Predicting Ground-Water Nitrate-Nitrogen Impacts

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Abstract

The buildup of nitrates in upper ground-water zones is a potential cumulative effect of on-site sewage disposal practices which is not addressed by standard siting and design criteria. Literature concerning the contribution and fate of nitrogen beneath septic tank disposal fields is reviewed. From these findings, convenient, simplified methods are developed for estimating long-term ground-water nitrate increases on an area-wide basis. The methods are presented in a manner useful to engineers, planners, and regulatory agencies for routine evaluation of existing and proposed land developments and for design of large, common disposal systems. Typical solutions are shown graphically to illustrate the relative importance of various factors, including development density, rainfall recharge, and soil denitrification. Predicted values are compared with actual monitoring data for three California communities to verify the reasonableness of the suggested methods. Several possible regulatory applications are suggested.

Introduction

The use of on-site subsurface sewage disposal systems, in particular septic tank disposal fields, has long been recognized as one of the most effective means of dealing with domestic waste-water problems in rural settings. Many soils have a high capacity to accept, filter, and assimilate sewage effluent. Also, in sparsely populated areas, the availability of large amounts of open land tends to minimize possible water quality or public health effects associated with such sewage disposal practices. There is now, however, a growing trend to make permanent use of on-site systems for large-scale urban fringe, rural residential, and recreational developments. Small, unsewered communities are also tending more and more to maintain and continue with the use of septic tanks rather than embarking on major sewerage construction projects.

During the past several years, water quality and public health agencies and researchers throughout the country have worked to develop guidelines and criteria to improve on-site sewage disposal practices. The aim has been to minimize potential health and water quality problems associated with the siting, design, construction, and maintenance of such systems. The main concern is the protection of water supplies and general public health from the standpoint of bacterial contamination and disease transmission. Protection of ground-water quality, for example, is achieved by requiring a specified vertical separation distance between the disposal system and the highest expected rise of the water table. This provides an unsaturated soil zone wherein high degrees of physical, biological, and chemical treatment occur. Surface waters are similarly protected by the establishment of lateral setback requirements.

An important water quality issue that previously has not been addressed in guidelines and regulations is that of the persistent or increasing effect of large numbers of systems in concentrated areas. For example, many substances contained in sewage are soluble and may move relatively unaffected through the soil to accumulate in underlying ground waters or discharge to adjacent surface waters. Also, under certain conditions, the total volume of sewage discharged from many systems may alter local ground-water levels to the point of affecting the performance of individual systems or the degree of treatment provided by the soil system (Finnemore and Hantzsche, 1983).

The buildup of nitrate in ground water is potentially one of the most significant long-term consequences of on-

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site sewage disposal practices. With each new proposal for development there is a growing need to quantify and evaluate possible changes in ground-water quality that may result. What are most needed are convenient and reliable analytical tools that can be used by regulatory agencies, engineers, and others to make assessments early in the planning process.

Nitrogen Contributions and Transformations

Nitrogen is present in high concentrations in septic tank effluent primarily as ammonium-nitrogen (75-80%), with organic nitrogen making up the remainder (Otis et al., 1975). Total nitrogen concentrations in such effluent have been reported to vary from 25 mg/l to as much as 100 mg/l, the average generally being in the range of 35 to 45 mg/l (U.S. EPA, 1980). Walker et al. (1973a) estimated the typical annual nitrogen contribution from a family of four to be about 33 kg. For a residential lot size of 0.25 acres, this nitrogen contribution would be more than 200 times the amount that would typically be introduced naturally from mineralization of soil organic nitrogen and precipitation.

Upon introduction into the soil through subsurface disposal fields, nitrogen may undergo various transformations, the most important being nitrification and denitrification.

Nitrification may be broadly defined as the biological conversion of nitrogen in organic or inorganic compounds from a reduced to a more oxidized state (Alexander, 1965). The predominant end product is nitrate (NO_3^-) because it is a stable anionic species. This also explains its high degree of mobility in the soil. Virtually complete nitrification of ammonium-nitrogen has been found to occur in the unsaturated zone in well-aerated soil below septic tank disposal fields (Walker et al., 1973b). The resulting nitrate may then pass easily through the soil along with percolating effluent and other recharge waters. Immobilization of NO_3^- by plants or through microbial uptake into biomass may occur to a limited extent, but these are generally considered to be insignificant NO_3^- sinks (Alexander, 1965; Lance, 1972), and thus largely ineffective in reducing the amount of NO_3^- available for percolation to ground water.

Denitrification refers to the biological or chemical reduction of nitrate and nitrite to volatile gases, usually nitrous oxide and molecular nitrogen or both (Broadbent and Clark, 1967). It is the only mechanism in the soil that can effect significant reduction of nitrate in percolating effluent (Alexander, 1965; Lance, 1972). The most favorable soil conditions for denitrification are (a) the abundance of organic carbon sustrate, (b) high soil moisture content, and (c) high soil pH (Broadbent and Clark, 1967; NAS, 1978). The rate of denitrification appears to be independent of nitrate concentration over a fairly wide range (Broadbent and Clark, 1967).

