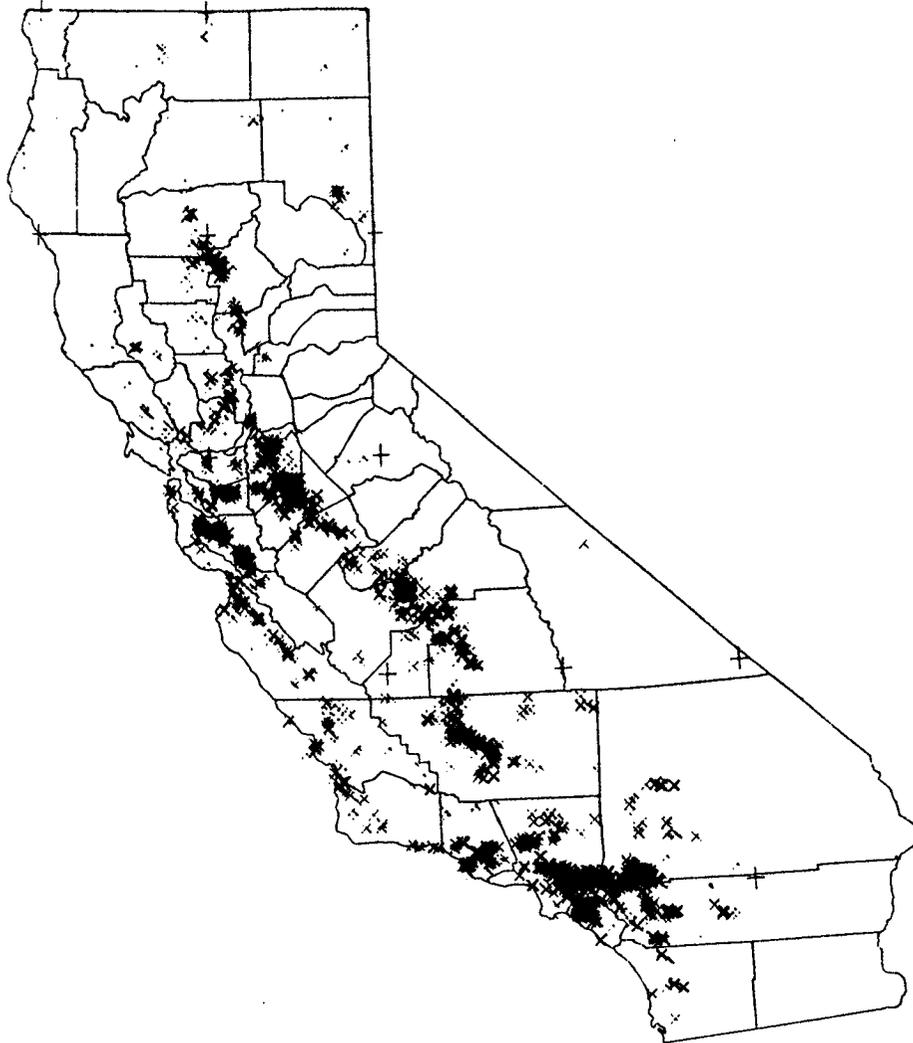


# NITRATE AND AGRICULTURE IN CALIFORNIA



Nitrate Working Group  
California Department of Food and Agriculture

NITRATE AND CALIFORNIA AGRICULTURE

NITRATE WORKING GROUP  
CALIFORNIA DEPARTMENT OF FOOD AND AGRICULTURE  
FEBRUARY, 1989

This report is transmitted by the Nitrate Working Group to Jack C. Parnell, Director of Food and Agriculture for your review and consideration. We appreciate the opportunity to address this subject and provide recommendations for the mutual benefit of water quality and California agriculture.

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## EXECUTIVE SUMMARY

Ground water monitoring has shown an increase in nitrate levels during the past several decades. This increase in nitrate can be attributed to the increase in both the population and food production. In order to produce more food, greater amounts of nitrogen fertilizer are used and livestock is raised in more concentrated operations. Greater numbers of people mean more sewage and industrial sources of nitrate.

The greater use of nitrogen fertilizer and concentrated livestock production has increased the amount of mineral and organic nitrogen in the environment. The potential for nitrate to reach the ground water is expanded due to the increase in nitrogen in the environment.

The health effects of nitrate in drinking water are subject to controversy. The ingestion of nitrate by infants has been documented to cause methemoglobinemia (blue baby syndrome). The direct linkage between nitrate in drinking water and cancer or birth defects is inconclusive. The California maximum contaminant level (MCL) for nitrate in drinking water is 45 milligrams per liter (mg/L). Levels of nitrate in ground water which exceed 45 mg/L reduce the available supplies of drinking water and impose significant costs to modify the nitrate levels to reach the standard.

The levels of nitrate in ground water in California are reviewed in this report. Several regions of the state have significantly high levels of nitrate in ground water. These levels demonstrate the need to establish immediate and effective programs for the reduction of nitrate.

There are three major sources of nitrate found in ground water; leaching from crop production, urban sewage, and concentrated animal waste.

This report addresses nitrate controls for crop and livestock production. Nitrate reaching ground water is highly variable, and depends on a range of factors including soil type, crop, irrigation, manure and fertilizer management, climatic and hydrologic conditions.

Because of the diversity and complexity of nitrate contributed by agricultural sources, no one simple solution to the problem is feasible. This report outlines various management alternatives for fertilizer application, manure handling and irrigation.

This report recommends that the Department of Food and Agriculture facilitate the following activities:

1. Identify nitrate sensitive areas throughout the state.
2. Establish a list of priority areas in which nitrate control programs should be implemented.
3. In cooperation with local government and agriculture, establish nitrate management programs in priority areas.
4. Develop best management practices to be incorporated into local nitrate management programs.
5. Establish a research and demonstration project on nitrate control through irrigation, fertilizer and manure management.

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## Introduction

In March 1988, the Director of Food and Agriculture appointed a twelve member working group to address the contribution of nitrate into ground water from agricultural operations. The group was made up of individuals from agribusiness, State government and the University of California.

The purpose of the Nitrate Working Group was as follows:

- A. To develop an overview of the issue of nitrate in ground water and to examine how various agricultural operations may contribute nitrate to ground water.
- B. To develop appropriate guidelines for the reduction of nitrate in ground water resulting from agricultural operations. The guidelines should take into account both economic and environmental considerations.
- C. To inform the agricultural industry and policy makers about the nitrate issue and of ways to reduce the potential of introducing nitrate into ground water.

Much has been written on the subject of nitrate in ground water. This report is not intended to be another discussion on the subject of nitrate, but as a vehicle to initiate change in how this issue is addressed by agriculture, government, and the general public.

It is the intent of the Nitrate Working Group that this report will bring the issue into the proper perspective and provide practical information on what steps can be taken by farming operations to reduce the contribution of nitrate into ground water.

There are no simple means of reducing the nitrate contribution to ground water. Crop selection, soil types, climatic conditions, irrigation and fertilizer management must all be taken into consideration. Any plans to control nitrate contamination from agricultural operations must be developed on a case by case basis.

With our present knowledge, one of the best ways to control nitrate is through on-farm management programs. This report emphasizes the development of best management practices and product use guidelines for agriculture.

While this report focuses on visible agricultural practices such as fertilizer application and animal husbandry, it should be noted that nitrate in ground water comes from many different sources. Industrial operations, septic systems, and municipal waste treatment facilities and landfills are examples of significant nonfarm sources of nitrate.

During the past decade, California has made great strides in the mitigation of point source contamination of ground water. Many potential sources of nitrate contribution have been modified to prevent intrusion into the ground water.

A problem in determining the extent of agriculture's contribution of nitrate in ground water is the difficulty in identifying the specific sources of nitrate. Nitrate is very persistent and it is difficult to determine if the nitrate is from current or past operations or from natural or man-made sources in the area. Finally, it is difficult to quantify the level of nitrate contribution from a single source because there may be a myriad of potential sources of contribution above an aquifer.

While this report provides a comprehensive perspective of the nitrate issue as it relates to agriculture, it is not intended to be an academic document. It hopefully will provide a foundation by which agriculture, policy makers and the academic community can work together to effectively control the amount of nitrate in ground water which result from agricultural operations.

## CHAPTER 1: AN OVERVIEW OF NITROGEN AND NITRATE

### 1A: THE NITROGEN CYCLE

The nitrogen cycle (figure 1) describes the flow of the various forms of nitrogen between four major reservoirs in the environment. The major nitrogen reservoirs are the atmosphere, the ocean, terrestrial soils, and underlying geology.

The atmosphere consists primarily of nitrogen and oxygen gases and, as such, is a reservoir of di-nitrogen gas. Other forms of nitrogen also exist in the atmosphere in smaller amounts.

The ocean contains all forms of nitrogen; dissolved nitrogen salts, dissolved gases, and organic matter. Of these, dissolved nitrogen gas ( $N_2$ ) is the most prevalent. The nitrate ( $NO_3$ ) and ammonium ions ( $NH_4^+$ ) are present in substantial amounts. Dissolved and particulate organic matter are present to a lesser degree.

Soils contain all forms of nitrogen. Humus is the most prevalent form of organic nitrogen, followed by living tissues of plants, microbes, and animals. The dissolved ions (primarily nitrate and exchangeable ammonium) in soil are highly transient and difficult to accurately estimate. Generally, such forms of nitrogen constitute less than 2% of the total nitrogen in soils.

Geologic reserves of nitrogen consist primarily of igneous and sedimentary rock, and coal. These reserves are largely inert, and contribute only minor amounts of nitrogen to the annual nitrogen cycle.

Nitrate ( $NO_3$ ) is the name given to both the solid and dissolved compounds of nitrogen and oxygen where the nitrogen atom is in the plus 5 valence state. Nitrate is highly soluble and stable in most aqueous

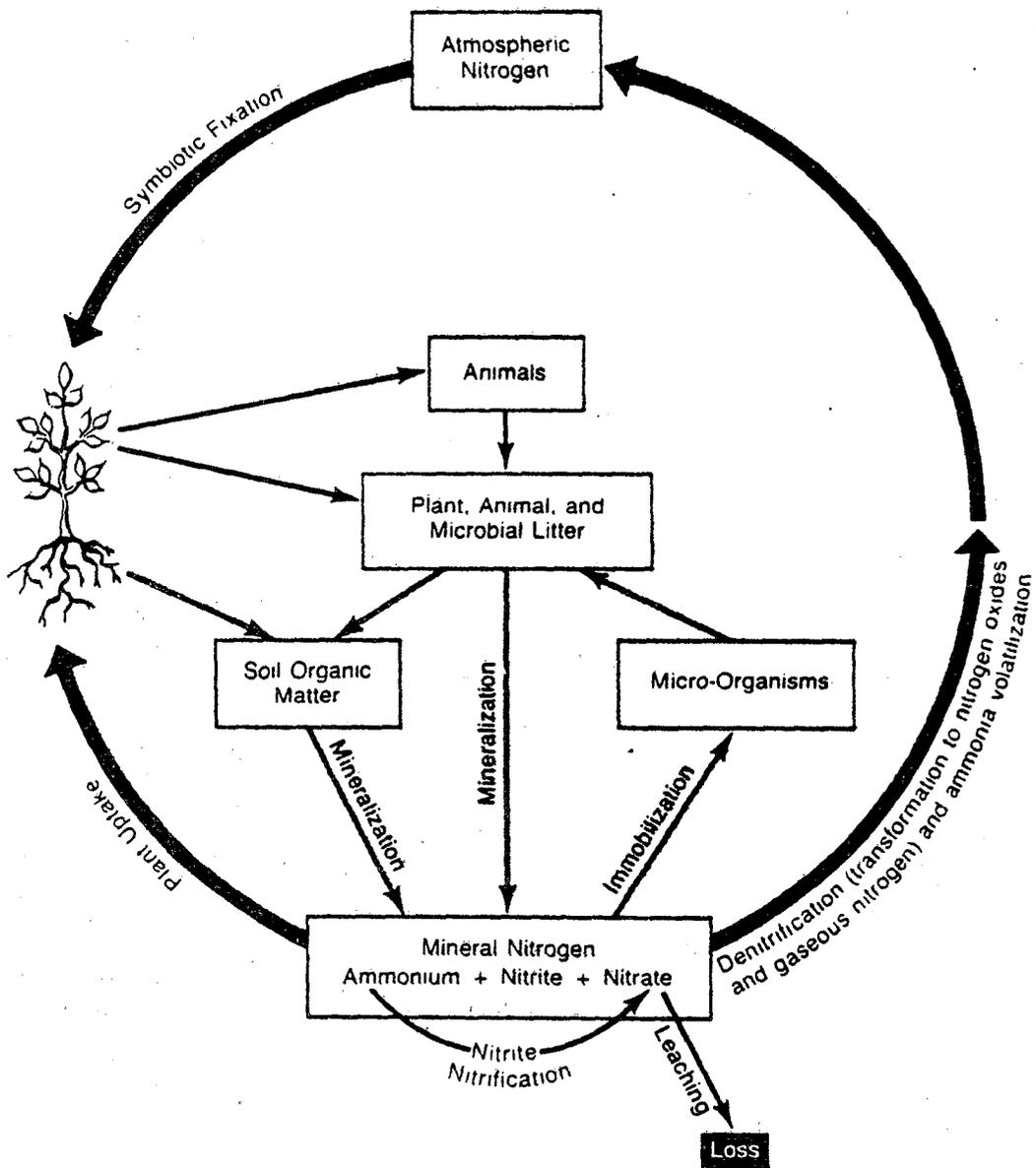


Figure 1.  
The nitrogen cycle. (Adapted from Reeder and Sabey 1987.)

environments. Globally, nitrogen in water resources represents only a small amount of the nitrogen in transit through the nitrogen cycle.

A number of processes are considered sources of nitrate because they access the four reservoirs to convert nitrogen into nitrate. Natural sources of fixed nitrogen are biological nitrogen fixation and lightning. The other important sources result from man's activities, including application of fertilizers, waste disposal, wood burning and fossil fuel combustion, industrial processing of nitrogen (e.g., into manufactured products), nitrogen released by domestic animals and man, and nitrogen fixation induced by agriculture and natural vegetation.

Bacteria play a primary role in the generation of "Fixed Nitrogen". "Fixed Nitrogen" refers to all compounds of nitrogen, except di-nitrogen gas itself. These are essential to all living things in small concentrations, but may be life-threatening in large concentrations.

