MORRO BASIN NITRATE STUDY

Prepared for the

City of Morro Bay

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EXECUTIVE SUMMARY

Water supply wells have been operated at the City's Highway 1 well field in the Morro basin since the 1950's. Increasing nitrates in ground water over time have been occurring at the well field since 1992. In 2002, nitrate concentrations in ground water at the well field began exceeding the California drinking water standard of 45 mg/l on a seasonal basis, and have been increasing approximately 7 mg/l per year.

The purpose of the study was to evaluate potential sources of dissolved nitrate contamination in ground water at the well field along Highway 1. Potential sources include agricultural and turf fertilizers, private septic system discharges, sewer exfiltration, animal operations, and miscellaneous sources. The results of this study indicate that the main source of nitrate contamination in ground water at the City's Highway 1 well field is from nitrogen fertilizer applications associated with vegetable farming operations in the lower Morro Valley.

Nitrate concentrations in ground water beneath farming operations in the lower Morro Valley have risen from an average of 34 mg/l in 1980 to an average of 160 mg/l in 2007. One of the largest increases in nitrogen loading occurred in 1988 or 1989, when a 120-acre parcel of previously non-irrigated land in the lower Morro Valley was converted to vegetable production. The intensity of farming has also increased in the lower Morro Valley, and now averages close to three crops per year per field.

Historical City well field production during the 1980's averaged 540 acre-feet per year, with nitrate concentrations averaging 6 mg/l. Since 2002, production from the well field has averaged 100 acre-feet per year, with nitrate concentrations close to 50 mg/l. This shift in nitrate concentrations is a result of changes in the proportion and concentration of the two main sources of fresh water recharge to the well field. These sources of recharge are subsurface inflow from the lower Morro Valley through the narrows, and Morro Creek stream seepage.

Most of the limited ground water production at the well field now occurs during late fall when the State Water Project shuts down for annual maintenance. Lower production reduces the amount of recharge from stream seepage adjacent to the well field, which had historically diluted nitrate concentrations coming into the area from the lower Morro Valley. Without significant dilution from stream seepage, and with increased nitrogen loading from high intensity farming in the lower Morro Valley, nitrate concentrations at the City well field began exceeding the drinking water standard in 2002, and are still increasing.

Options for mitigating the problem of elevated nitrate contamination in ground water at the City's Highway 1 well field include reducing the nitrogen load from agricultural fertilizer applications, increasing the proportion of total recharge from stream seepage below the narrows through increased well field production, and reducing nitrates in produced ground water by treatment/blending. The latter option would not reduce the actual nitrate concentrations in ground water at the well field, but could be used as an interim measure while one or both of the first two options are implemented.

INTRODUCTION

Cleath & Associates was retained by the City of Morro Bay (City) to complete a nitrate study of the Morro Valley ground water basin (Morro basin). The purpose of the study was to evaluate potential sources of dissolved nitrate contamination in ground water at the City's well field along Highway 1.

The City has operated water supply wells at the Highway 1 well field in the Morro basin since the 1950's. Dissolved nitrogen concentrations were generally below 20 mg/l as nitrate (NO_3) through the 1980's, and below 30 mg/l NO_3 during the 1990's. In 2002, nitrate concentrations in ground water from two of the City's Highway 1 wells (MB-3 and MB-4) began exceeding the state drinking water standard of 45 mg/l NO_3 on a seasonal basis. In the last two years, NO_3 concentrations at the other two Highway 1 wells (MB-14 and MB-15) have also begun exceeding the drinking water standard.

The potential sources for nitrate contamination include agricultural and turf fertilizers, private septic system discharges, sewer exfiltration, animal, and miscellaneous sources. Work completed for the study to investigate these sources included compilation of historical data sets on water quality, water levels, precipitation, and stream flow, a land use survey, collection and analysis of ground water, surface water, and raw wastewater samples, and data analysis and interpretation.

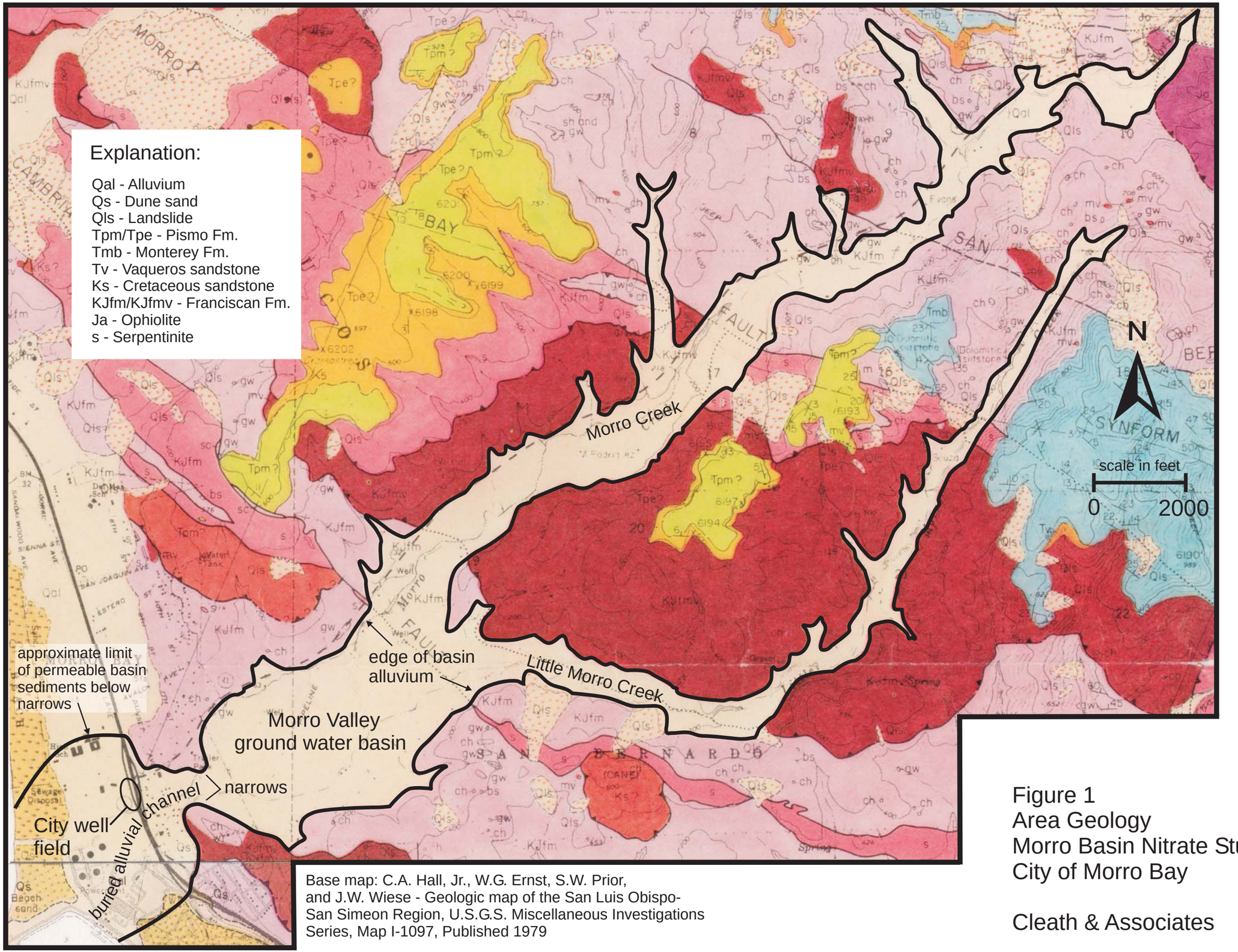
This report presents information in four sections: Hydrogoelogy, Land Use, Nitrogen Loading, and Water Quality. The information developed in these four sections is then used in a fifth section, Source of Nitrate Contamination, to discuss and interpret the information. Conclusions are followed by a final section on Mitigation, where applicable management goals and practices are referenced.

HYDROGEOLOGY

The Department of Water Resources Bulleting 118 describes the Morro basin as encompassing 1,200 acres of alluvium, dune sand, and terrace deposits. The basin underlies the valley drained by Morro Creek and is bounded on the west by the Pacific Ocean and elsewhere by Cretaceous to Jurassic age Franciscan Formation rocks (DWR, 2004).

At the west end of the Morro Valley is a narrows formed by bedrock where the valley is less than 1,000 feet across. Downstream of the narrows, alluvial deposits from the valley are overlain in part by dune sands and also grade laterally into less permeable sediments associated with the near-shore depositional environment. The deepest portion of the valley sediments between the narrows and the coast follows an ancient stream channel alignment southwest toward the bay, while the active creek channel follows a more westerly alignment and drains directly into the ocean (Cleath & Associates, 1993a). Figure 1 shows the geology of the study area, which includes the Morro basin.

Not all of the alluvial areas overlie significant saturated thickness of basin sediments. When shallow alluvial deposits nearest the valley edge, including smaller tributary channels and the uppermost portion



Base map: C.A. Hall, Jr., W.G. Ernst, S.W. Prior, and J.W. Wiese - Geologic map of the San Luis Obispo-San Simeon Region, U.S.G.S. Miscellaneous Investigations Series, Map I-1097, Published 1979

Figure 1
Area Geology
Morro Basin Nitrate Study
City of Morro Bay

Cleath & Associates

of Little Morro Creek Valley are removed, the resulting basin area is approximately 1,200 acres. Most of the ground water in storage is contained in the basin area below the confluence of Morro Creek and Little Morro Creek valleys, which encompasses approximately 850 acres.

Ground Water Occurrence and Movement

Basin sediments consist predominantly of alluvial deposits in the Morro Valley, which extend approximately 60 to 80 feet beneath the valley floor. The alluvium is comprised of sand and gravel stream channel deposits and finer-grained flood plain deposits of silt, clay and sand. Unconsolidated sedimentary deposits near the shore include beach and dune sands, and lagoonal fine grained sediments.

Two aquifer zones have been identified within basin sediments (Brown and Caldwell, 1981 and Cleath & Associates, 1993a). The deeper aquifer zone is typically overlain by sandy clays, which had been interpreted as creating confining conditions in the lower basin area (Brown and Caldwell, 1981). More recent studies, however, including ground water modeling for the sea water desalination plant wells and pumping test for a methyl-tertiary butyl ether (MTBE) plume investigation near the City well field, have concluded that the basin aquifer system is unconfined to leaky-confined (Cleath & Associates, 1993a and Aqui-Ver, 2003). Correlations between nitrate concentrations at the City well field and stream flow also support an unconfined aquifer system.

Ground water upstream of the narrows moves toward the coast. Equal-elevation ground water contour lines for fall 1954 (DWR, 1958) and spring 1970 (DWR 1972) and show southwesterly hydraulic gradients in the upper Morro Valley between 0.009 and 0.011 feet of decline in head per horizontal foot of distance (ft/ft), and 0.003 to 0.008 ft/ft in the lower valley, with up to 0.015 ft/ft through the narrows. Ground water elevation contour maps prepared for fall of 1977, 1980, 1982 (Cleath & Associates, 1993a) and 1991 (Cleath & Associates 1993b) also show ground water moving toward the coast, with up to 0.02 ft/ft of hydraulic gradient through the narrows.

Ground water movement below the narrows is controlled by the City well field. When the wells are in production, a pumping depression develops that draws water radially toward the wells, including sea water during drought. During non-pumping periods, ground water flow below the narrows is toward the coast at a nominal hydraulic gradient of 0.005 ft/ft (Aqui-Ver, 2005).

City Ground Water Production

The City has operated eight wells in the Morro Basin according to historical records (MB-1, MB-2, MB-3, MB-4, MB-5, MB-13, MB-14, and MB-15). Four of the eight wells comprise the Highway 1 well field (MB-3, MB-4, MB-14, and MB-15) which has accounted for most of the City production from the basin since 1980. Figure 2 summarizes well field production. City well production in the Morro basin and the Highway 1 well field since 1966 is included in Appendix A.

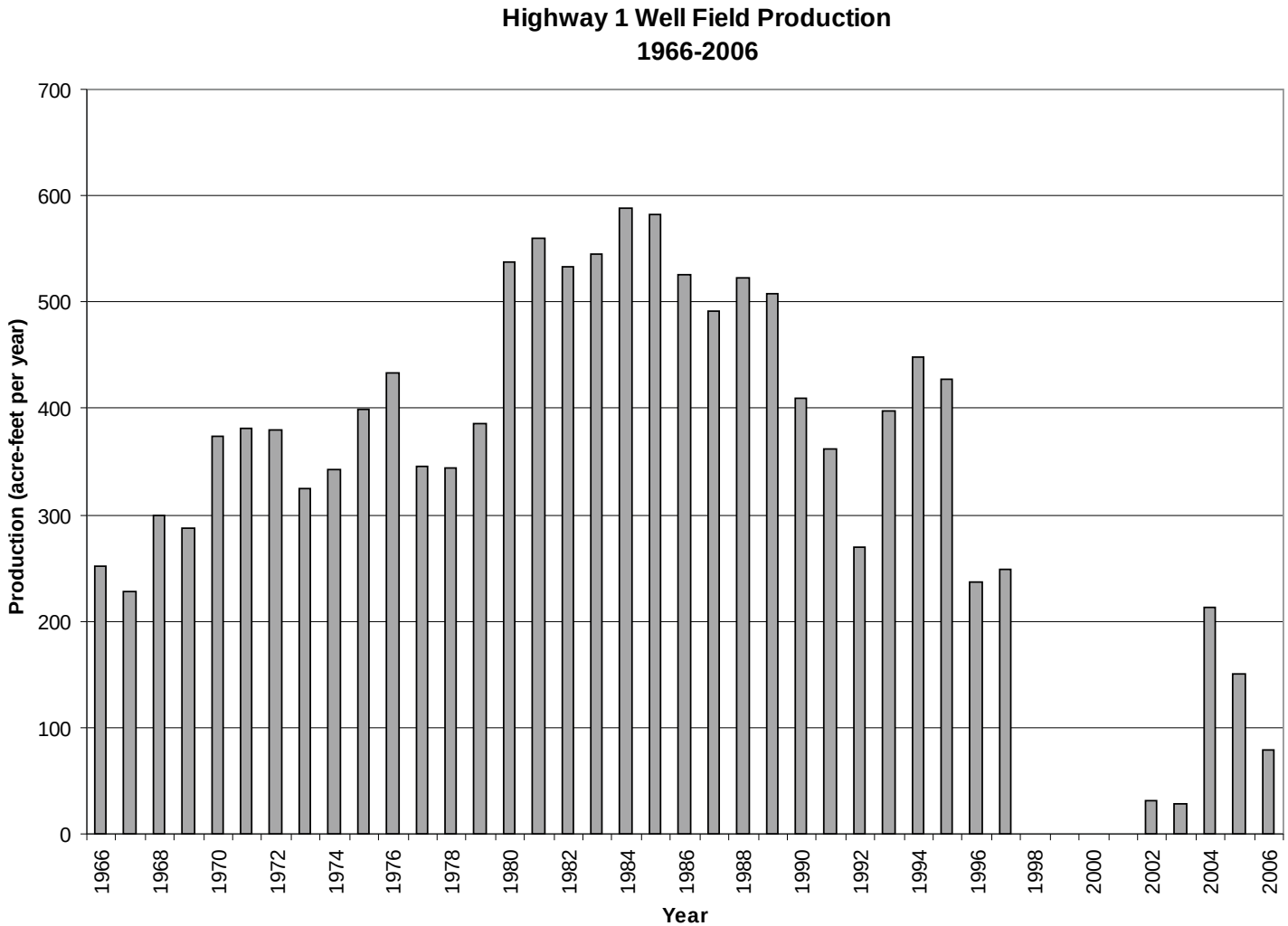


Figure 2
Highway 1 Well Field Production
Morro Basin Nitrate Study
City of Morro Bay

Cleath & Associates

The Highway 1 well field produced an average of 540 acre-feet per year for the community supply during the 1980's. In the 1990's, well field production was reduced during the drought due to sea water intrusion and stopped entirely in late 1997 with the first State Water Project deliveries. Average production between 1990 and 1997 was 350 acre-feet per year. In 1999, MTBE was detected in wastewater at the City wastewater treatment plant. Subsequent investigation in 2000 identified an MTBE plume in groundwater near the Highway 1 well field and it was not until 2002 that limited well field production was restarted to supply water during scheduled state water shutdowns (Aqui-Ver, 2003). In the last five years, well field production has varied widely, with an average of approximately 100 acre-feet per year.

Ground Water Recharge below Narrows

Ground water in storage below the narrows extracted by City wells during non-drought periods is replenished primarily from Morro Creek stream seepage, percolation of precipitation, and subsurface inflow. During drought, sea water intrusion becomes a major component of recharge. Sea water is not a source of nitrate contamination, however, and the mechanics of intrusion are not pertinent to this investigation. Subsurface underflow through the narrows and stream seepage from Morro Creek are influenced by ground water levels, which are in turn influenced by ground water production from the well field. Production from City wells is an important factor in determining the contribution of recharge from each source.

Percolation of Precipitation

Direct percolation of precipitation into Morro basin sediments below the narrows occurs seasonally. There are approximately 275 acres overlying the basin below the narrows. Rainfall at the fire station in Morro Bay has averaged 16.8 inches per year between 1958 and 2006 (SLO County Public Works records); the average annual rainfall over the basin below the narrows is estimated to be 385 acre-feet.

Development often tends to increase percolation of precipitation compared to native conditions by concentrating runoff in swales or detention basins. The relatively flat topography and proximity of the creek and bay likely precludes any increased recharge, however, and may even reduce it. Much of the increased runoff from pavements, parking lots, roofs, etc, runs directly to the creek and bay.

The amount of deep percolation of precipitation can be highly variable, ranging from approximately 3 percent to over 20 percent. For the purposes of this study, a value of 10 percent percolation of precipitation is considered reasonable, based on Cleath & Associates' experience. That would result in a nominal 40 acre-feet per year of recharge to the basin below the narrows.

Subsurface inflow

Subsurface ground water flow through the narrows can be estimated using cross-sectional flow area, aquifer permeability, and hydraulic gradient. The narrows is approximately 800 feet wide. Permeable sediments extend to a depth of approximately 50 feet below sea level, with two aquifer zones totaling approximately 30 feet of saturated sediments. Outside of drought, ground water elevations at the narrows between spring and fall typically fluctuate by five feet or less, and are close to 10 feet above sea level (e.g. hydrograph for MB-13 located close to the narrows; Appendix B). Static ground water elevations at the Highway 1 well field have shown seasonal fluctuations of close to 20 feet historically, with ground water elevations between sea level and -10 to -20 feet elevation. In recent years, static water level fluctuations have typically been 5 feet or less, with ground water elevations a few feet above sea level (e.g. hydrograph for MB-3; Appendix B).

The hydraulic gradient between the narrows and the highway fluctuates between approximately 0.015 ft/ft and 0.019 ft/ft when the well field is in full production (through 1990), based on a comparison between MB-13 and MB-3 water levels. When the well field is in limited production, the hydraulic gradient is estimated to fluctuate between 0.008 ft/ft and 0.014 ft/ft.

Mass transport modeling for MTBE used hydraulic conductivity values of 40 ft/day, 90 ft/day, and 160 ft/day to represent conditions below the narrows (Aqui-Ver, Inc., 2003). Ground water basin flow modeling for sea water well field operations was calibrated using hydraulic conductivities ranging from 4 ft/day to 100 ft/day in the narrows, with an average of 22 ft/day over the entire saturated thickness (Cleath & Associates, 1993b). Assuming an average hydraulic conductivity of 40 ft/day for the permeable aquifer zones, subsurface inflow through the narrows would be estimated at close to 140 acre-feet per year under historical conditions (full well field production) and 90 acre-feet per year under current conditions (Appendix C).

Stream Flow Seepage

Stream flow is the greatest source of fresh water recharge to basin sediments. Hydrographs show seasonal recovery of water levels immediately follow periods of stream flow. The average annual quantity of stream flow recharging basin waters below the narrows on an annual basis has decreased significantly between historical and current conditions, due to the reduction in ground water extractions. Stream flow seepage makes up the difference between well field extractions and whatever recharge subsurface inflow and direct percolation of precipitation can provide (except for periods of sea water intrusion during drought).

Under 1980's historical conditions, when Highway 1 well field extractions averaged 540 acre-feet per year, the distribution of sources of recharge replenishing these extractions are estimated at 140 acre-feet from subsurface inflow, 40 acre-feet from direct percolation of precipitation, and 360 acre-feet per year

from stream flow seepage. Under current conditions, with well field extractions averaging only 100 acre-feet per year, this entire amount could be replenished without any stream flow recharge.

It is recognized that there are ongoing ground water extractions downstream of the narrows which are not associated with the Highway 1 well field. There is also subsurface outflow to the ocean and bay. These extractions and the outflow create seasonal basin storage declines which is replenished by stream flow seepage but which does not significantly change recharge dynamics at the City well field.

LAND USE

A land use survey was conducted in September 2007. The purpose of the survey is to identify current land uses as they relate to potential nitrate loading in the ground water basin. Categories for the land use survey include irrigated crops, animal enclosures and grazing lands, parks/play fields, septic systems (outside city limits), and sewer lines (inside city limits).

Crop Survey

The results of the September 2007 crop survey are shown in Figure 3. A comparison of current irrigated agricultural acreage with prior crop surveys is shown in Table 1.

Table 1
Irrigated Acreage 1977-2007
Morro/Little Morro Creek Valleys

Crop Type	Irrigated Acreage					
	1977	1984	1992	1995	2001	2007
Truck (except legumes)	35	48	150	167	151	174
Legumes	11	89	228	371	193	--
Field	70	69	--	--	--	6
Pasture	61	57	10	18	9	5
Orchard	59	187	258	361	562	798
Total	236	450	646	917	915	983

Notes: Orchard planting is not restricted to the valley floor.
Survey by DWR in 1977, 1984 and 1995.
Survey by Cleath & Associates in 1992, 2001, and 2007 w/ assistance from County records.

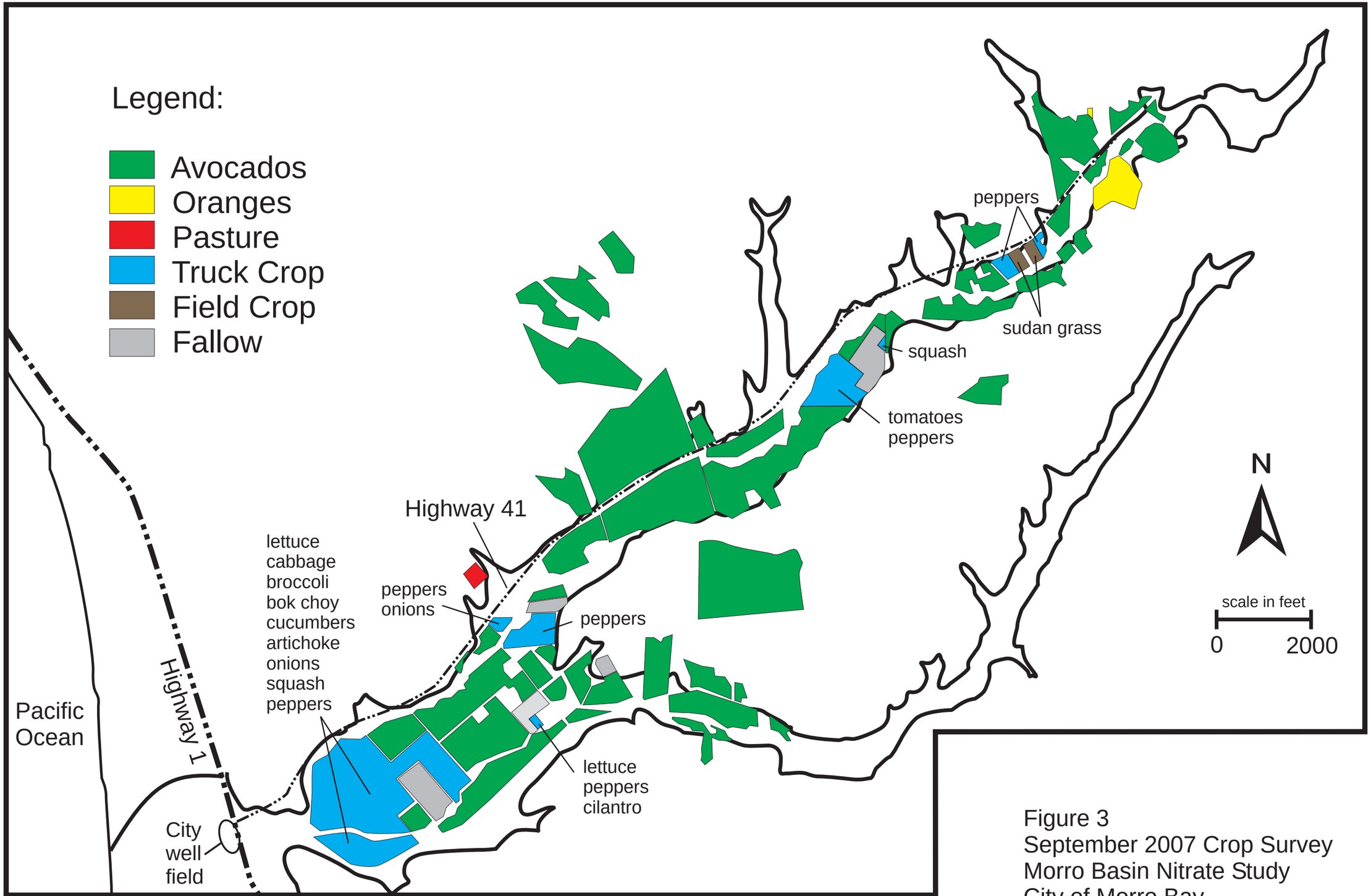


Figure 3
September 2007 Crop Survey
Morro Basin Nitrate Study
City of Morro Bay

Cleath & Associates

Field reconnaissance September 2007
using aerial photograph as base map

The most consistent trend in crops during the last 30 years is the steady increase in Avocado orchards. Avocado plantings have replaced many areas in the Morro Valley which were formerly in non-irrigated grains and field crops (1977 and 1985), and most recently peas (1995, 2001). Further expansion of the avocado growing areas to the hillsides above the valley floor also accounts for some of this increase.

