Case: 444.n2 LOAD (kg/ha)	Case: 444.n2 CONC. (mg/l)	Case: 245.n2 LOAD (kg/ha)	Case: 245.n2 CONC. (mg/l)	Case: 446.n2 LOAD (kg/ha)	Case: 446.n2 CONC. (mg/l)
1	LL	LC	LL	LC	LL	LC	LL	LC	LL	LC	LL	LC	LL	LC	LL	LC
2	LL	LC	LL	LC	LL	LC	LL	LC	LL	LC	LL	LC	LL	LC	LL	LC
3	LL	LC	LL	LC	LL	LC	0.0907	0.011	LL	LC	LL	LC	LL	LC	LL	LC
4	LL	LC	LL	LC	LL	LC	1.37	0.188	LL	LC	LL	LC	LL	LC	LL	LC
5	LL	LC	0.0030	LC	0.0110	0.001	2.01	0.251	0.0351	0.004	0.0012	LC	LL	LC	LL	LC
6	0.0121	LC	0.396	0.039	0.841	0.078	2.13	0.242	1.11	0.103	0.246	0.022	LL	LC	0.0398	0.003
7	0.288	0.023	1.18	0.215	1.84	0.307	1.32	0.229	2.47	0.373	1.13	0.161	LL	LC	0.699	0.070
8	1.16	0.132	2.12	0.431	2.72	0.485	1.53	0.262	3.05	0.576	2.09	0.368	LL	LC	2.36	0.274
9	9.65	0.533	4.94	0.599	4.91	0.544	1.99	0.236	6.11	0.637	5.41	0.548	LL	LC	6.17	0.470
10	17.55	0.990	5.31	0.586	5.15	0.508	2.39	0.271	5.98	0.616	6.06	0.572	0.0081	0.001	6.42	0.492
11	14.60	0.994	4.87	0.591	4.55	0.526	2.61	0.344	5.43	0.620	5.08	0.549	0.0995	0.009	4.92	0.452
12	11.66	0.850	4.36	0.564	4.27	0.517	1.92	0.276	5.10	0.606	5.34	0.571	0.635	0.056	4.66	0.438
13	11.79	0.767	5.07	0.605	5.08	0.573	1.56	0.211	6.24	0.696	6.06	0.585	2.15	0.178	5.01	0.438
14	7.14	0.809	4.60	0.729	4.56	0.694	1.41	0.237	4.95	0.790	4.95	0.675	2.74	0.327	4.17	0.472
15	10.62	0.918	5.56	0.760	4.88	0.686	1.67	0.262	5.16	0.797	6.14	0.762	4.41	0.510	4.51	0.542
16	11.95	1.049	3.89	0.634	3.80	0.561	1.97	0.290	4.05	0.668	5.29	0.720	6.02	0.680	5.22	0.583
17	9.51	1.004	4.31	0.568	3.81	0.493	1.88	0.263	4.87	0.610	4.83	0.591	7.67	0.811	4.86	0.509
18	13.33	0.813	5.43	0.569	5.17	0.528	2.69	0.329	6.31	0.621	5.84	0.569	12.33	0.887	5.24	0.437
19	11.47	0.788	4.06	0.575	4.44	0.554	2.27	0.303	5.33	0.672	5.29	0.595	10.84	0.945	5.23	0.470
20	16.83	0.867	6.49	0.625	6.51	0.595	2.35	0.260	7.73	0.701	7.20	0.605	16.60	0.997	6.74	0.521
21	11.86	0.929	5.73	0.673	6.21	0.658	1.90	0.252	7.11	0.808	6.43	0.651	14.23	1.040	5.51	0.526
22	15.21	1.066	7.55	0.666	8.16	0.637	2.88	0.277	9.42	0.797	9.63	0.706	19.56	1.082	8.90	0.596
23	17.52	1.145	6.18	0.594	6.49	0.564	2.04	0.230	7.60	0.706	7.86	0.664	16.63	1.060	7.84	0.630
24	13.90	1.141	4.64	0.619	5.27	0.591	1.87	0.241	5.46	0.669	5.78	0.637	12.00	1.041	6.08	0.565
25	11.99	1.104	4.21	0.615	4.14	0.534	1.28	0.197	4.79	0.680	4.62	0.632	10.27	1.093	4.75	0.529
26	15.09	1.028	4.94	0.523	4.91	0.468	1.92	0.215	5.63	0.586	5.89	0.606	13.17	1.128	5.63	0.544
27	9.67	0.988	4.27	0.476	3.90	0.411	1.83	0.229	5.18	0.552	4.90	0.515	13.30	1.208	5.21	0.517
28	8.76	0.923	1.80	0.436	2.47	0.388	2.13	0.301	2.77	0.529	3.32	0.488	11.17	1.292	4.10	0.486
29	15.49	0.869	4.12	0.468	4.39	0.419	2.04	0.226	5.61	0.524	5.43	0.457	21.21	1.344	6.07	0.449
30	9.43	0.822	3.51	0.483	3.81	0.476	1.62	0.238	4.99	0.591	4.01	0.465	12.79	1.281	3.45	0.416
31	8.21	0.865	3.13	0.567	3.69	0.543	1.86	0.291	4.26	0.658	4.05	0.551	11.47	1.241	3.52	0.429
32	7.41	0.885	3.31	0.602	3.38	0.508	1.41	0.231	4.19	0.687	4.37	0.633	9.89	1.215	3.37	0.453
33	10.83	0.918	4.28	0.567	4.30	0.491	1.66	0.230	5.50	0.629	5.92	0.632	12.85	1.128	5.07	0.528
34	9.18	0.996	4.05	0.555	4.56	0.547	2.05	0.276	5.53	0.677	5.38	0.626	10.20	0.999	4.99	0.560
35	17.33	1.040	6.21	0.658	5.88	0.560	2.79	0.325	7.41	0.696	7.33	0.642	14.28	0.958	6.99	0.561
36	13.29	1.121	4.82	0.660	4.79	0.528	2.64	0.304	5.80	0.666	5.90	0.594	11.23	0.892	7.30	0.579
37	21.46	1.070	8.28	0.673	7.90	0.619	2.52	0.251	10.10	0.742	8.64	0.622	15.09	0.871	7.54	0.526

NOTE: LL - less than 0.0001 kg/ha; LC - less than 0.001 mg/l.