Most nitrogen balance studies of fertilizer application have indicated a large nitrogen deficit attributable to denitrification. Losses range from 1 to 75 percent of the applied nitrogen, but are typically between 10 and 25 percent (Broadbent and Clark, 1967). These rates of denitrification are generally considered to also apply to waste waters disposed of to land, although, according to the EPA, no thorough nitrogen-balance studies have been reported which either substantiate or refute this assertion (U.S. EPA, 1981). One of the few detailed studies of nitrogen beneath septic tank disposal fields is the work of Walker et al. (1973a, 1973b). This work found denitrification to be an insignificant nitrate removal mechanism in unsaturated sandy soils, as deep as 15 to 20 feet, due to the lack of anaerobic conditions and organic material which support denitrifying bacteria. It was thus suggested that the only active mechanism of lowering the nitrate content in such situations is dilution by higher quality ground water or by recharge waters.

Simplified Prediction of Ground-Water Nitrate Buildup

In the long-term, water quality in the upper saturated zone is closely approximated by the quality of percolating recharge waters. This is the critical ground-water zone in which potential nitrate impacts are likely to be most strongly expressed. A simplified prediction of the nitrate impacts of on-site sewage disposal systems over a defined geographical area can thus be made by constructing a mass balance, considering only inputs from waste water and recharge of rainfall (also meant to include snowmelt) and losses due to denitrification in the soil column and the upper portion of the aquifer.

The expression for the resultant average concentration, n_r, of nitrate-nitrogen in recharge water is given by

$$n_r = \frac{In_w(1 - d) + Rn_b}{(I + R)} \tag{1}$$

in which I = volume rate of waste water entering the soil averaged over the gross developed area, in inches per year; n_w = total nitrogen concentration of waste water, in milligrams per liter; d = fraction of nitrate-nitrogen loss due to denitrification in the soil; R = average recharge rate of rainfall, in inches per year; and n_b = background nitrate-nitrogen concentration of rainfall recharge at the water table, exclusive of waste-water influences, in milligrams per liter.

In this expression, the value of n_r is computed simply as the weighted average nitrate-nitrogen concentration of percolating rainfall and waste water, adjusted for expected losses due to soil denitrification. A critical simplifying assumption in equation (1) is that there is uniform and complete mixing of waste water and percolating rainfall over the entire developed area, and that this is completed at the water table. This assumption is made to allow calculation of a predicted mean nitrate-nitrogen concentration for the area as a whole. In reality, such complete, uniform mixing would not be expected to occur because of the irregular spatial and temporal distribution of waste-water loading and rainfall recharge. Nevertheless, the predicted value should correspond with the mean concentration in the ground water determined from representative sampling.

Full conversion of nitrogen to nitrate is also assumed in equation (1). This is a reasonable assumption in most cases.

The approximation of nitrate concentrations obtained from equation (1) also ignores dispersion, lateral flow, and mixing with ground-water flow from upgradient areas. These processes would generally contribute to additional reduction of nitrate-nitrogen concentrations in ground water to the extent that the nitrate-nitrogen concentration of ground-water flow from upgradient areas is lower. Equation (1) thus provides a conservative (worst case) first approximation of ground-water nitrate-nitrogen concentration resulting from the combined effect of on-site sewage disposal systems and precipitation. This is for estimation of long-term effects (i.e., over years) on ground-water quality, and is not intended for prediction of seasonal changes.

A common land use planning dilemma is that of determining acceptable development densities, sometimes referred to as the carrying capacity of the land. From the standpoint of ground-water nitrate-nitrogen impacts, the critical minimum gross acreage per developed lot, A, may be defined as that which would result in a value of n_r equal to 10 mg/l, the commonly accepted drinking-water limit. By setting $I = 0.01344\ W/A$ and $n_r = 10$ mg/l, and then rearranging equation (1), A is then given by

$$A = \frac{0.01344W[n_w - dn_w - 10]}{R(10 - n_b)} \qquad (2)$$

in which A is expressed in terms of gross acres/dwelling unit (DU); W is the average daily waste-water flow per dwelling unit, in gallons; and 0.01344 is a conversion factor having units acre inch day DU yr^{-1} gal^{-1}.

Typical Solutions

Solution of the foregoing equations requires input data for several disposal system and site variables, all of which can have a significant effect on the predicted nitrate-nitrogen concentration. Graphical solutions are presented here for typical ranges of these variables, as an aid in selecting appropriate values, and in identifying situations of potential concern.

The predicted resultant average ground-water nitrate-nitrogen concentration, n_r, computed from equation (1) is plotted for convenience in Figure 1 against the fraction of waste-water recharge, I, relative to rainfall recharge, R, for a selected range of values for soil denitrification, d, and waste-water nitrogen loading, n_w. Background nitrate-nitrogen loading, n_b, typically falls in the range of 0.5 to 1.0 mg/l, and is assumed here to be 1.0 mg/l. Exceptions to this would be if the area has large numbers of confined livestock or significant expanses of fertilized crops or turf areas (e.g., parks), which would tend to increase background nitrate-nitrogen loadings above the typical values suggested here. The results plotted in Figure 1 show a wide range of potential effects, highly sensitive to the initial selection of values for n_w and d. Two curves are plotted for the average value of $n_w = 40$ mg/l, with denitrification rates of 0 and 0.25, respectively. The typical range is represented on the high and low sides by the curves for (a) $n_w = 50$ mg/l, $d = 0$ and (b) $n_w = 30$ mg/l, $d = 0.25$. The curve for $n_w = 40$ mg/l and $d = 0.25$ would be considered the most representative of typical on-site sewage disposal situations (U.S. EPA, 1980; 1981). In addition to proper selection of values of n_w and d, the importance of