The short, mild winters of the central coast allow farming on a year-round basis. The harvested acreage may be several times the farmed acreage, due to multiple cropping. Lands that are fallow during a crop survey may be planted the following month. Water use estimates for crops are adjusted to account for multiple cropping, but fertilizer applications are estimated on a per crop basis, therefore, adjustment of farmed acreage to account for multiple crops would be necessary for comparing fertilizer use from year to year.

Information on multiple cropping for surveys prior to 1995 is not readily available. There were some adjustments to the irrigated land acreage made in prior surveys to account for the use of fallow land, but details of crop rotations were not available until 1995 when spring, fall, and summer surveys were reported. Beginning in 2001, cropping information is also available for specific fields from the County of San Luis Obispo.

Higher intensity farming resumed in the lower Morro Valley in 1988 or 1989 following the conversion of 120-acres of non-irrigated valley floor to truck crops (Cleath & Associates, 1993b). In 1995, the DWR crop survey shows an average of 2.3 truck crops per year per field.

Beginning in 2001, data provided by the County Department of Agriculture/Measurement Standards was used to estimate the ratio of truck crops per year per field (except peas, which are allowed a maximum of two plantings per year per field). Where the data showed four or more crops in a field (up to seven are reported), it was assumed that two or more of the crops were being grown during the same season, such that no more than three crop rotations were allowed for any single field. Using this method, the data indicated 2.4 truck crops per year per field in 2001, 2.7 per year in 2002, and 2.8 to 2.9 in the last five years.

For surveys prior to 1995, a nominal 2.3 truck crops per year per field were assigned, except for peas and beans (legumes), which were allowed two growing seasons. The harvested acreage adjustments to 1995, 2001, and 2007 surveys are shown in Table 2.

Table 2
Harvested Acreage Adjustments 1977-2007
Morro/Little Morro Creek Valleys

Crop Type	Harvested Acreage (adjusted for multiple crops)					
	1977	1984	1992	1995	2001	2007
Truck (except legumes)	81	110	345	384	362	505
Legumes (peas/beans)	22	178	456	742	386	--
Field	70	69	--	--	--	6
Pasture	61	57	10	18	9	5
Orchard	59	187	258	361	562	798
Total	293	601	1069	1505	1319	1314

Note: Harvested acreage adjustments are for fertilizer use estimates only, not for water use.

Other Land Uses

Approximately 70 residential septic systems discharge to land overlying the ground water basin. Most of the residences are in Little Morro Creek Valley or upper Morro Creek Valley. There are less than 20 septic systems identified in the lower basin area, below the confluence of the two creek valleys.

The largest volume of wastewater generated within the study area (outside of the City limits) is Rancho Colina, a residential development with approximately 68 permanent mobile homes, a recreational vehicle park with up to 57 spaces (with sewer hook-up), and clubhouse/office facilities. Raw wastewater effluent is collected, treated, and then discharged to a spray field located on adjacent property outside of the ground water basin. The spray field serves as irrigated pasture for grazing.

The wastewater treatment facilities for Morro Bay and Cayucos are also within the study area and overlie the ground water basin. The sewer mains are located along Main Street and along Atascadero Road.

Several horse facilities were observed during the survey. These consisted of relatively small operations of three to eight horses each. Evidence of cattle grazing was observed on open lands surrounding the valley.

One park (Lila Keiser Park) is located within the study area. This park is adjacent to the City's Highway 1 well field and includes approximately five acres of play field turf grass. Another set of play fields within the study area is located at Morro Bay High School, and includes an estimated 15 acres of turf grass.

NITROGEN LOADING

The potential sources for nitrate contamination to ground water evaluated herein include agricultural and turf fertilizers, private septic system discharges, sewer exfiltration, animal operations, and miscellaneous sources. Nitrogen loading from each of these potential sources is discussed below.

Agricultural Fertilizers

The application of fertilizer with nitrogen is a common practice in commercial farming. Many factors affect the nitrogen (N) requirement of crops, and different growers may have different approaches to fertilizer use. The estimates discussed below are provided for general discussion purposes.

The 2007 crop survey categories in the study area included various truck crops (mostly lettuce and peppers), a field crop (sudan), pasture, avocados, and oranges. Prior crop surveys also included significant acreage in pasture, green beans, tomatoes, and peas, which have been identified separately for fertilizer calculations. To compare the nitrogen loading potential for the crop survey years, the applied nitrogen of various crop types published by the University of California were averaged and are presented in Table 3.

Table 3
Estimates for Applied Nitrogen per Crop

Crop Type	UC Source	Applied Nitrogen as pounds N per acre		
		Low	High	Average
Truck (lettuce)	Pub. 8098	120	200	160
Truck (hot peppers)	Pub. 7244	150	250	200
Truck (peas)	Pub. 7233	75	130	100
Truck (tomatoes)	Pub. 8017	125	350	240
Truck (green beans)	Pub. 7240	60	120	100
Field (sudan)	Circ. 104-F	assume 3 cuttings		200
Pasture	assume none (forage)			0
Orchard (avocado <5 yrs)	UCCE 2002	6	66	36
Orchard (mature avocado)	UCCE 2002	--		100

Using the above values as guidelines, estimates of the relative nitrogen applications for each crop survey year based on harvested acreage have been developed. Truck crops (except legumes) average 190 pounds N per acre, legumes average 100 pounds/acre, field crops average 200 pounds per acre (three harvests per year), and avocado averages 36 pounds N per acre for young trees and 100 pounds per acre for mature trees. The resulting nitrogen fertilizer applications are as follows:

1977: 37,000 pounds N
1985: 67,000 pounds N
1992: 135,000 pounds N
1995: 180,000 pounds N
2001: 157,000 pounds N
2007: 169,000 pounds N

The above estimates for nitrogen applications do not account for any nitrogen removal from harvest, which is substantial, and therefore are not estimates of nitrate loading to ground water. There are many variables, such as soil types, fertilizer type, crop rotations, weather patterns, irrigation practices and other individual grower practices that affect the potential for the applied nitrogen to leach to ground water. Crop residues recycled into the soils are also associated with the agricultural fertilizer source. Nitrate loading factors with spreadsheet calculations are included in Appendix D.

Turf Fertilizers

No fertilizers are applied to the play fields at Lila Keiser park. The play fields at Morro Bay High School are outside of the ground water basin in an area that doesn't provide significant recharge to the basin. Any fertilizer applications at the high school would not be expected to affect ground water quality at the City well field.

Private Septic System Discharges

Septic systems discharge nitrogen primarily as ammonia and ammonium. Total nitrogen in septic system discharges is typically in the 40-60 mg/l N range. Assuming a discharge of 200 gallons per day, a residential septic system would be releasing approximately 30 pounds N per year to the soils. For 70 systems overlying the basin, the potential nitrogen loading, with no reduction due to subsurface denitrification, would be approximately 2,100 pounds per year.

Rancho Colina mobile home park is another possible source of nitrogen loading. The number of permanent mobile homes (68) is similar to the number of ranch homes in the basin, and the nitrogen loads could be equivalent. Rancho Colina, however, collects the effluent and, after treatment, discharges the wastewater to spray fields outside of the basin. The nitrogen uptake capacity of grasses would significantly reduce the nitrogen load leaching beneath the soils.

Sewer Exfiltration

The nitrogen concentrations associated with raw wastewater leakage (liquid) from Morro Bay and Cayucos would be close to the lower limit for septic system discharges, averaging 35 mg/l N as ammonia (MRS, 2006). Flow averages 1.2 million gallons (3.7 acre-feet) per day to the treatment plant, and treated effluent is discharged to an ocean outfall. An acre-foot of effluent contains an estimated 100 pounds of N; the total nitrogen load in the effluent reaching the wastewater treatment plant is approximately 130,000 pounds N per year.

Animal Operations

For nitrate loading estimates, the nitrogen content of horse manure is assumed to be 13 pounds N per ton (UCCE, publ. # NG7-97). A 1,000-pound horse produces roughly 9 tons of manure per year, equivalent to 120 pounds of nitrogen. Assuming a total of ten horse facilities in the basin (seven were observed) averaging six horses each, the total nitrogen load from horses, before attenuation due to ammonia volatilization, soil/plant fixation, and denitrification, would be approximately 7,200 pounds N per year.

Cattle grazing is evident on open lands in the watershed. One herd of about 20 head was observed during the survey, but there are likely more in the surrounding hills. The location of the cattle operations outside of the ground water basin and the large grazing areas would reduce nitrogen loading compared to the horses, on a per animal basis. For the purposes of comparing nitrogen loading for different land uses, the order of magnitude for nitrogen loading from animal sources is estimate at 10,000 pounds N per year.

Miscellaneous Sources

Miscellaneous sources of nitrogen loading include native nitrogen-fixing plants, grading/erosion, and weed abatement, all of which involve the nitrification and leaching of organic nitrogen in soils, which can accumulate in the root zone from plant debris. Crop residue recycled into the soils is not considered part of the miscellaneous sources, but it is directly associated with the agricultural fertilizer source.

The nitrogen load from miscellaneous sources is likely not significant relative to the other sources discussed above. There are few native or open space areas remaining in the basin. Plant debris or sediment that was not flushed out to the ocean during storm events would accumulate along the stream channels, where the available nitrogen could be used for plant growth along the riparian corridor.

Nitrogen Loading Summary

Agricultural fertilizer and municipal wastewater effluent are between one and two orders of magnitude greater in gross nitrogen content than the other sources considered. Agricultural fertilizer nitrogen is

applied directly to the soils overlying the ground water basin, while wastewater effluent is piped to the treatment plant and discharged to the ocean. Therefore, among the various nitrogen sources, agricultural fertilizer has the greatest potential for nitrate contamination to ground water.

WATER QUALITY

The focus of this report is investigating nitrate contamination in ground water produced by the City well field along Highway 1. Potential sources of nitrate loading to the basin are discussed above. Finding the connection between the potential sources of loading and the actual source of contamination at the Highway 1 well field involves consideration of both historical and current water quality.

Samples of stream flow and ground water were collected in August 2007 from 22 locations in the ground water basin. All samples were analyzed for the irrigation minerals suite at Creek Analytical Laboratories (San Luis Obispo). In addition, ground water samples collected from the City wells along Highway 1 were analyzed for nitrogen and oxygen isotopes of nitrate. Water sampling results are discussed below. Laboratory reports are in Appendix E.

Historical Trends in Nitrate Concentrations

Historical water quality data was compiled from City records, the EPA Storet Legacy database, and available reports. The pertinent trends in nitrate concentrations are at the City wells and the area hydraulically upgradient (lower Morro Valley).

Highway 1 Well Field

Nitrate concentrations in ground water have been monitored at City wells in the Morro basin for over 50 years (Appendix F). Dissolved nitrogen concentrations were generally below 20 mg/l NO_3 through the 1980's, and below 30 mg/l NO_3 during the 1990's. A chemograph showing nitrate concentrations over time at municipal supply well MB-3 is shown in Figure 4. The graph indicates that sometime during the mid to late1990's, nitrate concentrations began to rise at the well. Chemographs for the other Highway 1 wells show increased nitrates as early as 1992, although wells MB-14 and MB-15 were not impacted as greatly as MB-3 and MB-4 (Appendix F).

In 2002, nitrate concentrations in ground water from two of the City's Highway 1 wells (MB-3 and MB-4) began exceeding the state Maximum Contaminant Level (MCL) for drinking water of 45 mg/l NO_3 on a seasonal basis. In the last two years, NO_3 concentrations at the other two Highway 1 wells (MB-14 and MB-15) have also begun exceeding the MCL.

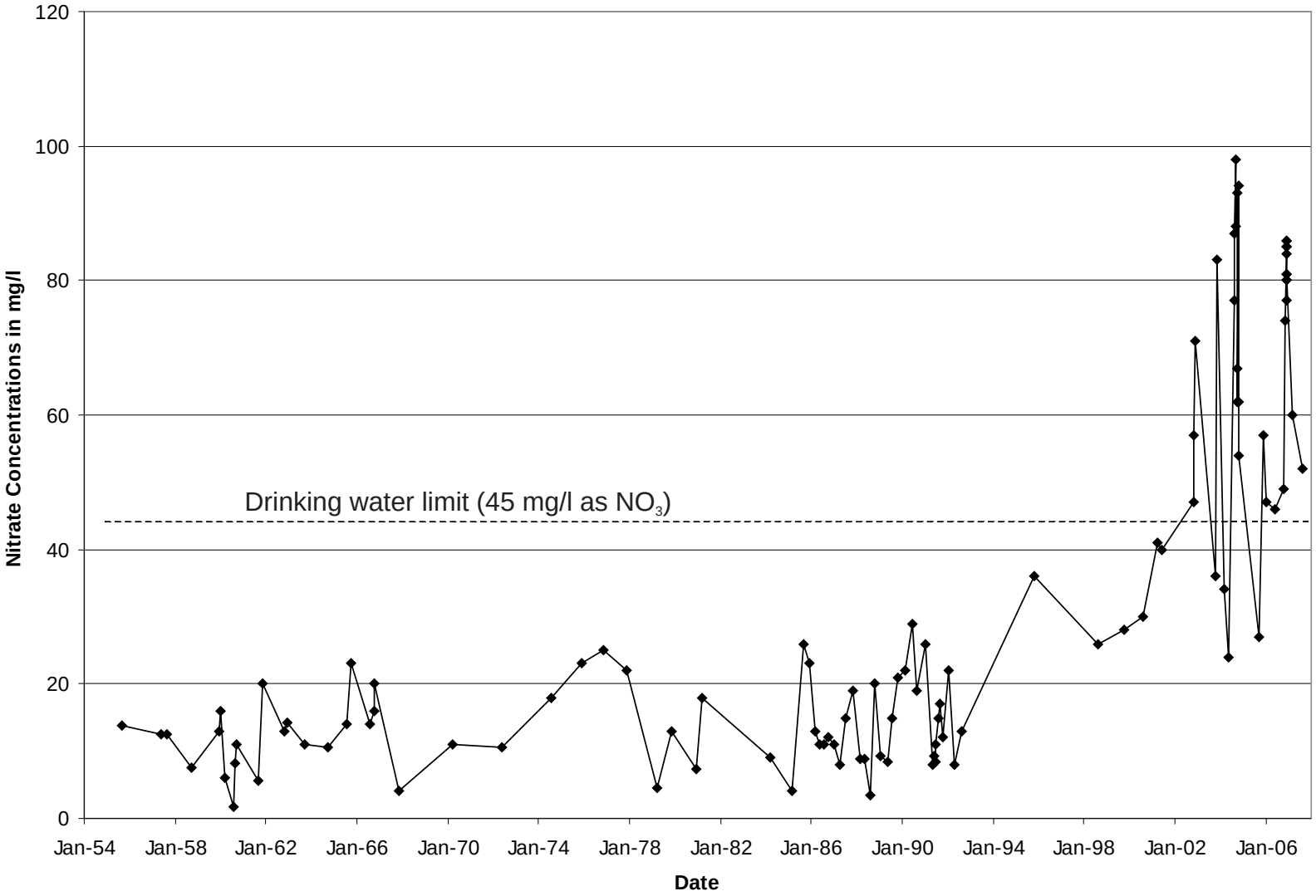


Figure 4
Well MB-3
Nitrate Concentrations
Morro Basin Nitrate Study
City of Morro Bay

Cleath & Associates

Apart from the trend of increasing nitrates over the last decade, there are also seasonal fluctuations in nitrate concentrations. Figure 5 compares seasonal fluctuations in nitrate concentrations at MB-3 with precipitation, stream flow, water levels and production during the historical period with the most available data (October 1984 - October 1992).

A review of Figure 5 shows correlations between all the data sets. Nitrate concentrations are typically greatest in the fall, when water levels are lowest. This period also coincides with the greatest production from the well field. Nitrate concentrations begin to decline with the onset of winter rain and stream flow, and are typically lowest in the spring, when static water levels have fully recovered. Production is also lowest during the wet season. The spring baseline nitrate concentrations at well MB-3 over the historical period reviewed were generally below 10 mg/l NO_3 and increase by 10 to 20 mg/l during the summer and early fall.

Lower Morro Valley

The lower Morro Valley refers the valley floor immediately upstream of the narrows. In December 1980, five wells in the lower Morro Valley were sampled for water quality. Nitrate concentrations ranged from 26 mg/l to 41 mg/l, with an average of 34 mg/l NO_3. Water samples collected at that time from the City well field ranged from 3.1 mg/l to 7.3 mg/l, with an average of 5.3 mg/l NO_3 (Brown & Caldwell, 1981).

According to the Brown & Caldwell report, historical data for a well in the lower Morro Valley (Giannini well) shows seasonal fluctuations between approximately 15 mg/l and 45 mg/l from 1975 to 1977. Text in the report also references a sampling in November 1979, during which the Giannini well nitrate concentration was within the range of other lower Morro Valley wells. The report concludes (page 3-9):

> *These [Giannini well nitrate concentration] values, therefore, are considered to be representative of the seasonal nitrate changes in the Cabrillo [lower Morro Valley] wells. Concentrations of nitrates increase in the spring but reduce in the winter months to a low in January.*

The seasonal fluctuations in the Giannini well described above are not entirely consistent with those observed at the City's wells. Nitrate concentrations at the City wells typically decline in the spring. It may be that the timing of the Giannini well data set (1975-1977), which coincides with a severe drought period, is the reason for the apparent difference. During the 1990-91 drought, nitrate concentrations at City wells MB-3 and MB-4 continued to increase through the spring. The reduction of nitrates during winter months at the Giannini well is consistent with City well trends.

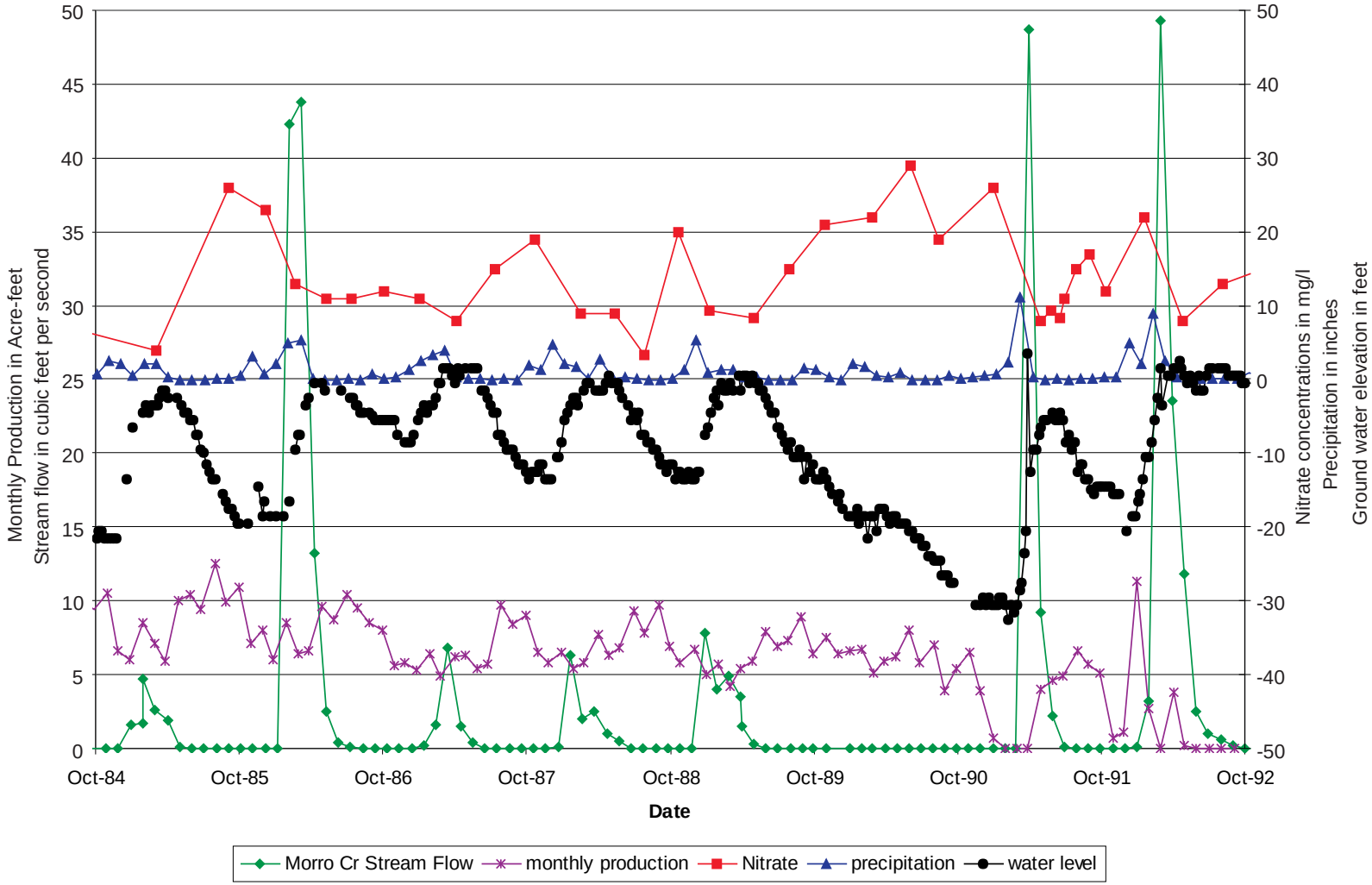


Figure 5
Well MB-3
Seasonal Correlations 1984-1992
Morro Basin Nitrate Study
City of Morro Bay

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Recent Trends in Nitrate Concentrations

Beginning in 2002, nitrate concentrations in MB-3 have exceeded the drinking water standard on a seasonal basis (Figure 4). The pattern of fluctuations, however, appears linked to well field production. Nitrate concentration peaks between 2002 and 2006 coincide with full scale production at the well field, which occurs annually around November during the State Water Project shut downs. Historically, nitrate concentrations in November were in decline, rather than peaking.

Recent nitrate concentrations in the basin are shown in Figure 6. There was little to no nitrate reported in samples collected from the upper portions of the creek valleys. The majority of the nitrate mass in the basin is in the lower Morro Valley area, where concentrations reached 220 mg/l NO_3. Below the narrows, nitrate concentrations at the City well field ranged from 38 mg/l to 52 mg/l NO_3.

A general trend of increasing nitrates over time is discernable at the City's Highway 1 well field. Seasonally adjusted nitrate concentrations at the well field have been increasing at close to 7 mg/l NO_3 per year over the last five years.