The transformation processes that directly involve the nitrate ion are nitrification, assimilation, and denitrification. Nitrification is the formation of nitrate from ammonia accomplished by specialized bacteria in an oxygen rich environment. Assimilation is the incorporation of nitrate into organic nitrogen by plants and animals. Denitrification is the conversion of nitrate into di-nitrogen gas ( $N_2$ ) and oxides of nitrogen ( $NO_x$ ).

Although natural processes are the largest source of nitrate in the environment, man's activities will exceed the natural production of nitrate. These activities include promotion of the natural process of nitrogen fixation (e.g., growing legumes), application of fertilizers, consumption of products that contain fixed nitrogen (e.g., food), and energy use (e.g., electricity generation).

## **1B: THE MEASURE OF NITRATE IN WATER**

Nitrogen is present in ground water almost entirely as the nitrate ion, but minor amounts of nitrite or ammonium may be present. A dual and often confusing system of reporting the nitrogen content in water is used and care must be exercised to insure a proper understanding of the laboratory analyses.

Nitrate can be expressed (1) on the basis of ionic weight per unit of volume or (2) as the weight of the nitrogen content. The former case yields a result nearly 4.4 times higher than the latter for the same quantity of nitrate. Therefore, the California drinking water standard or maximum contaminant level (MCL) of 45 mg/L of nitrate ( $\text{NO}_3$ ) is nearly the equivalent of the EPA Safe Drinking Water Act Interim Health Standard of 10 mg/L for nitrate as nitrogen ( $\text{NO}_3\text{-N}$ ). Frequently, results are reported in both values in the same text and may be confused unless they are clarified as nitrate or as nitrate-nitrogen. In this report, nitrate will be expressed in terms of the maximum contaminant level of the California Drinking Water Standard or 45 mg/L.

## **1C: SOURCES OF NITROGEN AND NITRATES**

The primary source of nitrogen is the earth's atmosphere, which is about 78 weight percent di-nitrogen ( $\text{N}_2$ ) gas. Most fixed or non-gaseous nitrogen accumulated in the soil is a result of atmospheric nitrogen that has been chemically or biologically converted into mineral salts or living or non-living organic matter. There is an additional fraction that is contained in the various mineral constituents of the earth's crust.

The major repository of mineral and organic nitrogen, which is of concern from an environmental standpoint, is that part of the earth between the surface and the saturated zones which make up the ground water reservoir, as well as the reservoir itself.

Ultimately, all of that nitrogen has the potential to be transformed into nitrate which is soluble and moves with water through the soil profile. The transformations which take place in the soil environment are biologically controlled, and include the conversion of atmospheric  $N_2$  into the organic pool, the conversion to inorganic forms such as  $NH_3$ ,  $NH_4^+$ ,  $NO_2^+$ ,  $NO_3^-$  and others, and the release of gaseous forms such as and  $NH_3$ .

In most ecosystems, including those of intensive agriculture, most of the nitrogen moves between the organic and mineral fractions, and the atmosphere. There is also the potential for movement below the biologically active zone of the soil, which can result in the buildup of nitrates. This occurs both in natural undisturbed sites and where man's activities have influenced below-ground systems.

#### **Urban Growth**

The rapid and continuing expansion of California's population has created substantial human waste disposal problems. The population centers of Southern California, the San Francisco Bay area, and the interior and coastal valleys all share in the problem of increasing nitrate in the ground water. High or increasing nitrate levels can also be found at or near most of the semi-rural areas where population increases have taken place. The areas around Redding, Chico, Modesto, Visalia, Salinas, and Santa Maria are relevant examples. Many of these draw some or all of their municipal water supplies from underground sources.

The sources of nitrate contributed by urban areas include waste from sewage and food processing, industrial wastes, both fixed and mobile combustion of fossil fuels which produce oxides of nitrogen ( $\text{NO}_x$ ), and the application of nitrogen-containing fertilizers to landscape, garden, and recreation facilities.

### **Agriculture**

The nitrate contributions of the various agricultural components fall into two broad categories: point sources, and non-point contributors.

Point sources may include fertilizer manufacturing and storage, livestock, dairy, poultry, and swine operations which represent both historical and current contributors to ground water nitrates. The main factors associated with animal operations include both the storage of silage and the storage and disposal of animal wastes.

Fertilizer manufacturers and distributors have historically been sources of potential nitrate contamination. Environmental compliance regulations administered by various federal and state agencies have reduced these as current contributors. The primary sources from those facilities were synthetic nitrogen materials, including various ammonium and nitrate salts and urea. Essentially, any nitrogen source can be converted to nitrate once in the soil and, therefore, can be a potential contributor of nitrate to ground water. Currently, both manufacturers and distributors operate under permits which prohibit the discharge of nitrogen-containing materials where ground water contamination might occur.

The most significant non-point sources include farming operations where animal manure or nitrogen-containing fertilizers are applied. Fertilizer applications, when associated with porous soils and excessive application

of irrigation water or in areas with shallow water tables, have contributed to the increase in ground water nitrates. Additionally, areas within the state which are vulnerable are those where multiple plantings of high nitrogen-requiring, low use-efficiency vegetable and truck crops are grown. The high nitrogen requirement and the production of up to three crops per year make the total nitrogen applied several times the normal application rate for most other systems.

The size and distribution of the population within the state, along with the traditional co-mingling of agriculture and urbanization, often make a determination of the various contributors of nitrate very difficult.

#### **ID: PUBLIC HEALTH CONCERNS OF NITRATE**

The public health concerns of nitrate in drinking water are subject to controversy, not only regarding the maximum safety limits, but whether or not nitrate is harmful at all. While nitrate in itself may be relatively harmless in small quantities, nitrite, which may be formed in the stomach from the ingestion of nitrate, appears to cause various harmful effects.

The public health standards established for nitrate in drinking water in 1962 were based on the suggested relationship between high nitrate in drinking water and infant methemoglobinemia (the blue baby syndrome). No cases of this disease have been reported in the United States when the water contained less than 45 mg/L nitrate. Some reported incidents have occurred when the nitrate content has been as low as 50 mg/L. The references dealing with this subject are voluminous and will not be discussed here.

In a simplified form, the blue baby syndrome is caused by the conversion of nitrate to nitrite in the stomach of the infant which has not yet developed

a normal level of acidity (or the direct ingestion of nitrite), and the subsequent reaction of the nitrite with hemoglobin in the blood to form methemoglobin which has a reduced capacity to carry oxygen. It is the importance of other factors involved in these conversions which leads many to believe that the role of nitrate alone is relatively innocuous and is the subject of controversy.

It is generally believed that levels of nitrate above 45 mg/L in drinking water may cause infant methemoglobinemia with potentially fatal results. The most recent evaluations have held that the 45mg/L standard protects against this hazard and should not be altered.

Two other health hazards which have been loosely related to high nitrate water are cancer and birth defects. The direct relationship between these hazards and nitrate is inconclusive. Of concern in these studies is the interaction of nitrite (a reduction product of nitrate) with secondary amines present in the stomach to form N-nitrosoamines. Almost all N-nitroso compounds tested in animals have been shown to be carcinogenic, but there is no direct evidence implicating them as human carcinogens.

Investigations with inconclusive results have been performed in Europe, the mid-western U.S., and in Asia on the possible relationship between areas where high nitrate drinking water is present and the prevailing cancer rates. The difficulty in establishing any relationship stems from the lengthy induction period of most cancers and the relatively low exposure levels of nitrate in drinking water.

While there are no definitive answers to the effects of nitrate in drinking water, there is a widespread public interest in the problem. Because of

the potential public health concern, a surge of interest has been generated by state, federal, and worldwide organizations which may result in answers to some of the outstanding questions.

#### **IE: ECONOMIC EFFECTS OF NITRATE**

The economic effects of high levels of nitrate in drinking water within California have not been comprehensively studied. The tangible costs are easily recognized. These include the costs of well relocation or deepening, wellhead treatment to remove nitrogen, and imported water costs for blending or replacement. Less tangible costs include land use restrictions, denial of loans for lack of a suitable water supply, and a reduced tax base.

When the nitrate level in a public water supply reaches or exceeds the state standard, positive steps must be taken to reduce the nitrate to an acceptable level. This may be done by blending with water from another source, deepening the well if lower nitrate levels are to be found at greater depths, or replacing the well with a new one where nitrate levels are acceptable. The decision may be to close the well or to remove the nitrate through wellhead treatment. Deeper wells and special surface seals are being required by county regulatory agencies where nitrate is a threat.

All of the above are expensive and the costs are subsequently passed on to the public. For example, wellhead treatment processes for nitrate removal have been estimated by the Orange County Water District to cost about \$375 per million gallons. Many millions of dollars a year are also spent to accomplish other methods of nitrate remedial measures. The total funding requested from the Department of Health Services in 1986 by small and large public water systems for remedial measures because of nitrate violations

was \$48.7 million. The total funds expended because of nitrate problems is substantially larger than this because many water systems resolve their own problems and do not apply for funding.

The less tangible costs, generally associated with land use restrictions are not easily determined. Septic tank prohibitions generally involve sewage treatment plant and sewer line construction costs.

## **CHAPTER TWO: NITRATE IN GROUND WATER IN CALIFORNIA**

### **2A: THE STORET DATA BASE**

Nitrate information in the STORET data base was used to prepare maps of the occurrence of nitrate problems in California. Figures 2 and 3 are these maps. Figure 2 illustrates well locations where the nitrate level has been recorded at or above the State Maximum Contaminant Level of 45 mg/L nitrate between 1975 and 1987. Figure 3 illustrates well locations where nitrate has been recorded between 20 and 44 mg/L between 1975 and 1987. Figure 3 identifies those areas which exceed natural background levels of nitrate and are approaching the State Maximum Contaminant Level.

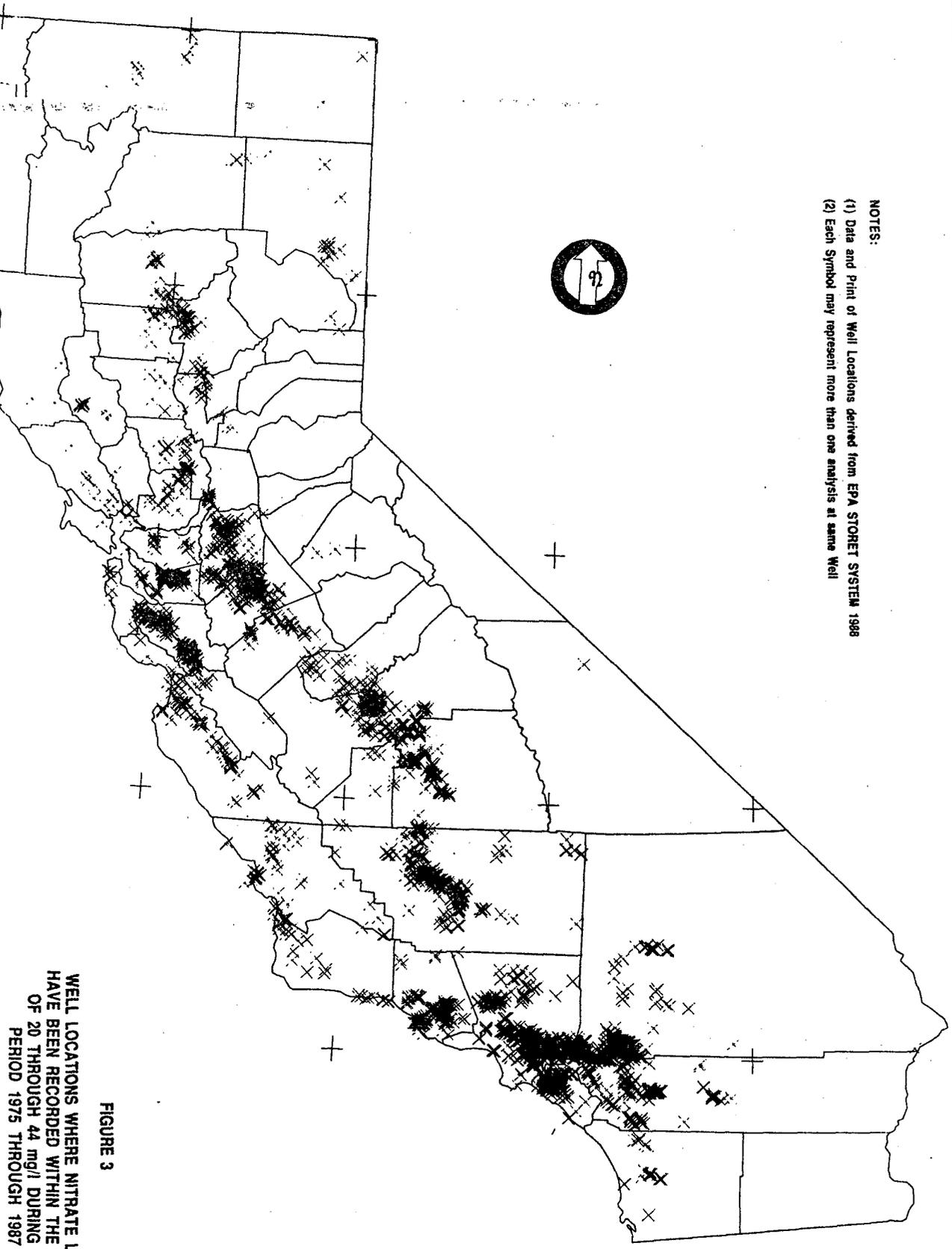
In compiling the information on nitrate problem areas discussed below, it was found that the STORET data base does not contain information on all nitrate problems that exist in California. Therefore, Figures 2 and 3 must be regarded as illustrative, but not comprehensive or complete.

The following information on the extent of ground water contamination by nitrate in California has been compiled by the State Water Resources Control Board. The sources of information include federal, state, and local government agency records, water purveyor records, academic investigations, research efforts and texts, and various other reputable published and unpublished material.