Table 35. (Continued) Long-term PRZM Simulations for Nitrate (as Nitrogen)

YEAR	Case: 453.n2 LOAD (kg/ha)	CONC. (mg/l)	Case: 454.n2 LOAD (kg/ha)	CONC. (mg/l)	Case: 455.n2 LOAD (kg/ha)	CONC. (mg/l)	Case: 456.n2 LOAD (kg/ha)	CONC. (mg/l)	Case: 257.n2 LOAD (kg/ha)	CONC. (mg/l)	Case: 463.n2 LOAD (kg/ha)	CONC. (mg/l)	Case: 465.n2 LOAD (kg/ha)	CONC. (mg/l)	Case: 266.n2 LOAD (kg/ha)	CONC. (mg/l)
1	LL	LC	LL	LC	LL	LC	LL	LC	LL	LC	LL	LC	LL	LC	LL	LC
2	LL	LC	LL	LC	LL	LC	LL	LC	LL	LC	LL	LC	LL	LC	LL	LC
3	LL	LC	LL	LC	LL	LC	LL	LC	LL	LC	LL	LC	LL	LC	LL	LC
4	0.0005	LC	LL	LC	LL	LC	LL	LC	LL	LC	LL	LC	LL	LC	LL	LC
5	0.196	0.018	0.0010	LC	LL	LC	LL	LC	LL	LC	0.0416	0.004	0.0261	0.002	LL	LC
6	3.38	0.258	0.249	0.021	0.0191	0.002	0.0114	0.001	LL	LC	1.51	0.122	1.36	0.099	LL	LC
7	5.15	0.560	1.38	0.174	0.266	0.034	0.431	0.039	LL	LC	3.57	0.418	4.06	0.392	LL	LC
8	3.96	0.603	2.50	0.389	0.960	0.151	2.05	0.220	LL	LC	3.79	0.552	4.81	0.548	LL	LC
9	5.78	0.538	5.78	0.550	3.71	0.366	6.38	0.465	LL	LC	6.32	0.552	7.03	0.524	LL	LC
10	5.63	0.525	5.92	0.547	5.92	0.537	6.87	0.514	LL	LC	5.62	0.502	5.81	0.460	LL	LC
11	4.30	0.509	4.75	0.519	5.29	0.548	5.56	0.453	LL	LC	4.96	0.526	5.12	0.431	0.0003	LC
12	4.49	0.497	5.19	0.538	5.16	0.531	4.58	0.413	0.0029	LC	5.00	0.513	4.98	0.449	0.0088	0.001
13	5.90	0.595	5.61	0.532	5.87	0.532	5.17	0.410	0.0720	0.005	5.99	0.572	6.54	0.526	0.171	0.011
14	4.55	0.676	4.42	0.608	4.23	0.534	4.19	0.446	0.349	0.033	4.81	0.664	4.88	0.576	0.513	0.059
15	5.01	0.632	6.01	0.690	5.49	0.621	4.68	0.511	0.930	0.104	5.54	0.644	4.97	0.487	1.36	0.153
16	4.21	0.544	5.66	0.682	6.13	0.702	5.22	0.546	2.10	0.228	4.56	0.534	4.29	0.429	3.26	0.310
17	5.04	0.564	4.88	0.561	5.76	0.664	4.56	0.467	3.19	0.376	4.57	0.519	4.48	0.451	4.67	0.506
18	6.63	0.621	5.96	0.554	6.01	0.553	5.21	0.417	9.42	0.591	6.15	0.568	6.02	0.489	11.08	0.752
19	5.60	0.639	5.91	0.592	6.51	0.559	5.61	0.446	10.18	0.795	5.39	0.576	6.28	0.497	12.95	0.908
20	8.64	0.685	7.72	0.592	8.05	0.572	6.74	0.489	13.73	0.865	8.14	0.616	7.68	0.550	14.66	0.916
21	6.62	0.723	6.62	0.648	6.59	0.596	5.34	0.487	11.35	0.852	6.51	0.673	6.05	0.581	10.45	0.887
22	7.28	0.660	9.04	0.671	9.86	0.640	8.87	0.561	14.80	0.861	7.71	0.652	8.01	0.550	15.01	0.931
23	6.28	0.611	7.24	0.612	7.85	0.612	7.55	0.584	13.36	0.930	6.83	0.594	6.30	0.506	12.71	0.950
24	5.15	0.612	5.66	0.585	6.25	0.570	6.38	0.540	11.83	0.942	5.42	0.600	5.58	0.496	11.09	0.948
25	4.42	0.615	4.40	0.593	4.92	0.556	4.99	0.500	10.78	0.909	4.63	0.591	4.42	0.475	9.94	0.931
26	5.15	0.529	5.28	0.553	5.42	0.495	5.93	0.499	12.24	0.906	5.62	0.522	5.52	0.460	11.82	0.918
27	5.04	0.532	4.74	0.489	4.64	0.455	4.82	0.463	9.01	0.889	4.87	0.503	4.57	0.454	8.13	0.900
28	3.26	0.534	3.70	0.484	3.86	0.433	4.22	0.452	7.89	0.881	3.37	0.498	4.08	0.430	7.88	0.915
29	6.64	0.544	5.96	0.454	5.66	0.406	5.93	0.420	14.68	0.922	6.50	0.501	6.05	0.427	14.79	0.966
30	5.83	0.627	4.43	0.464	4.03	0.416	3.75	0.393	10.72	0.982	5.43	0.544	4.81	0.476	9.85	1.034
31	4.67	0.665	4.40	0.545	4.09	0.460	3.68	0.412	9.92	1.052	4.54	0.619	4.95	0.544	10.02	1.110
32	4.21	0.661	4.65	0.622	4.58	0.545	3.82	0.447	9.84	1.125	3.84	0.595	4.52	0.517	9.54	1.172
33	5.87	0.626	6.13	0.621	5.69	0.548	5.33	0.510	13.74	1.186	5.78	0.595	5.47	0.525	13.20	1.215
34	5.70	0.657	5.72	0.632	5.13	0.553	4.62	0.502	11.86	1.206	5.51	0.614	5.11	0.554	9.72	1.194
35	7.05	0.612	7.31	0.598	7.25	0.564	6.88	0.513	19.22	1.165	7.36	0.601	6.59	0.495	17.64	1.158
36	5.71	0.592	5.79	0.531	6.07	0.503	6.90	0.538	15.64	1.129	5.44	0.528	5.72	0.476	12.58	1.116
37	10.53	0.721	8.68	0.577	7.72	0.511	7.38	0.485	18.57	1.005	9.60	0.637	8.92	0.569	17.47	1.019