General Mineral Characterization

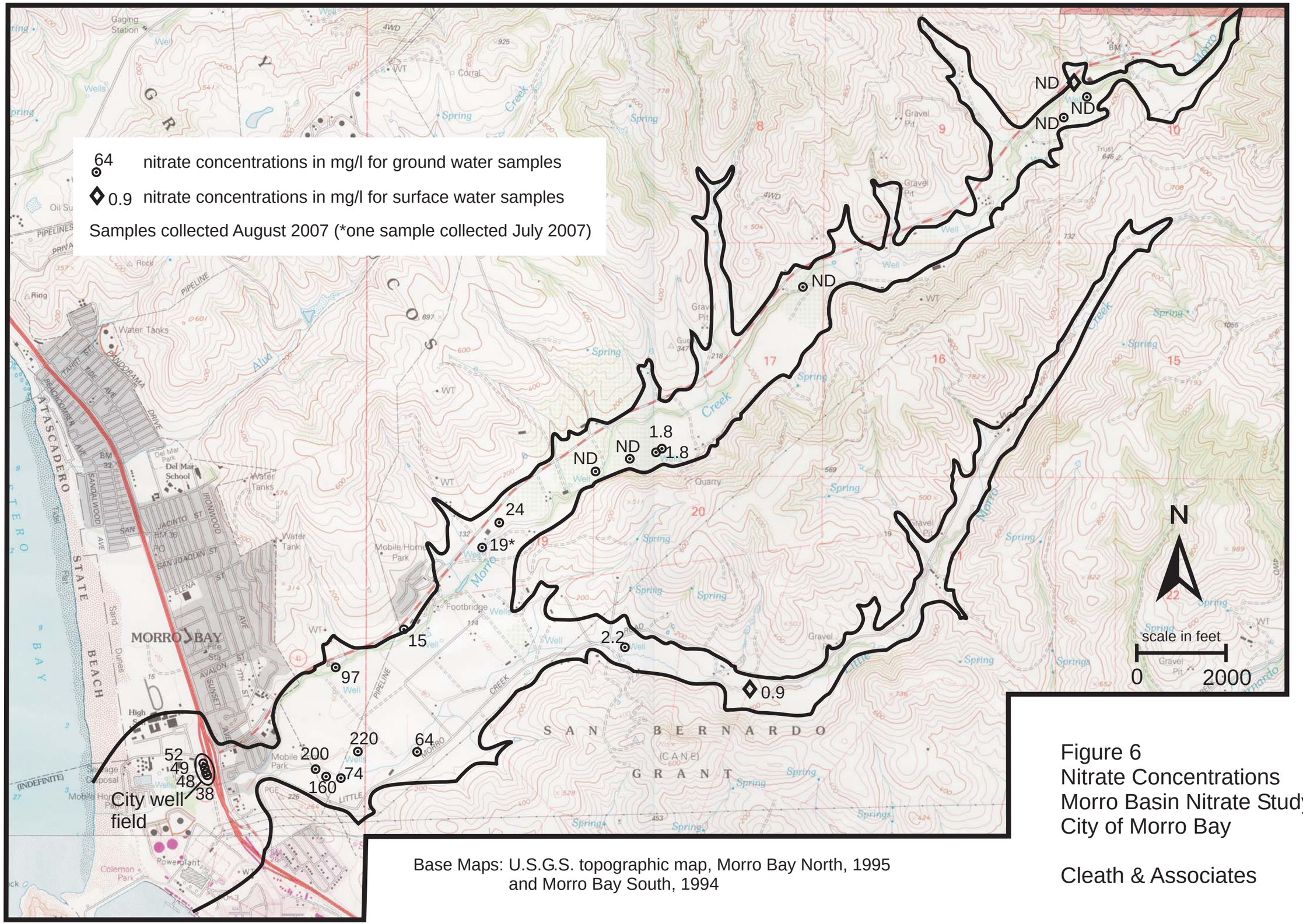
Ground water from the City well field and other wells sampled is typically magnesium-calcium bicarbonate in character, which is consistent with the base flow from the surrounding watershed. The exception is Well P, which has sodium-magnesium chloride-bicarbonate water. The water from Well P, located approximately 1,000 feet west of the City limits along Highway 41, also has twice the salinity (as total dissolved solids) of any other well in the basin and is an anomaly. Stiff diagrams with total dissolved solids concentrations for the sampled wells, along with sample locations, are shown in Figure 7.

There is a steady increase in ground water salinity between the upstream and downstream portions of the Morro Valley. The uppermost portion is close to 400 mg/l total dissolved solids (TDS). Upstream of the confluence with Little Morro Creek Valley, TDS concentrations are between 540 mg/l and 670 mg/l. In the lower valley area, TDS concentrations range from 690 mg/l to 1000 m/gl (excluding Well P).

TDS concentrations decrease slightly below the narrows. Ground water from the City well field contained between 640 mg/l and 760 mg/l TDS.

Wastewater Quality

Raw wastewater samples were collected on October 2, 2007 from the Cayucos and Morro Bay sewer pipes along Atascadero Road and from the inflow pipe at the headworks building of the wastewater treatment plant. Analytical Results of the samples are in Appendix G.



Base Maps: U.S.G.S. topographic map, Morro Bay North, 1995 and Morro Bay South, 1994

Figure 6
Nitrate Concentrations
Morro Basin Nitrate Study
City of Morro Bay

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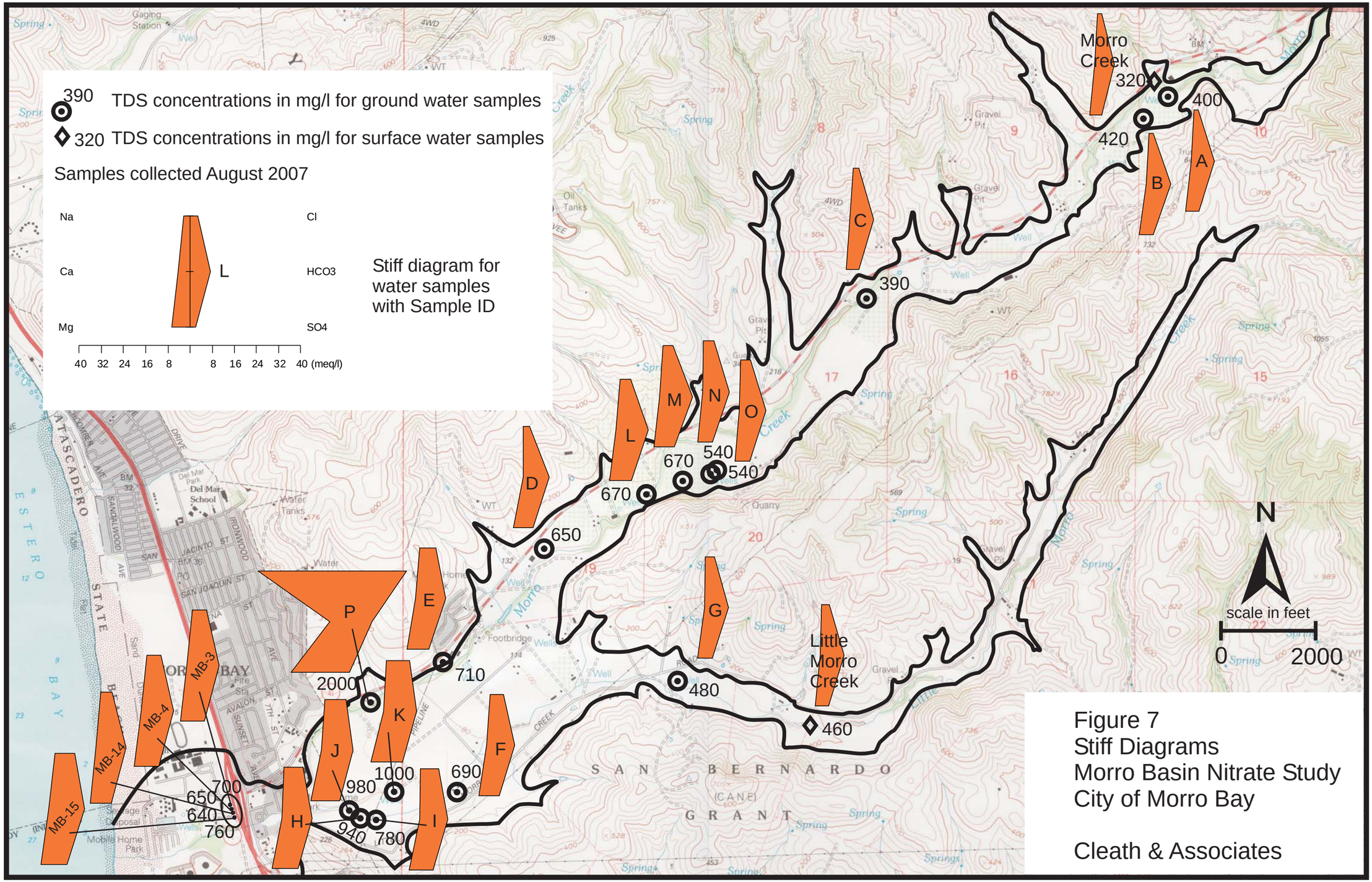

Figure 7
Stiff Diagrams
Morro Basin Nitrate Study
City of Morro Bay

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Raw wastewater samples from the Cayucos and Morro Bay sewer lines had a sodium bicarbonate-chloride character, while the sample from the headworks influent pipe (which is the combined sewer flow) was a sodium chloride-bicarbonate water. Sodium, chloride, and total dissolved solids (TDS) concentrations measured at the headworks building were greater than at either of the two individual sewer pipe water samples. The sodium concentrations increased from 160-180 mg/l in the sewer lines to 250 mg/l at the headworks, while chloride concentration increased from 190-230 mg/l in the sewer lines to 440 mg/l at the headworks. TDS concentrations increased from 810-940 mg/l in the sewer lines to 1,100 mg/l at the headworks.

The increase in salinity is interpreted to be due to fluctuations in the effluent composition over time. Effluent samples collected from the sewer lines were single event grab samples, while the sample collected at the headworks building was composited over a 24-hour period. The composited sample incorporated periods of higher effluent salinity from industrial discharges that are known to occur. Another possibility would be infiltration of brackish water into the line between the manholes and the plant, although that section of line was lined less than 10 years ago.

Nitrogen concentrations in water from the Cayucos sewer line measured 35 mg/l ammonia-N, 8.9 mg/l nitrate-N, 7.5 mg/l nitrite-N, and 6.2 mg/l organic-N. Nitrogen concentrations in water from the Morro Bay sewer line measured 28 mg/l ammonia-N, and 17 mg/l organic-N. Nitrogen concentrations in wastewater at the headworks building measured 27 mg/l ammonia-N, 5.7 mg/l nitrate-N, 1.3 mg/l nitrite-N, and 14 mg/l organic-N.

The wastewater treatment plant is capable of primary and secondary treatment, and does not include nitrogen removal. Dissolved general mineral constituents and nitrogen are not significantly different between the raw and treated effluent at the plant. Treated effluent ammonia nitrogen was measured at or below 33 mg/l in 2005, averaging 26.5 mg/l in monthly samples, and at or below 35 mg/l in 2006, averaging 25.4 mg/l in monthly samples (MRS, 2006 and 2007). General mineral data on treated effluent is reported for three samples collected July 8 through July 15, 1999 (Carollo, 2000). The treated effluent in 1999 was dominated by sodium chloride and is similar to the recent raw effluent sample at the headworks.

Figure 8 compares the major ionic composition of Morro basin ground water and wastewater for various data sets. All current and historical ground water for the lower Morro Valley and the City well field plots within a relatively close grouping of magnesium-calcium bicarbonate water (Well P excepted), while the wastewater samples are sodium bicarbonate-chloride and sodium chloride-bicarbonate waters.

Nitrate-Nitrogen and Nitrate-Oxygen Isotopes

Nitrate-nitrogen and nitrate-oxygen isotopes can be useful to ground water investigations. Shifts in isotope ratios (fractionation) may occur for various reasons in the subsurface, however, and the results of isotope studies are subject to interpretation and reconciliation with other methods of investigation.

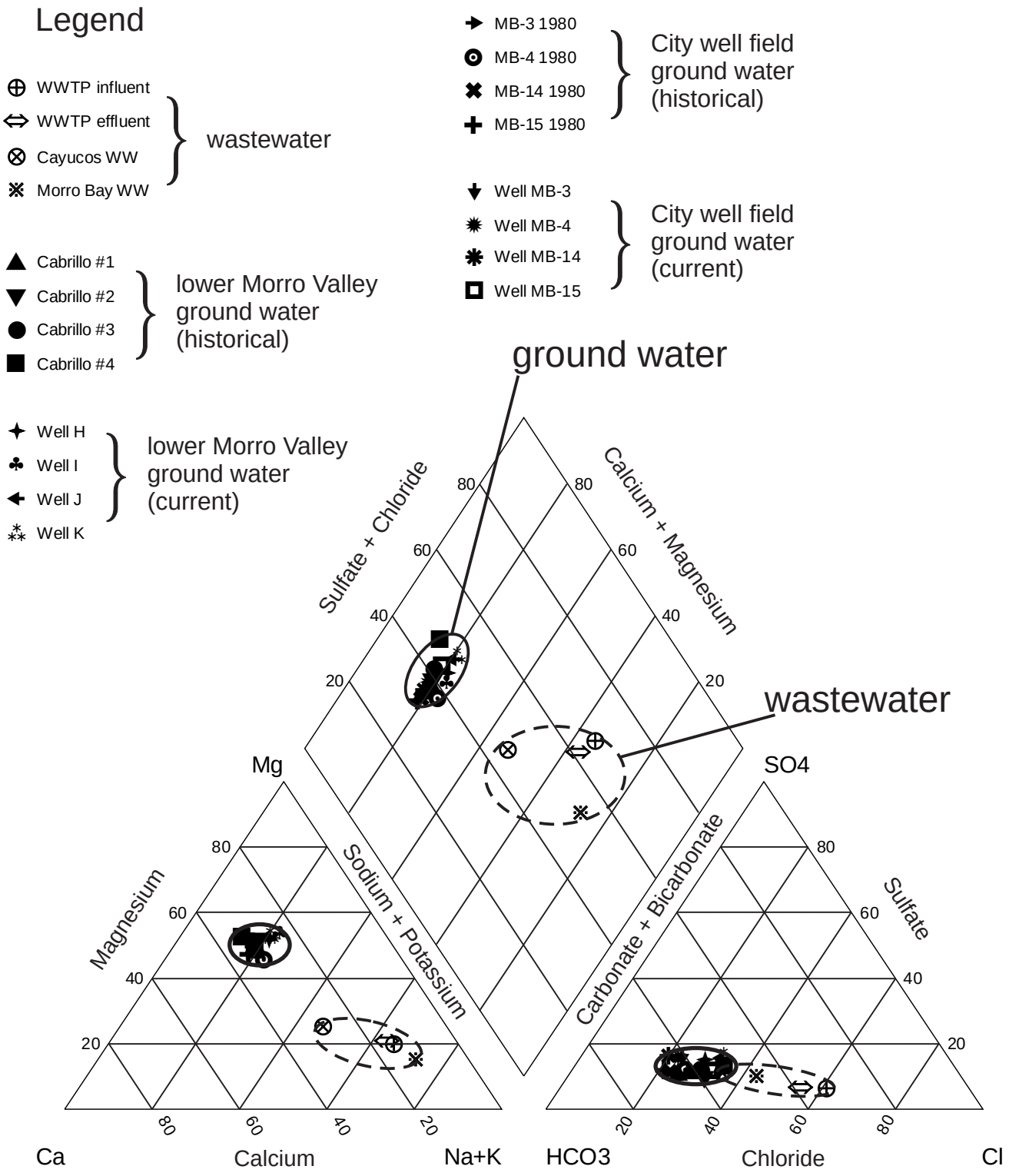

Figure 8
Piper Diagram
Morro Basin Nitrate Study
City of Morro Bay

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Ground water samples from each of the four City wells at the Highway 1 well field were collected on September 22, 2007 for isotope analyses. Analyses of the $\delta^{15}N$ and $\delta^{18}O$ isotope ratios of nitrate in ground water were performed by Zymax Forensics (San Luis Obispo). The results of the analyses are presented in Table 4.

Table 4
Nitrate Isotope Results
Highway 1 Well Field

Sample ID	$\delta^{15}N$ ($^0/_{00}$)	$\delta^{18}O$ ($^0/_{00}$)
MB-15	7.9	16.0
MB-14	7.1	12.9
MB-4	8.8	13.1
MB-3	10.0	13.6

Interpretation of the isotope data follows below. The laboratory analytical report is included in Appendix E.

SOURCE OF NITRATE CONTAMINATION

The potential sources of nitrate contamination to ground water at the City's Highway 1 well field include agricultural and turf fertilizers, private septic system discharges, sewer exfiltration, animal operations, and miscellaneous sources. Of these, turf fertilizers, private septic system discharges, animal operations, and miscellaneous sources are not considered capable of significant contributions to nitrate contamination at the well field. The rationale for eliminating these sources are:

- Turf fertilizers are not used at the community park next to the well field. The other lands uses overlying the basin near the site (City maintenance yard, power plant, trailer parks, and commercial businesses) do not have significant turf/fertilized landscape areas. The high school play fields to the north are outside of the ground water basin.

- Private septic systems and animal operations are distributed at low density in the middle and upper portions of Morro Valley and in Little Morro Creek valley. The nitrate concentrations in these areas are much lower than those measured at the City well field.

- Miscellaneous sources, including native nitrogen-fixing plants, grading/erosion, and weed abatement have a low nitrogen loading potential compared to other sources and were not noted in the lower Morro Valley, where nitrate concentrations in ground water are highest.

There are two remaining potential sources of nitrate contamination to ground water, agricultural fertilizer applications and sewer exflitration. Each of these are considered in detail below.

Sewer Exfiltration

Sewer exfiltration is the leakage of raw wastewater from a sewer system into the ground. The potential for sewer exfiltration as the source of nitrate contamination in ground water has been evaluated based on a review of the local sewer system, the general mineral quality of local wastewater and the isotope results. These evaluations, detailed below, indicate that sewer exfiltration is not a major source of nitrate contamination in ground water at the City well field.

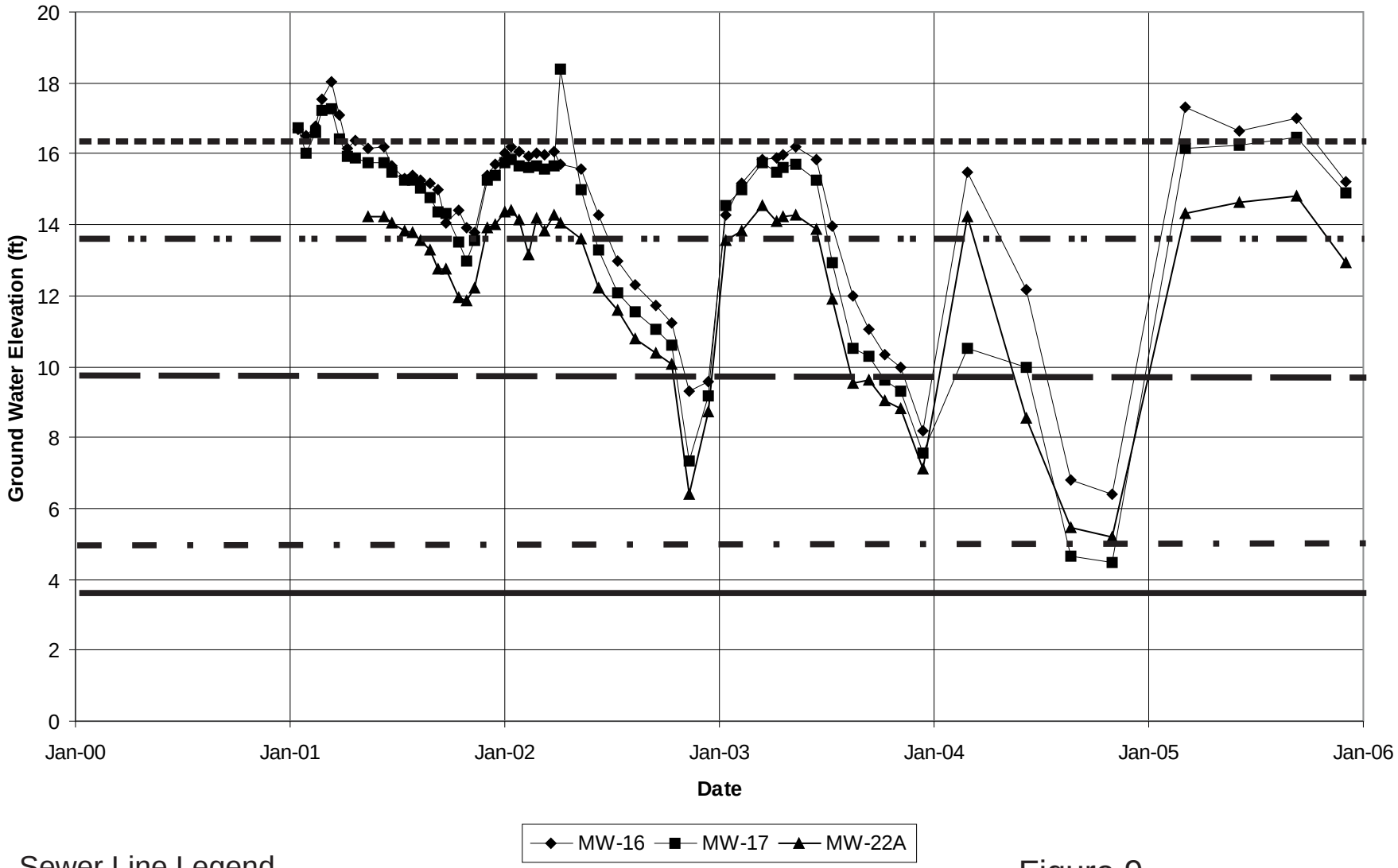
Sewer System

Water level monitoring data indicate shallow ground water elevations along the sewer line corridors in the vicinity of the City well field fluctuate between approximately 6 and 16 feet above sea level (Aqui-Ver, 2005). Sewer line elevations along Atascadero Road and Main Street opposite the City Well field are below 10 feet elevation, but rise to elevations of 14 to 16 feet above sea level along Main street north of Highway 41.

Effluent flows through the sewer pipe under gravity, without back pressure, into the headworks building at the treatment plant. Therefore, in the event of a rupture in the sewer line, water will flow into the pipe (infiltration) when ground water levels are above the pipe elevation, rather than flowing out of the pipe in the vicinity of the City well field.

A comparison of shallow ground water elevations near the sewer trenches (based on monitoring wells MW-16, MW-17, and MW-22A) is shown in Figure 9. A site plan with well locations and sewer lines is shown in Figure 10. There is a hydraulic potential for sewer exfiltration from both Morro Bay and Cayucos sewer lines along Main street when the City well field is pumping. Along Atascadero Road, the potential is negligable. In fact, local infiltration near the treatment plant was documented by City personnel in 1999, and repairs to the line were made (Aqui-Ver, 2003).