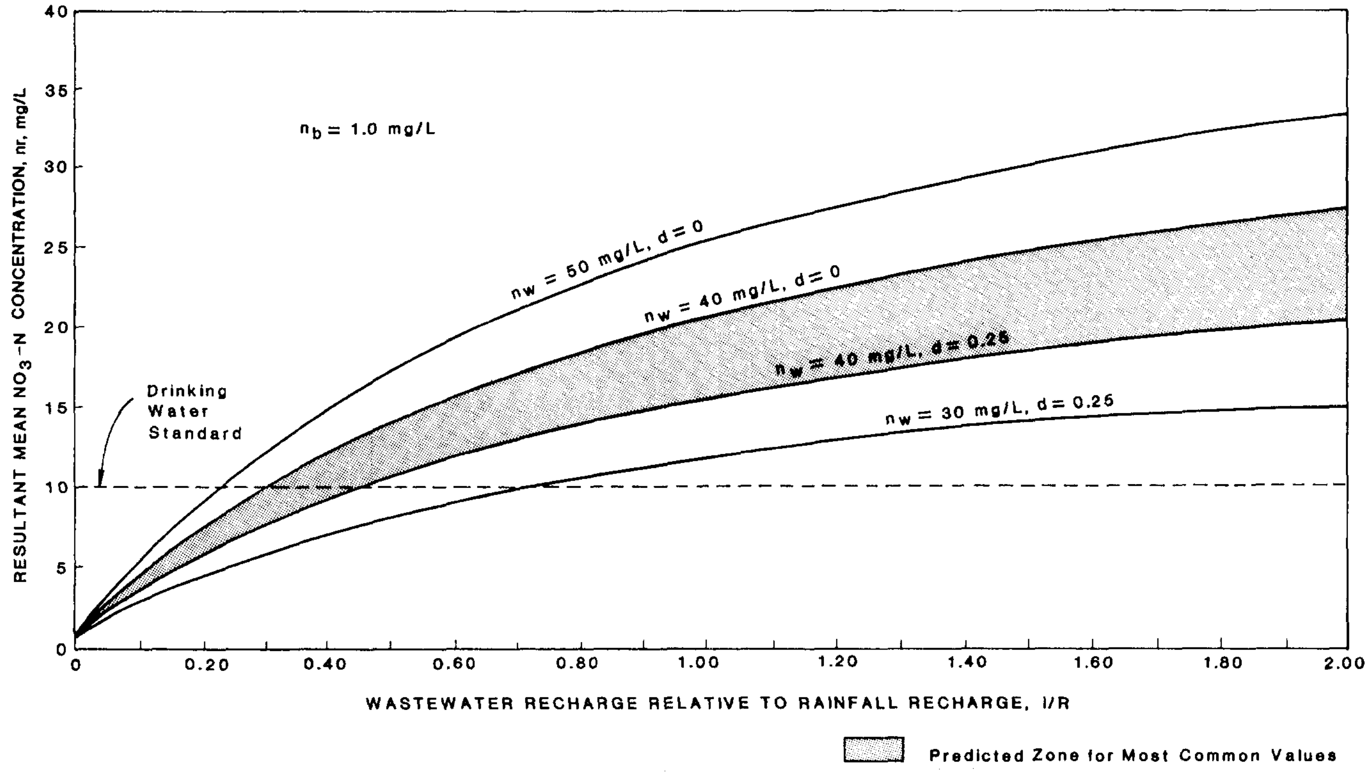

Fig. 1. Resultant ground-water nitrate-nitrogen concentration as a function of effluent quality, denitrification, and I/R.

accurately estimating the quantity of recharge waters is clearly evident, particularly in cases of higher nitrogen loading and lower denitrification rates.

In Figure 2, the critical minimum gross acreage per lot, A, is plotted against the annual rate of rainfall recharge, R, for a selected range of values for n_w and d, with $n_b = 1.0$ mg/l as before. In this instance the long-term waste-water flow, W, is assumed equal to 150 gal/day per DU, on the basis of an average expected occupancy of three persons per residence and 50 gal/person/day. The U.S. EPA (1980) cites 45 gal/day as the typical per capita flow for residential dwellings. The influence of climate and the water balance is seen to be significant, particularly for lower ranges of R, i.e., drier climates. Thus, in desert areas, very large lots may be necessary.

In typical new developments of single family residences, practical lot size limits exist because of minimum space requirements for site development, disposal fields, roadways, open space, etc. These limits may be on the order of 0.25 to 1.0 gross acres per dwelling unit, depending on local codes and specific development plans. As seen in Figure 2, such practical or statutory limits may often be more stringent than the critical minimum gross acreage per lot, A, determined from equation (2). This is particularly true as R values increase.

Case Study Examples

To demonstrate and test their validity, the preceding methods for assessing nitrate impacts were compared against the actual ground-water quality data for three California communities. All three of these communities rely on individual on-site systems for sewage disposal. In each case ground-water contamination by nitrates has been documented by extensive monitoring programs. The three communities reviewed here as case study examples are: (1) the Bolinas Mesa area in Marin County; (2) the Chico area in Butte County; and (3) the Baywood-Los Osos area in San Luis Obispo County (Figure 3).

Description of Study Areas

The general physical characteristics of the three study areas are summarized in Table 1. Background on the study sites is discussed below.