NOTE: LL = less than 0.0001 kg/ha; LC = less than 0.001 mg/l.

Table 35. (Continued) Long-term PRZM Simulations for Nitrate (as Nitrogen)

YEAR	Case: 473.n2 LOAD (kg/ha)	Case: 473.n2 CONC. (mg/l)	Case: 475.n2 LOAD (kg/ha)	Case: 475.n2 CONC. (mg/l)	Case: 533.n2d LOAD (kg/ha)	Case: 533.n2d CONC. (mg/l)	Case: 534.n2d LOAD (kg/ha)	Case: 534.n2d CONC. (mg/l)	Case: 635.n2d LOAD (kg/ha)	Case: 635.n2d CONC. (mg/l)	Case: 443.n2d LOAD (kg/ha)	Case: 443.n2d CONC. (mg/l)	Case: 444.n2d LOAD (kg/ha)	Case: 444.n2d CONC. (mg/l)	Case: 446.n2d LOAD (kg/ha)	Case: 446.n2d CONC. (mg/l)
1	LL	LC	LL	LC	LL	LC	LL	LC	LL	LC	LL	LC	LL	LC	LL	LC
2	LL	LC	LL	LC	LL	LC	LL	LC	LL	LC	LL	LC	LL	LC	LL	LC
3	LL	LC	LL	LC	LL	LC	LL	LC	LL	LC	LL	LC	LL	LC	LL	LC
4	0.0001	LC	LL	LC	LL	LC	LL	LC	LL	LC	LL	LC	LL	LC	LL	LC
5	0.0943	0.008	0.0020	LC	LL	LC	LL	LC	LL	LC	LL	LC	LL	LC	LL	LC
6	2.04	0.166	0.503	0.035	LL	LC	LL	LC	LL	LC	LL	LC	LL	LC	LL	LC
7	3.94	0.448	3.58	0.289	LL	LC	LL	LC	LL	LC	0.0002	LC	LL	LC	LL	LC
8	3.73	0.538	5.17	0.519	LL	LC	LL	LC	LL	LC	0.0019	LC	LL	LC	LL	LC
9	6.25	0.521	7.61	0.508	LL	LC	LL	LC	LL	LC	0.0492	0.005	LL	LC	LL	LC
10	5.62	0.490	5.87	0.435	0.0007	LC	0.0007	LC	LL	LC	0.254	0.026	0.0038	LC	LL	LC
11	5.32	0.510	5.13	0.395	0.0154	0.002	0.0139	0.002	LL	LC	0.617	0.070	0.0466	0.005	0.0001	LC
12	5.18	0.508	4.62	0.410	0.0760	0.010	0.0849	0.010	0.0001	LC	1.23	0.146	0.244	0.026	0.0050	0.001
13	6.67	0.598	6.01	0.449	0.241	0.029	0.275	0.031	0.0013	LC	2.11	0.235	0.717	0.069	0.0609	0.005
14	4.98	0.658	4.76	0.509	0.406	0.064	0.431	0.066	0.0064	0.001	2.00	0.319	1.02	0.139	0.224	0.025
15	5.21	0.584	5.31	0.462	0.819	0.112	0.811	0.114	0.0248	0.004	2.44	0.376	1.73	0.215	0.558	0.067
16	4.53	0.489	4.42	0.390	1.07	0.174	1.16	0.172	0.0678	0.010	2.85	0.470	2.13	0.290	1.14	0.128
17	4.42	0.502	4.30	0.409	1.79	0.236	1.84	0.238	0.149	0.021	4.04	0.506	2.90	0.355	1.90	0.199
18	5.92	0.545	5.92	0.448	3.15	0.330	3.03	0.310	0.334	0.041	5.50	0.541	4.48	0.437	3.52	0.294
19	5.35	0.541	6.36	0.478	2.78	0.393	3.14	0.391	0.511	0.068	4.43	0.559	4.47	0.502	4.13	0.372
20	7.92	0.595	6.92	0.486	4.70	0.452	4.77	0.436	0.911	0.101	7.23	0.656	6.47	0.544	5.36	0.415
21	6.08	0.648	5.32	0.537	4.26	0.501	4.53	0.479	1.02	0.135	5.50	0.626	5.74	0.581	4.58	0.437
22	7.49	0.618	6.94	0.504	6.51	0.574	6.79	0.530	1.74	0.167	7.69	0.650	8.52	0.624	7.04	0.471
23	6.88	0.575	6.36	0.487	5.84	0.561	6.19	0.537	1.70	0.192	7.10	0.660	7.11	0.601	5.98	0.481
24	5.62	0.587	5.44	0.464	4.46	0.596	4.88	0.547	1.65	0.213	5.66	0.694	5.60	0.617	5.23	0.485
25	4.69	0.571	4.45	0.466	4.05	0.593	4.23	0.546	1.49	0.231	4.78	0.679	4.41	0.603	4.41	0.490
26	5.87	0.505	5.90	0.449	5.80	0.613	5.94	0.566	2.13	0.238	7.36	0.766	6.04	0.621	5.12	0.494
27	4.90	0.509	4.70	0.460	5.57	0.621	5.52	0.581	1.94	0.243	6.56	0.700	6.06	0.637	4.89	0.485
28	3.85	0.494	4.68	0.458	2.76	0.670	3.90	0.612	1.76	0.249	3.78	0.721	4.51	0.664	4.20	0.498
29	6.52	0.484	6.08	0.432	5.49	0.624	6.38	0.609	2.32	0.257	8.03	0.750	7.95	0.669	6.94	0.514
30	5.50	0.549	4.56	0.436	4.50	0.619	4.70	0.586	1.82	0.267	5.59	0.661	5.60	0.649	4.50	0.543
31	4.55	0.594	4.46	0.494	3.50	0.634	4.06	0.597	1.77	0.277	4.25	0.656	4.82	0.656	4.62	0.563
32	3.67	0.548	4.60	0.521	3.63	0.660	4.04	0.608	1.71	0.280	4.05	0.663	4.46	0.647	4.29	0.576
33	5.48	0.568	5.11	0.479	4.63	0.614	4.90	0.561	1.96	0.271	5.83	0.666	5.55	0.593	5.64	0.587
34	5.18	0.595	4.71	0.509	4.25	0.583	4.44	0.533	2.04	0.275	4.91	0.602	5.07	0.590	5.04	0.564
35	6.80	0.559	6.98	0.521	5.59	0.593	5.47	0.521	2.38	0.277	6.17	0.580	6.52	0.571	6.96	0.559
36	5.15	0.503	5.61	0.466	4.17	0.570	4.57	0.504	2.30	0.265	5.11	0.587	5.45	0.548	6.70	0.532
37	9.24	0.618	7.90	0.497	6.33	0.515	5.81	0.455	2.66	0.265	8.20	0.602	7.21	0.519	7.13	0.497