Despite a hydraulic potential for exfiltration along Main Street when the City well field is pumping, gravity sewer leaks quickly become plugged by sewer film and settleable solids in the sewage, theoretically reaching steady-state leakage rates in approximately one hour. A research study conducted at several locations in Germany, where sewer systems are generally older and in poor condition, showed



Sewer Line Legend

- Cayucos line on Main Street north of Hwy 41 near MW-16
- Morro Bay line on Main Street north of Hwy 41 near MW-16
- Morro Bay line on Main Street south of Hwy 41 near MW-17
- Cayucos line on Atascadero Road near MW-22A
- Morro Bay line on Atascadero Road near MW-22A

Figure 9
Sewer Line and
Ground Water Elevations
Morro Basin Nitrate Study
City of Morro Bay

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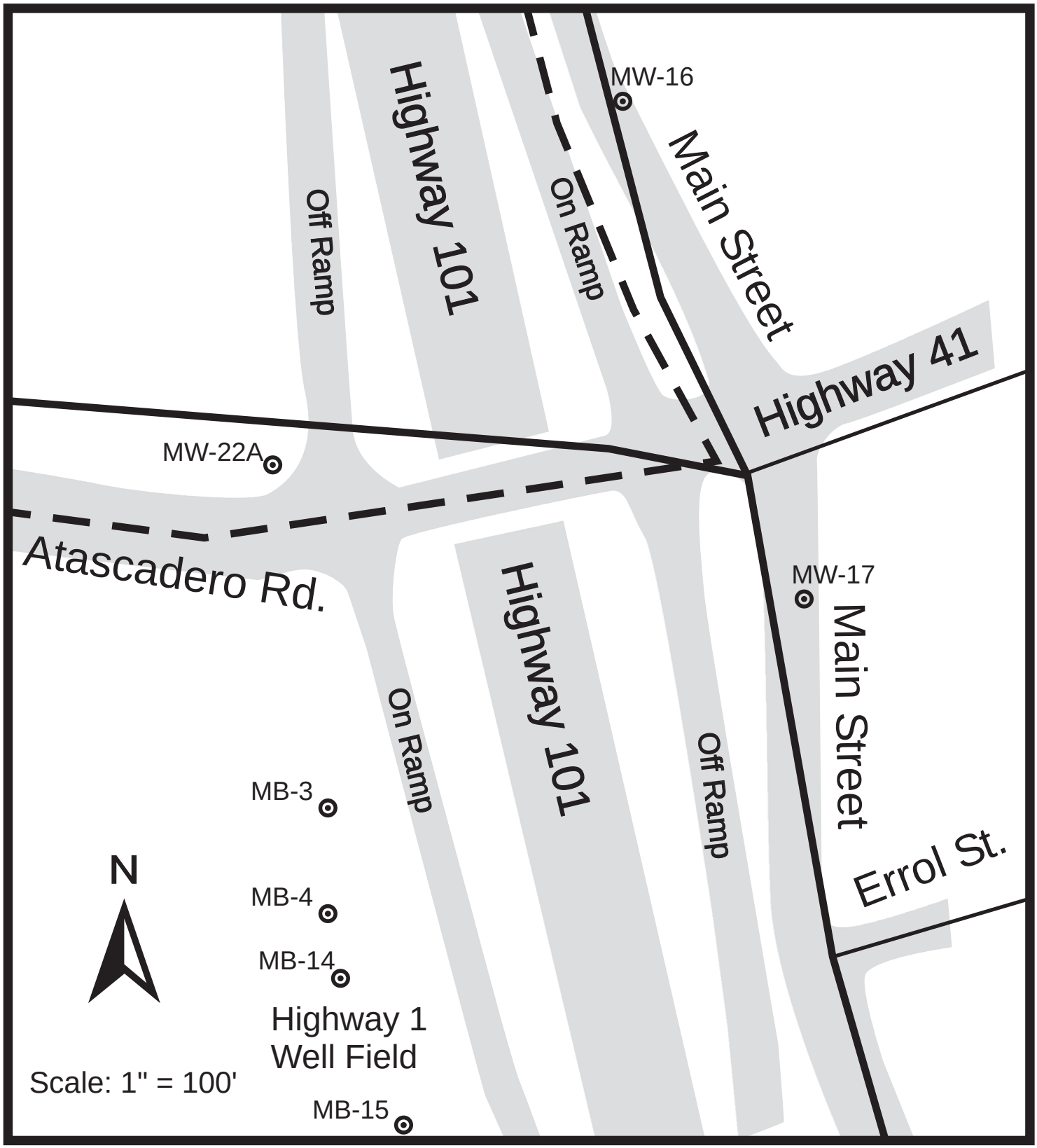

Morro Bay Sewer Main

Cayocos Sewer Main

Figure 10
Well and Sewer Pipe Locations
Morro Basin Nitrate Study
City of Morro Bay

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that when system pressure heads are below the sewer pipe crown (typical for gravity sewers) exfiltration rates were minimal (Amick and Burgess, 2000).

A review of sewer inflow fluctuations was performed for 2005 and 2006 (Figure 11). As shown in Figure 11, daily fluctuations of sewer effluent reaching the plant progresses through weekly cycles, with local highs occurring on weekends. There was little opportunity for sewer exfiltration in the vicinity of the City well field in 2005 due to elevated water levels, and the nitrate levels at the well field were also lower than normal, which is interpreted to be a dilution effect from the high precipitation. In 2006, however, nitrate levels reached new highs in ground water samples collected from wells MW-14 and MW-15. Water levels declined in the well field area, compared to 2005, and provided an opportunity for exfiltration from sewer pipes along Main Steet. All other things being equal, an increase in sewer exfiltration would result in less effluent flow to the wastewater treatment plant.

A comparison of plant inflow does show some differences between 2005 and 2006 during the second half of the year (the first half is influenced by infiltration from precipitation). The 30-day flow averages are a close match beginning in June, then slightly separates in early July and again in August and September (estimated at 30,000 gallons per day lower inflow in 2006 compared to 2005). The average inflows are closely matched again in October and stay relatively equal through the end of the year, with another slight separation in 30-day average flow for a few days during the second week of December.

There are a few possible reasons for the slight differences in flow described above, the simplest being actual differences in sewer system base flows, rather than sewer exfiltration. In fact, the timing of the observed differences in flow are not consistent with sewer exfiltration. There is no rationale for exfiltration to apparently stop in October and November 2006. The State Water Project shutdown began November 7, 2006, and nitrate concentrations at the well field increased before any potential indication of renewed sewer exfiltration is noted in the flow comparison.

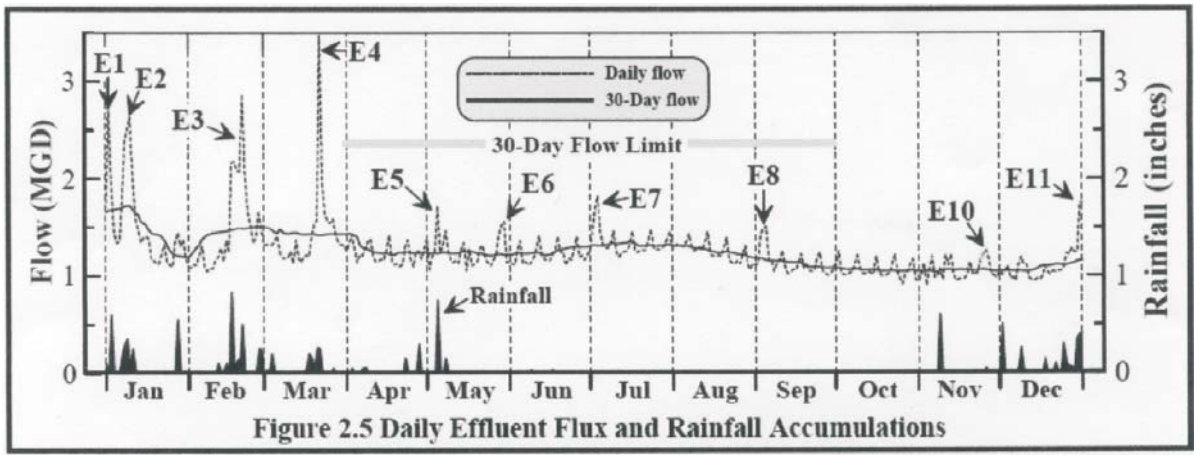
Clearly, there are many difficulties in attempting to assess seasonal sewer exfiltration through comparing pipe elevations, water levels and wastewater treatment plant inflows. Nevertheless, this preliminary analysis suggests that sewer exfiltration into the Morro basin is possible, but that it is not likely a significant source of nitrogen contamination to the City well field.

General Mineral Water Quality

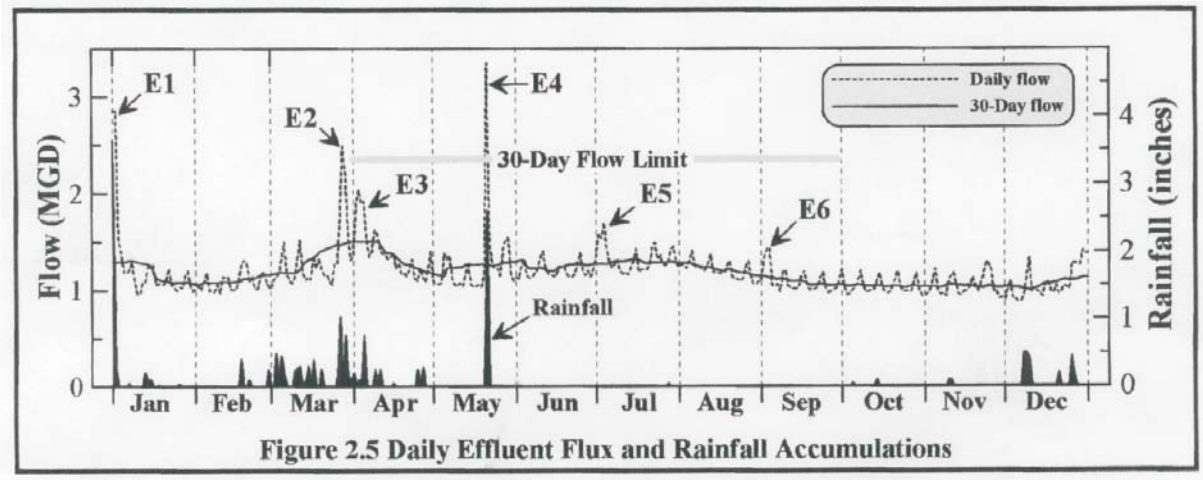
Mixing calculations have been performed to evaluate what changes in local ground water general mineral quality would be expected to occur if sewer water exfiltration were the principal source of increased nitrate concentrations at the City well field.

City well MB-3 was used for the calculations. This well has experienced the greatest amount of nitrate contamination. Table 5 below summarizes the mixing assumptions.

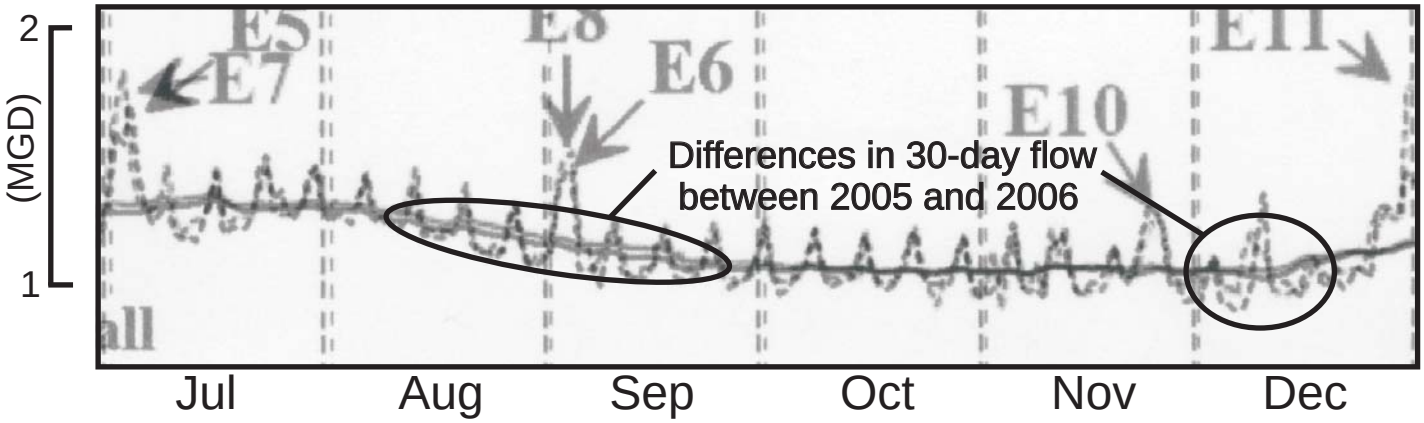
WWTP Inflow 2005



WWTP Inflow 2006



July-December comparison detail



Flow charts reproduced from:
MRS, 2005
MRS, 2006

2006 timing advanced slightly to match 2005 weekly fluctuations

Figure 11
Daily WWTP Plant Inflow
Morro Basin Nitrate Study
City of Morro Bay

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Table 5
Mixing Assumptions for Sewer Exfiltration

Description	Well MB-3 (1980's ave.)	Cayucos WW	Morro Bay WW	WWTP	Well MB-3 (2006 ave.)
NO_3	13 mg/l	228 mg/l	124 mg/l	125 mg/l	74 mg/l
Minimum mix		28%	55%	54%	

Note: Mixing requirements assume all ammonia converts to nitrate with no denitrification.

Mixing calculations show that without denitrification in the subsurface, sewer exfiltration contributions of 28 percent to 55 percent in ground water (by volume) would be needed to increase nitrate concentrations at City well MB-3 from 13 mg/l (average during 1980's) to 74 mg/l (average during 2006). More wastewater mixing would be needed if denitrification were taking place. Maximum nitrate concentrations at the well field have exceeded 90 mg/l NO_3.

Figure 12 presents the type of water that would be expected (without ion exchange) from mixing 30-55 percent wastewater (Cayucos, Morro Bay, and WWTP influent sources) with historical ground water at MB-3. All of the the six potential mixtures plot outside of the Morro basin ground water group. The current general mineral quality of water at the City well field cannot be matched theoretically when using wastewater as the source of nitrogen.

Ion exchange activity within the aquifer matrix can change the character of source waters, and a mixture of two waters may not end up as theoretically predicted. For the 30-55 percent wastewater mixtures to shift toward the composition of Morro basin ground water, there would need to be a significant depletion in sodium (>50 percent) along with enrichment of calcium and magnesium in solution. This type of cation exchange is observed at the City well field during periods of sea water intrusion.

Chloride and sulfate anions are relatively conservative in solution, however, and an evaluation of the anion mixing results shows that for the 30-55 percent wastewater mixtures to shift toward the composition of nitrate-impacted water at the City well field, there would also need to be a significant depletion in chloride (>50 percent) along with enrichment of sulfate and bicarbonate in solution (Figure 13). This would not be part of a natural ion exchange process near the well field.

Stable Isotope Results

Manure and septic system effluent is typically represented in isotope literature as having $\delta^{15}N$ of nitrate values greater than +10 $^0/_{00}$, which distinguishes it from synthetic fertilizers, which have $\delta^{15}N$ values closer to 0 $^0/_{00}$ (e.g. Clark and Fritz, 1997). It is interesting, however, that range of measured values for animal

Legend

▲ 55% wastewater mixtures (Cayucos, MB, and WWTP influent mixed with historical MB-3 ground water)

● 30% wastewater mixtures (Cayucos, MB, and WWTP influent mixed with historical MB-3 ground water)

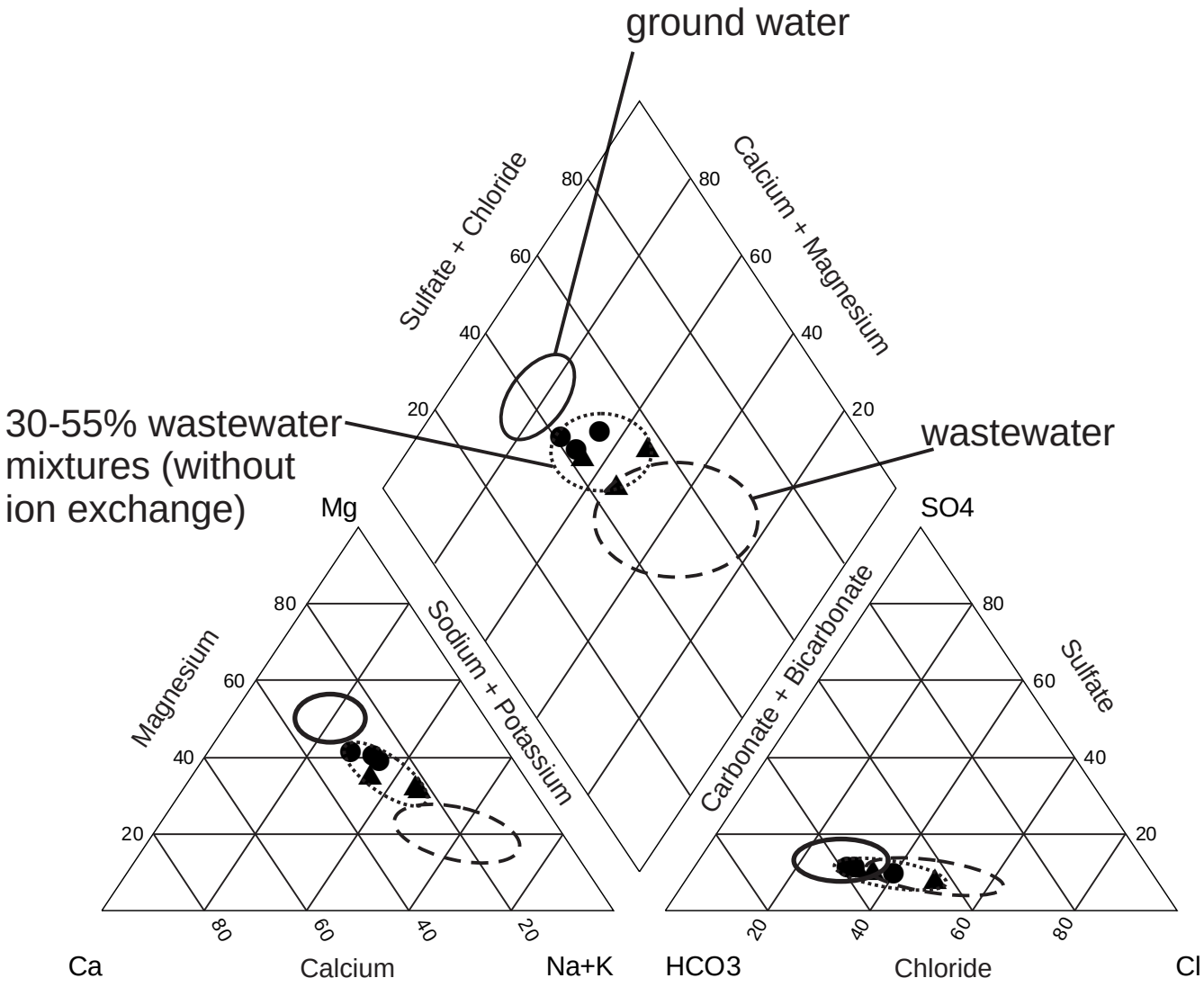

Figure 12
Ground Water / Wastewater Mixing
Morro Basin Nitrate Study
City of Morro Bay

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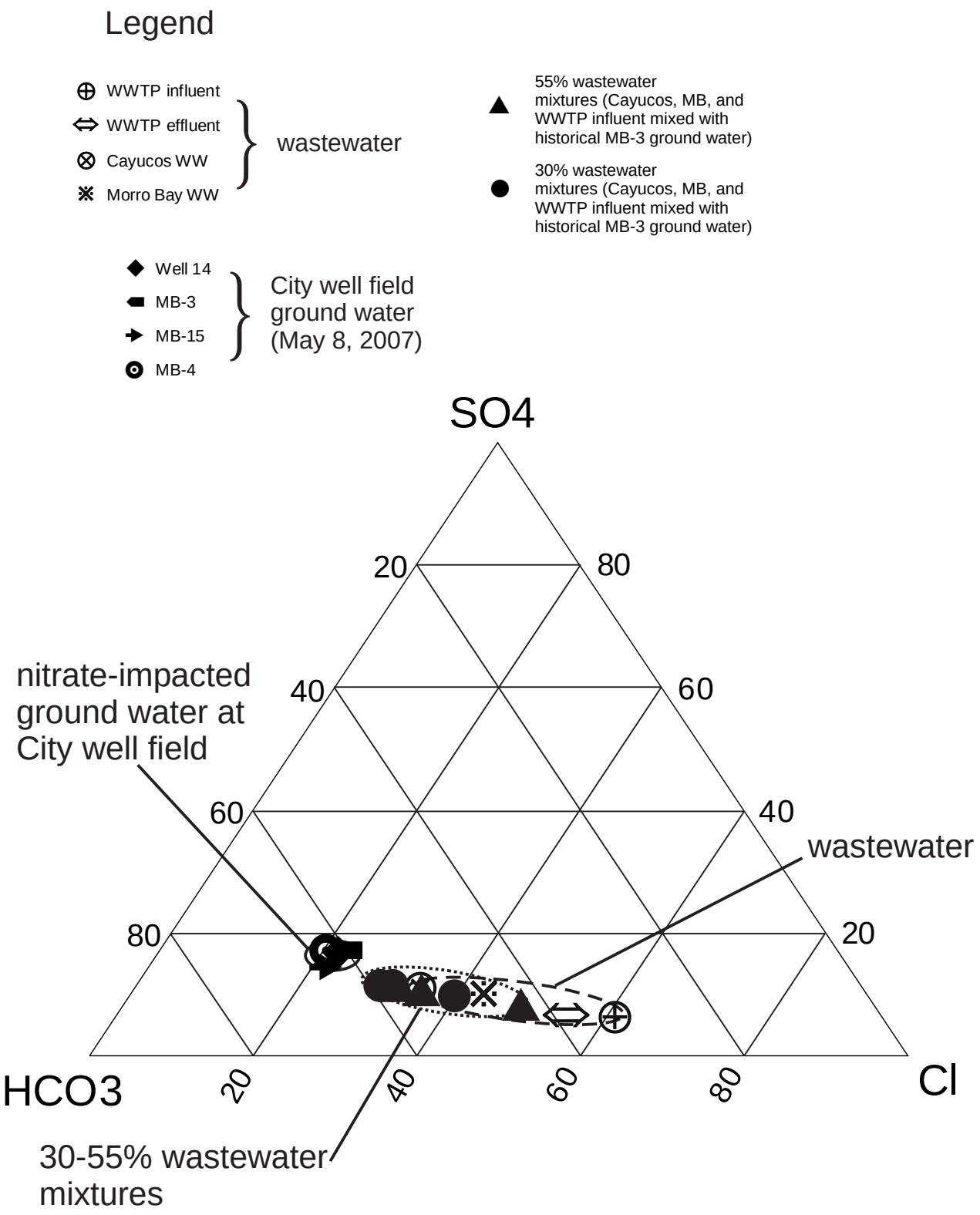

Figure 13
Anion Mixing
Morro Basin Nitrate Study
City of Morro Bay

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waste is quite broad, and that only the solid waste is ^{15}N enriched, while urine is $\delta^{15}N$ depleted. As reported by Kendall (1998):

> *The increases in $\delta^{15}N$ in animal tissue and solid waste relative to diet are due mainly to the excretion of isotopically light N in urine or its equivalent (Wolterink et al., 1979). Animal waste products may be further enriched in ^{15}N because of volatilization of ^{15}N-depleted ammonia, and subsequent oxidation of much of the residual waste material may result in nitrate with a high $\delta^{15}N$. By this process, animal waste with a typical $\delta^{15}N$ value of about +5‰ is converted to nitrate with $\delta^{15}N$ values generally in the range of +10 to +20‰ (Kreitler, 1975; 1979), and human and other animal waste become isotopically indistinguishable under most circumstances (an exception is Fogg et al., 1998).*

Volitilization of ammonia would not necessarily be significant from deep sewer exfiltration near the water table or inside sewer pipe. Furthermore, the composition of sewer exfiltration in the subsurface would not include solid waste which, according to Kendall (1998) is the specific component of sewage which is $\delta^{15}N$ enriched. Sewer exfiltration, therefore, may contain $\delta^{15}N$ values significantly below +10 $^0/_{00}$.

Another aspect of isotope analysis that results in overlapping ranges of $\delta^{15}N$ for various sources is isotope fractionation. For example, microbial denitrification can enrich the ^{15}N composition of residual dissolved nitrate and lead to nitrate derived from fertilizer having $\delta^{15}N$ values close to sewage nitrogen (Jeffrey et al, 2002). Therefore, the range of $\delta^{15}N$ in nitrate values at the City well field (+7 ‰ to +10 ‰) could be accounted for by sewer exfiltration without significant ammonia volitilization and denitrification, by a mixture of nitrate input from sewer exfiltration and synthetic fertilizers, or by synthetic fertilizers with ammonia volatilization and/or denitrification.

The other stable isotope analyzed in ground water from the City well field was the oxygen-nitrate isotope ^{18}O. The $\delta^{18}O$ of nitrate in septic effluent and animal waste is typically below +5 ‰, while synthetic nitrate fertilizer has $\delta^{18}O$ of nitrate values greater than +20 ‰ (Clark and Fritz, 1997). Nitrate derived from the biological nitrification of synthetic ammonium fertilizers should have much lower $\delta^{18}O$ of nitrate values (Aravena at al, 1993). This is because the oxygen used for synthetic nitrate fertilizer production is derived from the atmosphere, where $\delta^{18}O$ (of air) values are +23 ‰, while the oxygen used during the biological nitrification of ammonia is partially derived from local waters, which have depleted $\delta^{18}O$ (of H_2O) values, compared to the international standard (various authors after Hollocher, 1984). The $\delta^{18}O$ (of H_2O) in nearby Los Osos ground water, for example, is typically -5 to -6 ‰ (Cleath & Associates, 2005).