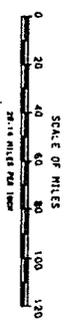
### **2B: THE SOUTHERN CALIFORNIA COASTAL AREA**

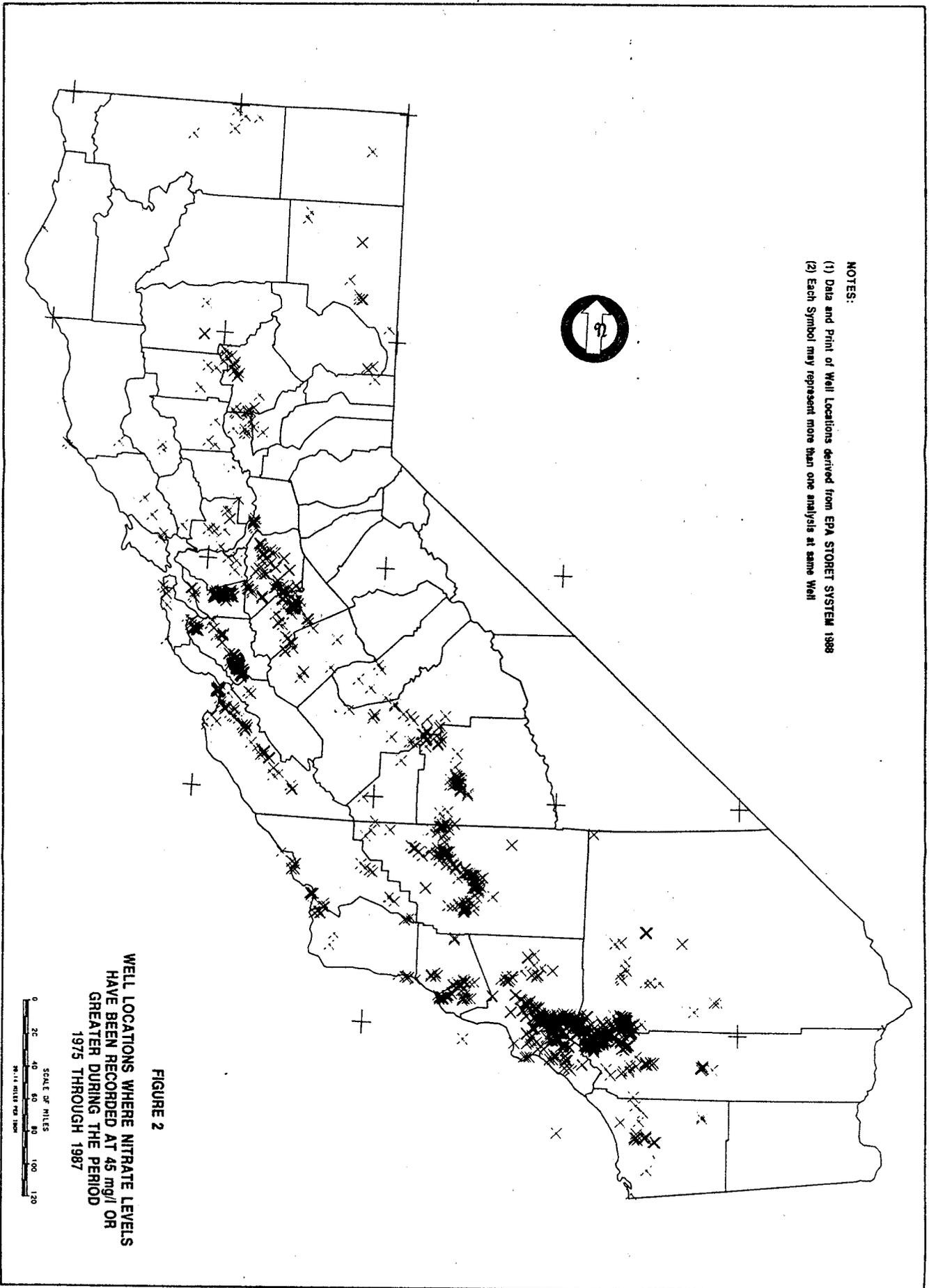
The south coastal area, including all or parts of the counties of Ventura, Los Angeles, Orange, San Diego, San Bernardino, and Riverside, uses imported water provided by the City of Los Angeles and the Metropolitan Water District of Southern California (MWD). A report published by MWD shows that at least 344 wells, or about 12% of the wells sampled in its

NOTES:  
 (1) Data and Print of Well Locations derived from EPA STORET SYSTEM 1988  
 (2) Each Symbol may represent more than one analysis at same Well



**FIGURE 3**  
 WELL LOCATIONS WHERE NITRATE LEVELS  
 HAVE BEEN RECORDED WITHIN THE RANGE  
 OF 20 THROUGH 44 mg/l DURING THE  
 PERIOD 1975 THROUGH 1987





service area, exceed the State MCL for nitrate and are no longer used as a source of drinking water. The loss of ground water production for domestic use from increased total dissolved solids and nitrates is about 43,000 acre-feet/year, or about 4% of the annual production of this area. In contrast, organic chemical contamination has reduced the ground water production in the area about 0.5% to date.

In Orange County the nitrate problem was recognized early and action has been initiated by the Orange County Water District. Nitrate concentrations exceeding 45 mg/L affect about 250,000 acre-feet of ground water underlying about 22 square miles. The high nitrate ground water is found primarily in shallow aquifers in Westminster, Garden Grove, Fullerton, Anaheim, and Irvine. Recent data show that 51 municipal wells have been closed because of nitrates and 13 wells produce water that must be blended to reduce nitrate levels.

The suspected sources of the high nitrate waters in Orange County are human activities such as sewage leachfields, industrial operations, dairies, landscaping, and agricultural operations. In addition, the Santa Ana River carries an increasing nitrogen load into Orange County from the upper Santa Ana Basin.

The Upper Santa Ana River watershed is located in the southwest corner of San Bernardino County, in western Riverside County, and the very eastern part of Los Angeles County. The areas of San Bernardino, Redlands, Highlands, East Highlands, Loma Linda, and adjacent to the Santa Ana River have nitrate in ground water exceeding the State MCL. Studies by the U.S. Geological Survey (USGS) and others have implied that past agricultural practices and sewage treatment facilities are primarily responsible for the elevated levels.

The Los Angeles area contains 108 municipal wells exceeding the State MCL for nitrate. The causes of this poor quality ground water are believed to be past septic system practices and a history of agricultural activities.

San Diego County has probably noticed the effects of nitrate contamination least because of its strong dependence on imported surface water supplies. However, nitrate degradation of ground water is occurring. Three areas have experienced nitrate contamination to such a degree that new water well ordinances recently enacted are functioning as potential prohibitions for building permits.

Several areas in Ventura County have experienced elevated nitrate problems. The Santa Rosa area must limit ground water extraction for drinking water purposes because of high nitrate and total dissolved solids. In the vicinity of Oxnard, both the upper and lower aquifer have experienced elevated nitrate levels.

#### **2C: THE SAN JOAQUIN VALLEY**

The San Joaquin Valley is the southern part of the Great Central Valley of California and includes all or part of San Joaquin, Stanislaus, Merced, Madera, Fresno, Kings, Tulare and Kern counties. In general, the Valley has two major ground water units; a deeper confined system in the central and western portion and a shallow, generally unconfined system that extends the entire length of the valley.

The problems in San Joaquin County appear to be concentrated in Lodi, Manteca, Ripon, Escalon and Tracy. The County Environmental Health Department has set restrictions on well construction in Tracy and Manteca. The cause of the elevated nitrate levels have not been conclusively determined, but it is suspected to be fertilizer and animal waste.

Twenty five small water systems and four large water systems in Stanislaus County requested financial aid from Department of Health Services in 1987 to remedy nitrate problems. On the west side of the Valley nitrate exceeding the State MCL has been recorded near Westley and Crows Landing. It is believed that most of these occurrences are the result of agricultural activities in soils with high water tables.

In Merced County existing problems appear to be most pronounced along Highway 99. Atwater, Winton, Livingston, Delhi, and Hilmar have all been affected by nitrates. A study of the Hilmar area currently being conducted by the Regional Water Quality Control Board has shown that within an approximately 36 square mile area, about 60% of the wells sampled (69) exceed the State MCL. These high nitrate levels are believed to be caused primarily by dairy waste leachate and fertilizers.

On the western side of Merced County, nitrate exceeding the State MCL from undetermined sources has been found in ground water from Newman to Gustine, around Los Banos, and near South Dos Palos.

There appear to be fewer nitrate problems in Madera County than in neighboring counties. Four areas which have nitrate levels well above background levels in ground water are Chowchilla, Dairyland, Berenda, and along the border of the San Joaquin River near Ripperdan.

Ground water nitrate values above the State MCL have been recognized in Fresno County for many years. Past studies of the Fresno-Clovis area show that elevated nitrate levels are present throughout the city area and to the west. These studies have independently targeted septic tanks, winery wastes, fertilizer use, and urban runoff wells as nitrate sources.

Areas in eastern Fresno County where nitrate exceeds the State MCL also include Raisin City, Caruthers, Laton, Kingsburg, Reedley and Orange Cove. The most probable sources of these occurrences are agricultural activities.

Areas in Fresno County on the west side of the valley where nitrate is above the State MCL include Mendota, Firebaugh, Kerman, Cantua Creek, and Coalinga. Agricultural activities are considered a source of these problems although there are deposits of naturally occurring high nitrate soils along the western edge of the Valley in Fresno County that also contribute.

Current data show Kings County to be relatively free of high nitrate concentrations with the exception of historic isolated occurrences around the Hanford and Lemoore areas and in Avenal on the west side of the Kettleman Hills.

Along the eastern border of the San Joaquin Valley in Tulare County is a discontinuous belt of high nitrate ground water which extends from Reedley in Fresno County southward through Tulare County past Delano, McFarland and Bakersfield in Kern County. This ill-defined belt appears to be associated with fruit orchards, citrus, and other agricultural crops in Tulare County and a zone of loose, permeable, sandy soils. Ten of the thirty-three small public water systems which have been in violation of the nitrate drinking water standard and which are within the general boundaries of this zone, have applied to Department of Health Services for financial aid in renovating their systems to address nitrate problems.

Areas which have been affected include Dinuba, Yettam, Lemon Cove, Woodlake, Lindsay, Strathmore, Porterville, Ducor, and Richgrove. Other isolated areas of high nitrate in Tulare County have occurred near Traver, Goshen, Visalia, and Tulare.

The continuation of the discontinuous belt of high nitrate waters as described in Tulare County continues through Kern County. High nitrate ground water, some of which is more than twice as high as the State MCL, is found near Delano, McFarland, Wasco, Shafter, Famosa, Rosedale, Bakersfield, Arvin, Edison, Lamont, and along the southern border of the Kern Lake bed. Very high levels have also been found along the western border of the Buena Vista lake bed near Maricopa and Taft and northwest of Lost Hills.

Thirty-four small public water systems in Kern County have exceeded the state drinking water standard at one time or another, of which 19 presently continue to exceed the standard. Fourteen small water systems and two large water systems in Kern County applied to the Department of Health Services in 1987 for financial assistance to remedy their nitrate problems.

In a 1982 ground water quality study performed by the Kern County Water Agency (KCWA) and the Kern County Health Department, it was shown that the areas of greatest nitrate concentration in the unconfined ground waters were found to be in the sandy soils along the east side of the basin where agricultural development began many years ago. Areas where nitrate levels approach or exceed the State MCL increased in size from an estimated 49 square miles in 1958 to 372 square miles in 1979.

Nitrate problems in Kern County are also found in the confined aquifer system near the eastern edge of the confining clay layer where intercommunication of the upper and lower ground water bodies is most apt to occur. In 1979, ground waters in the confined aquifer underlying a 45 square mile area were approaching or had already exceeded the state standard for nitrate.

## **2D: THE SACRAMENTO VALLEY**

This area consists of all or part of the following counties: Tehama, Butte, Glenn, Lake, Colusa, Sutter, Yolo, and Sacramento. U.S. Geological Survey studies (1984) of about 700 wells in this area, concluded that nearly one-third of the wells in the Sacramento Valley are undergoing significant increases in nitrate concentrations. Data suggests the following most probable sources: 1) surface contamination in shallow wells; 2) pollution from septic systems; and 3) leaching of fertilizers applied to croplands, particularly orchard areas.

Nitrate concentrations exceeding the drinking water MCL have severely impacted Chico and the city of Sutter, and less severely impacted Knights Landing, Arbuckle, Yuba City, Gridley, Red Bluff, and Corning.

In Sutter County, about 20 small public water well systems had nitrate levels over the State standard in 1986. Some of these wells were shallow, while others were as deep as deemed safe, since deeper wells in parts of this county may encounter arsenic and other problems. A limited sampling of private wells in use in Sutter County by the County Environmental Health Department indicated that about 75% of the sample group were over the State MCL.

In Tehama County, nitrate exceeding the State standard has been found in the Red Bluff suburbs on the east bank of the Sacramento River. The critical problem area is not extensive at this time.

## **2E: THE CENTRAL COAST**

The Central Coastal Area is defined as the counties of Santa Cruz, San Benito, Monterey, San Luis Obispo, and Santa Barbara. Several problem areas exist.

A study of the Pajaro Valley in Santa Cruz County shows that a significant amount of the valley contains ground water in which nitrate exceeds the State MCL. It has been suggested that excessive fertilization in sandy soils and improper well construction may be responsible for the largest part of this ground water degradation. The County Environmental Health Department has indicated that ground water from about one in four wells in this area exceeds the State MCL for nitrate. Other areas in Santa Cruz County which have experienced elevated nitrate levels are the San Lorenzo Valley, an area in mid-county served by the Central Water District, and Scotts Valley. These areas are most probably experiencing high nitrate levels from septic tank waste disposal systems.

The Salinas River Valley and the Northern end of Monterey County has elevated nitrate levels in ground water. In 1986, twenty-two small water systems from the County applied to the Department of Health Services for financial assistance to remedy nitrate problems.

Data prepared by the Monterey County Flood Control and Water Conservation district show that presently 48% of all monitored wells in the unconfined aquifer areas of the Salinas Valley exceed the drinking water MCL of 45 mg/L. The sources linked to these nitrate levels are suspected to be agriculture and related activities.

A Prunedale ground water quality study found that of the 154 private and public wells serving the area, 27% exceeded the State MCL. Contamination was occurring in both private and public water systems and in both shallow and deep aquifers.

Data from the Monterey County Environmental Health Department shows high nitrate in the Salinas River Valley in the areas of San Ardo to San Lucas,

King City, Greenfield, Soledad, Gonzales on the east of the River, Soledad to Salinas on the west of the River, areas surrounding Salinas, and in the vicinities of Santa Rita, Prunedale, Moss Landing, and Los Lomas.