NOTE: LL - less than 0.0001 kg/ha; LC - less than 0.001 mg/l.

Table 35. (Continued) Long-term PRZM Simulations for Nitrate (as Nitrogen)

YEAR	Case: 453.n2d LOAD (kg/ha)	Case: 453.n2d CONC. (mg/l)	Case: 454.n2d LOAD (kg/ha)	Case: 454.n2d CONC. (mg/l)	Case: 455.n2d LOAD (kg/ha)	Case: 455.n2d CONC. (mg/l)	Case: 456.n2d LOAD (kg/ha)	Case: 456.n2d CONC. (mg/l)	Case: 463.n2d LOAD (kg/ha)	Case: 463.n2d CONC. (mg/l)	Case: 465.n2d LOAD (kg/ha)	Case: 465.n2d CONC. (mg/l)	Case: 473.n2d LOAD (kg/ha)	Case: 473.n2d CONC. (mg/l)	Case: 475.n2d LOAD (kg/ha)	Case: 475.n2d CONC. (mg/l)
1	LL	LC	LL	LC	LL	LC	LL	LC	LL	LC	LL	LC	LL	LC	LL	LC
2	LL	LC	LL	LC	LL	LC	LL	LC	LL	LC	LL	LC	LL	LC	LL	LC
3	LL	LC	LL	LC	LL	LC	LL	LC	LL	LC	LL	LC	LL	LC	LL	LC
4	LL	LC	LL	LC	LL	LC	LL	LC	LL	LC	LL	LC	LL	LC	LL	LC
5	LL	LC	LL	LC	LL	LC	LL	LC	LL	LC	LL	LC	LL	LC	LL	LC
6	0.0001	LC	LL	LC	LL	LC	LL	LC	LL	LC	LL	LC	LL	LC	LL	LC
7	0.0030	LC	LL	LC	LL	LC	LL	LC	LL	LC	LL	LC	LL	LC	LL	LC
8	0.0170	0.003	LL	LC	LL	LC	LL	LC	0.0002	LC	LL	LC	0.0005	LC	LL	LC
9	0.202	0.019	LL	LC	LL	LC	LL	LC	0.0117	0.001	0.0045	LC	0.0224	0.002	0.0001	LC
10	0.773	0.072	0.0018	LC	LL	LC	LL	LC	0.141	0.013	0.0806	0.006	0.219	0.019	0.0082	0.001
11	1.19	0.140	0.0239	0.003	0.0001	LC	LL	LC	0.501	0.053	0.486	0.041	0.744	0.071	0.119	0.009
12	2.18	0.242	0.166	0.017	0.0027	LC	0.0017	LC	1.09	0.112	1.30	0.117	1.44	0.141	0.525	0.047
13	3.34	0.337	0.622	0.059	0.0431	0.004	0.0333	0.003	2.19	0.209	2.66	0.214	2.75	0.247	1.83	0.137
14	2.66	0.396	0.835	0.115	0.157	0.020	0.150	0.016	2.17	0.300	2.71	0.320	2.51	0.332	2.17	0.232
15	3.42	0.431	1.68	0.193	0.475	0.054	0.468	0.051	3.13	0.363	3.89	0.382	3.46	0.388	3.72	0.323
16	3.84	0.496	2.30	0.278	0.925	0.106	1.10	0.115	3.51	0.410	4.24	0.423	3.93	0.424	4.43	0.391
17	4.40	0.493	3.05	0.350	1.58	0.182	1.88	0.193	4.09	0.465	4.35	0.438	4.23	0.481	4.40	0.418
18	5.47	0.512	4.44	0.412	2.99	0.275	3.61	0.289	5.44	0.502	5.73	0.465	5.49	0.506	5.60	0.424
19	4.65	0.530	4.84	0.485	4.28	0.367	4.71	0.375	4.85	0.518	6.02	0.477	5.15	0.520	5.72	0.430
20	7.35	0.583	6.73	0.516	6.36	0.452	5.75	0.417	7.17	0.542	6.79	0.486	7.22	0.542	6.31	0.443
21	5.13	0.560	5.64	0.553	5.63	0.509	4.68	0.427	5.52	0.571	5.02	0.482	5.24	0.557	4.38	0.442
22	6.48	0.587	7.80	0.579	8.48	0.550	7.12	0.450	6.63	0.561	7.03	0.482	6.56	0.541	6.08	0.442
23	6.18	0.601	6.95	0.588	7.43	0.579	5.97	0.462	6.40	0.557	5.92	0.475	6.42	0.536	5.64	0.432
24	5.31	0.631	5.56	0.574	6.47	0.589	5.48	0.464	5.22	0.578	5.48	0.488	5.28	0.552	5.14	0.439
25	4.50	0.626	4.44	0.599	5.09	0.574	4.58	0.458	4.59	0.587	4.65	0.500	4.57	0.556	4.23	0.443
26	6.75	0.694	5.65	0.592	6.39	0.584	5.49	0.462	6.49	0.603	6.19	0.516	6.72	0.577	6.09	0.464
27	5.96	0.628	5.92	0.612	5.94	0.582	4.77	0.459	6.15	0.635	5.42	0.539	5.92	0.615	4.87	0.477
28	4.05	0.662	4.73	0.619	5.26	0.591	4.35	0.466	4.30	0.635	5.18	0.545	4.65	0.596	4.98	0.488
29	8.00	0.656	8.55	0.651	8.47	0.607	6.85	0.485	7.86	0.605	7.56	0.534	7.86	0.585	6.99	0.497
30	5.44	0.585	5.85	0.614	6.03	0.622	4.86	0.509	6.15	0.617	5.20	0.515	5.96	0.595	5.28	0.504
31	4.16	0.591	4.97	0.616	5.40	0.608	4.76	0.533	4.34	0.591	4.64	0.510	4.25	0.555	4.29	0.476
32	3.88	0.609	4.49	0.602	4.85	0.578	4.63	0.542	3.51	0.543	4.25	0.487	3.55	0.529	4.19	0.475
33	5.67	0.604	5.54	0.561	5.90	0.568	5.76	0.550	5.40	0.556	4.81	0.462	5.25	0.544	5.08	0.477
34	5.02	0.579	4.91	0.542	4.96	0.534	4.87	0.529	4.98	0.555	4.30	0.467	4.68	0.538	4.28	0.462
35	6.40	0.555	6.54	0.535	6.27	0.488	6.92	0.516	6.85	0.560	6.15	0.462	6.64	0.546	6.02	0.450
36	5.60	0.581	5.78	0.530	5.72	0.474	6.35	0.495	5.24	0.509	5.69	0.472	5.10	0.498	5.51	0.458
37	8.84	0.605	7.56	0.503	7.01	0.463	6.96	0.457	8.26	0.549	7.36	0.470	7.96	0.533	7.41	0.466