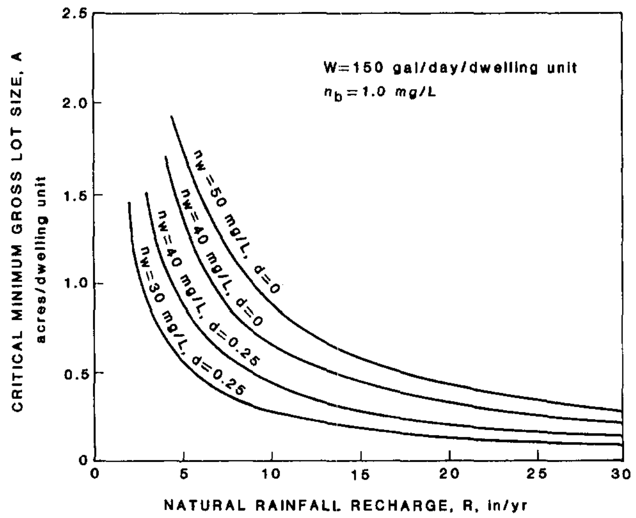

Fig. 2. Influence of effluent quality, denitrification, and rainfall recharge on critical lot size.

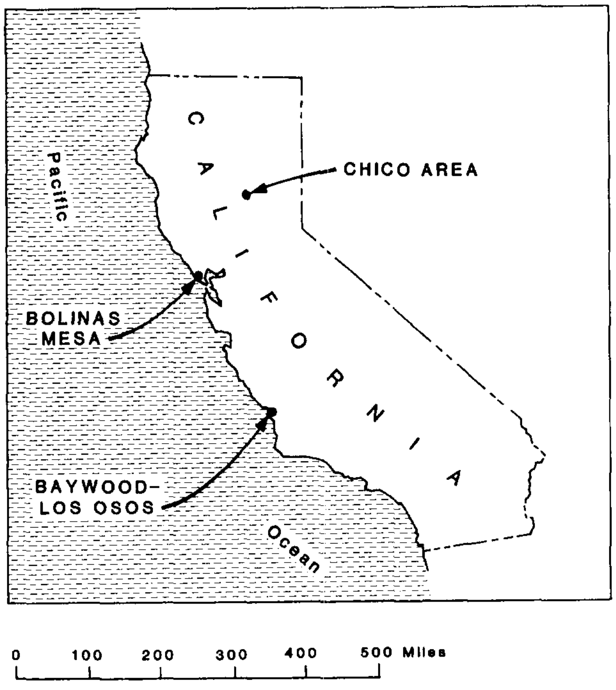

Fig. 3. Location of three case study communities in California.

Table 1. Physical Characteristics of the Case Study Areas

Characteristic	*Bolinas Mesa area*	*Chico area*	*Baywood/Los Osos*
Landform	Marine terrace	Valley floor	Coastal dune
Topography	0 to 5%	0 to 2%	3 to 5%
Soils	Sandy loam and sandy clay loam	Sandy loam	Loamy sands and sand
Depth to ground water (ft)	2 to 6	15 to 20	15 to 30
Average rainfall (in./yr)	30.9	22.5	20.0
Estimated rainfall recharge (in./yr)	14.4	16.8	12.0

Sources: see text.

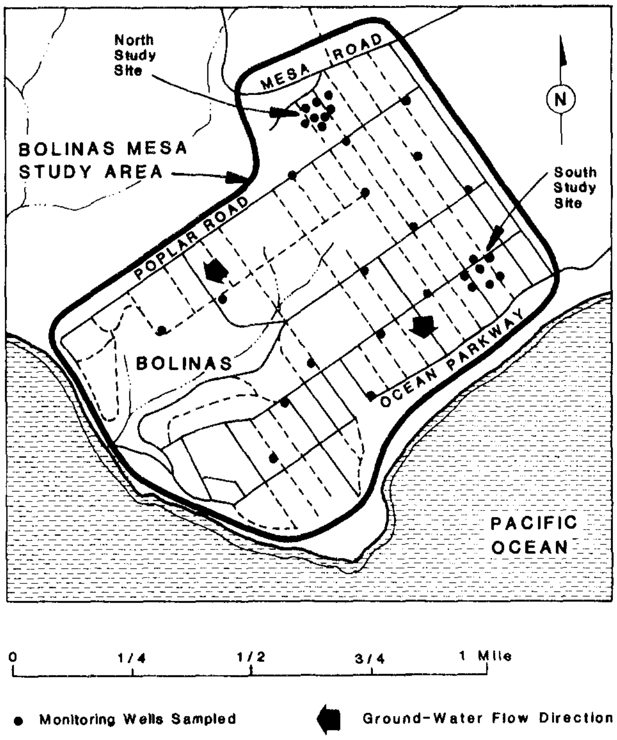

Fig. 4. Map of Bolinas Mesa study area.

Bolinas Mesa

The Bolinas Mesa area is a residential subdivision of approximately 240 acres located about 15 miles north of San Francisco. Initially created in the early 1900s, there are presently about 320 single family residences in the subdivision, on lots ranging from about 4,000 to 20,000 square feet in area (Figure 4). The subdivision occupies a coastal terrace, consisting of about 10 to 30 feet of sandy marine terrace deposits, overlying a gently sloping, relatively impermeable shale bedrock surface (Questa, 1987). Ground water collects in the terrace deposits as a result of local rainfall percolation, forming an unconfined water-table aquifer which varies from about five to 20 feet in saturated thickness. The water table fluctuates seasonally, rising typically to within two to four feet of ground surface during the winter months, and receding to depths of five to 10 feet or more during the summer and fall. The topography of the Bolinas Mesa is such that there are no streams or other significant sources of ground-water recharge that originate from outside of the immediate subdivision vicinity, making the study area relatively isolated from a hydrological perspective.