Areas in San Luis Obispo County where the nitrate levels have been found to exceed the state standard of 45 mg/L include Arroyo Grande, Oceano, Tri-Cities Mesa, Grover City, Morro Bay, Los Osos, Baywood, Cayucos, Pismo Beach, and Cuyama. In the areas of Arroyo Grande, Oceano and Grover City, where nitrate levels commonly are higher than the State MCL, sewage effluent from septic systems and the application of fertilizers are believed to be major sources. Past well construction and well abandonment practices appear to be responsible for some continuing degradation.

In Santa Barbara County, the Santa Maria and the Santa Ynez River Valleys have received the most impact from elevated nitrate levels. The Santa Maria Valley, contains ground water significantly exceeding the State MCL which is attributed to both non-point agricultural operations and industrial and municipal runoff. In the Santa Ynez River Basin, ground waters containing nitrate in excess of the State MCL are found in the areas of Lompoc, Buellton, Solvang, and Los Olivos. Agricultural activities have been named by the U.S. Geological Survey as the primary causes.

#### **2F: THE SAN FRANCISCO BAY AREA**

The Bay Area counties of Sonoma, Marin, Napa, Solano, Contra Costa, Alameda, Santa Clara and San Mateo all experienced nitrate problems. All have had significant historical agricultural activity. Areas in Sonoma County where nitrate values exceed the State MCL are in Petaluma, Rohnert Park, and Sebastopol.

The West Petaluma area became the subject of a Department of Water Resources study (1982) after the diagnosis of a case of infant methemoglobinemia (blue baby syndrome). It was determined that ground water contamination was caused by leachate from the wastes of poultry and dairy farms. The individual ranchettes in the area had shallow domestic wells which drew water from the contaminated zone.

In East Rohnert Park ongoing studies continue to find nitrate problems. The East Petaluma and Sebastopol areas have had historic land use similar to that of West Petaluma (dairies and poultry farms). They also exhibit elevated nitrate levels in ground water.

In Napa County, isolated areas of nitrate exceeding the State MCL have been found in the Napa Valley proper from south St. Helena to Rutherford. No specific sources have been identified.

In Solano County, areas east of Vacaville and Winters were found to contain nitrate exceeding the State MCL. No specific cause has been determined, but the land uses of these areas have historically been field crops and orchards. Similar isolated instances exist around Vallejo, Benicia, and south and east of Fairfield.

Nitrate exceeding the State MCL has been a continuing problem in the agricultural areas of Brentwood, Byron and Knightsen. Several of the large water system wells in the area have been closed. In the Knightsen area, over 90% of the shallow wells tested contain excess nitrate. Deep wells (over 150 feet deep) in the area have low nitrate values.

There are two primary areas where the nitrate levels in ground water exceed the State MCL in Alameda County. These areas are the Livermore Valley and the eastern shore of San Francisco Bay from Fremont north through San Leandro.

The Livermore Valley area of high nitrate extends from Altamont Pass west through Livermore and south into Arroyo Mocho, with several other small areas extending from Pleasanton to Dublin. The main contributors to these high nitrate zones are past agricultural practices, the historical presence of individual septic systems, and municipal waste disposal practices.

The other major area, the eastern shore of San Francisco Bay, was historically devoted to row-crop agriculture and orchards prior to low density housing development utilizing septic systems.

Santa Clara County has had a history of high nitrate levels in the southern part of the county. The two most impacted areas are near Old Gilroy and Morgan Hill. Suspected causes are septic systems in high water table areas and agricultural practices. Random occurrences are found northward into the San Jose area. EPA records show that the City of Morgan Hill's water system has wells which have been repeatedly in violation of the State MCL for nitrate since at least 1982.

With the exception of the Pescadero area, nitrate does not appear to be a problem in San Mateo County. During 1974, tests of Pescadero well systems showed that 41% of the systems produced water containing nitrate exceeding the State MCL. The suspected causes are septic systems and fertilizers.

#### **2G: THE NORTH COAST**

The north coast area consists of Del Norte, Humboldt, Mendocino, and Trinity counties with relatively few nitrate problems. One problem which exists in Del Norte County is near the town of Smith River where nitrate levels exceed the drinking water MCL in 14% of the wells recently sampled by the Regional Board. These wells are shallow, they have questionable surface seals, and they are in the vicinity of heavily fertilized lily bulb fields and dairy operations.

## **2H: THE NORTHEASTERN COUNTIES**

The northeastern counties of Siskiyou, Modoc, Shasta, Lassen, and Plumas have had only minor occurrences of nitrate problems. Usually these are related to septic systems.

## **2I: THE MOUNTAIN COUNTIES**

All or part of the following counties fall into the mountainous terrain of the Sierra Nevada Range: Sierra, Nevada, Placer, El Dorado, Amador, Alpine, Calaveras, Tuolumne, Mariposa, Madera, Fresno, Tulare, and Kern. Only isolated cases of high nitrate water has been found.

## **2J: THE DESERT AREAS**

The desert areas include all or parts of the counties of Mono, Inyo, northern Los Angeles, San Bernardino, eastern Kern, eastern Riverside, eastern San Diego, and Imperial. They have isolated nitrate problems. In San Bernardino County along the Mojave River, ground water with nitrate exceeding the drinking water standard is related to dairy wastes and a large urban population that has developed in the Victor Valley area on small unsewered lots.

In eastern Riverside County, the Hemet area and the Moreno area have been affected by high nitrate levels which exceed the drinking water MCL. Past agricultural practices are the suspected cause. Cathedral City near Palm Springs has historically had wells which exceed the State MCL. The suspected cause is septic systems. Small areas of high nitrate have been identified near dairies and poultry farms south of the Winchester area. Finally, the Anza-Borrego area in eastern San Diego County has nitrate in well water that exceeds the state standard. Agricultural practices and septic system practices are the suspected cause.

## CHAPTER THREE: ANIMAL AGRICULTURE AND NITRATE

### 3A: INTRODUCTION

Any agricultural operation involving intensive animal husbandry has significant quantities of manure which must be properly managed. If improperly managed, and with certain geologic, hydrologic, and climatic conditions, animal manure may be a potential source of ground water contamination. The existence of a dairy, feedlot, or poultry operation does not, however, automatically indicate that a nitrate contamination situation exists.

This chapter will discuss animal husbandry operations in California, manure management practices, potential contamination situations, and mitigation measures. While animal waste products are the principal sources of nitrate associated with animal operations, silage improperly stored is another potential contamination source.

California is a major producer of livestock and poultry products. California production nationally ranks first in eggs, second in dairy, second in sheep and lambs, seventh in beef and eighth in poultry. All of the above mentioned animals are raised in confined situations except for range cattle, sheep and lambs.

The nitrogen content of animal manure on a wet weight basis runs from a low of 0.38% for fresh dairy manure to a high 2.8% for fresh poultry manure. The nitrogen content drops rapidly during the first few weeks of open storage as nitrogen is lost to the atmosphere either from the conversion of urea to ammonia or through denitrification of nitrate to nitrogen or the remaining manure nitrogen can also change forms rapidly among ammonium ion ( $\text{NH}_4^+$ ), ammonia ( $\text{NH}_3$ ), nitrite ( $\text{NO}_2^-$ ), nitrate ( $\text{NO}_3^-$ ), and nitrogen gas ( $\text{N}_2$ ).

The relative amount of nitrogen is dictated by whether the manure is stored (and decomposed) under aerobic or anaerobic conditions. Aerobic conditions result in faster decomposition, the release of large amounts of nitrogen (primarily ammonia) to the atmosphere, and the formation of nitrate as an end product. This process can result in a 20% reduction in total nitrogen, but a 75% reduction in nitrogen available as fertilizer.

Anaerobic conditions result in slower decomposition with the conversion of organic nitrogen to ammonia which is maintained in the manure, and nitrogen gas. This process maintains more plant nutrients in the decomposed manure, but can produce offensive odors. However, modern anaerobic digestion systems retain odorous gases eliminating the odor problem.

While manures have a relatively low nitrogen content on a wet weight basis, the fact that they are produced in large quantities in confined areas results in a significant source of nitrogen.

Ground water contamination occurs as a result of the leaching of nitrate from manure downward into aquifers. This occurs when the stored manure is not isolated from the aquifer and when sufficient water is available to carry the nitrate down to the aquifer. In some areas, isolation of the stored manure occurs naturally by means of subsurface impermeable layers. In other areas, the livestock or poultry operator must isolate the manure by proper storage methods and proper water management techniques to prevent infiltration. Methods must also be used to assure that surface water supplies are not subject to contamination, as they may also contribute nitrate to ground water resources through infiltration.

### 3B: DAIRIES

Milk production is the number one agricultural industry in California, with over one million cows on over 2,400 dairies. The major dairy counties in California in rank order are San Bernardino, Tulare, Stanislaus, Merced, Riverside, and San Joaquin.

Dairy cows, about 1,400 pounds in size, produce approximately 120 pounds of wet manure per day with nearly 8% volatile solids and a nitrogen content of 0.38% to 0.56%. This is approximately 250 pounds of nitrogen per day for a 500 cow dairy.

Collection methods from confinement areas include scraping of manure by tractors frequently, scraping infrequently, or flushing with water. The predominant storage, processing, and disposal methods include field application, holding or settling ponds and lagoons, solid/liquid separation, manure stacking and drying, composting, sales off the farm, and waste removal service. Manure collection and handling methods are used in various combinations depending on operator preference, environmental factors, and cost. Dairies, in contrast to other animal operations, have a much higher water usage largely due to milking activities and the more prevalent use of flush type manure collection systems.

Anaerobic digestion systems, which use bacterial fermentation of manure in the absence of oxygen, convert manure solids to biogas (60% methane, 40% CO<sub>2</sub>, and trace gases), liquid fertilizer and digested solids of uniform quality. The biogas can be used to generate electricity and hot water for the dairy, the liquid used for fertilizer and solids as bedding material or a soil amendment. A case study of one anaerobic digestion systems shows income and cost savings of approximately \$40,000 per year for the \$200,000 system on a 400 cow dairy.

Curbed concrete slabs for separated solids and tarped manure piles are effective storage for dairies located in the wetter climates of Northern California. Water quality laws require the isolation of clean rain water and run off from manure at livestock operations. This is important in situations of high water use and in areas of higher rainfall.

Opportunities exist in certain areas of California to market dairy manure as a soil amendment. Dr. L. J. Butler, agricultural economist at U.C. Davis, is currently conducting a marketing study throughout the state. Based on preliminary data, a good market exists in the Sacramento Valley where manure sells for \$6 to \$20 per ton. Small quantities of manure from the northern San Joaquin Valley are being marketed in the Salinas area for up to \$15 per ton including hauling costs. Dairy operators in the southern San Joaquin Valley are paid about \$3 per ton for manure hauled short distances. However, other regions offer little or no marketing opportunities as yet. These include the Sonoma/Marin area and the Chino Valley. In the latter, dairy operators pay an average of \$3 per ton to have the manure hauled away.

### **3C: BEEF**

Beef production is the number two agricultural industry in California, with over 2.5 million cows. Nearly 1.3 million head are raised on 38 feedlots.

The major beef feedlot counties in California in rank order are Imperial, Kern, Tulare, and Merced.

Beef cows (1,000 pounds in size) produce approximately 83 pounds of wet manure per day with a volatile solids content of over 9% and a nitrogen content of approximately 0.7%. The handling of manure in feedlot operations is usually less complex than with dairies. Dairy manure is

usually handled more frequently and more water is usually used on a dairy for washing manure from the milk barn. Most feedlot corrals have dirt floors which are scraped one to four times per year. Water use is limited to drinking water for the livestock and possibly dust control.

Due to the infrequency of manure handling, these operations have the potential of contributing nitrate to ground water. However, some studies conducted in the Bakersfield area indicate that in arid climates where manure has been compacted by animals over several years, soil nitrate levels are high only within the top five feet of soil and drop off rapidly below that depth. It was concluded that no leaching to groundwater was occurring and that the manure decomposes or stabilizes in place.

It has also been shown that for operations where the manured floor surface is kept wet, nitrate leaching to groundwater is more likely to occur, while for areas kept dry, nitrate leaching is unlikely. Thus, it is extremely important to divert water runoff away from manured areas. Methods which may be considered include dikes to keep water away from such areas and corral roofs. Other methods could include the elimination of manure mounds in corrals, grassy areas as a biofiltration mechanism and contaminated water collection and holding systems with subsequent proper disposal.

### **3D: POULTRY**

The poultry industry including eggs, broilers and turkeys is the fourth largest agricultural commodity in the state. In 1982, there were over 39 million laying hens in the state. Nearly 124 million broilers and 22 million turkeys were produced in California in 1982 on about 700 farms with a continuous inventory of 3,000 or more birds. The major producing counties for eggs are Riverside, San Bernardino, San Joaquin, Stanislaus, and Merced. The Major counties for broilers are Merced with over 63% of

the state's production, followed by Fresno, Tulare, San Joaquin, Stanislaus, and Sonoma. Fresno has about a third of the state's turkey production followed by Madera, Merced, Stanislaus, and Kings counties.

While poultry produce less manure per weight of animal (63 pounds per 1,000 pounds of birds per day) than cattle, the manure is higher in both volatile solids (16.8%) and nitrogen content (1.2%) of wet weight.

Manure handling on broiler and turkey farms is usually on an infrequent basis, though about one third of the operators scrape frequently. The manure is most often in areas sheltered from rain. Most broiler and turkey operators use rice hulls, sawdust and other wood wastes as collection material to more effectively remove the manure. This combined material is used as a soil amendment.

Laying operations generally handle manure in its raw form, with about half the operators scraping frequently and half scraping infrequently. The collected manure is either field applied, stockpiled, or held in lagoons.

Manure left to compost under the layer's cages can be reduced in volume by approximately 50%. While it is protected from moisture, leaching of the balance is rarely a problem.

Manure stockpiles and lagoons on poultry farms should be managed to minimize the leaching of nitrate to groundwater. Managing the flow of clean water to minimize or eliminate contact with manure is a key consideration.