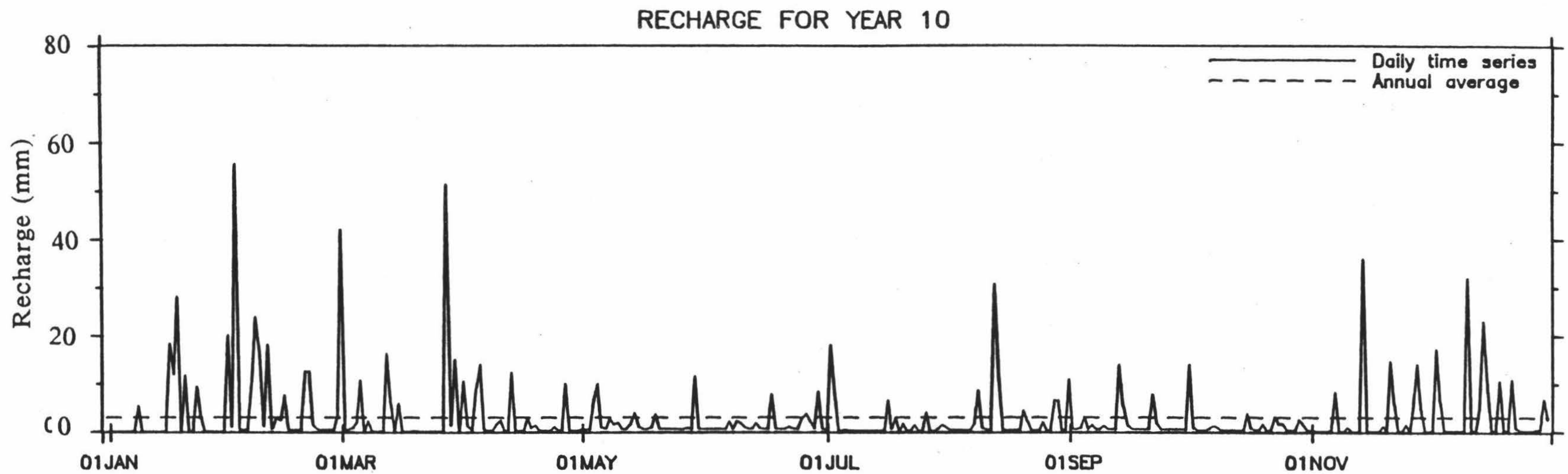
NOTE: LL - less than 0.0001 kg/ha; LC - less than 0.001 mg/l.