Using values of +23 ‰ $\delta^{18}O$ (air) and -6 ‰ $\delta^{18}O$ (irrigation water), the resulting $\delta^{18}O$ for nitrate originating from nitrification of ammonium, anhydrous ammonia, or urea-based fertilizer applications would be approximately +4 ‰. Commercial fertilizer mixtures often include ammonium nitrate (NH_4NO_3), which provides a portion of the nitrogen for immediate plant uptake (as nitrate) and a portion for slower-release uptake (as ammonium). $\delta^{18}O$ values for nitrate derived from ammonium nitrate

fertilizer would be close to +13 ‰ (+23 ‰ from the nitrate portion and +4 ‰ from the ammonium portion). Ammonium nitrate fertilizer may also be amended with calcium nitrate and potassium nitrate to provide the grower with a choice of proportions of immediate versus delayed nitrogen availability. The $\delta^{18}O$ for nitrate from these fertilizer would vary accordingly.

Isotope fractionation during denitrification also enriches $\delta^{18}O$ of nitrate values. The proportion of $\delta^{15}N$ enrichment to $\delta^{18}O$ enrichment in nitrate residual during denitrification has been found on many occasions to be 2:1 (e.g. Kendall, 1998).

The interpretation of the isotope data is presented in Figure 14, which shows the stable isotope results for the City well field with respect to potential sources and their respective enrichment products. The shaded areas represent stable isotope ratios that could be derived from 100 percent sewer exfiltration (lower graph area) or 100 percent synthetic nitrate fertilizer applications (upper graph area). The City well field isotope values plot between these shaded areas, therefore the nitrate contamination is interpreted to *not* be derived exclusively from sewer exfiltration or exclusively from nitrate fertilizer applications.

A range of stable isotope values for soil organic matter nitrate is included in Figure 14. Soil organic matter from decaying vegetation is a potentially significant source of nitrate in Morro Valley, where crop residues are plowed under. Ultimately, this source of nitrate is directly liked with agricultural fertilizer, representing a secondary phase of the nitrogen cycle. As such, the potential nitrogen loading from agricultural fertilizer applications includes input from crop residue and soil organic matter.

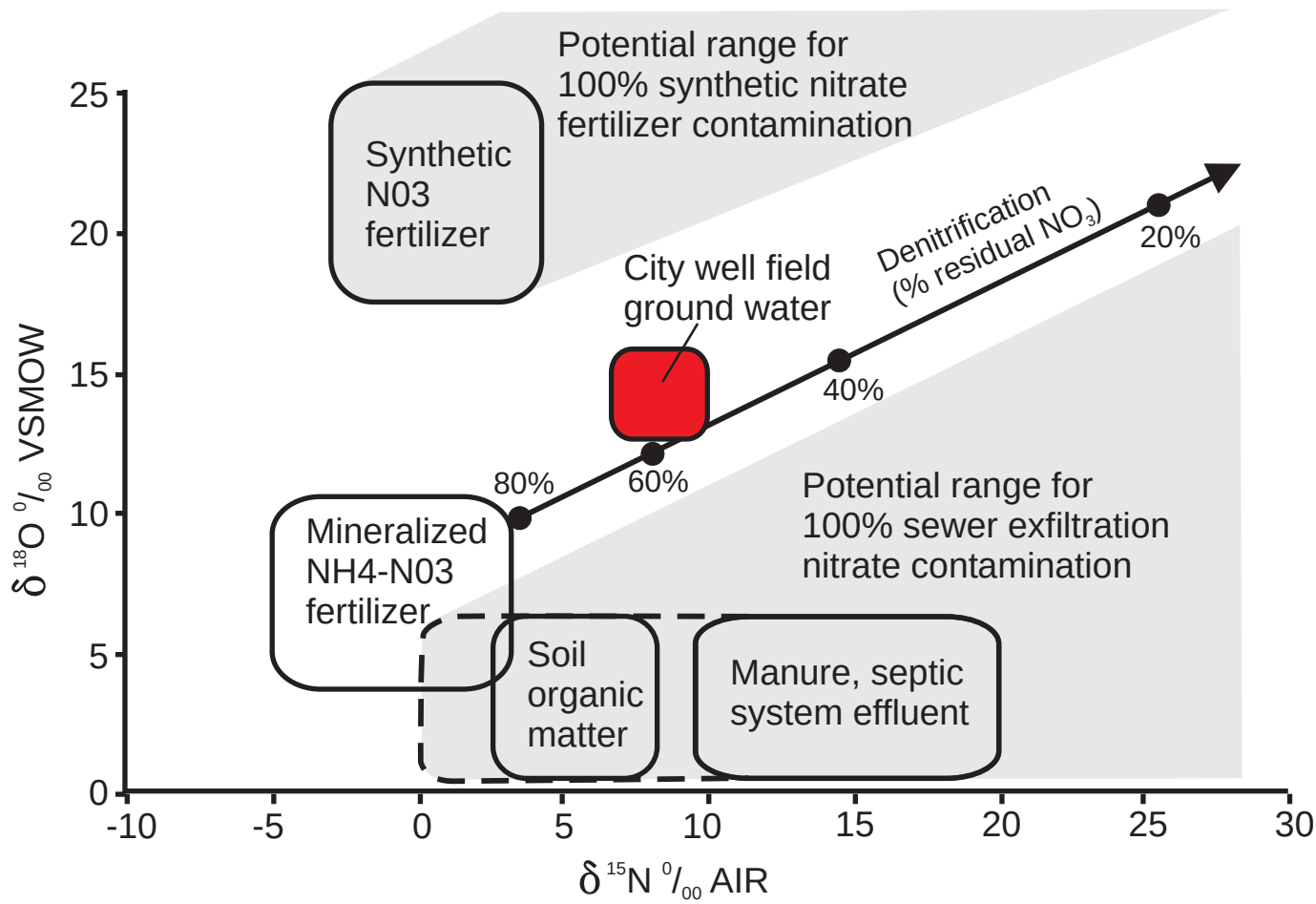
The possibilities for sources of nitrate contamination to ground water at the City's Highway 1 well field, based on the isotope data, are interpreted to be:

- Exclusively from ammonium fertilizer applications
- Mixtures of nitrate and ammonium fertilizer applications
- Mixtures of sewer exfiltration and fertilizer applications

Note that the above fertilizer sources are inclusive of secondary input from soil organic matter. Figure 14 also includes the theoretical percent of residual NO_3 following denitrification of ammonium nitrate fertilizer. The City well field isotope values fall within the 40-50 percent denitrification range (50-60% residual). It is interesting that 50-60 percent of the average NO_3 concentration in ground water beneath the agricultural fields in the lower Morro Valley is 80-96 mg/l NO_3, which is at the upper end of the range of concentrations measured in recent years at the well field.

Agricultural Fertilizer Applications

Much of the discussion relevant to evaluating agricultural fertilizer applications as a source of nitrate contamination has been included in the above general minerals and isotope discussion for sewer



Modified from Clark and Fritz (1997) to extend range of septic system / sewer exfiltration based on Kendall (1998)

$\delta^{18}O$ values for nitrate vary according to the values of local ground waters. Ranges shown are for ground water with $\delta^{18}O$ (H_2O) values of -10°/$_{oo}$ (Clark and Fritz, 1997).

Figure 14
Isotope Data Interpretation
Morro Basin Nitrate Study
City of Morro Bay

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exfiltration. Another aspect of the evaluation that is particularly relevant to identifying sources of nitrate in ground water at the City well field is recharge dynamics.

Recharge Dynamics

Recharge dynamics refers to the relationship between ground water inflow and outflow, which can significantly affect ground water quality. For example, the impact of agricultural fertilizer applications on nitrate concentrations in ground water at the City well field is directly related to the proportion of total ground water recharge coming from subsurface inflow through the narrows. The timing and magnitude of changes in nitrate concentrations at the well field can be explained by recharge dynamics.

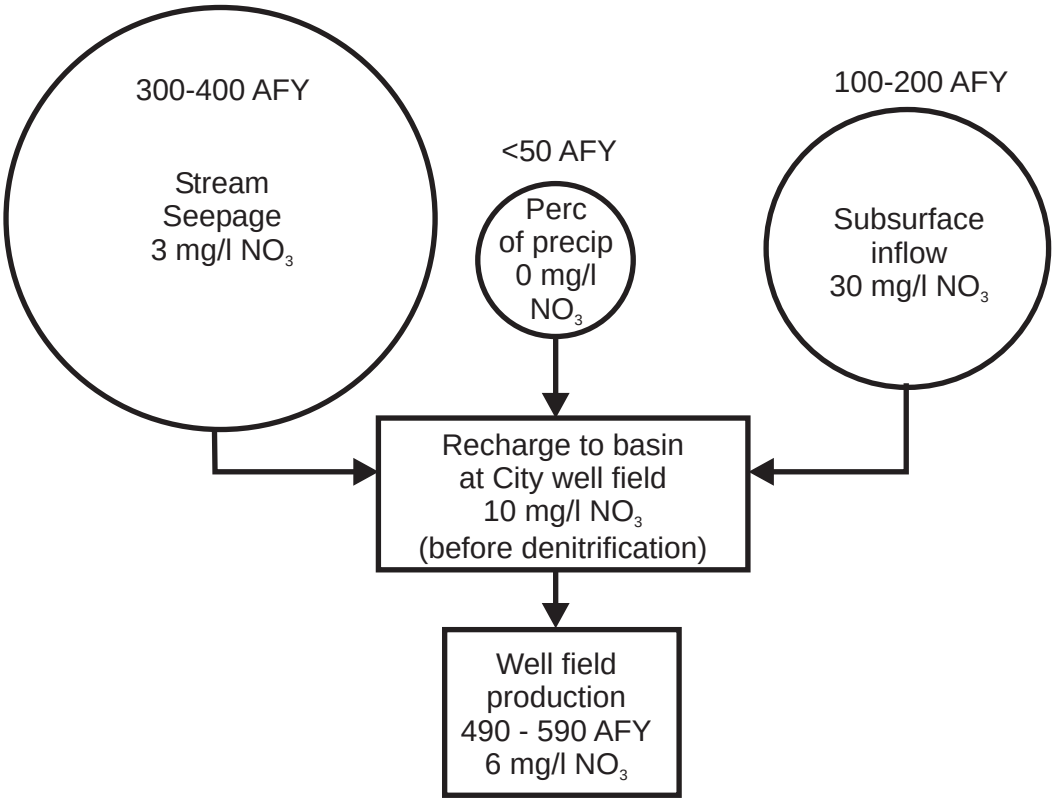
Nitrate concentrations in the lower Morro Valley have risen from an average of 34 mg/l in 1980 to an average of 160 mg/l in 2007. During this period, the estimated gross nitrogen load from agricultural fertilzer applications increased from 37,000 pounds N in 1977 to a high of 180,000 pounds N in 1995, with current rates close to 170,000 pounds N per year. As mentioned previously, one of the largest increases in nitrogen loading to the soils in the lower Morro Valley occurred in 1988 or 1989, when a 120-acre parcel of previously non-irrigated land in the lower valley was converted to truck crop production (Cleath & Associates, 1993). The ratio of harvested acreage to farmed acreage has also appeared to increase in the lower Morro Valley since approximately 2001, and now averages close to three crops per year per field.

By 1992, evidence of increasing nitrates was noted at City wells MB-14 and MB-15, followed by rises at the other wells through the mid to late 1990's (Appendix F). Major increases in nitrate concentrations began occurring in November 2002, which was the first year of significant well field production following the arrival of state water in 1997 and the detection of MTBE in groundwater near the well field in 2000. As discussed previously, the relative proportion of basin recharge to the City well field from Morro Valley subsurface inflow has increased since State Water Project deliveries began, compared to recharge coming from Morro Creek stream seepage.

The timing of increasing nitrate concentrations at the City well field may be explained by the combined processes of increased nitrogen loading in the lower Morro Valley, which resulted in moderate increases in nitrates at the City well field through the 1990's, and by subsequent increases in the proportion of subsurface recharge to the City well field coming from the lower Morro Valley. The change in recharge dynamics at the City well field is due to reduced well field production following state water deliveries and dissolved MTBE plume detection in groundwater, which has magnified the impact of increased nitrogen loading to the ground water basin.

The effect of recharge dynamics on nitrate concentrations is shown in Figure 15. Historical well field production during the 1980's averaged 540 acre-feet per year, but has averaged only 100 acre-feet per year since 2002. Nitrate concentrations at the City well field averaged 6 mg/l during the 1980's, and has averaged close to 50 mg/l over the last 5 years. This shift in nitrate concentrations, as shown in Figure

Historical Recharge (1980's)



Current Conditions

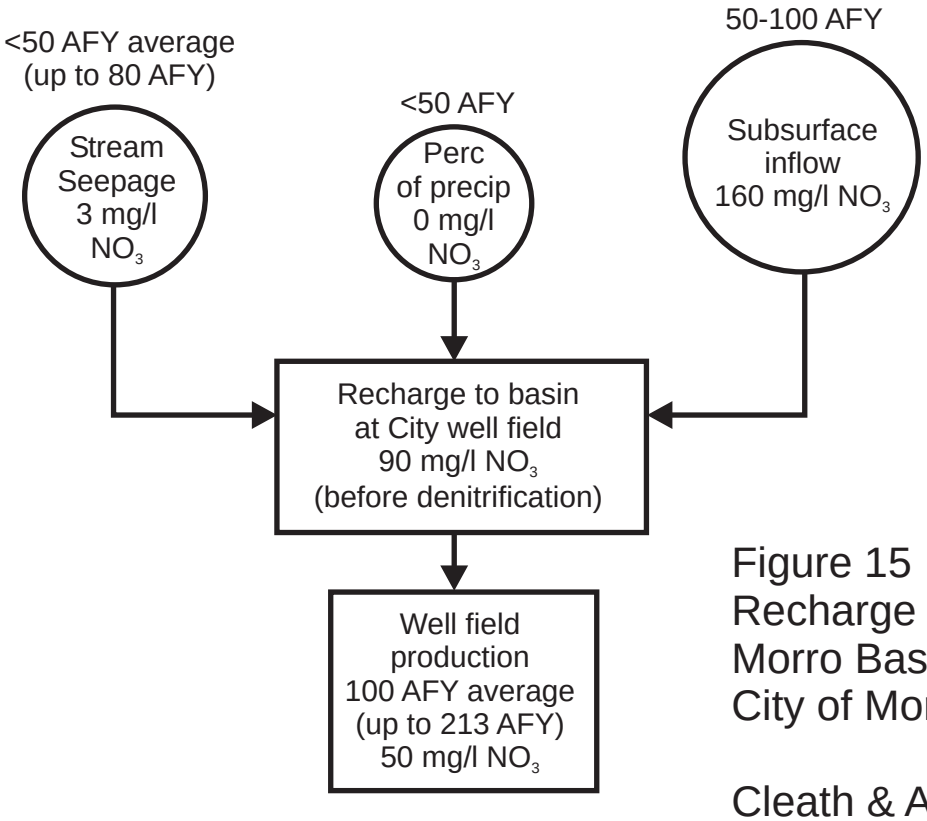


Figure 15
Recharge Dynamics
Morro Basin Nitrate Study
City of Morro Bay

Cleath & Associates

15, is a result of changes in the both the proportion and concentration of various sources of recharge. Significant denitrification is also indicated when comparing the theoretical nitrate concentration of the source mixtures, compared to the well field averages. The estimated amount of denitrification (55 to 60 percent residual) is consistent with the stable isotope results.

General Mineral Water Quality

General mineral water quality at the Highway 1 well field matches ground water from the Morro Valley, which is hydraulically upgradient of the well field (Figure 7). Within the Morro Valley, nitrate concentrations are much higher beneath farmed truck crops in the lower valley than any other area (Figure 6).

Mixing lower Morro Valley water with historical ground water at the well field matches current nitrate-impacted water quality. As is evident from Figure 8, both historical and current general mineral composition from both the lower Morro Valley and City well field areas are a fairly close match. Some salt buildup is noted in the lower Morro Valley, but the ground water from that area is still a closer match to the City well field water (even before mixing) than wastewater/ground water mixtures. In fact, the source mixing end member for lower Morro Valley water is Morro Creek stream seepage (rather than the historical City well field water used for wastewater mixing). Morro Creek stream seepage dilutes salt buildup in lower Morro Valley ground water, and produces the City well field water quality.

CONCLUSIONS

The results of this study indicate that the main source of nitrate contamination in ground water at the City's Highway 1 well field is from nitrogen fertilizer applications associated with vegetable farming operations in the lower Morro Valley. Historical land use trends, water quality trends, and recharge dynamics in the basin all support this conclusion. Stable isotope results indicate the nitrate contamination can be derived from any of three sources:

- Exclusively from ammonium fertilizer applications
- Mixtures of nitrate and ammonium fertilizer applications
- Mixtures of sewer exfiltration and fertilizer applications

Sewer exfiltration is not a major source of nitrate contamination in ground water at the City well field, based on an evaluation of sewer system and water quality information.

MITIGATION

There are three basic options for mitigating the problem of elevated nitrate contamination in ground water at the City's Highway 1 well field. These options can be combined, and are:

- Reducing nitrogen loading from agricultural fertilizer applications
- Increasing the proportion of total recharge from stream seepage below the narrows
- Reducing nitrates in produced ground water by treatment/blending

Each option would have specific costs, potential environmental impacts, and participating parties/ agencies. More work would be needed to explore the feasibility and effectiveness of these options, and to identify the regulatory and legal issues.

Reducing nitrate concentrations in ground water at the City's Highway 1 well field by reducing nitrogen loading from agriculture fertilizers in the lower Morro Valley involves participation by the growers. A compilation of management goals and practices for cool-season vegetables, such as those grown in the Morro Valley, is included in Appendix H (UC Publication 8097, 2003). This publication addresses nitrogen fertilizer applications and is designed to fit within the framework of the farm water quality management plan, which is required of local farm operators by the Central Coast Regional Water Quality Control Board under Order No. R3-2004-0117.

Increasing the proportion of total recharge from stream seepage below the narrows involves increasing production at the Highway 1 well field. The lower nitrate concentration of steam flow would provide dilution for elevated nitrate concentrations moving through the narrows from the lower Morro Valley. This option presents some additional constraints, since the produced water, at least initially, will have elevated nitrates.

The option for reducing nitrates by treatment/blending at the wellhead would not reduce the actual nitrate concentrations in ground water at the well field, which are increasing over time. Ground water treatment during State Water Project shutdowns could be used as an interim measure while one or both of the first two options are implemented.

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APPENDIX A

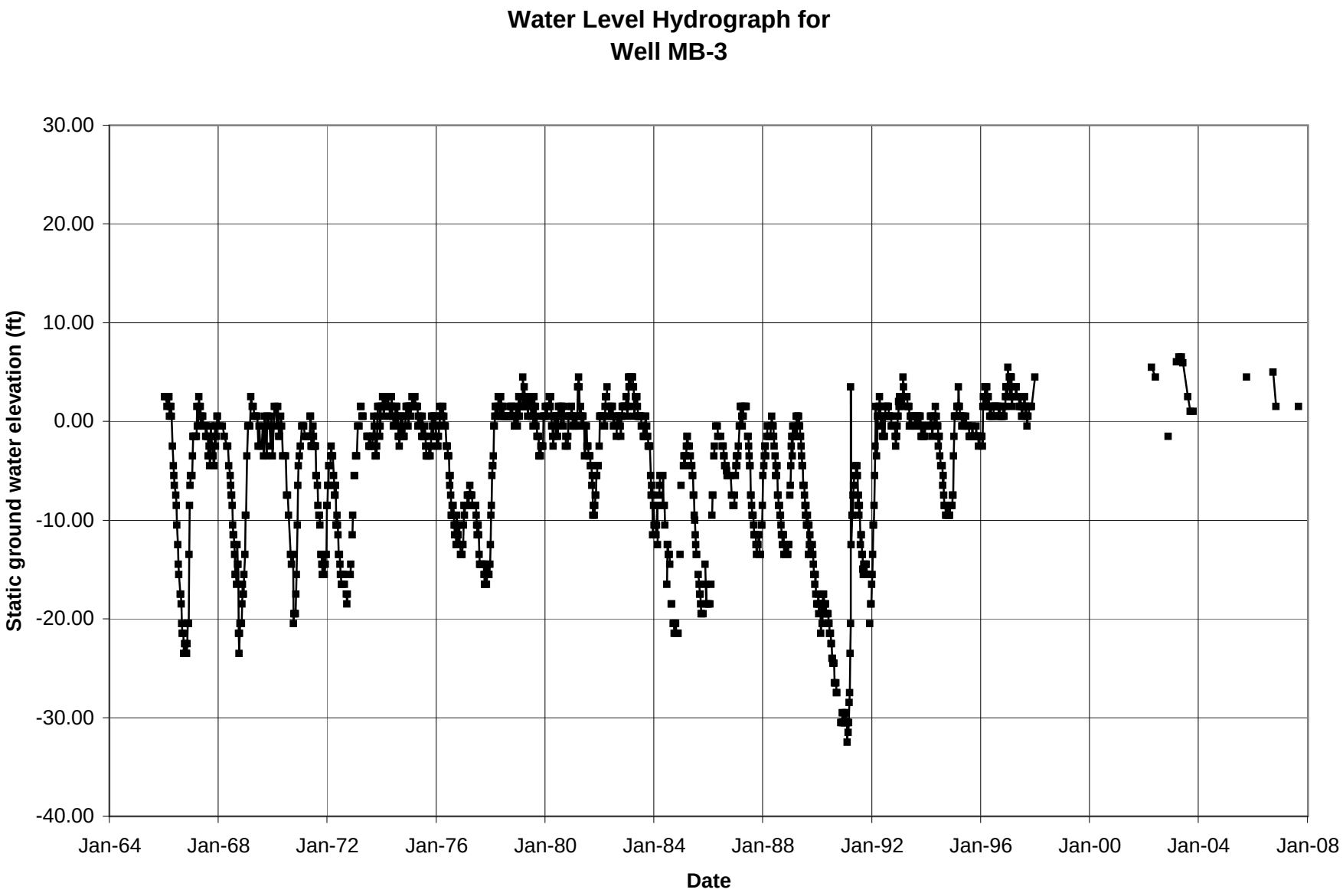
City Highway 1 Well Field Production

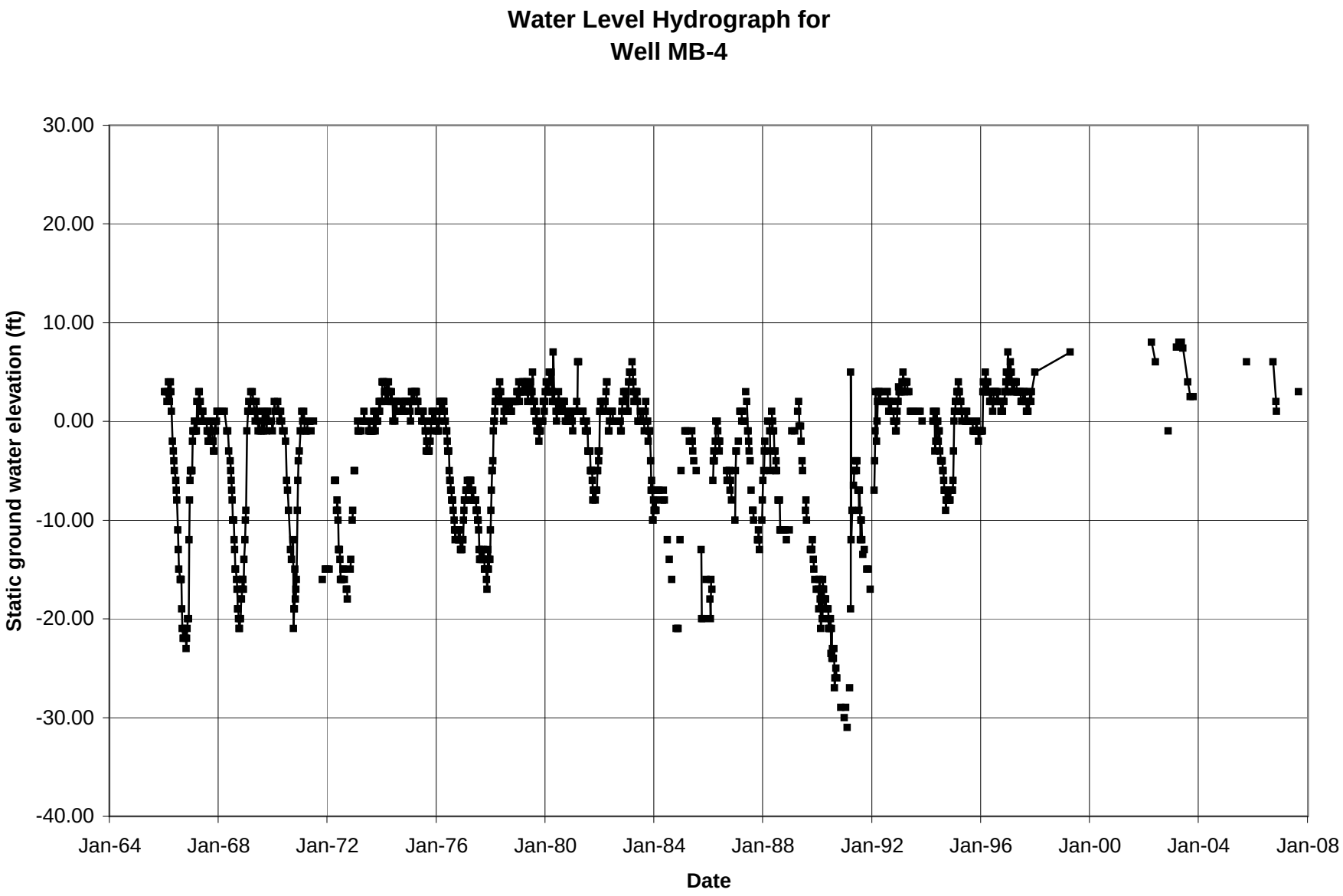
City Well Production in Morro Basin
1966-2006