### **3E: SWINE**

California does not have a large swine producing industry, however over 200 operations with 50 or more animals exist in the state. Tulare county,

followed by Fresno, San Joaquin, San Luis Obispo, Merced, Riverside, and San Bernardino counties represent most of the state's production of 185,000 head based on 1982 data.

Swine produce manure at a rate of 57 pounds per 1,000 pounds of live animals per day. The volatile solids content is approximately 7% of wet weight and the nitrogen content is about 0.83%. Most swine farms use water flush systems to remove manure on a daily basis into a lagoon or settling pond, while some scrape frequently. Proper management of flush water and effluent, and lagoon and pond construction and maintenance are the key considerations to preclude ground water contamination for these operations. Again, proper separation of clean water from manure and manure water is the key consideration to minimizing the potential for groundwater contamination.

### **3F: SILAGE**

Silage pits and bunkers may also be a source of ground water contamination by nitrate. Care should be taken to protect them from rain by properly covering them. In some situations (i.e. high water tables) the pits and bunkers may also have to be lined to assure no ground water contamination. Such care would also ensure proper ensiling of the feed. The relatively new method of ensiling in large polyethylene bags is a method some operations have gone to, and provides the proper isolation of the silage from the environment.

### **3G: CONCLUSIONS**

Counties with the largest dairy, livestock and poultry industries, are San Bernardino and Riverside (the Chino Valley area) and Imperial counties in the south, Merced, Stanislaus, Fresno, Kern, and Tulare counties in the San Joaquin Valley, and Sonoma county on the coast. Except for Imperial

County, all of these counties also have an identified problem of nitrate in ground water. Figures 4 through 8 are maps showing the distribution of livestock production in California.

The complex interaction of many factors contribute to the potential for nitrate contamination of ground water. One livestock operation, under certain conditions can cause serious ground water contamination.

Conversely, the mere existence of a livestock operation does not mean that ground water is automatically being contaminated. Proper monitoring and testing is the only way to determine if a problem exists or not.

The first step in any management program to reduce nitrate contribution to ground water is to conduct analysis of water and soil to determine the extent of nitrate contamination. If a current problem exists, proper mitigation measures should be employed based on the design of the existing facility including land availability, environmental factors, including rainfall and geology, and technical feasibility.

The key to good manure management is good water management. Without excess water to transport the nitrate downward through the soil to ground water, the problem would not exist. However, in areas of high water tables, or high rainfall, proper water management may be difficult but necessary to achieve.

Information and technical assistance on manure management is available from the Cooperative Extension, USDA Soil Conservation Service and Regional Water Quality Control Boards.

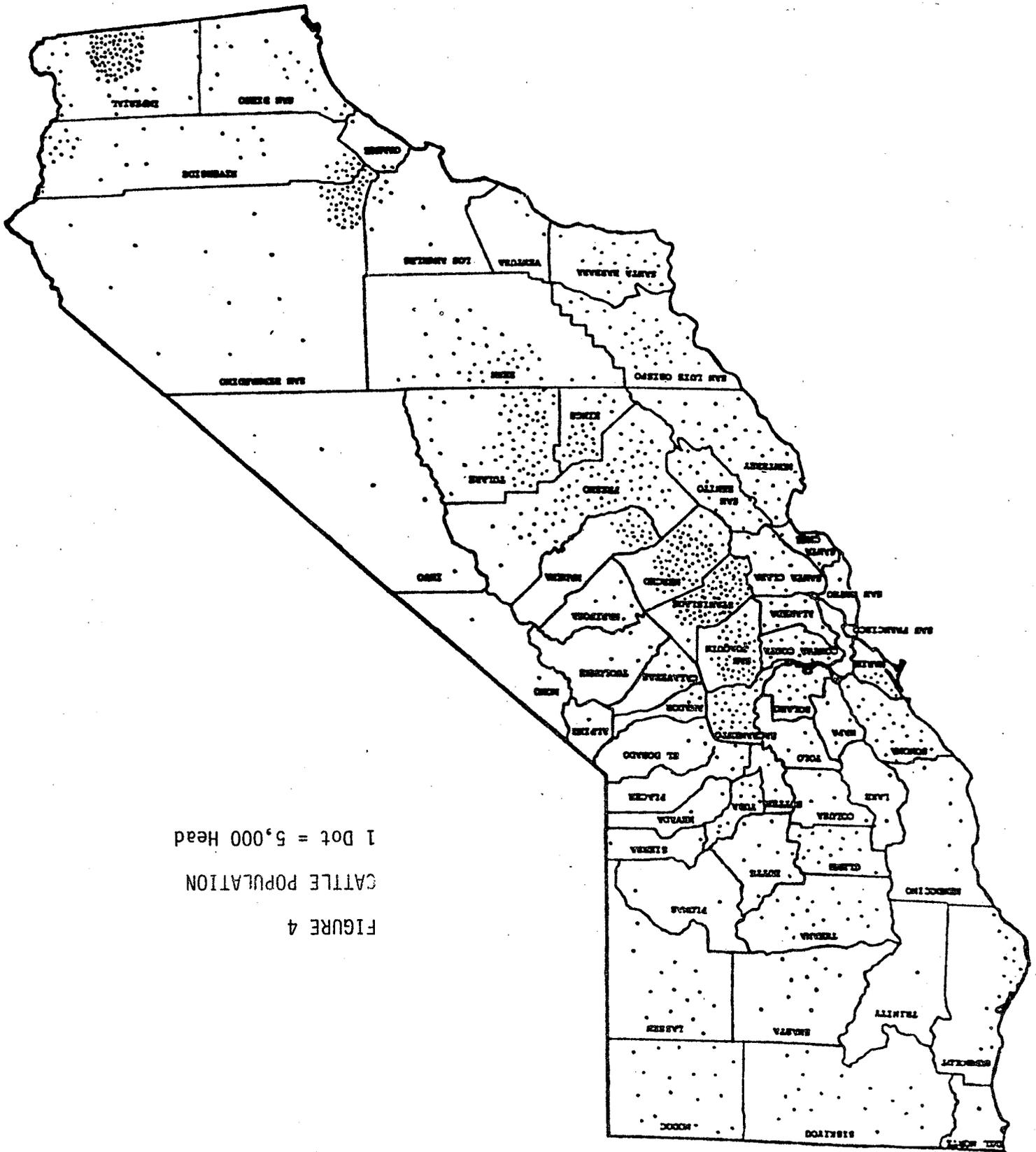


FIGURE 4  
 CATTLE POPULATION  
 1 Dot = 5,000 Head

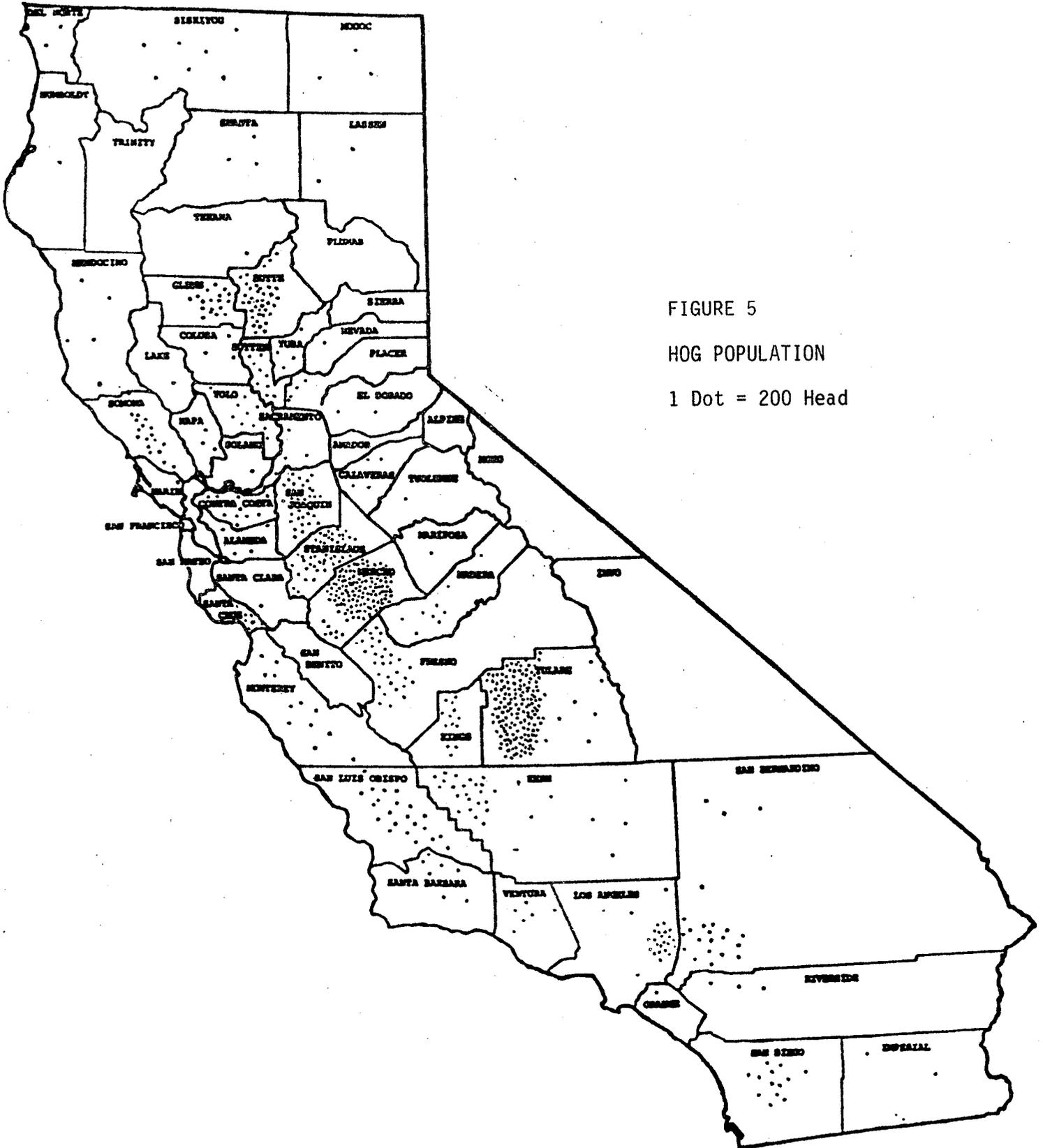
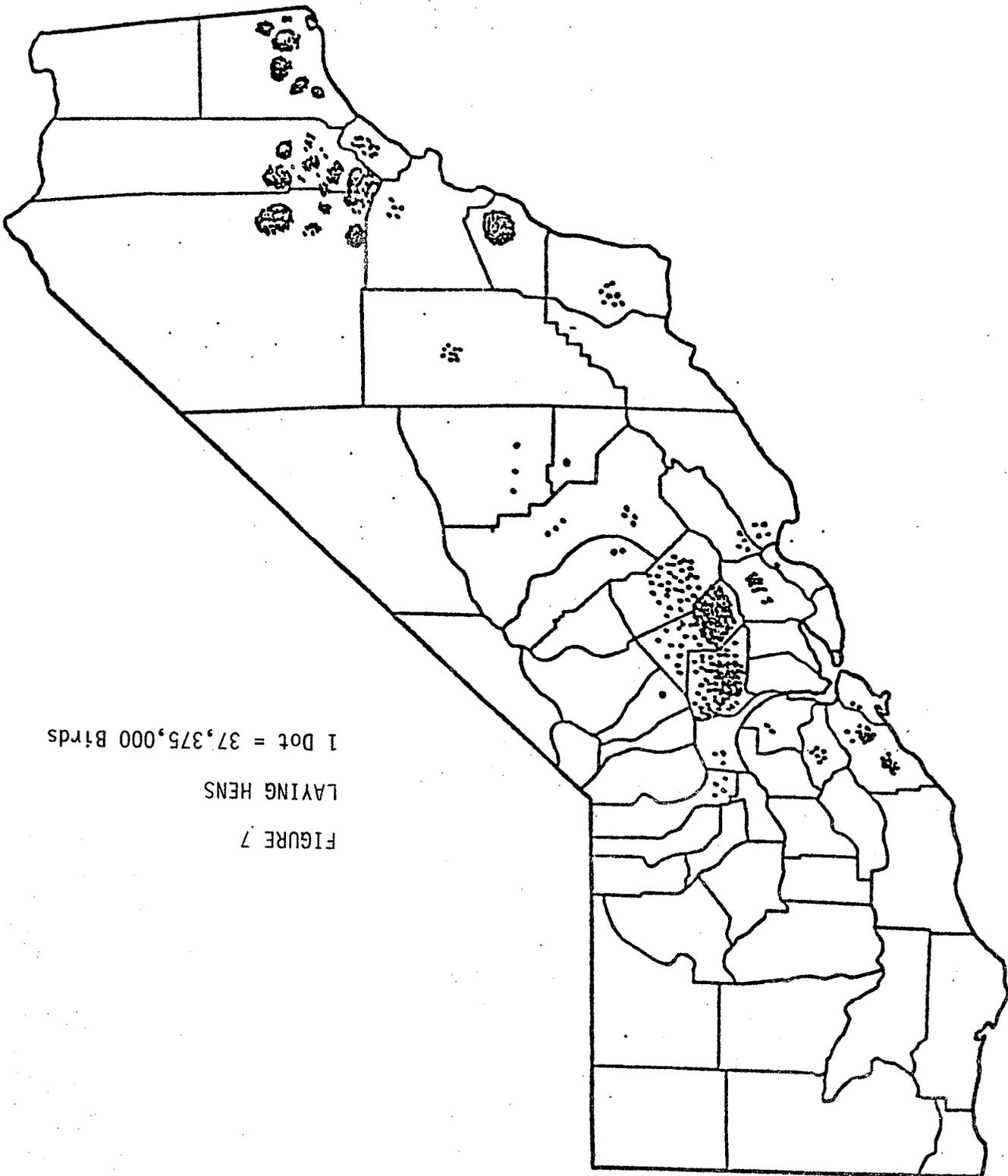


FIGURE 5  
 HOG POPULATION  
 1 Dot = 200 Head





1 Dot = 37,375,000 Birds

LAYING HENS

FIGURE 7



## CHAPTER FOUR: IRRIGATION MANAGEMENT

### 4A: NITRATE MOVEMENT IN SOIL

Nitrate movement in soil is very limited except as it is transported by water. Because nitrate is soluble in water and not absorbed by soil, it can be transported to ground water by percolation below the root zone. One means of reducing nitrate movement to the ground water is by reducing water flow. The amount of nitrate transported to ground water can be modified by irrigation management.