Table 36

Long-term PRZM Simulations in Waiawa Valley

YEAR	Case: 454v.d3 LOAD (kg/ha)	Case: 454v.d3 CONC. (ug/l)	Case: 454v.d2 LOAD (kg/ha)	Case: 454v.d2 CONC. (ug/l)	Case: 454v.d3d LOAD (kg/ha)	Case: 454v.d3d CONC. (ug/l)	Case: 454v.d2d LOAD (kg/ha)	Case: 454v.d2d CONC. (ug/l)	Case: 454v.d1d LOAD (kg/ha)	Case: 454v.d1d CONC. (ug/l)	Case: 154v.n3 LOAD (kg/ha)	Case: 154v.n3 CONC. (mg/l)	Case: 454v.n2 LOAD (kg/ha)	Case: 454v.n2 CONC. (mg/l)	Case: 454v.n2d LOAD (kg/ha)	Case: 454v.n2d CONC. (mg/l)
1	LDL	LDC	LDL	LDC	LDL	LDC	LDL	LDC	LDL	LDC	LNL	LNC	LNL	LNC	LNL	LNC
2	0.00011	0.013	LDL	LDC	LDL	LDC	LDL	LDC	LDL	LDC	LNL	LNC	0.0060	0.001	LNL	LNC
3	0.01060	0.954	0.00186	0.167	0.00009	0.008	0.00001	0.001	LDL	LDC	0.0327	0.002	1.154	0.104	0.0138	0.001
4	0.03206	3.470	0.01023	1.107	0.00093	0.101	0.00017	0.019	0.00008	0.009	0.9082	0.074	4.395	0.476	0.2432	0.026
5	0.04769	4.319	0.01920	1.739	0.00309	0.280	0.00084	0.076	0.00043	0.039	6.091	0.417	6.592	0.597	1.465	0.133
6	0.05259	4.382	0.02382	1.985	0.00532	0.443	0.00179	0.149	0.00100	0.083	15.55	0.863	6.265	0.522	3.692	0.308
7	0.03643	4.578	0.01561	1.962	0.00371	0.466	0.00139	0.175	0.00082	0.103	9.218	0.963	4.290	0.539	3.393	0.427
8	0.01878	2.927	0.00887	1.383	0.00229	0.356	0.00088	0.138	0.00053	0.082	7.354	0.954	3.434	0.535	3.047	0.475
9	0.01818	1.729	0.00851	0.809	0.00257	0.245	0.00104	0.099	0.00063	0.060	13.02	0.939	5.444	0.518	5.266	0.501
10	0.02827	2.615	0.01066	0.986	0.00274	0.253	0.00110	0.101	0.00066	0.061	15.17	0.897	6.725	0.622	5.592	0.517
11	0.03794	4.146	0.01319	1.442	0.00244	0.267	0.00086	0.094	0.00050	0.054	11.75	1.015	6.970	0.762	4.979	0.544
12	0.03555	3.686	0.01632	1.692	0.00334	0.346	0.00109	0.113	0.00060	0.062	16.36	1.201	5.667	0.588	5.732	0.594
13	0.03108	2.946	0.01403	1.329	0.00378	0.358	0.00141	0.134	0.00081	0.077	15.72	1.096	5.530	0.524	6.562	0.622
14	0.02343	3.222	0.00925	1.271	0.00232	0.319	0.00091	0.125	0.00055	0.075	8.285	0.941	4.282	0.589	4.424	0.608
15	0.02084	2.393	0.00908	1.042	0.00218	0.251	0.00082	0.094	0.00049	0.056	10.40	0.937	5.306	0.610	5.173	0.594
16	0.01660	1.999	0.00704	0.848	0.00189	0.228	0.00072	0.086	0.00042	0.050	9.493	0.974	4.721	0.568	4.897	0.590
17	0.01979	2.277	0.00760	0.875	0.00185	0.213	0.00069	0.080	0.00040	0.047	10.19	0.987	5.465	0.629	5.108	0.588
18	0.03047	2.832	0.01165	1.082	0.00249	0.231	0.00087	0.081	0.00049	0.046	15.87	1.034	7.495	0.697	6.405	0.595
19	0.03193	3.200	0.01256	1.259	0.00266	0.267	0.00090	0.091	0.00050	0.050	14.93	1.163	6.467	0.648	6.211	0.623
20	0.05018	3.846	0.02080	1.595	0.00444	0.341	0.00152	0.116	0.00084	0.065	23.91	1.232	7.723	0.592	8.363	0.641
21	0.05100	4.999	0.02145	2.102	0.00482	0.472	0.00171	0.168	0.00098	0.096	17.01	1.123	6.067	0.594	6.459	0.633
22	0.08450	6.273	0.03788	2.812	0.00832	0.617	0.00299	0.222	0.00174	0.129	18.12	1.076	7.379	0.548	8.256	0.613
23	0.07469	6.310	0.03648	3.083	0.00931	0.787	0.00352	0.297	0.00207	0.175	15.90	0.957	5.758	0.487	6.957	0.588
24	0.05676	5.863	0.02871	2.966	0.00786	0.812	0.00320	0.331	0.00196	0.203	10.74	0.815	4.438	0.459	5.325	0.550
25	0.02510	3.382	0.01229	1.656	0.00382	0.515	0.00164	0.221	0.00103	0.139	7.242	0.773	3.268	0.440	3.847	0.518
26	0.02798	2.932	0.01330	1.393	0.00399	0.418	0.00171	0.179	0.00108	0.113	9.567	0.757	4.455	0.467	4.729	0.496
27	0.02542	2.625	0.01039	1.073	0.00295	0.304	0.00125	0.129	0.00078	0.080	8.995	0.759	5.358	0.553	4.638	0.479
28	0.02181	2.852	0.00832	1.088	0.00193	0.253	0.00074	0.097	0.00045	0.059	7.497	0.823	5.014	0.656	3.723	0.487
29	0.04494	3.417	0.01840	1.400	0.00413	0.314	0.00146	0.111	0.00084	0.064	17.12	0.971	8.024	0.610	6.917	0.526
30	0.04463	4.680	0.01762	1.848	0.00378	0.396	0.00134	0.140	0.00076	0.080	13.30	1.076	6.201	0.650	5.437	0.570
31	0.04035	4.999	0.01691	2.095	0.00353	0.438	0.00123	0.152	0.00069	0.085	11.75	1.144	4.764	0.590	4.805	0.595
32	0.02062	2.759	0.00996	1.334	0.00262	0.351	0.00096	0.129	0.00055	0.073	10.50	1.150	3.699	0.495	4.520	0.605
33	0.01818	1.841	0.00840	0.850	0.00252	0.255	0.00101	0.102	0.00060	0.060	13.96	1.060	5.216	0.528	5.832	0.591
34	0.02088	2.308	0.00837	0.926	0.00225	0.249	0.00091	0.100	0.00054	0.060	11.40	0.984	5.620	0.621	5.168	0.571
35	0.04481	3.666	0.01620	1.325	0.00311	0.254	0.00112	0.091	0.00065	0.053	17.75	1.056	9.004	0.737	7.037	0.576
36	0.04605	4.221	0.02010	1.843	0.00401	0.368	0.00133	0.122	0.00074	0.068	16.02	1.222	6.386	0.585	6.749	0.619
37	0.09297	6.181	0.04176	2.776	0.00938	0.624	0.00337	0.224	0.00195	0.130	23.45	1.137	8.166	0.543	9.509	0.632

NOTE: LDL = less than 0.00001 kg/ha; LDC = less than 0.001 μg/l; LNL = less than 0.0001 kg/ha; LNC = less than 0.001 mg/kg.