Chico Area

The Chico study area consists of approximately 4,550 acres (7.1 square miles) surrounding the City of Chico, located in the northern part of the Sacramento Valley (Figure 5). The city itself is served by a central sewage treatment facility, so it is not considered part of the study area. The area around the city consists of a mix of single and multifamily residential units and commercial development, with a density of approximately three dwelling units per acre (CSWRCB, 1989). The Chico area is situated on recent alluvial fan materials derived from volcanic sediments and mudflows originating in the hills to the east of Chico (DWR, 1984). The alluvial deposits average about 40 to 50 feet in thickness and consist of unconsolidated cobbles, gravel and sand, and minor amounts of clay. These deposits support a shallow unconfined aquifer that is recharged directly by infiltration from precipitation, local runoff, and discharge from subsurface sewage disposal. Older alluvium immediately underlies the recent alluvium and extends to depths of nearly 450 feet. It is characterized mostly by thick clay layers and cemented sand and gravel. In this zone, ground water occurs mainly in thin uncemented sand and gravel lenses under semiconfined conditions, recharged by vertical leakage from the overlying recent alluvium and from incised streams east of Chico.

Baywood-Los Osos

The Baywood-Los Osos area is an unincorporated coastal community located west of the City of San Luis Obispo, immediately south of Morro Bay (Figure 6). The majority of the area was subdivided largely for residential development in the early 1900s but significant development did not occur until the 1950s. The area impacted by on-site sewage disposal systems comprises about 2,350 acres, with a present density of approximately two to two and a half dwelling units per acre, and typical lot sizes in the range of 5,000 to 10,000 square feet (CRWQCB, 1983). The Baywood-Los Osos community is situated in the western end of Los Osos Valley, in an area dominated by marine sediments and dune deposits (DWR, 1973; Zipp, 1979). The valley is believed to consist of a single, unconfined aquifer system with a few isolated confined areas. The primary aquifer consists of alluvium, sand dune deposits, and a thick underlying siltstone known as the Paso Robles Formation. The sand dune deposits are as much as 250 feet in thickness and, historically, this formation has served as the principal source of supply to pumping wells. The water table in the area occurs at depths ranging typically from 15 to 30 feet below ground surface.

Summary

Table 2 summarizes, for each of the three study areas, the development characteristics that are pertinent to the assessment of nitrate loading impacts. For Chico and Baywood-Los Osos the data and calculated quantities are shown for the respective study areas as a whole. For the Bolinas Mesa area, data are also shown for two smaller subareas within the overall study area which are labeled, respectively, the North and South study sites. This was possible because of the very site-specific data available for these two subareas. No similar subarea data were readily available for the Chico and Baywood-Los Osos study areas.

The overall land area and the number of dwelling units for each area were obtained from maps and published documents prepared by the various county and state agencies that have studied the respective areas. The density (dwelling units per acre) and average gross acreage per lot (acres per dwelling unit) were computed directly from the given figures