Year	All City Wells in Basin (acre-feet)	Highway 1 Wells Only (acre-feet)
1966	585	252
1967	663	227
1968	641	299
1969	547	287
1970	732	373
1971	643	382
1972	581	379
1973	509	325
1974	529	342
1975	578	399
1976	581	433
1977	434	345
1978	458	344
1979	506	386
1980	559	537
1981	561	560
1982	535	533
1983	547	546
1984	588	588
1985	582	582
1986	550	525
1987	541	491
1988	528	522
1989	512	507
1990	549	409
1991	427	362
1992	270	270
1993	397	397
1994	448	448
1995	427	427
1996	237	237
1997	249	249
1998	0	0
1999	0	0
2000	0	0
2001	0	0
2002	32	32
2003	29	29
2004	213	213
2005	150	150
2006	79	79

APPENDIX B

Well Field Hydrographs
(Including MB-13 at the narrows)


Water Level Hydrograph for
Well MB-3
30.00
20.00
10.00
0.00
-10.00
-20.00
-30.00
-40.00
Static ground water elevation (ft)
Jan-64
Jan-68
Jan-72
Jan-76
Jan-80
Jan-84
Jan-88
Jan-92
Jan-96
Jan-00
Jan-04
Jan-08
Date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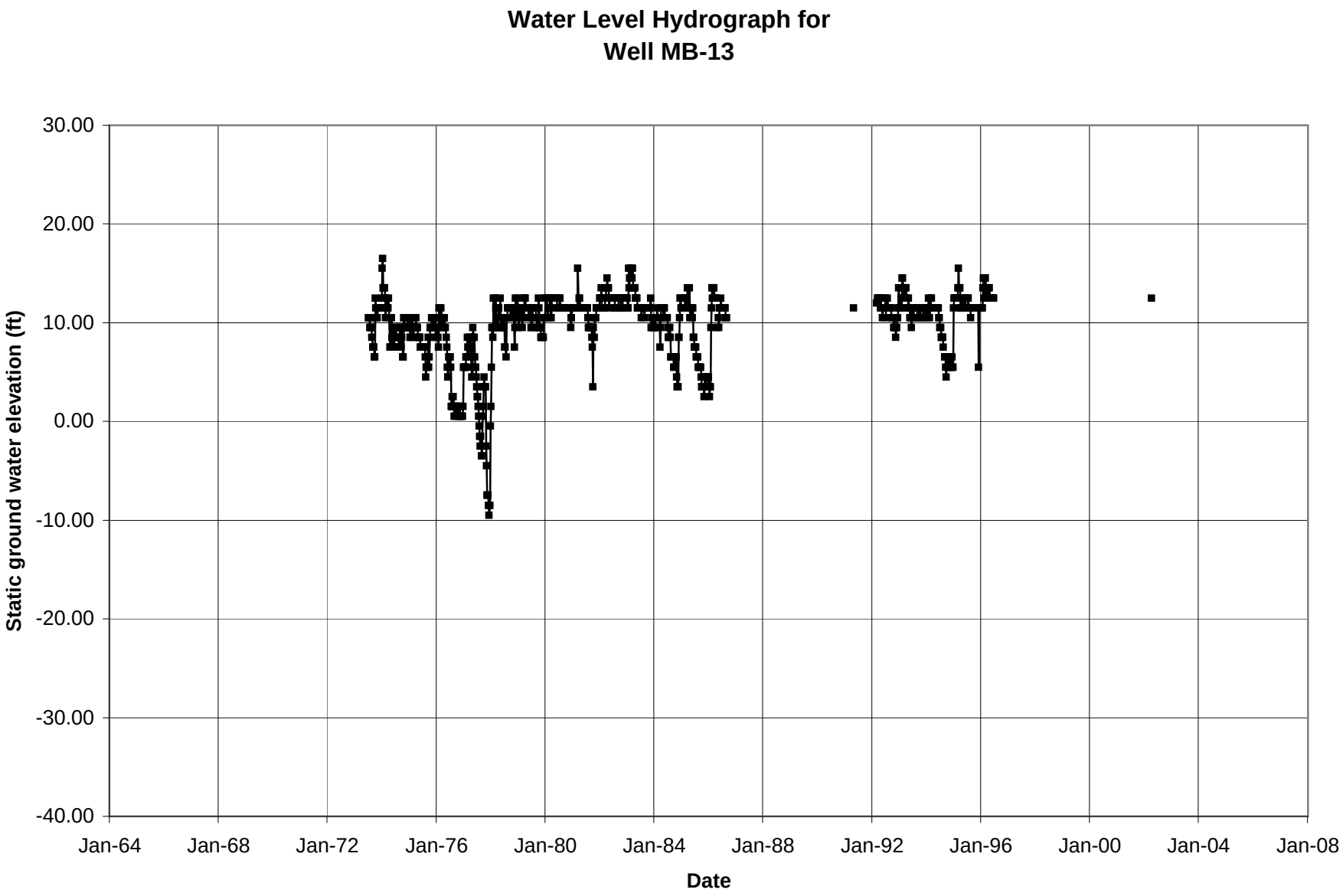
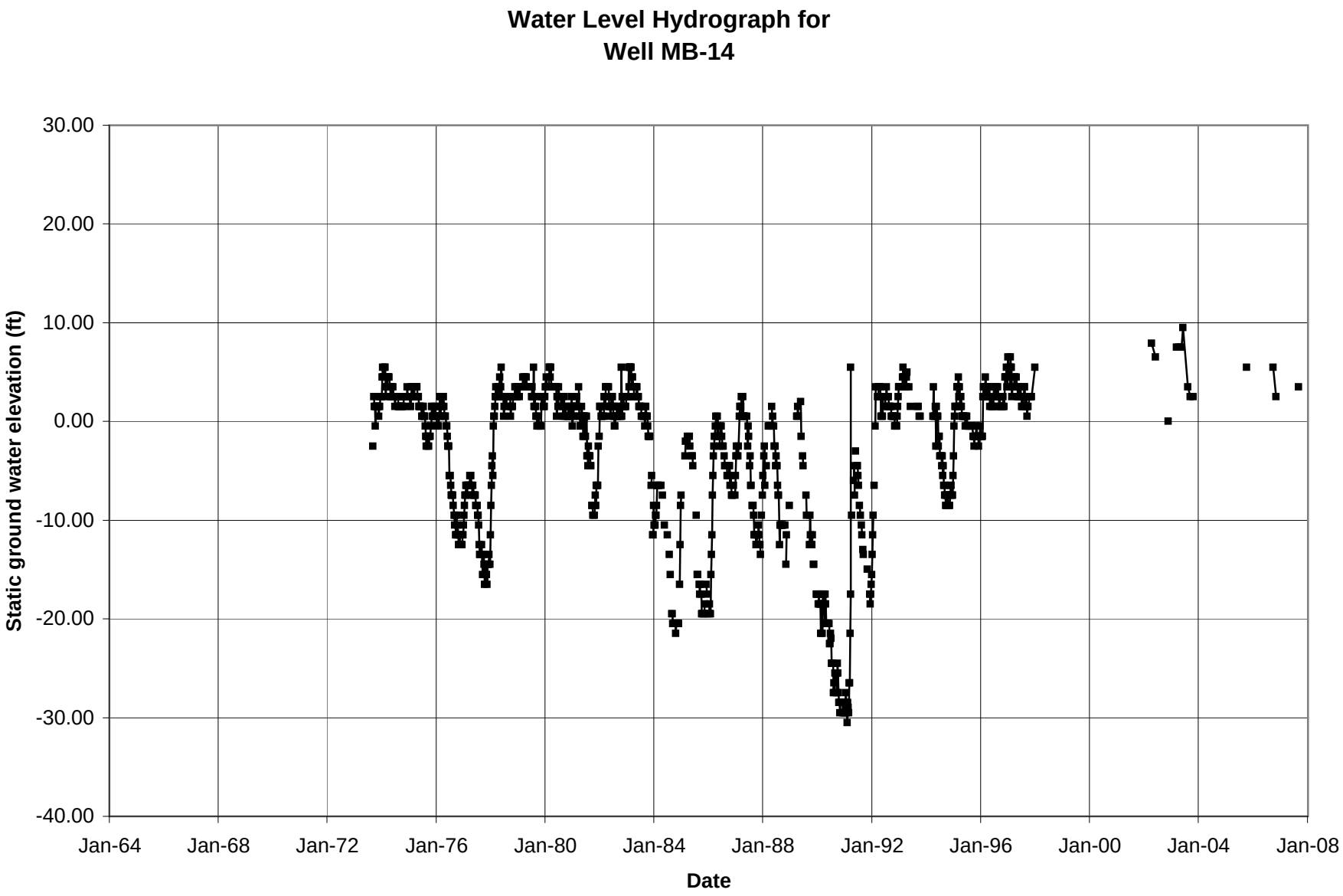
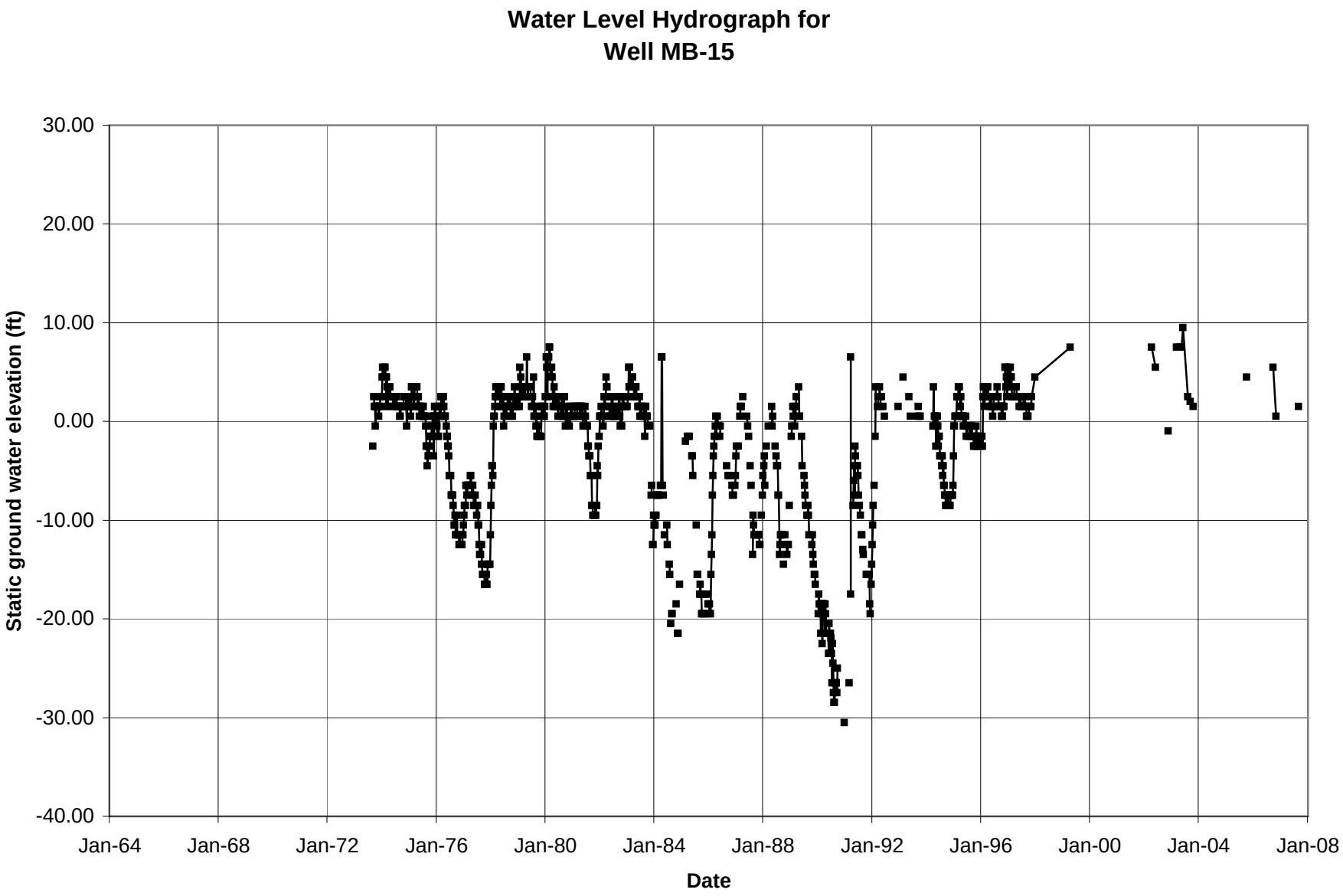
Well MB-4
30.00
20.00
10.00
0.00
-10.00
-20.00
-30.00
-40.00
Static ground water elevation (ft)
Jan-64
Jan-68
Jan-72
Jan-76
Jan-80
Jan-84
Jan-88
Jan-92
Jan-96
Jan-00
Jan-04
Jan-08
Date


Water Level Hydrograph for
Well MB-13
30.00
20.00
10.00
0.00
-10.00
-20.00
-30.00
-40.00
Static ground water elevation (ft)
Jan-64
Jan-68
Jan-72
Jan-76
Jan-80
Jan-84
Jan-88
Jan-92
Jan-96
Jan-00
Jan-04
Jan-08
Date


Water Level Hydrograph for
Well MB-14
30.00
20.00
10.00
0.00
-10.00
-20.00
-30.00
-40.00
Static ground water elevation (ft)
Jan-64
Jan-68
Jan-72
Jan-76
Jan-80
Jan-84
Jan-88
Jan-92
Jan-96
Jan-00
Jan-04
Jan-08
Date


Water Level Hydrograph for
Well MB-15
30.00
20.00
10.00
0.00
-10.00
-20.00
-30.00
-40.00
Static ground water elevation (ft)
Jan-64
Jan-68
Jan-72
Jan-76
Jan-80
Jan-84
Jan-88
Jan-92
Jan-96
Jan-00
Jan-04
Jan-08
Date

APPENDIX C

Subsurface Inflow Calculations at Narrows

Subsurface Inflow
through Narrows

Historical Conditions (1980's)

Width of basin at narrows	800	ft
average saturated thickness	30	ft
Cross-sectional flow area	24000	ft sq.
Aquifer hydraulic conductivity (K)	40	ft/day
Hydraulic gradient (i)	0.017	
Flow (Q = KiA)	16320	ft 3/day
Q	136.7	AFY

Current Conditions (since 2002)

Width of basin at narrows	800	ft
average saturated thickness	30	ft
Cross-sectional flow area	24000	ft sq.
Aquifer hydraulic conductivity (K)	40	ft/day
Hydraulic gradient (i)	0.011	
Flow (Q = KiA)	10560	ft 3/day
Q	88.5	AFY

APPENDIX D

Nitrogen Loading Factors

Nitrogen Loading Calculations
Morro Valley

Farmed acreage

	Year					
	1977	1984	1992	1995	2001	2007
Truck (except legumes)	35	48	150	167	151	174
Legumes	11	89	228	371	193	0
Field	70	69	0	0	0	6
Pasture	61	57	10	18	9	5
Orchard	59	187	258	361	562	798
Total	236	450	646	917	915	983

Harvested acreage separated by N categories

multiplier (truck)	2.3	2.3	2.3	2.3	2.4	2.9
Truck (except legumes)	80.5	110.4	345	384.1	362.4	504.6
Legumes (x 2 multiplier)	22	178	456	742	386	0
Field (sudan)	70	69	0	0	0	6
Pasture	61	57	10	18	9	5
Orchard (<5 years)		64	36	52	101	118
Orchard (mature)	59	123	222	309	461	680

N loading unit rates (#N per acre)

Truck (except peas)	190	190	190	190	190	190
Legumes	100	100	100	100	100	100
Field (sudan - 3 cuttings)	200	200	200	200	200	200
Pasture	0	0	0	0	0	0
Orchard (<5 years)	36	36	36	36	36	36
Orchard (mature)	100	100	100	100	100	100

Gross N loading (#/year)

	Year					
	1977	1984	1992	1995	2001	2007
Truck & Field	31495	52576	111150	147179	107456	97074
Orchard	5900	14604	23496	32772	49736	72248
Total	37395	67180	134646	179951	157192	169322

APPENDIX E

Laboratory Reports for Ground Water and Surface Water Samples

CREEK ENVIRONMENTAL LABORATORIES, INC.
A Minority-owned Business Enterprise
141 SUBURBAN ROAD, SUITE C-5 • SAN LUIS OBISPO, CA 93401 • (805) 545-9838 • FAX (805) 545-0107

Spencer Harris
Cleath & Associates
1390 Oceanaire Drive
San Luis Obispo, CA 93405

Log Number: 07-C10472
Order: 04305
Project: Morro Bay Nitrate Study
Received: 08/16/07
Printed: 08/30/07

REPORT OF ANALYTICAL RESULTS

Sample Description	Sampled By	Sampled Date @ Time	Matrix
Little Morro Creek Upstream	Spencer Harris	08/16/07@14:45	Aqueous

Analyte	Result	DLR	Dilution Factor	Units	Method	Date Analyzed	Date Prepared	Batch
Total Alkalinity as CaCO3	340	2	1	mg/L	SM 2320B	08/26/07		7808
Chloride	44	1	1	mg/L	EPA 300.0	08/17/07		7619
Electrical Conductance	750	1	1	umhos/cm	SM 2510	08/16/07		7558
Nitrate as N	0.2	0.1	1	mg/L	EPA 300.0	08/17/07		7619
Nitrate as NO3	0.9	0.4	1	mg/L	EPA 300.0			
pH	8.3	0.1	1	pH units	SM 4500-H B	08/16/07		7558
Sulfate	33	0.5	1	mg/L	EPA 300.0	08/17/07		7619
Total Dissolved Solids	460	10	1	mg/L	SM 2540 C	08/23/07		7831
Sodium Adsorption Ratio	1.1	0.1	1		EPA 200.7	08/29/07		8012
Boron	0.09	0.05	1	mg/L	EPA 200.8	08/29/07		8005
Calcium	48	0.03	1	mg/L	EPA 200.8	08/29/07		8005
Copper	Not Detected	0.05	1	mg/L	EPA 200.8	08/29/07		8005
Iron	Not Detected	0.1	1	mg/L	EPA 200.8	08/29/07		8005
Magnesium	54	0.03	1	mg/L	EPA 200.8	08/29/07		8005
Manganese	Not Detected	0.02	1	mg/L	EPA 200.8	08/29/07		8005
Potassium	0.9	0.1	1	mg/L	EPA 200.8	08/29/07		8005
Sodium	44	0.05	1	mg/L	EPA 200.8	08/29/07		8005
Zinc	Not Detected	0.05	1	mg/L	EPA 200.8	08/29/07		8005
Hardness	340	1	1	mg/L CaCO3	EPA 200.8	08/30/07		8009

DLR = Detection Limit for Reporting. Results of "Not Detected" are below DLR.

CREEK ENVIRONMENTAL LABORATORIES

Lab Director, Michael Ng

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Spencer Harris
Cleath & Associates
1390 Oceanaire Drive
San Luis Obispo, CA 93405

Log Number: 07-C10467
Order: 04305
Project: Morro Bay Nitrate Study
Received: 08/16/07
Printed: 08/30/07

REPORT OF ANALYTICAL RESULTS

Sample Description	Sampled By	Sampled Date @ Time	Matrix
Morro Creek Upstream	Spencer Harris	08/16/07@10:00	Aqueous

Analyte	Result	DLR	Dilution Factor	Units	Method	Date Analyzed	Date Prepared	Batch
Total Alkalinity as CaCO3	290	2	1	mg/L	SM 2320B	08/26/07		7807
Chloride	22	1	1	mg/L	EPA 300.0	08/17/07		7619
Electrical Conductance	610	1	1	umhos/cm	SM 2510	08/16/07		7558
Nitrate as N	Not Detected	0.1	1	mg/L	EPA 300.0	08/17/07		7619
Nitrate as NO3	Not Detected	0.4	1	mg/L	EPA 300.0			
pH	8.1	0.1	1	pH units	SM 4500-H B	08/16/07		7558
Sulfate	36	0.5	1	mg/L	EPA 300.0	08/17/07		7619
Total Dissolved Solids	320	10	1	mg/L	SM 2540 C	08/22/07		7756
Sodium Adsorption Ratio	0.6	0.1	1		EPA 200.7	08/29/07		8012
Boron	0.10	0.05	1	mg/L	EPA 200.8	08/29/07		8005
Calcium	40	0.03	1	mg/L	EPA 200.8	08/29/07		8005
Copper	Not Detected	0.05	1	mg/L	EPA 200.8	08/29/07		8005
Iron	Not Detected	0.1	1	mg/L	EPA 200.8	08/29/07		8005
Magnesium	50	0.03	1	mg/L	EPA 200.8	08/29/07		8005
Manganese	Not Detected	0.02	1	mg/L	EPA 200.8	08/29/07		8005
Potassium	0.5	0.1	1	mg/L	EPA 200.8	08/29/07		8005
Sodium	22	0.05	1	mg/L	EPA 200.8	08/29/07		8005
Zinc	Not Detected	0.05	1	mg/L	EPA 200.8	08/29/07		8005
Hardness	300	1	1	mg/L CaCO3	EPA 200.8	08/30/07		8009

DLR = Detection Limit for Reporting. Results of "Not Detected" are below DLR.

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Spencer Harris
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Log Number: 07-C10465
Order: 04305
Project: Morro Bay Nitrate Study
Received: 08/16/07
Printed: 08/30/07

REPORT OF ANALYTICAL RESULTS

Sample Description	Sampled By	Sampled Date @ Time	Matrix
Well "A"	Spencer Harris	08/16/07@09:45	Aqueous

Analyte	Result	DLR	Dilution Factor	Units	Method	Date Analyzed	Date Prepared	Batch
Total Alkalinity as CaCO3	340	2	1	mg/L	SM 2320B	08/26/07		7807
Chloride	21	1	1	mg/L	EPA 300.0	08/17/07		7619
Electrical Conductance	670	1	1	umhos/cm	SM 2510	08/16/07		7558
Nitrate as N	Not Detected	0.1	1	mg/L	EPA 300.0	08/17/07		7619
Nitrate as NO3	Not Detected	0.4	1	mg/L	EPA 300.0			
pH	7.7	0.1	1	pH units	SM 4500-H B	08/16/07		7558
Sulfate	32	0.5	1	mg/L	EPA 300.0	08/17/07		7619
Total Dissolved Solids	400	10	1	mg/L	SM 2540 C	08/22/07		7756
Sodium Adsorption Ratio	0.6	0.1	1		EPA 200.7	08/29/07		8012
Boron	0.10	0.05	1	mg/L	EPA 200.8	08/29/07		8005
Calcium	43	0.03	1	mg/L	EPA 200.8	08/29/07		8005
Copper	Not Detected	0.05	1	mg/L	EPA 200.8	08/29/07		8005
Iron	Not Detected	0.1	1	mg/L	EPA 200.8	08/29/07		8005
Magnesium	55	0.03	1	mg/L	EPA 200.8	08/29/07		8005
Manganese	0.09	0.02	1	mg/L	EPA 200.8	08/29/07		8005
Potassium	0.4	0.1	1	mg/L	EPA 200.8	08/29/07		8005
Sodium	23	0.05	1	mg/L	EPA 200.8	08/29/07		8005
Zinc	Not Detected	0.05	1	mg/L	EPA 200.8	08/29/07		8005
Hardness	330	1	1	mg/L CaCO3	EPA 200.8	08/30/07		8009

DLR = Detection Limit for Reporting. Results of "Not Detected" are below DLR.