Note: See Table 32, Appendix F for explanation of simulation case identification

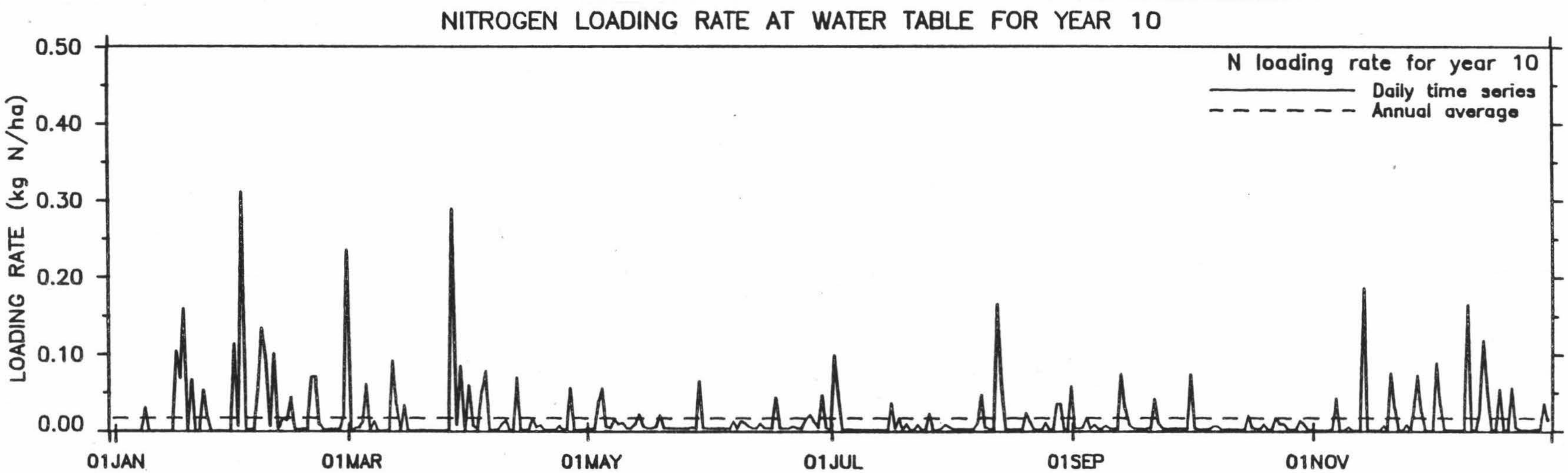
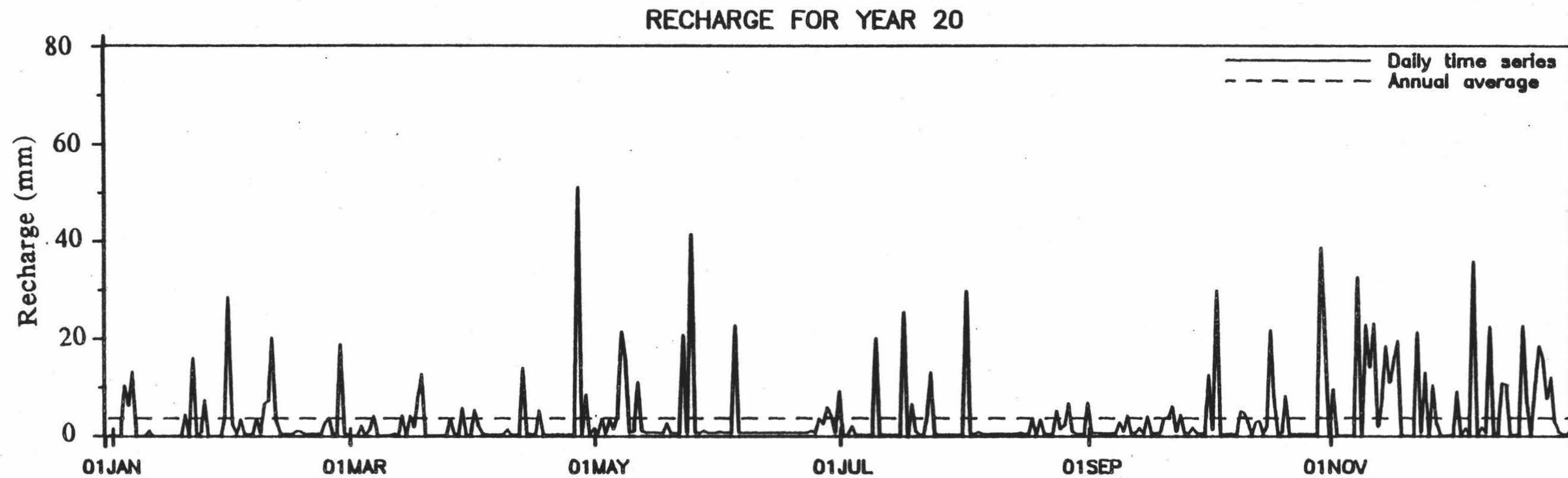


Figure 42. Daily time series vs. annual mean for long-term PRZM simulation, (a) Year 10, case 454.n2