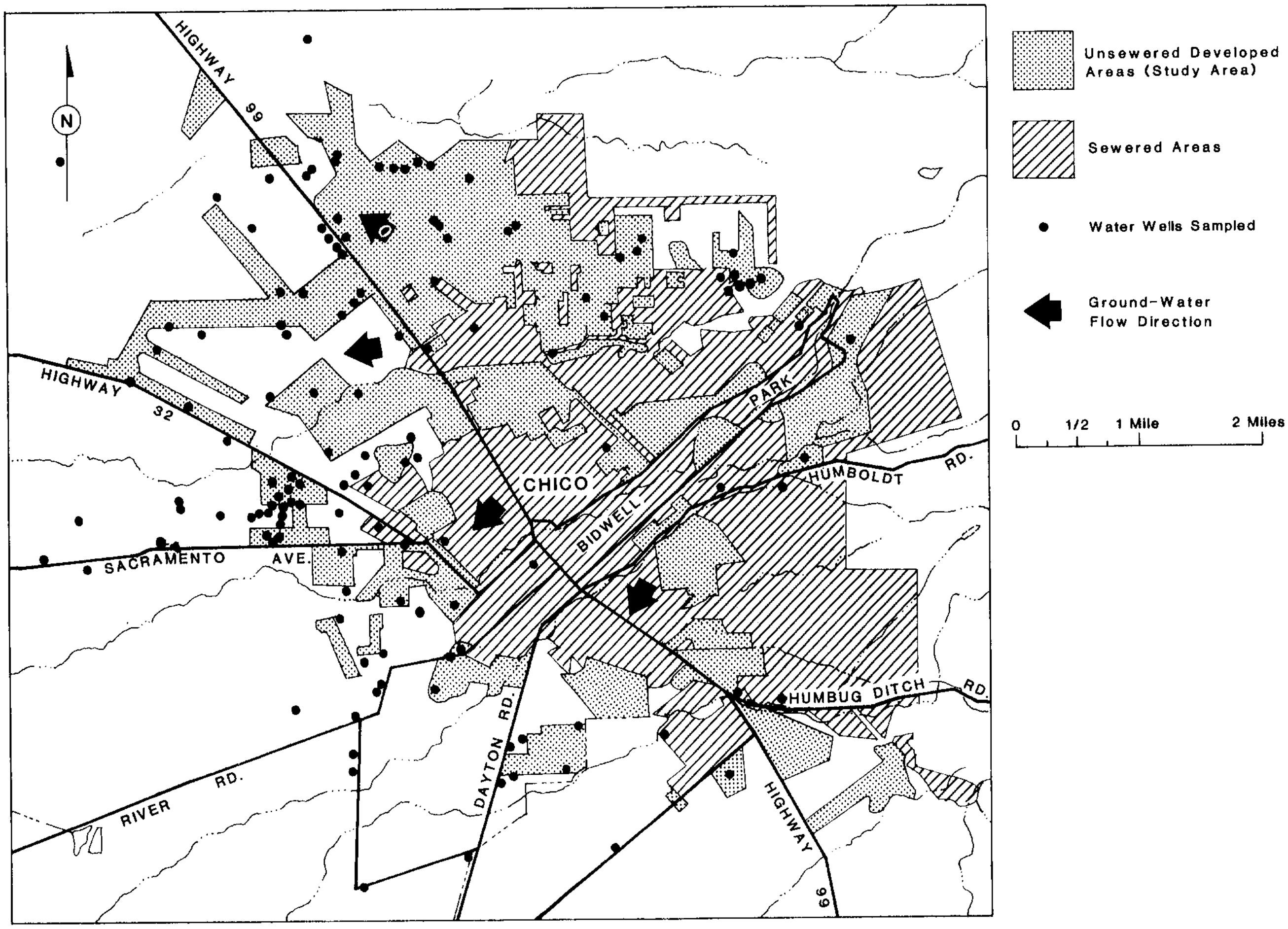

Fig. 5. Map of Chico study area.

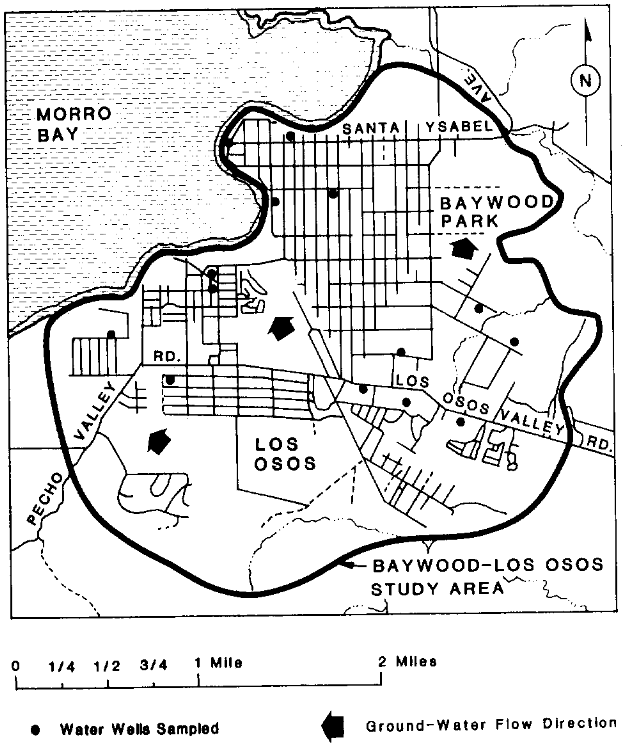

Fig. 6. Map of Baywood-Los Osos study area.

for land area and dwelling units. The waste-water loading (inches/year) reflects the discharge from all existing waste-water systems, averaged over the entire study area. An assumption of 150 gpd/DU was used for this calculation. The final entry expresses the waste-water loading, I, as a fraction of the annual rainfall recharge, R, for each study area (from Table 1).

Ground-Water Quality Data

In each of the three study areas, the effects of septic systems on ground-water quality have been a concern of the local health department and the respective California Regional Water Quality Control Board (there are nine such Regional Boards in California). As a result of these concerns, water quality sampling programs were conducted (DWR, 1984; CSWRCB, 1989; CRWQCB, 1983/84; Questa, 1987). Representative data compiled from these sampling programs are summarized in Table 3.

For the Bolinas Mesa area, some 30 ground-water monitoring wells were installed in the shallow marine terrace aquifer specifically for the purpose of monitoring septic system effects on ground waters. Well locations are shown on Figure 4. Samples were collected during the 1985-86 water year (October-September) and were analyzed for nitrate-nitrogen, ammonia, and total Kjeldahl nitrogen

Table 2. Development Characteristics of the Case Study Areas

Characteristic	*Bolinas Mesa area*				
	North study site	*South study site*	*Area wide*	*Chico area*	*Baywood/Los Osos*
Land area (acres)	2.75	1.72	240	4,550	2,350
No. of dwelling units (DU)	8	9	320	13,650	5,170
Density (DU/gross acre)	2.9	5.2	1.3	3.0	2.2
Gross average acreage per lot, A (acres)	0.34	0.19	0.69	0.33	0.45
Average waste-water loading over gross area, I (in./yr)	5.8	10.5	2.6	6.0	4.4
Relative waste-water loading, I/R	0.40	0.73	0.18	0.35	0.37

Sources: see text.

Table 3. Ground-Water Nitrate-Nitrogen Data Summary

Study area	*Density of wells sampled (wells per acre)*	*No. of wells sampled*	*Total samples*	*Range of NO_3-N concentrations (mg/l)*		
				Minimum	*Mean*	*Maximum*
Bolinas Mesa						
• North study site	2.55	7	21	1.5	11.7	64.9
• South study site	4.07	7	21	1.5	13.9	51.0
• Total area	0.125	30	58	0.7	5.3	64.9
Chico area	0.0286	130	289	0.0	9.6	40.6
Baywood-Los Osos						
• Upgradient wells	0.00511*	6	21	0.0	4.5	13.4
• Downgradient wells	0.00681*	8	32	0.0	10.4	40.0

*Based on estimated apportionment of total area.
Sources: See text.