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Log Number: 07-C10466
Order: 04305
Project: Morro Bay Nitrate Study
Received: 08/16/07
Printed: 08/30/07

REPORT OF ANALYTICAL RESULTS

Sample Description	Sampled By	Sampled Date @ Time	Matrix
Well "B"	Spencer Harris	08/16/07@09:50	Aqueous

Analyte	Result	DLR	Dilution Factor	Units	Method	Date Analyzed	Date Prepared	Batch
Total Alkalinity as CaCO3	380	2	1	mg/L	SM 2320B	08/26/07		7807
Chloride	22	1	1	mg/L	EPA 300.0	08/17/07		7619
Electrical Conductance	730	1	1	umhos/cm	SM 2510	08/16/07		7558
Nitrate as N	Not Detected	0.1	1	mg/L	EPA 300.0	08/17/07		7619
Nitrate as NO3	Not Detected	0.4	1	mg/L	EPA 300.0			
pH	7.4	0.1	1	pH units	SM 4500-H B	08/16/07		7558
Sulfate	31	0.5	1	mg/L	EPA 300.0	08/17/07		7619
Total Dissolved Solids	420	10	1	mg/L	SM 2540 C	08/22/07		7756
Sodium Adsorption Ratio	0.5	0.1	1		EPA 200.7	08/29/07		8012
Boron	0.10	0.05	1	mg/L	EPA 200.8	08/29/07		8005
Calcium	43	0.03	1	mg/L	EPA 200.8	08/29/07		8005
Copper	Not Detected	0.05	1	mg/L	EPA 200.8	08/29/07		8005
Iron	2.4	0.1	1	mg/L	EPA 200.8	08/29/07		8005
Magnesium	59	0.03	1	mg/L	EPA 200.8	08/29/07		8005
Manganese	0.68	0.02	1	mg/L	EPA 200.8	08/29/07		8005
Potassium	0.4	0.1	1	mg/L	EPA 200.8	08/29/07		8005
Sodium	22	0.05	1	mg/L	EPA 200.8	08/29/07		8005
Zinc	Not Detected	0.05	1	mg/L	EPA 200.8	08/29/07		8005
Hardness	350	1	1	mg/L CaCO3	EPA 200.8	08/30/07		8009

DLR = Detection Limit for Reporting. Results of "Not Detected" are below DLR.

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Lab Director, Michael Ng

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Log Number: 07-C10468
Order: 04305
Project: Morro Bay Nitrate Study
Received: 08/16/07
Printed: 08/30/07

REPORT OF ANALYTICAL RESULTS

Sample Description	Sampled By	Sampled Date @ Time	Matrix
Well "C"	Spencer Harris	08/16/07@11:00	Aqueous

Analyte	Result	DLR	Dilution Factor	Units	Method	Date Analyzed	Date Prepared	Batch
Total Alkalinity as CaCO3	330	2	1	mg/L	SM 2320B	08/26/07		7807
Chloride	28	1	1	mg/L	EPA 300.0	08/17/07		7619
Electrical Conductance	730	1	1	umhos/cm	SM 2510	08/16/07		7558
Nitrate as N	Not Detected	0.1	1	mg/L	EPA 300.0	08/17/07		7619
Nitrate as NO3	Not Detected	0.4	1	mg/L	EPA 300.0			
pH	7.4	0.1	1	pH units	SM 4500-H B	08/16/07		7558
Sulfate	44	0.5	1	mg/L	EPA 300.0	08/17/07		7619
Total Dissolved Solids	390	10	1	mg/L	SM 2540 C	08/22/07		7756
Sodium Adsorption Ratio	0.7	0.1	1		EPA 200.7	08/29/07		8012
Boron	0.10	0.05	1	mg/L	EPA 200.8	08/29/07		8005
Calcium	54	0.03	1	mg/L	EPA 200.8	08/29/07		8005
Copper	Not Detected	0.05	1	mg/L	EPA 200.8	08/29/07		8005
Iron	0.5	0.1	1	mg/L	EPA 200.8	08/29/07		8005
Magnesium	52	0.03	1	mg/L	EPA 200.8	08/29/07		8005
Manganese	0.67	0.02	1	mg/L	EPA 200.8	08/29/07		8005
Potassium	0.6	0.1	1	mg/L	EPA 200.8	08/29/07		8005
Sodium	30	0.05	1	mg/L	EPA 200.8	08/29/07		8005
Zinc	0.07	0.05	1	mg/L	EPA 200.8	08/29/07		8005
Hardness	350	1	1	mg/L CaCO3	EPA 200.8	08/30/07		8009

DLR = Detection Limit for Reporting. Results of "Not Detected" are below DLR.

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Lab Director, Michael Ng

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Log Number: 07-C10469
Order: 04305
Project: Morro Bay Nitrate Study
Received: 08/16/07
Printed: 08/30/07

REPORT OF ANALYTICAL RESULTS

Sample Description	Sampled By	Sampled Date @ Time	Matrix
Well "D"	Spencer Harris	08/16/07@12:30	Aqueous

Analyte	Result	DLR	Dilution Factor	Units	Method	Date Analyzed	Date Prepared	Batch
Total Alkalinity as CaCO3	380	2	1	mg/L	SM 2320B	08/26/07		7807
Chloride	100	10	10	mg/L	EPA 300.0	08/20/07		7636
Electrical Conductance	1,100	1	1	umhos/cm	SM 2510	08/16/07		7558
Nitrate as N	5.4	0.1	1	mg/L	EPA 300.0	08/17/07		7619
Nitrate as NO3	24	0.4	1	mg/L	EPA 300.0			
pH	7.2	0.1	1	pH units	SM 4500-H B	08/16/07		7558
Sulfate	60	0.5	1	mg/L	EPA 300.0	08/17/07		7619
Total Dissolved Solids	650	10	1	mg/L	SM 2540 C	08/23/07		7831
Sodium Adsorption Ratio	1.2	0.1	1		EPA 200.7	08/29/07		8012
Boron	0.12	0.05	1	mg/L	EPA 200.8	08/29/07		8005
Calcium	54	0.03	1	mg/L	EPA 200.8	08/29/07		8005
Copper	Not Detected	0.05	1	mg/L	EPA 200.8	08/29/07		8005
Iron	Not Detected	0.1	1	mg/L	EPA 200.8	08/29/07		8005
Magnesium	78	0.03	1	mg/L	EPA 200.8	08/29/07		8005
Manganese	Not Detected	0.02	1	mg/L	EPA 200.8	08/29/07		8005
Potassium	0.4	0.1	1	mg/L	EPA 200.8	08/29/07		8005
Sodium	58	0.05	1	mg/L	EPA 200.8	08/29/07		8005
Zinc	0.23	0.05	1	mg/L	EPA 200.8	08/29/07		8005
Hardness	460	1	1	mg/L CaCO3	EPA 200.8	08/30/07		8009

DLR = Detection Limit for Reporting. Results of "Not Detected" are below DLR.

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Log Number: 07-C10470
Order: 04305
Project: Morro Bay Nitrate Study
Received: 08/16/07
Printed: 08/30/07

REPORT OF ANALYTICAL RESULTS

Sample Description	Sampled By	Sampled Date @ Time	Matrix
Well "E"	Spencer Harris	08/16/07@13:45	Aqueous

Analyte	Result	DLR	Dilution Factor	Units	Method	Date Analyzed	Date Prepared	Batch
Total Alkalinity as CaCO3	400	2	1	mg/L	SM 2320B	08/26/07		7808
Chloride	150	10	10	mg/L	EPA 300.0	08/20/07		7636
Electrical Conductance	1,200	1	1	umhos/cm	SM 2510	08/16/07		7558
Nitrate as N	3.3	0.1	1	mg/L	EPA 300.0	08/17/07		7619
Nitrate as NO3	15	0.4	1	mg/L	EPA 300.0			
pH	7.4	0.1	1	pH units	SM 4500-H B	08/16/07		7558
Sulfate	66	0.5	1	mg/L	EPA 300.0	08/17/07		7619
Total Dissolved Solids	710	10	1	mg/L	SM 2540 C	08/23/07		7831
Sodium Adsorption Ratio	1.0	0.1	1		EPA 200.7	08/29/07		8012
Boron	0.11	0.05	1	mg/L	EPA 200.8	08/29/07		8005
Calcium	80	0.03	1	mg/L	EPA 200.8	08/29/07		8005
Copper	0.16	0.05	1	mg/L	EPA 200.8	08/29/07		8005
Iron	Not Detected	0.1	1	mg/L	EPA 200.8	08/29/07		8005
Magnesium	88	0.03	1	mg/L	EPA 200.8	08/29/07		8005
Manganese	Not Detected	0.02	1	mg/L	EPA 200.8	08/29/07		8005
Potassium	0.9	0.1	1	mg/L	EPA 200.8	08/29/07		8005
Sodium	52	0.05	1	mg/L	EPA 200.8	08/29/07		8005
Zinc	Not Detected	0.05	1	mg/L	EPA 200.8	08/29/07		8005
Hardness	560	1	1	mg/L CaCO3	EPA 200.8	08/30/07		8009

DLR = Detection Limit for Reporting. Results of "Not Detected" are below DLR.

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Lab Director, Michael Ng

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Log Number: 07-C10471
Order: 04305
Project: Morro Bay Nitrate Study
Received: 08/16/07
Printed: 08/30/07

REPORT OF ANALYTICAL RESULTS

Sample Description	Sampled By	Sampled Date @ Time	Matrix
Well "F"	Spencer Harris	08/16/07@14:15	Aqueous

Analyte	Result	DLR	Dilution Factor	Units	Method	Date Analyzed	Date Prepared	Batch
Total Alkalinity as CaCO3	370	2	1	mg/L	SM 2320B	08/26/07		7808
Chloride	100	10	10	mg/L	EPA 300.0	08/20/07		7636
Electrical Conductance	1,100	1	1	umhos/cm	SM 2510	08/16/07		7558
Nitrate as N	14	0.1	1	mg/L	EPA 300.0	08/17/07		7619
Nitrate as NO3	64	0.4	1	mg/L	EPA 300.0			
pH	7.6	0.1	1	pH units	SM 4500-H B	08/16/07		7558
Sulfate	66	0.5	1	mg/L	EPA 300.0	08/17/07		7619
Total Dissolved Solids	690	10	1	mg/L	SM 2540 C	08/23/07		7831
Sodium Adsorption Ratio	1.0	0.1	1		EPA 200.7	08/29/07		8012
Boron	0.10	0.05	1	mg/L	EPA 200.8	08/29/07		8005
Calcium	74	0.03	1	mg/L	EPA 200.8	08/29/07		8005
Copper	Not Detected	0.05	1	mg/L	EPA 200.8	08/29/07		8005
Iron	Not Detected	0.1	1	mg/L	EPA 200.8	08/29/07		8005
Magnesium	81	0.03	1	mg/L	EPA 200.8	08/29/07		8005
Manganese	Not Detected	0.02	1	mg/L	EPA 200.8	08/29/07		8005
Potassium	0.8	0.1	1	mg/L	EPA 200.8	08/29/07		8005
Sodium	53	0.05	1	mg/L	EPA 200.8	08/29/07		8005
Zinc	0.12	0.05	1	mg/L	EPA 200.8	08/29/07		8005
Hardness	520	1	1	mg/L CaCO3	EPA 200.8	08/30/07		8009

DLR = Detection Limit for Reporting. Results of "Not Detected" are below DLR.

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Lab Director, Michael Ng

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Log Number: 07-C10473
Order: 04305
Project: Morro Bay Nitrate Study
Received: 08/16/07
Printed: 08/30/07

REPORT OF ANALYTICAL RESULTS

Sample Description	Sampled By	Sampled Date @ Time	Matrix
Well "G"	Spencer Harris	08/16/07@15:05	Aqueous

Analyte	Result	DLR	Dilution Factor	Units	Method	Date Analyzed	Date Prepared	Batch
Total Alkalinity as CaCO3	360	2	1	mg/L	SM 2320B	08/26/07		7808
Chloride	51	1	1	mg/L	EPA 300.0	08/17/07		7619
Electrical Conductance	800	1	1	umhos/cm	SM 2510	08/16/07		7558
Nitrate as N	0.5	0.1	1	mg/L	EPA 300.0	08/17/07		7619
Nitrate as NO3	2.2	0.4	1	mg/L	EPA 300.0			
pH	7.7	0.1	1	pH units	SM 4500-H B	08/16/07		7558
Sulfate	36	0.5	1	mg/L	EPA 300.0	08/17/07		7619
Total Dissolved Solids	480	10	1	mg/L	SM 2540 C	08/23/07		7831
Sodium Adsorption Ratio	1.1	0.1	1		EPA 200.7	08/29/07		8012
Boron	0.09	0.05	1	mg/L	EPA 200.8	08/29/07		8005
Calcium	46	0.03	1	mg/L	EPA 200.8	08/29/07		8005
Copper	Not Detected	0.05	1	mg/L	EPA 200.8	08/29/07		8005
Iron	Not Detected	0.1	1	mg/L	EPA 200.8	08/29/07		8005
Magnesium	61	0.03	1	mg/L	EPA 200.8	08/29/07		8005
Manganese	Not Detected	0.02	1	mg/L	EPA 200.8	08/29/07		8005
Potassium	0.6	0.1	1	mg/L	EPA 200.8	08/29/07		8005
Sodium	46	0.05	1	mg/L	EPA 200.8	08/29/07		8005
Zinc	Not Detected	0.05	1	mg/L	EPA 200.8	08/29/07		8005
Hardness	360	1	1	mg/L CaCO3	EPA 200.8	08/30/07		8009

DLR = Detection Limit for Reporting. Results of "Not Detected" are below DLR.

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Lab Director, Michael Ng

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Log Number: 07-C10504
Order: 04318
Project: Morro Bay Nitrate Study
Received: 08/17/07
Printed: 08/30/07

REPORT OF ANALYTICAL RESULTS

Sample Description	Sampled By	Sampled Date @ Time	Matrix
Well "H"	Spencer Harris	08/17/07@12:00	Aqueous

Analyte	Result	DLR	Dilution Factor	Units	Method	Date Analyzed	Date Prepared	Batch
Total Alkalinity as CaCO3	380	2	1	mg/L	SM 2320B	08/26/07		7811
Chloride	140	10	10	mg/L	EPA 300.0	08/20/07		7636
Electrical Conductance	1,400	1	1	umhos/cm	SM 2510	08/17/07		7718
Nitrate as N	37	0.1	1	mg/L	EPA 300.0	08/17/07		7619
Nitrate as NO3	160	0.4	1	mg/L	EPA 300.0			
pH	7.3	0.1	1	pH units	SM 4500-H B	08/17/07		7718
Sulfate	97	0.5	1	mg/L	EPA 300.0	08/17/07		7619
Total Dissolved Solids	940	10	1	mg/L	SM 2540 C	08/23/07		7831
Sodium Adsorption Ratio	1.3	0.1	1		EPA 200.7	08/29/07		8012
Boron	0.11	0.05	1	mg/L	EPA 200.8	08/29/07		8005
Calcium	88	0.03	1	mg/L	EPA 200.8	08/29/07		8005
Copper	Not Detected	0.05	1	mg/L	EPA 200.8	08/29/07		8005
Iron	0.1	0.1	1	mg/L	EPA 200.8	08/29/07		8005
Magnesium	100	0.03	1	mg/L	EPA 200.8	08/29/07		8005
Manganese	Not Detected	0.02	1	mg/L	EPA 200.8	08/29/07		8005
Potassium	0.8	0.1	1	mg/L	EPA 200.8	08/29/07		8005
Sodium	77	0.05	1	mg/L	EPA 200.8	08/29/07		8005
Zinc	0.07	0.05	1	mg/L	EPA 200.8	08/29/07		8005
Hardness	640	1	1	mg/L CaCO3	EPA 200.8	08/30/07		8009

DLR = Detection Limit for Reporting. Results of "Not Detected" are below DLR.

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Lab Director, Michael Ng

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Log Number: 07-C10505
Order: 04318
Project: Morro Bay Nitrate Study
Received: 08/17/07
Printed: 08/30/07

REPORT OF ANALYTICAL RESULTS

Sample Description	Sampled By	Sampled Date @ Time	Matrix
Well "I"	Spencer Harris	08/17/07@12:15	Aqueous

Analyte	Result	DLR	Dilution Factor	Units	Method	Date Analyzed	Date Prepared	Batch
Total Alkalinity as CaCO3	380	2	1	mg/L	SM 2320B	08/26/07		7811
Chloride	140	10	10	mg/L	EPA 300.0	08/20/07		7636
Electrical Conductance	1,200	1	1	umhos/cm	SM 2510	08/17/07		7718
Nitrate as N	17	0.1	1	mg/L	EPA 300.0	08/17/07		7619
Nitrate as NO3	75	0.4	1	mg/L	EPA 300.0			
pH	7.2	0.1	1	pH units	SM 4500-H B	08/17/07		7718
Sulfate	76	0.5	1	mg/L	EPA 300.0	08/17/07		7619
Total Dissolved Solids	780	10	1	mg/L	SM 2540 C	08/23/07		7831
Sodium Adsorption Ratio	1.4	0.1	1		EPA 200.7	08/29/07		8012
Boron	0.12	0.05	1	mg/L	EPA 200.8	08/29/07		8005
Calcium	71	0.03	1	mg/L	EPA 200.8	08/29/07		8005
Copper	Not Detected	0.05	1	mg/L	EPA 200.8	08/29/07		8005
Iron	Not Detected	0.1	1	mg/L	EPA 200.8	08/29/07		8005
Magnesium	95	0.03	1	mg/L	EPA 200.8	08/29/07		8005
Manganese	Not Detected	0.02	1	mg/L	EPA 200.8	08/29/07		8005
Potassium	0.7	0.1	1	mg/L	EPA 200.8	08/29/07		8005
Sodium	75	0.05	1	mg/L	EPA 200.8	08/29/07		8005
Zinc	Not Detected	0.05	1	mg/L	EPA 200.8	08/29/07		8005
Hardness	570	1	1	mg/L CaCO3	EPA 200.8	08/30/07		8009

DLR = Detection Limit for Reporting. Results of "Not Detected" are below DLR.

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Lab Director, Michael Ng

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Log Number: 07-C10506
Order: 04318
Project: Morro Bay Nitrate Study
Received: 08/17/07
Printed: 08/30/07

REPORT OF ANALYTICAL RESULTS

Sample Description	Sampled By	Sampled Date @ Time	Matrix
Well "J"	Spencer Harris	08/17/07@12:20	Aqueous

Analyte	Result	DLR	Dilution Factor	Units	Method	Date Analyzed	Date Prepared	Batch
Total Alkalinity as CaCO3	390	2	1	mg/L	SM 2320B	08/26/07		7811
Chloride	170	10	10	mg/L	EPA 300.0	08/20/07		7636
Electrical Conductance	1,600	1	1	umhos/cm	SM 2510	08/17/07		7718
Nitrate as N	45	0.1	1	mg/L	EPA 300.0	08/17/07		7619
Nitrate as NO3	200	0.4	1	mg/L	EPA 300.0			
pH	7.1	0.1	1	pH units	SM 4500-H B	08/17/07		7718
Sulfate	110	0.5	1	mg/L	EPA 300.0	08/17/07		7619
Total Dissolved Solids	980	10	1	mg/L	SM 2540 C	08/23/07		7831
Sodium Adsorption Ratio	1.4	0.1	1		EPA 200.7	08/29/07		8012
Boron	0.11	0.05	1	mg/L	EPA 200.8	08/29/07		8005
Calcium	94	0.03	1	mg/L	EPA 200.8	08/29/07		8005
Copper	Not Detected	0.05	1	mg/L	EPA 200.8	08/29/07		8005
Iron	0.2	0.1	1	mg/L	EPA 200.8	08/29/07		8005
Magnesium	110	0.03	1	mg/L	EPA 200.8	08/29/07		8005
Manganese	Not Detected	0.02	1	mg/L	EPA 200.8	08/29/07		8005
Potassium	0.8	0.1	1	mg/L	EPA 200.8	08/29/07		8005
Sodium	80	0.05	1	mg/L	EPA 200.8	08/29/07		8005
Zinc	Not Detected	0.05	1	mg/L	EPA 200.8	08/29/07		8005
Hardness	690	1	1	mg/L CaCO3	EPA 200.8	08/30/07		8009

DLR = Detection Limit for Reporting. Results of "Not Detected" are below DLR.

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Lab Director, Michael Ng

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Log Number: 07-C10507
Order: 04318
Project: Morro Bay Nitrate Study
Received: 08/17/07
Printed: 08/30/07

REPORT OF ANALYTICAL RESULTS

Sample Description	Sampled By	Sampled Date @ Time	Matrix
Well "K"	Spencer Harris	08/17/07@12:30	Aqueous

Analyte	Result	DLR	Dilution Factor	Units	Method	Date Analyzed	Date Prepared	Batch
Total Alkalinity as CaCO3	400	2	1	mg/L	SM 2320B	08/26/07		7811
Chloride	180	10	10	mg/L	EPA 300.0	08/20/07		7636
Electrical Conductance	1,700	1	1	umhos/cm	SM 2510	08/17/07		7718
Nitrate as N	50	0.1	1	mg/L	EPA 300.0	08/17/07		7619
Nitrate as NO3	220	0.4	1	mg/L	EPA 300.0			
pH	7.2	0.1	1	pH units	SM 4500-H B	08/17/07		7718
Sulfate	120	0.5	1	mg/L	EPA 300.0	08/17/07		7619
Total Dissolved Solids	1,000	10	1	mg/L	SM 2540 C	08/24/07		7882
Sodium Adsorption Ratio	1.4	0.1	1		EPA 200.7	08/29/07		8012
Boron	0.12	0.05	1	mg/L	EPA 200.8	08/29/07		8005
Calcium	100	0.03	1	mg/L	EPA 200.8	08/29/07		8005
Copper	Not Detected	0.05	1	mg/L	EPA 200.8	08/29/07		8005
Iron	0.1	0.1	1	mg/L	EPA 200.8	08/29/07		8005
Magnesium	120	0.03	1	mg/L	EPA 200.8	08/29/07		8005
Manganese	Not Detected	0.02	1	mg/L	EPA 200.8	08/29/07		8005
Potassium	0.9	0.1	1	mg/L	EPA 200.8	08/29/07		8005
Sodium	88	0.05	1	mg/L	EPA 200.8	08/29/07		8005
Zinc	Not Detected	0.05	1	mg/L	EPA 200.8	08/29/07		8005
Hardness	760	1	1	mg/L CaCO3	EPA 200.8	08/30/07		8009

DLR = Detection Limit for Reporting. Results of "Not Detected" are below DLR.