A distinction between nitrate concentration in the water percolating below the root zone and the total quantity of nitrate transported in a given period of time, i.e., mass emissions, must be made. Irrigation management leading to low concentrations of nitrate in percolating water below the root zone could result in high amounts of nitrate flow, or vice versa. In adopting irrigation management strategies to reduce ground water pollution, it is important to identify whether the goal is to reduce concentrations or amount. In general, when a material is discharged into the environment, its negative effects depend on the assimilative capacity for that constituent. The environment is negatively impacted when the amount discharged exceeds the assimilative capacity. For nitrate, the assimilative capacity is a function of the volume of the ground water body under consideration. Since the volume of water percolating through the soil to the ground water is expected to be relatively small compared to that of the ground water body, changes in flow rates would not greatly affect the assimilative capacity. In this regard, the total amount of nitrate which must be assimilated in the ground water body, would be a better index than concentration in establishing a management strategy to reduce pollution.

The remainder of this chapter will use total amount as the criterion for evaluating irrigation management strategies to reduce ground water pollution by nitrate.

#### **4B: RESEARCH ON NITRATE FLOW**

The total amount of nitrate flow depends on the amount of nitrate dissolved in soil-water and the volume of water percolating per unit time. The amount is at least partially dependent on the applications of nitrogen and can be altered by management of fertilizer input. On the other hand, volume of flow beyond the root zone is dependent on irrigation management which is the primary focus of this chapter.

The University of California conducted an extensive research project entitled, "Nitrate in Effluents from Irrigated Lands," which was sponsored by the National Science Foundation in the 1970s.

The research consisted of three categories: (1) monitoring of nitrate and water below the root zone from several farms under which there was free drainage to the ground water; (2) monitoring concentrations and amounts of nitrate in tile drainage water from several farms which had perched water tables and tile drainage systems installed; and (3) concentrations and amounts of nitrate flow below the root zone of experimental plots on which fertilizer and irrigation management was controlled.

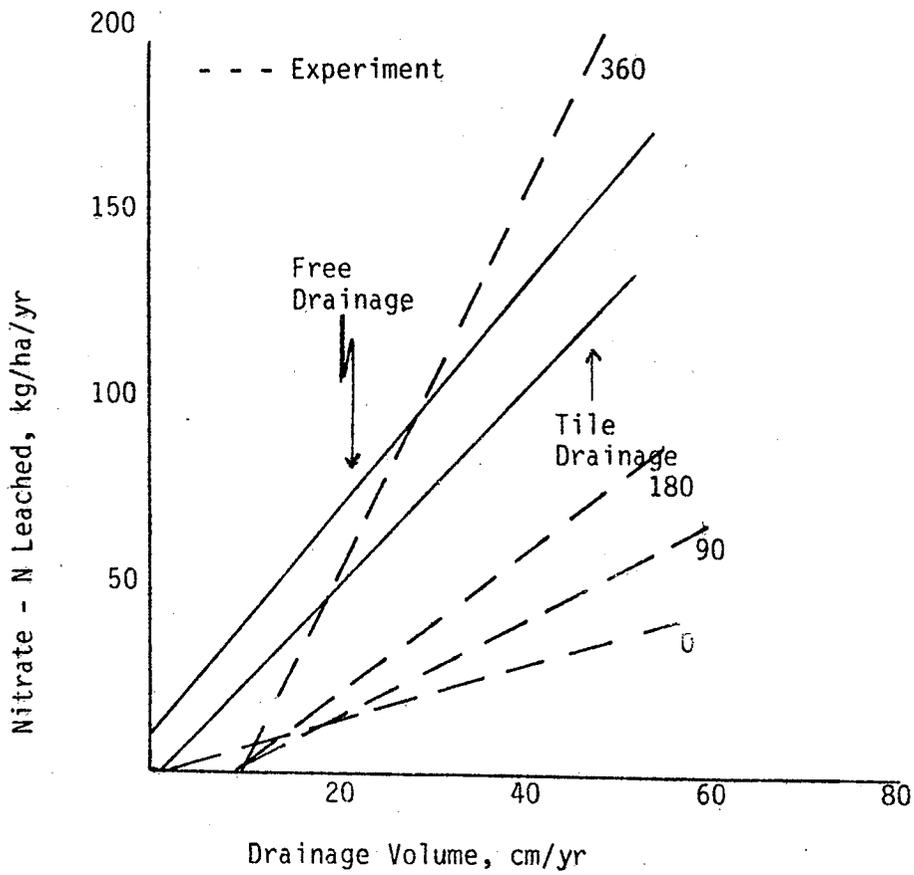
The amount of nitrogen moving beyond the root zone would be expected to be related to the amount applied, and to the drainage volume. Data from several diverse farming operations were used to find relationships between the amount and concentration of nitrates below the root zone and drainage volumes and nitrogen applications. The amount of nitrate flow was significantly correlated with drainage volume, nitrogen application, and a combination of nitrogen application and drainage volume. On the other

hand, there was no significant correlation of concentration with drainage volume or nitrogen application. These results clearly indicate that both nitrogen application and water moving below the root zone have significant effects on the amount of nitrogen carried to the ground water.

The results from farms with tile drains were very similar to the results from farms with free drainage to the ground water. The relationship between the amount of nitrate flow and drainage volume is illustrated in Figure 9. Also illustrated in Figure 9 are the results from the experiment in which various nitrogen and water applications were made to the experimental plots. Increasing drainage volume resulted in increased amount of nitrate below the root zone in the experimental plots as well as the farm studies. The field experiments were done at several nitrogen application rates. The experiment provided a separate curve for each nitrogen application to the corn crop. Increasing the nitrogen rate increased nitrate flow for a given drainage volume. Even without any nitrogen application, there was a considerable amount of nitrogen leached below the root zone if the drainage volume was high. However, with low drainage volumes very little nitrate was moved below the root zone, even under the very highest nitrogen application rate. Clearly, irrigation management as it affects drainage volumes, can significantly affect potential ground water pollution from nitrates derived from croplands.

Farmers normally do not know how much drainage volume is generated by their irrigation management. Because the data indicated a significant relationship between the amount of nitrogen leached and the drainage volume, it was postulated that farmers may have learned from experience to compensate for high drainage volumes by using more nitrogen fertilizer. The data from the free drainage and the tile-drainage sites were analyzed

Fig. 9-  
N Leaching & Soil Drainage



for a correlation between applied nitrogen and drainage volume. A statistically significant trend observed was that farmers apply more nitrogen under cases where higher drainage flow occurred, presumably to compensate for the nitrogen lost by leaching. These results demonstrate that nitrogen fertilizer inputs and water management are related, and one cannot be evaluated without the other.

The amount of nitrate flow can be reduced by reducing both the drainage volume and the nitrogen input. Thus, there is a potential for managing nitrate flow. However, nitrate concentrations were not correlated with other management variables and apparently are not subject to control over a wide range of soils, crops and water-management systems.

#### **4C: REDUCING DEEP PERCOLATION**

Deep percolation is produced by infiltration of water in amounts which exceed the soil capacity within the crop root zone. The term "infiltrated water" is the amount of water which penetrates the soil surface and recharges the soil profile. This differs from applied water which includes runoff from the field that does not penetrate the soil. Although the primary reason for irrigation is providing water for crop evapotranspiration (ET), a small amount of extra water creating deep percolation is needed for salinity control. Deep percolation and thus the potential for carrying nitrate below the root zone can not be completely eliminated in an irrigated agricultural system. The management goal is to minimize deep percolation.

Irrigation applications in excess of the water-holding capacity of soil can be caused by various factors: (1) inadequate or inaccurate information on the water holding capacity of the soil at the time of irrigation; (2) irrigation systems which do not provide adequate control over the amount of

applied water resulting in application of excess water; (3) nonuniformity of irrigation application due to nonuniformity of soils or irrigation systems leading to application of excess water to parts of the field.

Farmers commonly prefer to fill the soil profile to capacity before planting the crop (pre-irrigation). To apply a correct pre-irrigation amount, two items of information are required: the soil water holding capacity and the amount of water already stored in the soil. Reasonably accurate information on soil water holding capacity of various soils is available in soil survey reports which can be obtained from county extension offices and the Soil Conservation Service. Information on the water already in the soil, however, is usually not well known without soil sampling. Soil sampling to determine soil water content is laborious, expensive, and not commonly done by farmers.

While the purpose of pre-plant irrigation is to recharge the soil profile, the purpose of irrigating during the growing season is to resupply the soil profile with water lost through ET. Information on rates of ET losses is required to properly schedule the time and amount of irrigation. The Department of Water Resources California Irrigation Management Information System (CIMIS) is one source of ET information. This source of information is reliable and accessible to the farmer. There are, however, sources of error in the ET estimates. Crop coefficients are empirically determined and subject to differences in growing conditions and irrigation systems.

Timing of irrigation may also be determined by other methods such as soil-water content monitoring by soil sampling or neutron probe, or by measuring plant stress using the pressure chamber or the infrared thermometer.

If the farmer has reliable information on the proper amount of water for recharging the profile with water during both pre-plant and growing season, he must precisely apply this amount to avoid deep percolation. Pressurized irrigation systems, such as sprinkler and drip, allow precise control of the amount of applied water. A surface irrigation system, such as furrow, does not allow as high precision on the application quantity as a pressurized system, but it can be improved to some degree by management adjustments. Small quantities are particularly difficult to apply with surface systems unless the infiltration rate is extremely low. Conversion from surface to pressurized irrigation systems would increase the control on application amount, particularly small amounts, and thus the control of deep percolation. Conversion, however, may not be feasible for economic or other reasons.

Even with accurate knowledge of the soil-water storage capacity and an irrigation system which precisely applies the desired amount, deep percolation will occur because of the nonuniformity of soil or irrigation systems. Nonuniformity prevents the farmer from applying the desired irrigation to all parts of the field. A compromise between over and under irrigating portions of the field must be made. Over-irrigation leads to deep percolation; under-irrigation leads to decreased yield. Both can occur in an irrigated field at the same time.

Clearly, the irrigation system which allows precision on the amount applied and provides a uniform distribution has the dual advantages of allowing high crop yields on all parts of the field with very low deep percolation. Pressurized irrigation systems allow precise control on the amount of application but may or may not provide better uniformity than surface irrigation systems. Sprinklers other than linear move systems may apply

water nonuniformly, particularly under windy conditions. The question is whether the increased costs for pressurized irrigation systems are offset by increased benefits. A study comparing the economics of different irrigation systems in the production of cotton in California found that with no costs or constraints on the amount of water percolating below the root system, the maximum profits were achieved with the furrow irrigation system. This finding is consistent with farmer practice where furrow irrigation is the predominant method used by farmers in California. The quantity of applied irrigation water to achieve the maximum profits for the different systems resulted in approximately a 4-fold increase in the amount of deep percolation from the furrow irrigation as compared to the pressurized systems other than solid set or hand move sprinklers.

In summary, strong documentation exists verifying that the amount of nitrogen percolating below the root zone is highly influenced by the amount of water percolating below the root zone. With furrow irrigation systems, there is a limit to the amount of deep percolation than can be reduced without greatly reducing yields because of nonuniform soils. Some pressurized irrigation systems have the potential for allowing irrigation to achieve high yields with low percolation rates. Costs for these pressurized systems, however, were higher than furrow irrigation and the additional costs may not be offset by equal economic benefits to the farmer unless there is some penalty imposed on the amount of deep percolation. An economic analysis on various irrigation systems for cotton production found that furrow irrigation is the most profitable means for the farmers unless they have costs or other constraints on the amount of deep percolation.

One significant uncontrollable factor which impacts nitrate movement by deep percolation is rainfall. While this may be of minor concern in the

Southern portion of the state, it may be a substantial factor in areas where rainfall is greater than 12 inches a year. This additional contribution of water can negatively impact an otherwise well managed irrigation program.

## CHAPTER FIVE: NITROGEN FERTILIZER MANAGEMENT

### 5A: ROLE OF NITROGEN IN CALIFORNIA AGRICULTURE

Among all fertilizers and soil amendments used in the U.S., nitrogen fertilizers are the most important. Since 1960, nitrogen fertilizer use in the country has increased about 300 percent. During that time, planted crop acreage has remained about the same while overall farm production has increased about 40 percent. Much of the increase in production is attributable to the increase in nitrogen fertilizer use.

In California, where the native levels of organic matter and nitrogen are low in many soils, applied nitrogen fertilizers make a crucial contribution to agricultural productivity. Nitrogen fertilizer use in California on nine to ten million acres stood at 342,000 tons (actual N) in 1965 and rose to about 570,000 tons in the early 1980's, a 67 percent increase. Since then, the tonnage has not increased. Typical rates of application on irrigated cropland range from no nitrogen (on much of the alfalfa crop) to low rates of 20 to 50 lb N/acre on some tree crops, to high rates of 150 to 300 lb N/acre for grain crops. Some grain and vegetable crop acreage receives higher annual rates.

The contribution of nitrogen fertilizer to California agriculture must be evaluated as much with regard to quality as to quantity of products grown. Appearance, texture, shipping and storage life of many fresh fruits, vegetables, and nuts is greatly influenced by nitrogen. Pasta and bread wheat markets require a high protein product of which nitrogen is a major determinant. The dairy, beef, and poultry industries in California demand high protein (i.e., high nitrogen) quality feeds. For some crops, both too little and too much nitrogen will result in lower yielding or lower quality

production. Examples are citrus, cotton, sugarbeets, lettuce, and grapes. Regulation of nitrogen supply to these crops is a subject of keen interest to farmers producing them.

#### **5B: MANAGEMENT OPTIONS**

This chapter presents the choices available to a farmer in managing nitrogen fertilizer and the effect that such choices can have on leaching of nitrate below the root zone. Management options can be categorized as follows:

1. On farm storage of fertilizer;
2. Selection of fertilizer material;
3. Selection of the rate applied per acre;
4. Timing of fertilizer application;
5. Method of application and placement of fertilizer; and,
6. Use of crop rotation, cover crops and green manure crops.

No universal formula exists that can be used by farmers to predict at a given location which fertilization practices will optimize yield and crop quality while minimizing the quantity of nitrate leached into the ground water. Still, it is possible to state generally accepted best management practices. It should be recalled that water is the carrier of nitrate in the environment. Irrigation management is of equal or greater importance in managing crop nutrition and controlling nitrate movement.