(Questa, 1987). The monitoring wells representing conditions in the North and South study sites were sampled three times, and the others were sampled once. Table 3 shows the total nitrogen expressed as NO_3-N, assuming that the other forms of nitrogen, which occur in small quantities, will in time convert to nitrate within the ground water. These values were obtained by summing the nitrate-nitrogen and total Kjeldahl nitrogen data.

Nitrate-nitrogen data for the Chico area were obtained from the sampling of existing water-supply wells located within the defined study area, and drawing from the shallow ground-water zones. Well locations are shown on Figure 5. These data were obtained and reported by the California Department of Water Resources, Department of Health Services and Regional Water Quality Control Board during the period of 1984-1989 (DWR, 1984; CSWRCB, 1989).

The data shown for Baywood-Los Osos were obtained from a special monitoring study conducted by the California Regional Water Quality Control Board during 1983-1984 water year (CRWQCB, 1983/84). Samples were obtained quarterly from a network of wells completed in the upper aquifer; these included active water-supply wells and monitoring wells. The wells were distributed relatively uniformly over the Baywood-Los Osos area, as shown on Figure 6. In comparison with the other two study areas, in the Baywood-Los Osos area a significantly larger fraction of the monitoring wells (6 out of 14) is upgradient of the major concentration of development; these wells are shown in the southeast quadrant of Figure 6. Therefore, the data are shown separately for the upgradient and downgradient group of wells. The downgradient wells would be expected to show the full effect of nitrate-nitrogen additions from the entire developed area.

Comparison with Predicted Values

The mean values for nitrate-nitrogen shown in Table 3 represent, for each of the study areas and subareas, the resultant concentration that may be compared with predicted values obtained from equation (1). A graphical plot of the mean nitrate-nitrogen data for the various areas is provided in Figure 7; for comparison with predicted values, the curves of Figure 1 are included.

As indicated, the observed values for all areas, except the upgradient wells for Baywood-Los Osos, fall within the envelope defined by the curves of predicted values. This evidence of close correspondence between actual and predicted values confirms the validity of this method for estimating the area-wide nitrate effects on ground water from on-site sewage disposal systems.

With respect to the upgradient group of wells for Baywood-Los Osos, one would expect the nitrate-nitrogen concentration to be considerably less than that predicted by equation (1), because these wells are not affected by the majority of the development in the study area. This is borne out by the results in Table 3 and Figure 7, which show that the mean nitrate-nitrogen concentration in the upgradient wells is 43 percent of that observed in the downgradient wells.

Discussion

Factors to be considered when using the simplified mass balance method presented in this paper include the following:

1. The method incorporates only the vertical component of ground-water recharge, ignoring any dilution effects of lateral ground-water inflow from upgradient areas. From a planning and regulatory perspective, this is an appropriate, conservative (worst case) approach. One must consider that the nitrate-nitrogen concentrations in ground-water inflow from upgradient areas may also increase over time in response to waste-water loading or other land use activities in those areas, thus making unreliable any estimates of the degree of dilution due to lateral ground-water inflow. In circumstances where lateral ground-water inflow is determined to be significant and can be assigned a reliable constant long-term nitrate-nitrogen concentration, then the use of a mass balance model which includes such a lateral flow component, e.g., Wehrmann (1984), may be appropriate. However, even in such cases, the vertical recharge from waste water and rainfall will tend to accumulate and remain in a layer at the water table, largely unaffected by lateral inflow. This is due to the slow vertical mixing that occurs in horizontal ground-water flow. Use of the methods in this paper will protect against nitrate-nitrogen concentrations in such upper layers exceeding safe limits.

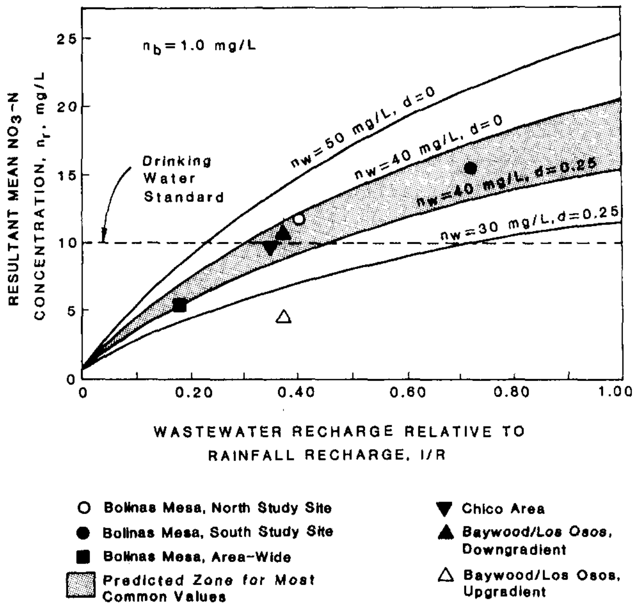

Fig. 7. Comparison of actual and predicted nitrate-nitrogen concentrations in ground water.

2. The nitrate-nitrogen concentrations predicted by the methods of this paper are long-term values. First, the development of an area to its ultimate density and waste-water loading rates may take many years. Second, depending upon the thickness and nature of the unsaturated zone, the travel time of effluent to the water table could vary from days to years. Finally, where the vertical recharge of waste water and rainfall adds to ground water in deep aquifers having little lateral flow, deep mixing will be a long-term process. Such deep mixing could be caused by deep pumping wells, leakage to even deeper aquifers, and ground-water outflow.