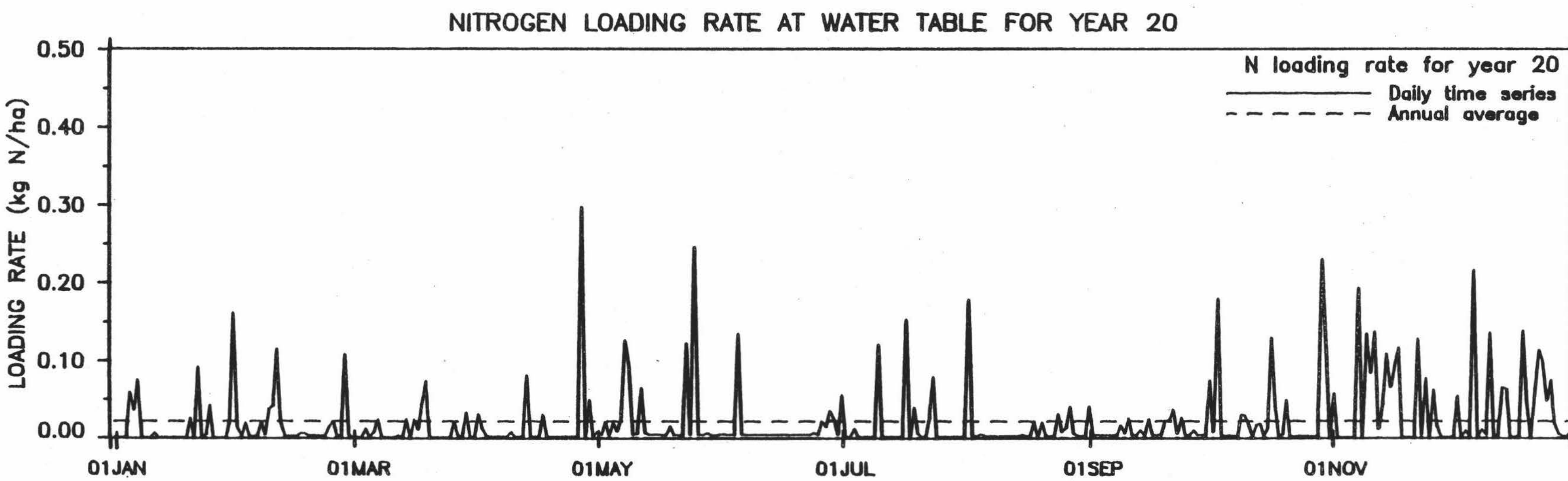


Figure 42. (Continued) Daily time series vs. annual mean for long-term PRZM simulation, (b) Year 20, case 454.n2

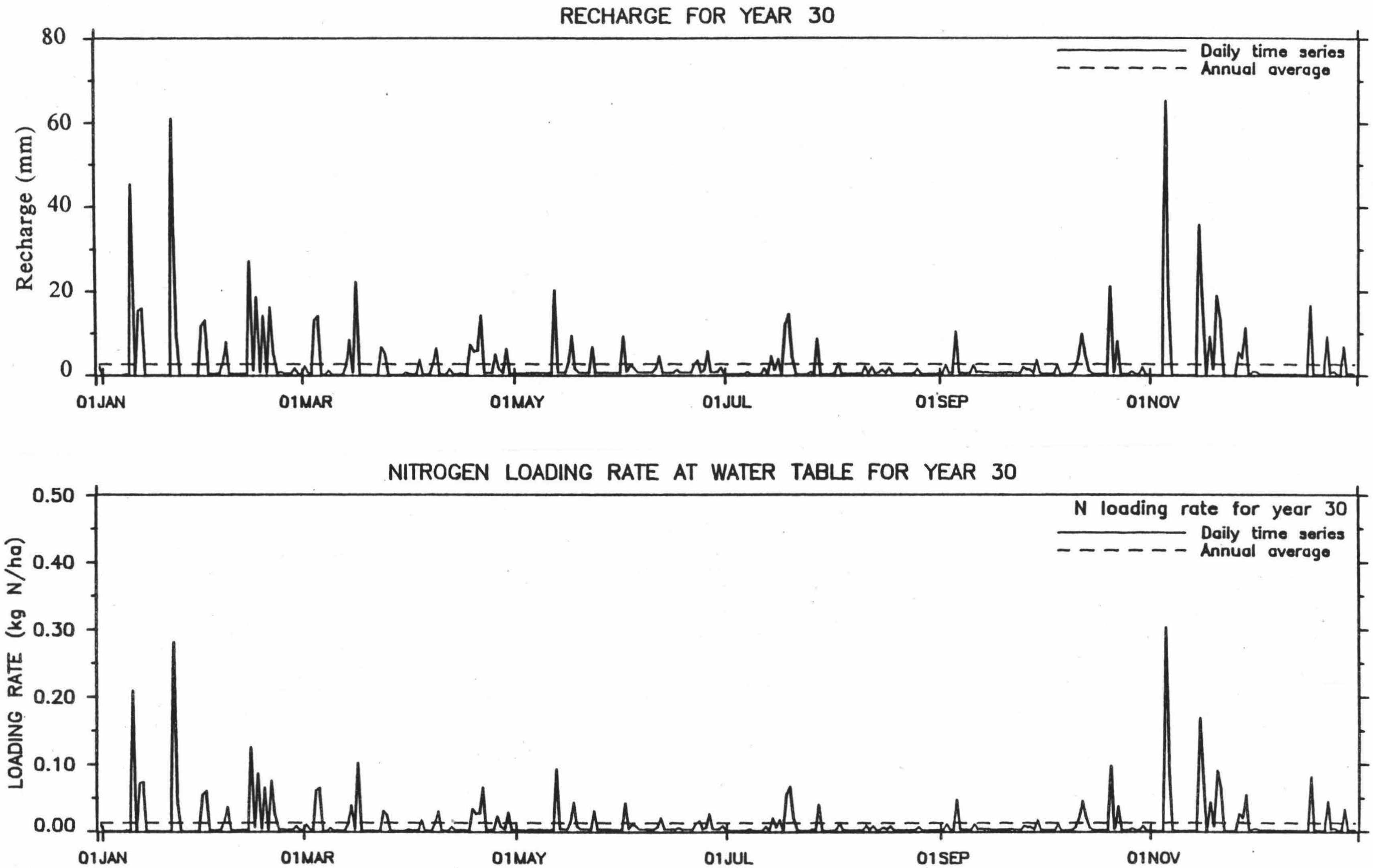


Figure 42. (Continued) Daily time series vs. annual mean for long-term PRZM simulation, (c) Year 30, case 454.n2

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