#### **5C: ON-FARM STORAGE OF FERTILIZER**

Fertilizers are either applied commercially or by the farmer. In the latter case, fertilizers are often stored temporarily on the farm. On-farm storage facilities, if inadequately constructed and maintained, can serve

as a point source of nitrate contamination. Spillage of fertilizer and rinse water during transfer of fertilizer can also contaminate water. Improved on-farm storage and transfer procedures, e.g. impermeable foundations and containment structures, similar to that required for dealers would control this potential source of contaminate.

#### **5D: SELECTION OF NITROGEN FERTILIZER MATERIALS**

The most common nitrogen fertilizer sources and the main transformations that they undergo are shown in Figure 10. Ammonia, either as a gas (anhydrous ammonia) or dissolved in water (aqua ammonia), and urea-ammonium nitrate solutions account for a large proportion of the nitrogen fertilizer used by California's farmers. The reasons for their popularity are their widespread availability, low cost, and agronomic effectiveness. Farmers generally select materials according to cost per unit nitrogen and compatibility with application equipment. In some situations growers select specific materials for agronomic performance. Examples include the use of ammonia or urea for rice production and the use of nitrate-containing materials (calcium ammonium nitrate, calcium nitrate, UAN-32) on winter vegetables and fertilization of trees and vines.

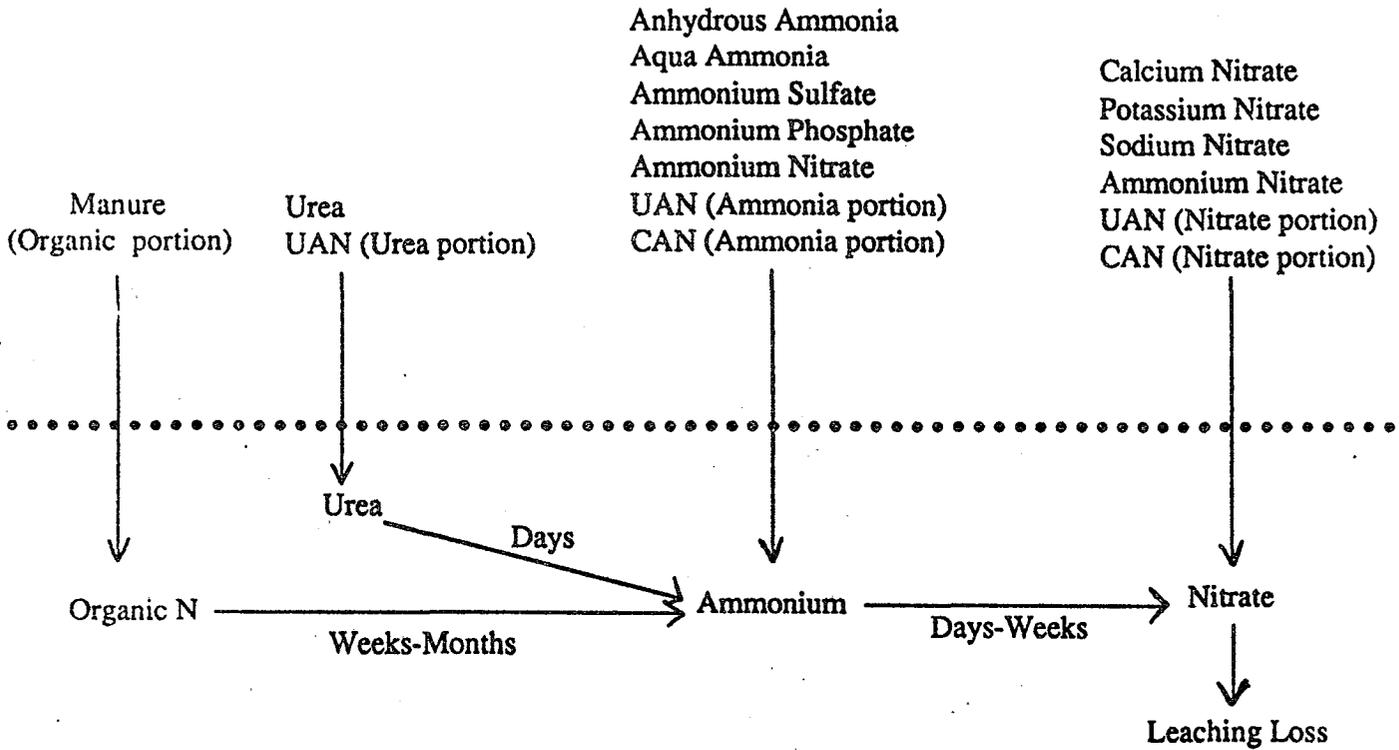
Furthermore, in many situations, all other factors being equal, different nitrogen fertilizer materials may result in a similar amount of nitrate being leached into the ground water. Ammonium and urea will, in moist, warm soil, be converted rather quickly to nitrate as shown in Figure 1. Several exceptions to this generalization are discussed here.

#### **Nitrogen Applied in Cold, Flooded, or Acidic Environments**

Strongly acidic soil pH values (<5.0) or cold temperatures (<40° F) will result in very slow conversion of ammonium to nitrate. Such conditions do not prevail in California. Ammonium also converts slowly to nitrate in

**Figure 10: MAJOR FERTILIZER NITROGEN SOURCES AND FERTILIZER NITROGEN TRANSFORMATIONS IN THE SOIL.**

Time periods indicated are for warm, moist soil.



UAN - Urea Ammonium Nitrate

CAN - Calcium Ammonium Nitrate

flooded rice soils. But rice farmers use very little nitrate, and in any case, heavy clay soils, low leaching rates, and high denitrification rates keep most nitrate from being transported below the root zone.

Nitrate applied to winter vegetables (e.g. lettuce in the Imperial Valley) will be leached rather quickly if heavy rainfall occurs after application. In contrast, ammonium will not be leachable until converted to nitrate, which under cool temperatures will take months. Farmers use nitrate containing materials because of the faster response by the crop.

#### **Application of Urea to Soils**

Under most conditions found in cropped soils in California, urea is converted to ammonium in a few days. However, when it is still in the urea form, it is almost as mobile as nitrate. Applied to coarse textured soil and immediately subjected to a large irrigation or rain, much of it would be leached below the root zone before it was converted to the nearly immobile ammonium form. Under such conditions, urea is not a good choice compared to ammonium containing materials.

#### **Use of Nitrification Inhibitors**

These are materials applied with ammonium fertilizers (or urea) that significantly slow the conversion of ammonium to nitrate in the soil leading to greater nitrogen uptake by the crop and lower leaching and denitrification losses. Only one material, nitrapyrin, is currently registered in California, and only for use on cotton, rice, and grain crops. A second material, dicyandiamide (DCD), is used commercially as a nitrification inhibitor on a very limited acreage. Large numbers of field trials have been performed with these materials, especially nitrapyrin, but most of the tests were conducted outside of California. Some data show significantly reduced nitrate leaching losses, especially in coarse and

medium-textured soils. In California, nitrogen trials conducted in Monterey county with celery, lettuce, cauliflower, and strawberries showed encouraging results. Lower amounts of applied nitrogen proved of equal effectiveness to the current practices. Unfortunately, nitrapyrin is not registered for use on vegetable crops.

Nitrification inhibitors appear to hold some promise for reducing applied nitrogen rates and leaching losses especially where the current practice is to apply high rates of ammonium in coarse and medium-textured soils before the period of maximum crop nitrogen uptake. Nitrification inhibitors are not a panacea, but more tests in California are justified.

#### **Synthetic Slow Release Fertilizers**

Several slow release products have achieved some market success. These include coated materials such as sulfur coated urea, slowly soluble compounds like ureaformaldehyde and isobutylidene diurea, and materials like Osmocote that consist of pellets encapsulated in a porous membrane. Because cost of slow release fertilizers is two or three times that of conventional fertilizers per unit of nitrogen, they have proven economical only on such crops as greenhouse flowers, strawberries, and turfgrass. In California nearly all commercial strawberries receive slow release nitrogen. Tests have shown that under some conditions, nitrate leaching losses are reduced compared to that which occurs with soluble sources of nitrogen. However, even with the most sophisticated of release mechanisms, it is not possible to precisely match the fertilizer release rate with the desired rate of plant nitrogen uptake under all likely environmental conditions. Technological improvements and price reductions would increase the role for these materials.

### **Animal Manures**

It is widely believed that nitrate in ground water is an undesired result of the use of synthetic fertilizers, and that substitution of animal manure or some other "natural" fertilizer for the synthetic fertilizer would reduce water pollution. This is not the case. Numerous studies show that nitrate leaching can occur from cropland fertilized with animal manure. Factors other than the material per se, such as rate of material applied, soil characteristics, and irrigation water management, are the main determinants of the amount of nitrate leached. Animal manures are already used in significant amounts by California's farmers. Manure is a more heterogeneous and less predictable source of nitrogen than synthetic fertilizer sources. Generally, it is also harder to apply uniformly.

In regions with heavy livestock concentrations, the large amount of manure requiring disposal may lead to application rates well in excess of that required to fertilize the crop. Composting of manure mixed with crop residues such as cotton gin trash or rice hulls (now being done commercially on a limited scale) can help solve this problem by creating a more stable, well-defined product with a wider range of markets than the original unprocessed waste. On the negative side, composting is costly and results in a loss of nitrogen to the air as ammonia. Furthermore some of the benefits of compost claimed by its adherents are poorly documented.

### **5E: FERTILIZER APPLICATION RATE**

Research conducted by the University of California in the 1970's clearly shows that the volume of water drained below the root zone, and rate of nitrogen fertilizer applied, are the main factors influencing the amount of nitrate leached below the root zone of irrigated cropland. The research also shows that, in general, the amount of nitrate leached greatly

increases only if the amount of fertilizer nitrogen applied exceeds that required to achieve optimum yield. Choosing the optimum rate is complicated and in many cases has to be based on what apparently has worked in the past under similar weather, soil conditions, and water management system.

The following information is needed to determine the economic optimum nitrogen rate:

1. Crop nitrogen uptake;
2. Fertilizer nitrogen carried over from previous crop;
3. Amount of nitrogen that will be released by soil organic matter and by animal manure;
4. Amount of nitrogen in the irrigation water;
5. Portion of applied fertilizer nitrogen, residual fertilizer nitrogen, and nitrogen released from organic matter that will be recovered by the crop; and
6. Fertilizer and crop prices.

These factors are discussed briefly below.

**Crop Nitrogen Uptake:** Farmers can predict total amount of nitrogen absorbed by the crop per acre by combining knowledge of the expected nitrogen content of the crop with a realistic estimate of the yield. However, for some crops, nitrogen uptake associated with optimum quality exceeds that required for maximum yield. Farmers may, in such cases, apply luxury amounts of fertilizer to ensure high quality. U.C. farm advisor nitrogen fertilizer rate experiments, in some cases, have shown that the rate of nitrogen required for optimum yield and quality is less than that used by many farmers. In other trials, the typical farm rate has been either correct or too low. However, it should be noted that fertilizer

response in small plots may differ from that on commercial fields.

**Amount of Available (nitrate, ammonium) Nitrogen in Soil:** At the beginning of the crop season, some nitrate and ammonium are present as a result of residual fertilizer nitrogen and mineralization of organic matter during the interval between cropping periods. In some cases, researchers in California claim to have found useful correlations between soil nitrate levels and fertilizer nitrogen requirements. Such correlations have been developed on small plots and are very likely weaker on a commercial field scale due to the large variability typically found in irrigated soils. Furthermore, the soil inorganic nitrogen content is a "snapshot" of a very dynamic situation. Currently, procedures for using soil tests have been recommended by U.C. only for cotton and sugarbeets.

**Amount of Nitrogen Released from Organic Matter and Animal Manure:** In many situations, 50 percent or more of the nitrogen taken up by a crop will come from the decomposition of crop residues and other accumulated organic matter. This percentage is highly variable. The amount of nitrogen obtained by the crop from soil can vary from less than 50 to more than 200 lb/acre. Some promising procedures for estimating this quantity have been published in the scientific literature, but none have reached commercial status. A practical approach used by some farmers is to adjust the nitrogen fertilizer application rate according to crop history. For example, lettuce following sugarbeets, a crop which is known to deplete residual nitrogen in soil to very low levels, will require more fertilizer than a second lettuce crop following spring lettuce. Research by U.C. workers has resulted in recommendations for fertilization practices. Abshahi, Hills, and Broadbent, using N-15 as a tracer, estimated the nitrogen fertilizer value of sugarbeet residues to the following crop. Their results show that the residue associated with each ton of beet root harvested provides about

one pound of nitrogen fertilizer equivalent value to the following crop. Such information is lacking for most crop rotations in California. For example, with few exceptions, there are no California extension recommendations on how much nitrogen to credit to the following crop from legume (alfalfa, bean, clover, vetch) residues.

Estimating the nitrogen value of animal manure relative to synthetic soluble fertilizers is difficult. Many farmers do not know the water content or total nitrogen content of animal manure applied to their fields. Even if they know the total nitrogen applied, they must guess at the portion of the total nitrogen that will become available to the crop and to subsequent crops. Representative values are provided in the Western Fertilizer Handbook, 7th ed. for various types of manure, but actual values are greatly influenced by the amount of ammonia lost to the air, the age of the manure, the presence of bedding materials such as wood chips, and the temperature and moisture content of the soil with which the manure is mixed. More accurate procedures are needed.

**Nitrate Present in Irrigation Water:** Many farmers are irrigating with water that contains significant amounts of nitrate, but they may not be compensating with lower fertilization rates. Water that contains 10 mg/L nitrate-nitrogen has 27 pounds of nitrogen per acre foot. Many irrigation wells in the Salinas and San Joaquin Valleys contain that much nitrogen or more. Nitrate analysis of irrigation water is generally reliable and inexpensive and should be practiced routinely by farmers in certain areas of the state. Additional information is needed to show how to credit the nitrogen against the fertilizer requirements of particular crops, but even without this information, it should be possible to adjust fertilization practices.