3. The predictive equations are intended to be used to evaluate average, area-wide ground-water conditions. They do not yield results that can be applied to a single point, such as might be required for siting or protecting an individual well. This would entail a more detailed analysis of the areal and vertical distribution of nitrate-nitrogen in the ground water.

4. The simplified methods here do not explicitly account for other identifiable sources of nitrate-nitrogen, such as animal wastes and fertilizer applications. Livestock wastes contain very high levels of nitrogen which may be a significant contributor to ground-water nitrate-nitrogen concentrations, depending upon livestock densities, soil conditions, and waste handling practices. Wastes produced by a single horse, for example, contain twice as much nitrogen as that from a typical household. This potential source should be added to the mass balance analysis when considering areas where significant livestock populations exist or can be expected within the development area.

Lawn fertilizers contribute much less nitrate-nitrogen than do livestock. For typical residential subdivisions and rural communities, a reasonable assumption is that about 10 percent of the gross area is landscaped with turf that is fertilized. The nitrogen fertilizer rate for well-kept lawns is estimated by nurseries to be about 40 to 65 lbs per year per acre of turf. Typically, 50 to 75 percent of the applied nitrogen can be expected to be consumed by plant uptake and soil denitrification (WPCF, 1990). The resultant loading to ground water is then approximately in the range of 1 to 3 lbs per year per developed acre. For an assumed rainfall recharge rate of 12 inches/year, the resultant nitrate-nigrogen concentration from the leaching of fertilizer would be about 0.37 to 1.1 mg/l. In the simplified methods of this paper, this is considered to be substantially accounted for in the assumption of a background nitrate-nitrogen concentration of 0.5 to 1.0 mg/l. Where substantial portions of the site are devoted to turf, special accounting may need to be made for fertilizer nitrate-nitrogen contributions. Mass balance models by Tinker (1991) and the Center for Environmental Research (1985) incorporate a turf fertilizer component.

5. The curves of Figures 1 and 2 show the strong influence of the rainfall recharge component on the resultant nitrate-nitrogen concentration. The application of the methods presented in this paper and the reasonableness of the results are, therefore, limited by the accuracy with which the rainfall recharge fraction can be estimated or determined by the user. For best results, the user should perform a thorough water balance analysis using techniques such as those developed by the U.S.D.A. Soil Conservation Service (1964) or Thornthwaite and Mather (1955), or other information based on local studies.

Planning Applications

The nitrate assessment procedures outlined in this paper may have a number of land use and environmental planning applications. A principal advantage is the minimal requirement for data.

Zoning and Subdivision Proposals

Preliminary evaluation of potential water quality impacts is useful when broad land use planning decisions are being made. Computation of A or use of Figure 2 can provide an initial basis for determining appropriate development densities to assure protection of areal ground-water quality.

Residential subdivision proposals can be screened for potential long-term nitrate impacts by applying equations (1) and (2). The North Coast Regional Water Quality Control Board of California and several local health departments have adopted these procedures for this purpose. An indication of no potentially excessive nitrate buildup in ground water according to the analyses presented in this paper would obviate the need for further study. In the event that preliminary analyses indicate possible problems (e.g., planned development density exceeds $1/A$), further analyses might be required to define the ground-water system and potential effects more specifically. Also, mitigation measures and ground-water monitoring requirements may be formulated based on the preliminary nitrate predictions. Possible mitigation measures might include reducing development and sewage loading densities, incorporating nitrogen removal systems (Laak, 1982), or modifying the disposal system locations or design (Harkin et al., 1979).

Buildout in Existing Unsewered Areas

Continued buildout of certain existing development areas using on-site sewage disposal systems may pose significant long-term ground-water nitrate concerns. In cases where development density is approaching critical levels predicted by equation (2), then further analysis of possible localized problems and more complete study of the ground-water system is warranted. Ground-water monitoring may be used to verify the water quality concerns indicated by the predictive equations. The preliminary analyses using equations (1) and (2) provide a rational basis for the design of field monitoring programs. Specific mitigation measures, including modified design standards, might be appropriate for any additional development that would tend to aggravate observed ground-water quality problems.

Conclusions

The accumulation of nitrate in the upper saturated zone is a cumulative effect of on-site sewage disposal practices which has not been addressed by standard siting and design criteria. This paper presents a convenient method for estimating long-term increases in ground-water nitrate-nitrogen caused by on-site sewage disposal. The method is useful to practicing engineers and regulatory agencies for the general planning and evaluation of residential developments as well as for the site-specific design of on-site sewage disposal systems. This is evidenced by their adoption in parts of California.

The greatest potential for ground-water nitrate-nitrogen problems arises in areas of low rainfall recharge and high development density. The situation may be critical if local ground waters are used for domestic water supply. Existing communities and cluster developments using large, common septic tank disposal fields are also likely to be of significant concern because of the high concentration of waste-water disposal in a limited area. In newer developments, mandatory space requirements for roads, buildings, open space, etc., will sometimes keep the overall intensity of development and waste-water application below critical levels.

Comparison of predicted values with actual field sampling data for several case study locations in California confirms that the methods provide reasonable first approximations of nitrate-nitrogen effects in ground water from septic tank disposal fields. The agreement between predicted and observed values is sufficient to enable potential areas of concern to be identified, thus making the method an effective planning tool.

A promising application of these nitrate assessment procedures is for regulatory purposes. The limited data requirements and straightforward computations make the approach widely suitable for evaluation of zoning and land use plans, subdivision proposals, and continued development in unsewered areas. The need for mitigation measures, long-term monitoring, or more detailed site investigations can also be readily determined by use of these procedures.

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