**Estimating Nitrogen Losses from the Soil-Plant Environment:** Nitrogen can be lost from the system by leaching, denitrification, or volatilization from soil. Additionally, in several recent studies significant ammonia loss from plant tissue, mainly senescent grain crops, has been observed. Because of the multiple potential loss pathways and the complexity of the factors controlling the magnitude of such losses, it is difficult to predict the plant's recovery of fertilizer nitrogen even if all the other factors can be accurately estimated. Examples of recoveries in California and elsewhere are published in the scientific literature and typically range from 20 to 80 percent. Some progress has been made in developing simple management models for estimating denitrification and leaching losses in specific locations. For example, U.C. scientists have published methods for classifying soils according to their potential for denitrification. But there are no such models in actual commercial use.

**Crop and Fertilizer Prices:** In general, crop and fertilizer prices do not have a big influence on rate of fertilizer applied and amount of nitrate leached. Even for low value crops such as wheat, barley, and corn, the difference between the rate of nitrogen that results in maximum yield and that which results in the highest return on fertilizer dollar is not large and normally is well within the range of uncertainty regarding optimal fertilizer rate.

Because of the difficulty in determining the optimal rate of nitrogen, some method is needed for monitoring crop performance. A beneficial practice is the use of check plots or areas in the field fertilized by the farmer at a lower rate. Also, farmers can observe crop performance in sandier spots in the field. Often such areas will show nitrogen deficiency at a nitrogen rate that is adequate for the rest of the field. As mentioned above, the

usefulness of soil analysis is limited by large spatial and temporal variability. Plant analyses, in contrast, are more indicative of needs and future requirements. An obvious limitation of plant analysis is that results may come too late in the season to be of any use to the farmer. Nitrate critical levels for many crops are given in U.C. Bulletin 1879, Soil and Plant Tissue Testing in California. These critical values in combination with experience and other diagnostic methods can provide guidance in setting reasonable fertilizer rates. Standardization of laboratory methods and certification of laboratories can help ensure the usefulness of both tissue and soil analysis, as measurement of nitrate in soil and plant samples is subject to some error.

#### **5F: TIMING FERTILIZER APPLICATIONS**

Splitting nitrogen applications is widely practiced in irrigated crop production and can reduce nitrate leaching in comparison to the practice of applying all the nitrogen before planting. Most annual crops absorb only a small amount of nitrogen early in the growing season. Lettuce, for example, produces 70 percent of its growth and takes up a similar fraction of nitrogen in the last 21 days before harvest. In such cases, a small amount of nitrogen should be applied in a concentrated band before planting with most of the nitrogen applied when the root system is larger and can absorb it. The practice of applying large amounts of nitrogen before planting should be avoided particularly in areas where rain is expected after the application and before planting.

Other practices related to the timing of nitrogen fertilizer application are: Use of slow release and foliar fertilizers, application of fertilizers in the irrigation water, and improved irrigation management techniques. These are discussed in detail elsewhere.

## **5G: FERTILIZER APPLICATION METHODS**

Nitrogen fertilizer is applied to crops by a variety of methods. In some cases, the method of application or the resulting position of fertilizer can influence the amount of nitrogen recovered by the crop and the amount leached below the root zone. Three techniques with the potential to improve crop recovery of nitrogen are discussed here. They are banding of fertilizer, foliar application, and application in the irrigation water.

**Banding of Fertilizer:** Generally, preplant broadcast applications are not recommended. Small amounts applied in a concentrated band positioned below and to the side of the seed are efficiently recovered by plants in the seedling stage. This is especially effective in furrow irrigation because movement of water into the bed will tend to move nitrate up into the root zone rather than downward. In some cases, nitrogen can be broadcast before beds are formed then moved into the correct position by forming the beds.

**Foliar Fertilization:** Plants are able to absorb nitrogen through leaves and stems. Urea in particular is efficiently absorbed. By applying nitrogen to the plants, processes leading to leaching loss in the soil are largely avoided. Currently, urea and less commonly urea-ammonium nitrate solutions are foliarly applied to wheat, citrus, cotton, and other crops in California. Application through sprinklers does not constitute foliar application because nearly all the material is washed off foliage onto the soil. The main reason more fertilizer is not applied to foliage is that with available materials, only about 15 to 25 lb/acre of nitrogen can be applied at one time without burning the leaves. This represents only a small portion (10-25 percent) of the total nitrogen requirement of most crops in California. Where pesticides are frequently applied to crops, foliar fertilizer can be applied at the same time to reduce application

cost. It is probably possible, with no new technical breakthroughs to apply as much as 50 percent of the citrus nitrogen requirement to the foliage. Currently a slow release foliar nitrogen material is available, but the high price limits its use.

**Application of Fertilizer in Irrigation Water:** Fertigation (the application of fertilizer in irrigation water) is common in some cropping systems in California and is a good method for timing nitrogen applications to coincide with plant water uptake. For some crops, such as corn, it may be the only practical method for applying fertilizer when the crop has become too tall to permit entry of application equipment into the field. For short-season crops, fertigation is not as advantageous except on the sandier soils where leaching and low nutrient-holding capacity limit recovery of nitrogen applied earlier in the season.

Fertigation has its limits: Uniformity of nitrogen application can be no better than the uniformity of water application. In some situations, the nitrogen uniformity will be worse, for example when ammonia is injected into water applied in long furrow or basin runs. Managing water to reduce run-off, for example by the use of tailwater return systems, will not necessarily reduce leaching losses. Indeed, amount of tailwater and volume of deep percolation can be inversely related. Nitrogen leaching loss following fertigation has not been studied much. Work is required on this subject.

#### **5H: USE OF COVER CROPS AND CROP ROTATION**

The rotation of crops is generally accepted as beneficial to production. Legume (nitrogen fixing) crops such as vetch or bell beans are grown for green manure during the winter and then disked under in the spring to provide nitrogen to the following crop. Effects on nitrate leaching losses

are in part a matter of speculation. It is reasonable to believe that legumes are good scavengers of residual nitrate in the soil because it is known that the amount of biologically-fixed nitrogen is less in the presence of soil nitrate.

Other crop rotation practices that may reduce nitrate leaching are (1) growing alternating shallow and deep-rooted crops; (2) alternating crops that require a lot of nitrogen fertilizer or are known to be inefficient in nitrogen recovery with crops known to be N-efficient and/or N-sensitive, e.g., sugarbeets; (3) growing crops that have large harvest nitrogen removals, e.g., alfalfa, (4) growing cover crops during the winter and reducing the length of fallow periods.

Some support for these ideas can be found in the literature, but in general, the effect of these practices on nitrate leaching has not been measured.

Also, as with other practices, effect on nitrate leaching is not a major criterion for farmer management decisions. Pesticides, weeds, soil tilth, climate optimal use of equipment, and plant nutrition in conjunction with potential economic returns are considered by farmers in determining the best rotation.

## CHAPTER SIX: NITRATE SENSITIVE AREAS

### 6A: INTRODUCTION

Considerable bodies of ground water in California contain significant concentrations of nitrate that may have reached the groundwater from a variety of sources. This report addresses the agricultural sources of nitrate. The University of California research project which measured quantities of nitrate moving below the root zone from several fields found a wide range of values. Clearly, nitrate contribution to ground water from agriculture is associated with an array of complex interactions. This chapter will consider those factors important in determining the sensitivity of an area for ground water degradation by nitrate. A nitrate sensitive area is defined as one where ground water pollution by nitrate is highly probable and detrimental. The factors to be considered are (1) receiving waters, (2) soils, (3) crops, and (4) climate.

### 6B: RECEIVING WATERS

The sensitivity of an area to ground water degradation by nitrate depends on the nature and use of the ground water. Low sensitivity occurs if the receiving waters are not retrievable, or if retrievable, are used for purposes for which the nitrate content is not a liability. The nitrate concentration is not critical if the water is used for cleaning, cooling, or irrigation of most crops.

Nitrate concentration in the water is critical if the water is to be used as domestic or animal drinking supplies. Under the latter condition, benefits from reducing nitrate flow from a source to the ground water are high except for the following two cases: (1) Waters that are already contaminated to the point of being nonusable for domestic use without an expensive purification process and additional nitrate contributes very

little to the added process costs. (2) Of all the sources of nitrate to ground water, irrigated agriculture contributes an insignificant amount compared to the other sources.

#### **6C: SOILS**

Soils most sensitive to groundwater degradation by nitrate are those which have high water infiltration rates, high transmission rates through their profiles, and low denitrification potential. These are usually coarse-textured porous soils of low organic matter content with no layers in the profile to restrict water movement. Soils with low infiltration rates and low water and air transmissivities are not conducive to large drainage volumes which transport nitrate, and they also tend to develop an anoxic condition so that denitrification occurs. Denitrification removes nitrate as water percolates to the ground water. Clayey soils or soils that have clay layers or textural discontinuities in the profile typically have slow water movement, allow slow drainage volume and develop anoxic conditions. Sandy soils with high silt content and low structural stability can have some of the same low water and air transmissivities as clayey soils and well aggregated clay silts can have some features common with sandy soils if they are well aggregated to create relatively large volumes of macropores. Soil profiles can be rated into categories of leaching and denitrification potentials.

#### **6D: CROPS**

Crops that create a high potential for nitrate leaching are those with the following characteristics: 1) the nitrogen uptake in the crop is a small fraction of the total nitrogen applied to the crop, 2) the crop requires high nitrogen input and frequent irrigation to insure rapid vegetative growth, 3) the value of the crop is such that there is a tendency to add

excess nitrogen to insure no nitrogen deficiencies, and 4) the crop is not adversely effected when more than adequate amounts of nitrogen are supplied.

With annual crops for which only a small portion of the plant is removed at harvest, the rest of the plant which contains most of the absorbed nitrogen is turned back into the soil and mineralization of the organic nitrogen releases nitrate into the soil. With perennials, the nitrogen that is stored in the tissues such as roots and stems must be considered as nitrogen that is not cycling in the soil. Some green vegetables require rapid and uniform vegetative growth which allows the total crop to be harvested at one time and which provides quality produce for the market. Economics of the production of these crops demand high availability of nitrogen and water during relatively short periods of growth. With these crops there is usually no yield or quality reduction from more than adequate available nitrogen and because the benefits are high the manager cannot take the chance of less than an adequate nitrogen supply.

There are a number of crops that have a low potential for nitrate leaching. Alfalfa, for example, requires no nitrogen fertilizer inputs and efficiently uses the available nitrogen in the soil. Some legumes also receive only small amounts of nitrogen fertilizers as compared to the non-leguminous crops. Grapes typically require low nitrogen inputs. The mineral nitrogen in the soil profile of irrigated lands planted to grapes has been shown to contain low levels of nitrate.

Some crops are fertilized at limited rates for crop quality reasons. For example, sugar yield in a sugar beet crop is reduced from excess available nitrogen during the latter stages of growth. The application of nitrogen fertilizer to oranges affects the crop quality. In the decade following

the demonstration of a negative effect of excess available nitrogen on fruit quality and the development of leaf analysis to guide fertilizer application, the amount of nitrogen used on this crop in California decreased about 50%. Thus not all fruit crops and not all vegetable crops result in high nitrate leaching.

#### **6E: CLIMATE**

Leaching of nitrate from root zones is likely to increase when the amount of rainfall exceeds the water storage capacity of the soil profile. Under these conditions, benefits are to be achieved from management practices which reduce nitrate in the soil profile at the time when high precipitation is most likely. In climatic zones where precipitation is relatively low, some combination of fertilizer and irrigation management practices are to be considered. Perhaps the problem of nitrate in ground waters is most acute in Mediterranean climates which are characterized by winter rains removing nitrate from the root zones with soil temperatures high enough for mineralization and nitrification of the nitrogen from organic matter and from crop residues. These climates are also conducive to specialized fall and winter vegetable crops with high N demands and low removals in harvested material.

#### **6F: MAPPING FOR SENSITIVITY**

Maps can be created identifying areas with various levels of potential for ground water degradation from nitrates. These maps would be valuable in identifying primary areas for imposing a shift in agricultural practices leading to less nitrate pollution. Although this section identifies the factors to be considered in developing the maps, it is beyond the scope of the report to detail the procedures for preparing such maps.

## RECOMMENDATIONS OF THE NITRATE WORKING GROUP

After reviewing an extensive amount of information on the subject of nitrate and agriculture, the Nitrate Working Group offers the following recommendations to the Director of Food and Agriculture. These recommendations offer a practical approach to controlling nitrate contribution to ground water from agricultural operations and can be initiated by the Department of Food and Agriculture in the coming year.

Agricultural sources of nitrate can be categorized as being concentrated animal waste and dispersed leaching of nitrate from crop production. The amount of nitrate being contributed to ground water from agricultural sources varies greatly due to many factors. Soil types, irrigation practices, crop selection, and fertilizer management must be taken into account when considering the degree of nitrate leaching. Because of the complexity and diversity of the factors that involve nitrate contribution from agriculture, there is no simple solution that can be applied. The best approach to developing a workable nitrate control program is to establish local management programs in areas found to have a high level of nitrate sensitivity.

The Nitrate Working Group recommends that the Department establish a nitrate management program which includes the following components:

1. The Department should map areas in the state based on sensitivity to ground water pollution by nitrate. Existing nitrate levels, agricultural operations, soil types, hydrologic conditions and urban development should be considered in the mapping. The Department should work cooperatively with the State Water Resources Control Board, Department of Water Resources and other appropriate groups in developing the map and designating areas as being nitrate sensitive.

2. The Department should use the maps to establish a priority list of nitrate sensitive areas in which local nitrate management programs will be established. The most sensitive areas should receive the highest priority for establishing nitrate management programs.

3. The Department should work with the regional water quality control boards, resource conservation districts, local water districts, and agricultural interests in establishing local nitrate management programs. The programs should emphasize mitigation measures that can be practically incorporated into agricultural operations and are specific to the area.

4. The Department should work with the University of California to establish Best Management Practices (BMPs) that can be utilized in local nitrate management programs. This report summarizes an array of manure handling, fertilizer and irrigation management practices from which BMPs can be developed.

5. The Department, in cooperation with the UC Cooperative Extension, should sponsor a research and demonstration program on nitrate control through irrigation, fertilizer and manure management. The program should investigate new technologies, and emphasize practical management options for California agriculture. The information from the research and demonstration projects should be used in developing the local nitrate management programs.

6. The Department should evaluate the effectiveness of the local nitrate management programs by monitoring the adoption of the Best Management Practices and other voluntary mitigation measures by local farmers on a regular basis.

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