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Lab Director, Michael Ng

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Log Number: 07-C10508
Order: 04318
Project: Morro Bay Nitrate Study
Received: 08/17/07
Printed: 08/30/07

REPORT OF ANALYTICAL RESULTS

Sample Description	Sampled By	Sampled Date @ Time	Matrix
Well "L"	Spencer Harris	08/17/07@14:00	Aqueous

Analyte	Result	DLR	Dilution Factor	Units	Method	Date Analyzed	Date Prepared	Batch
Total Alkalinity as CaCO3	440	2	1	mg/L	SM 2320B	08/26/07		7811
Chloride	60	1	1	mg/L	EPA 300.0	08/17/07		7619
Electrical Conductance	1,000	1	1	umhos/cm	SM 2510	08/17/07		7718
Nitrate as N	Not Detected	0.1	1	mg/L	EPA 300.0	08/17/07		7619
Nitrate as NO3	Not Detected	0.4	1	mg/L	EPA 300.0			
pH	7.7	0.1	1	pH units	SM 4500-H B	08/17/07		7718
Sulfate	100	0.5	1	mg/L	EPA 300.0	08/17/07		7619
Total Dissolved Solids	670	10	1	mg/L	SM 2540 C	08/24/07		7882
Sodium Adsorption Ratio	1.0	0.1	1		EPA 200.7	08/29/07		8012
Boron	0.17	0.05	1	mg/L	EPA 200.8	08/29/07		8005
Calcium	80	0.03	1	mg/L	EPA 200.8	08/29/07		8005
Copper	Not Detected	0.05	1	mg/L	EPA 200.8	08/29/07		8005
Iron	Not Detected	0.1	1	mg/L	EPA 200.8	08/29/07		8005
Magnesium	79	0.03	1	mg/L	EPA 200.8	08/29/07		8005
Manganese	0.69	0.02	1	mg/L	EPA 200.8	08/29/07		8005
Potassium	0.9	0.1	1	mg/L	EPA 200.8	08/29/07		8005
Sodium	53	0.05	1	mg/L	EPA 200.8	08/29/07		8005
Zinc	Not Detected	0.05	1	mg/L	EPA 200.8	08/29/07		8005
Hardness	520	1	1	mg/L CaCO3	EPA 200.8	08/30/07		8009

DLR = Detection Limit for Reporting. Results of "Not Detected" are below DLR.

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Log Number: 07-C10509
Order: 04318
Project: Morro Bay Nitrate Study
Received: 08/17/07
Printed: 08/30/07

REPORT OF ANALYTICAL RESULTS

Sample Description	Sampled By	Sampled Date @ Time	Matrix
Well "M"	Spencer Harris	08/17/07@14:10	Aqueous

Analyte	Result	DLR	Dilution Factor	Units	Method	Date Analyzed	Date Prepared	Batch
Total Alkalinity as CaCO3	460	2	1	mg/L	SM 2320B	08/26/07		7811
Chloride	53	1	1	mg/L	EPA 300.0	08/17/07		7619
Electrical Conductance	1,000	1	1	umhos/cm	SM 2510	08/17/07		7718
Nitrate as N	Not Detected	0.1	1	mg/L	EPA 300.0	08/17/07		7619
Nitrate as NO3	Not Detected	0.4	1	mg/L	EPA 300.0			
pH	7.6	0.1	1	pH units	SM 4500-H B	08/17/07		7718
Sulfate	93	0.5	1	mg/L	EPA 300.0	08/17/07		7619
Total Dissolved Solids	670	10	1	mg/L	SM 2540 C	08/24/07		7882
Sodium Adsorption Ratio	1.2	0.1	1		EPA 200.7	08/29/07		8012
Boron	0.21	0.05	1	mg/L	EPA 200.8	08/29/07		8005
Calcium	78	0.03	1	mg/L	EPA 200.8	08/29/07		8005
Copper	Not Detected	0.05	1	mg/L	EPA 200.8	08/29/07		8005
Iron	Not Detected	0.1	1	mg/L	EPA 200.8	08/29/07		8005
Magnesium	75	0.03	1	mg/L	EPA 200.8	08/29/07		8005
Manganese	0.71	0.02	1	mg/L	EPA 200.8	08/29/07		8005
Potassium	0.9	0.1	1	mg/L	EPA 200.8	08/29/07		8005
Sodium	60	0.05	1	mg/L	EPA 200.8	08/29/07		8005
Zinc	Not Detected	0.05	1	mg/L	EPA 200.8	08/29/07		8005
Hardness	500	1	1	mg/L CaCO3	EPA 200.8	08/30/07		8009

DLR = Detection Limit for Reporting. Results of "Not Detected" are below DLR.

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Log Number: 07-C10510
Order: 04318
Project: Morro Bay Nitrate Study
Received: 08/17/07
Printed: 08/30/07

REPORT OF ANALYTICAL RESULTS

Sample Description	Sampled By	Sampled Date @ Time	Matrix
WEll "N"	Spencer Harris	08/17/07@14:15	Aqueous

Analyte	Result	DLR	Dilution Factor	Units	Method	Date Analyzed	Date Prepared	Batch
Total Alkalinity as CaCO3	380	2	1	mg/L	SM 2320B	08/26/07		7812
Chloride	54	1	1	mg/L	EPA 300.0	08/17/07		7619
Electrical Conductance	870	1	1	umhos/cm	SM 2510	08/17/07		7718
Nitrate as N	0.4	0.1	1	mg/L	EPA 300.0	08/17/07		7619
Nitrate as NO3	1.8	0.4	1	mg/L	EPA 300.0			
pH	7.6	0.1	1	pH units	SM 4500-H B	08/17/07		7718
Sulfate	54	0.5	1	mg/L	EPA 300.0	08/17/07		7619
Total Dissolved Solids	540	10	1	mg/L	SM 2540 C	08/24/07		7882
Sodium Adsorption Ratio	1.4	0.1	1		EPA 200.7	08/29/07		8012
Boron	0.26	0.05	1	mg/L	EPA 200.8	08/29/07		8005
Calcium	59	0.03	1	mg/L	EPA 200.8	08/29/07		8005
Copper	Not Detected	0.05	1	mg/L	EPA 200.8	08/29/07		8005
Iron	Not Detected	0.1	1	mg/L	EPA 200.8	08/29/07		8005
Magnesium	57	0.03	1	mg/L	EPA 200.8	08/29/07		8005
Manganese	1.0	0.02	1	mg/L	EPA 200.8	08/29/07		8005
Potassium	0.9	0.1	1	mg/L	EPA 200.8	08/29/07		8005
Sodium	62	0.05	1	mg/L	EPA 200.8	08/29/07		8005
Zinc	Not Detected	0.05	1	mg/L	EPA 200.8	08/29/07		8005
Hardness	380	1	1	mg/L CaCO3	EPA 200.8	08/30/07		8009

DLR = Detection Limit for Reporting. Results of "Not Detected" are below DLR.

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Log Number: 07-C10511
Order: 04318
Project: Morro Bay Nitrate Study
Received: 08/17/07
Printed: 08/30/07

REPORT OF ANALYTICAL RESULTS

Sample Description	Sampled By	Sampled Date @ Time	Matrix
Well "O"	Spencer Harris	08/17/07@14:20	Aqueous

Analyte	Result	DLR	Dilution Factor	Units	Method	Date Analyzed	Date Prepared	Batch
Total Alkalinity as CaCO3	370	2	1	mg/L	SM 2320B	08/26/07		7812
Chloride	48	1	1	mg/L	EPA 300.0	08/17/07		7619
Electrical Conductance	840	1	1	umhos/cm	SM 2510	08/17/07		7718
Nitrate as N	0.4	0.1	1	mg/L	EPA 300.0	08/17/07		7619
Nitrate as NO3	1.8	0.4	1	mg/L	EPA 300.0			
pH	7.6	0.1	1	pH units	SM 4500-H B	08/17/07		7718
Sulfate	53	0.5	1	mg/L	EPA 300.0	08/17/07		7619
Total Dissolved Solids	540	10	1	mg/L	SM 2540 C	08/24/07		7882
Sodium Adsorption Ratio	1.3	0.1	1		EPA 200.7	08/29/07		8012
Boron	0.25	0.05	1	mg/L	EPA 200.8	08/29/07		8005
Calcium	59	0.03	1	mg/L	EPA 200.8	08/29/07		8005
Copper	Not Detected	0.05	1	mg/L	EPA 200.8	08/29/07		8005
Iron	Not Detected	0.1	1	mg/L	EPA 200.8	08/29/07		8005
Magnesium	56	0.03	1	mg/L	EPA 200.8	08/29/07		8005
Manganese	0.26	0.02	1	mg/L	EPA 200.8	08/29/07		8005
Potassium	0.9	0.1	1	mg/L	EPA 200.8	08/29/07		8005
Sodium	58	0.05	1	mg/L	EPA 200.8	08/29/07		8005
Zinc	Not Detected	0.05	1	mg/L	EPA 200.8	08/29/07		8005
Hardness	380	1	1	mg/L CaCO3	EPA 200.8	08/30/07		8009

DLR = Detection Limit for Reporting. Results of "Not Detected" are below DLR.

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Lab Director, Michael Ng

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Log Number: 07-C10512
Order: 04318
Project: Morro Bay Nitrate Study
Received: 08/17/07
Printed: 08/30/07

REPORT OF ANALYTICAL RESULTS

Sample Description	Sampled By	Sampled Date @ Time	Matrix
Well "P"	Spencer Harris	08/17/07@14:45	Aqueous

Analyte	Result	DLR	Dilution Factor	Units	Method	Date Analyzed	Date Prepared	Batch
Total Alkalinity as CaCO3	690	2	1	mg/L	SM 2320B	08/26/07		7812
Chloride	970	20	20	mg/L	EPA 300.0	08/24/07		7814
Electrical Conductance	4,000	1	1	umhos/cm	SM 2510	08/17/07		7718
Nitrate as N	22	0.1	1	mg/L	EPA 300.0	08/17/07		7619
Nitrate as NO3	97	0.4	1	mg/L	EPA 300.0			
pH	7.4	0.1	1	pH units	SM 4500-H B	08/17/07		7718
Sulfate	230	0.5	1	mg/L	EPA 300.0	08/17/07		7619
Total Dissolved Solids	2,000	10	1	mg/L	SM 2540 C	08/24/07		7882
Sodium Adsorption Ratio	9.8	0.1	1		EPA 200.7	08/29/07		8012
Boron	0.89	0.05	1	mg/L	EPA 200.8	08/29/07		8005
Calcium	56	0.03	1	mg/L	EPA 200.8	08/29/07		8005
Copper	Not Detected	0.05	1	mg/L	EPA 200.8	08/29/07		8005
Iron	Not Detected	0.1	1	mg/L	EPA 200.8	08/29/07		8005
Magnesium	220	0.03	1	mg/L	EPA 200.8	08/29/07		8005
Manganese	Not Detected	0.02	1	mg/L	EPA 200.8	08/29/07		8005
Potassium	1.1	0.1	1	mg/L	EPA 200.8	08/29/07		8005
Sodium	720	0.05	1	mg/L	EPA 200.8	08/29/07		8005
Zinc	0.10	0.05	1	mg/L	EPA 200.8	08/29/07		8005
Hardness	1,000	1	1	mg/L CaCO3	EPA 200.8	08/30/07		8009

DLR = Detection Limit for Reporting. Results of "Not Detected" are below DLR.

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Lab Director, Michael Ng

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Kimberly Peeples
City of Morro Bay
955 Shasta
Morro Bay, CA 93442

Log Number: 07-C5970
Order: 02562
Received: 05/08/07
Printed: 05/17/07

RECEIVED
MAY 22 2007
City of Morro Bay
Public Services Department

REPORT OF ANALYTICAL RESULTS

Sample Description	Sampled By	Sampled Date @ Time	Matrix
Well #3	Alex Kuchenmeister	05/08/07@08:40	Drinking Water

Analyte	Result	DLR	Dilution Factor	Units	Method	Date Analyzed	Date Prepared	Batch
Carbonate Alkalinity as CaCO3	Not Detected	2	1	mg/L	SM 2320B	05/16/07		4778
Bicarbonate Alkalinity as CaCO3	370	2	1	mg/L	SM 2320B	05/16/07		4778
Hydroxide Alkalinity as CaCO3	Not Detected	2	1	mg/L	SM 2320B	05/16/07		4778
Total Alkalinity as CaCO3	370	2	1	mg/L	SM 2320B	05/16/07		4778
Chloride	99	1	1	mg/L	EPA 300.0	05/09/07		4627
Total Cyanide	Not Detected	0.005	1	mg/L	SM 4500-CN C,E	05/16/07	05/14/07	4804
Color	20	1	1	units	SM 2120B	05/08/07		4631
Electrical Conductance	1,200	1	1	umhos/cm	SM 2510	05/08/07		4631
Fluoride	0.4	0.1	1	mg/L	EPA 300.0	05/09/07		4627
Langlier Index (Corrosivity)	0.2	---	1	pH units	SM 2330B	05/17/07		4824
MBAS(Anionic Surfactants MW=340)	Not Detected	0.05	1	mg/L	SM 5540 C	05/10/07		4633
Nitrate as N	12	0.1	1	mg/L	EPA 300.0	05/09/07		4627
Nitrate as NO3	55	0.4	1	mg/L	EPA 300.0			
Nitrite as N	Not Detected	0.1	1	mg/L	EPA 300.0	05/09/07		4627
Odor	Not Detected	1	1	TON	SM 2150B	05/08/07		4631
pH	7.2	0.1	1	pH units	SM 4500-H B	05/08/07		4631
Sulfate	100	0.5	1	mg/L	EPA 300.0	05/09/07		4627
Total Dissolved Solids	690	10	1	mg/L	SM 2540 C	05/15/07		4808
Turbidity	3.5	0.1	1	NTU	SM 2130 B	05/08/07		4631
Calcium	80	0.03	1	mg/L	EPA 200.7	05/10/07	05/10/07	4638
Hardness	510	1	NA	mg/L CaCO3	EPA 200.7			
Iron	0.5	0.1	1	mg/L	EPA 200.7	05/10/07	05/10/07	4638
Mercury	Not Detected	0.001	1	mg/L	EPA 245.1	05/16/07	05/15/07	4801
Potassium	0.6	0.1	1	mg/L	EPA 200.7	05/10/07	05/10/07	4638
Magnesium	77	0.03	1	mg/L	EPA 200.7	05/10/07	05/10/07	4638
Sodium	49	0.05	1	mg/L	EPA 200.7	05/10/07	05/10/07	4638
Benzene	Not Detected	0.5	1	ug/L	EPA 524.2	05/10/07		4683
Bromobenzene	Not Detected	0.5	1	ug/L	EPA 524.2	05/10/07		4683
Bromochloromethane	Not Detected	0.5	1	ug/L	EPA 524.2	05/10/07		4683
Bromodichloromethane	Not Detected	0.5	1	ug/L	EPA 524.2	05/10/07		4683

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Log Number: 07-C5971
Order: 02562
Received: 05/08/07
Printed: 05/17/07

RECEIVED
MAY 22 2007
City of Morro Bay
Public Services Department

REPORT OF ANALYTICAL RESULTS

Sample Description	Sampled By	Sampled Date @ Time	Matrix
Well #4	Alex Kuchenmeister	05/08/07@08:45	Drinking Water

Analyte	Result	DLR	Dilution Factor	Units	Method	Date Analyzed	Date Prepared	Batch
Carbonate Alkalinity as CaCO3	Not Detected	2	1	mg/L	SM 2320B	05/16/07		4778
Bicarbonate Alkalinity as CaCO3	360	2	1	mg/L	SM 2320B	05/16/07		4778
Hydroxide Alkalinity as CaCO3	Not Detected	2	1	mg/L	SM 2320B	05/16/07		4778
Total Alkalinity as CaCO3	360	2	1	mg/L	SM 2320B	05/16/07		4778
Chloride	84	1	1	mg/L	EPA 300.0	05/09/07		4627
Total Cyanide	Not Detected	0.005	1	mg/L	SM 4500-CN C,E	05/17/07	05/17/07	4821
Color	5	1	1	units	SM 2120B	05/08/07		4631
Electrical Conductance	1,100	1	1	umhos/cm	SM 2510	05/08/07		4631
Fluoride	0.3	0.1	1	mg/L	EPA 300.0	05/09/07		4627
Langlier Index (Corrosivity)	0.3	---	1	pH units	SM 2330B	05/17/07		4824
MBAS(Anionic Surfactants MW=340)	Not Detected	0.05	1	mg/L	SM 5540 C	05/10/07		4633
Nitrate as N	14	0.1	1	mg/L	EPA 300.0	05/09/07		4627
Nitrate as NO3	62	0.4	1	mg/L	EPA 300.0			
Nitrite as N	Not Detected	0.1	1	mg/L	EPA 300.0	05/09/07		4627
Odor	Not Detected	1	1	TON	SM 2150B	05/08/07		4631
pH	7.3	0.1	1	pH units	SM 4500-H B	05/08/07		4631
Sulfate	93	0.5	1	mg/L	EPA 300.0	05/09/07		4627
Total Dissolved Solids	640	10	1	mg/L	SM 2540 C	05/15/07		4808
Turbidity	0.7	0.1	1	NTU	SM 2130 B	05/08/07		4631
Calcium	81	0.03	1	mg/L	EPA 200.7	05/14/07		4715
Hardness	530	1	NA	mg/L CaCO3	EPA 200.7			
Iron	0.1	0.1	1	mg/L	EPA 200.7	05/14/07		4715
Mercury	Not Detected	0.001	1	mg/L	EPA 245.1	05/16/07	05/15/07	4801
Potassium	0.8	0.1	1	mg/L	EPA 200.7	05/14/07		4715
Magnesium	79	0.03	1	mg/L	EPA 200.7	05/14/07		4715
Sodium	49	0.05	1	mg/L	EPA 200.7	05/14/07		4715
Benzene	Not Detected	0.5	1	ug/L	EPA 524.2	05/10/07		4683
Bromobenzene	Not Detected	0.5	1	ug/L	EPA 524.2	05/10/07		4683
Bromochloromethane	Not Detected	0.5	1	ug/L	EPA 524.2	05/10/07		4683
Bromodichloromethane	Not Detected	0.5	1	ug/L	EPA 524.2	05/10/07		4683

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Kimberly Peeples
City of Morro Bay
955 Shasta
Morro Bay, CA 93442

Log Number: 07-C5972
Order: 02562
Received: 05/08/07
Printed: 05/17/07

RECEIVED
MAY 29 2007
City of Morro Bay
Public Services Department

REPORT OF ANALYTICAL RESULTS

Sample Description	Sampled By	Sampled Date @ Time	Matrix
Well #14	Alex Kuchenmeister	05/08/07@08:50	Drinking Water

Analyte	Result	DLR	Dilution Factor	Units	Method	Date Analyzed	Date Prepared	Batch
Carbonate Alkalinity as CaCO3	Not Detected	2	1	mg/L	SM 2320B	05/16/07		4778
Bicarbonate Alkalinity as CaCO3	350	2	1	mg/L	SM 2320B	05/16/07		4778
Hydroxide Alkalinity as CaCO3	Not Detected	2	1	mg/L	SM 2320B	05/16/07		4778
Total Alkalinity as CaCO3	350	2	1	mg/L	SM 2320B	05/16/07		4778
Chloride	88	1	1	mg/L	EPA 300.0	05/09/07		4627
Total Cyanide	Not Detected	0.005	1	mg/L	SM 4500-CN C,E	05/17/07	05/17/07	4821
Color	20	1	1	units	SM 2120B	05/08/07		4631
Electrical Conductance	1,100	1	1	umhos/cm	SM 2510	05/08/07		4631
Fluoride	0.2	0.1	1	mg/L	EPA 300.0	05/09/07		4627
Langlier Index (Corrosivity)	0.1	---	1	pH units	SM 2330B	05/17/07		4824
MBAS(Anionic Surfactants MW=340)	Not Detected	0.05	1	mg/L	SM 5540 C	05/10/07		4633
Nitrate as N	16	0.1	1	mg/L	EPA 300.0	05/09/07		4627
Nitrate as NO3	72	0.4	1	mg/L	EPA 300.0			
Nitrite as N	Not Detected	0.1	1	mg/L	EPA 300.0	05/09/07		4627
Odor	Not Detected	1	1	TON	SM 2150B	05/08/07		4631
pH	7.1	0.1	1	pH units	SM 4500-H B	05/08/07		4631
Sulfate	91	0.5	1	mg/L	EPA 300.0	05/09/07		4627
Total Dissolved Solids	660	10	1	mg/L	SM 2540 C	05/15/07		4808
Turbidity	8.8	0.1	1	NTU	SM 2130 B	05/08/07		4631
Calcium	82	0.03	1	mg/L	EPA 200.7	05/14/07		4715
Hardness	530	1	NA	mg/L CaCO3	EPA 200.7			
Iron	0.7	0.1	1	mg/L	EPA 200.7	05/14/07		4715
Mercury	Not Detected	0.001	1	mg/L	EPA 245.1	05/16/07	05/15/07	4801
Potassium	1.0	0.1	1	mg/L	EPA 200.7	05/14/07		4715
Magnesium	79	0.03	1	mg/L	EPA 200.7	05/14/07		4715
Sodium	51	0.05	1	mg/L	EPA 200.7	05/14/07		4715
Benzene	Not Detected	0.5	1	ug/L	EPA 524.2	05/10/07		4683
Bromobenzene	Not Detected	0.5	1	ug/L	EPA 524.2	05/10/07		4683
Bromochloromethane	Not Detected	0.5	1	ug/L	EPA 524.2	05/10/07		4683
Bromodichloromethane	Not Detected	0.5	1	ug/L	EPA 524.2	05/10/07		4683

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Kimberly Peeples
City of Morro Bay
955 Shasta
Morro Bay, CA 93442

Log Number: 07-C5974
Order: 02562
Received: 05/08/07
Printed: 05/17/07

RECEIVED
MAY 22 2007
City of Morro Bay
Public Services Department

REPORT OF ANALYTICAL RESULTS

Sample Description	Sampled By	Sampled Date @ Time	Matrix
Well #15	Alex Kuchenmeister	05/08/07@09:00	Drinking Water

Analyte	Result	DLR	Dilution Factor	Units	Method	Date Analyzed	Date Prepared	Batch
Carbonate Alkalinity as CaCO3	Not Detected	2	1	mg/L	SM 2320B	05/16/07		4778
Bicarbonate Alkalinity as CaCO3	340	2	1	mg/L	SM 2320B	05/16/07		4778
Hydroxide Alkalinity as CaCO3	Not Detected	2	1	mg/L	SM 2320B	05/16/07		4778
Total Alkalinity as CaCO3	340	2	1	mg/L	SM 2320B	05/16/07		4778
Chloride	81	1	1	mg/L	EPA 300.0	05/09/07		4627
Total Cyanide	Not Detected	0.005	1	mg/L	SM 4500-CN C,E	05/17/07	05/17/07	4821
Color	20	1	1	units	SM 2120B	05/08/07		4631
Electrical Conductance	1,000	1	1	umhos/cm	SM 2510	05/08/07		4631
Fluoride	0.2	0.1	1	mg/L	EPA 300.0	05/09/07		4627
Langlier Index (Corrosivity)	0.1	---	1	pH units	SM 2330B	05/17/07		4824
MBAS(Anionic Surfactants MW=340)	Not Detected	0.05	1	mg/L	SM 5540 C	05/10/07		4633
Nitrate as N	7.8	0.1	1	mg/L	EPA 300.0	05/09/07		4627
Nitrate as NO3	34	0.4	1	mg/L	EPA 300.0			
Nitrite as N	Not Detected	0.1	1	mg/L	EPA 300.0	05/09/07		4627
Odor	Not Detected	1	1	TON	SM 2150B	05/08/07		4631
pH	7.2	0.1	1	pH units	SM 4500-H B	05/08/07		4631
Sulfate	74	0.5	1	mg/L	EPA 300.0	05/09/07		4627
Total Dissolved Solids	580	10	1	mg/L	SM 2540 C	05/15/07		4808
Turbidity	2.3	0.1	1	NTU	SM 2130 B	05/08/07		4631
Calcium	75	0.03	1	mg/L	EPA 200.7	05/15/07		4787
Hardness	470	1	NA	mg/L CaCO3	EPA 200.7			
Iron	0.4	0.1	1	mg/L	EPA 200.7	05/15/07		4787
Mercury	Not Detected	0.001	1	mg/L	EPA 245.1	05/16/07	05/15/07	4801
Potassium	0.6	0.1	1	mg/L	EPA 200.7	05/15/07		4787
Magnesium	68	0.03	1	mg/L	EPA 200.7	05/15/07		4787
Sodium	49	0.05	1	mg/L	EPA 200.7	05/15/07		4787
Aluminum	Not Detected	0.05	1	mg/L	EPA 200.8	05/10/07	05/10/07	4636
Antimony	Not Detected	0.006	1	mg/L	EPA 200.8	05/10/07	05/10/07	4636
Arsenic	Not Detected	0.002	1	mg/L	EPA 200.8	05/10/07	05/10/07	4636
Copper	Not Detected	0.05	1	mg/L	EPA 200.8	05/10/07	05/10/07	4636

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Spencer Harris
Cleath & Associates
1390 Oceanaire Drive
San Luis Obispo, CA 93405

Log Number: 07-C10664
Order: 04377
Project: Morro Bay Nitrate Study
Received: 08/22/07
Printed: 09/06/07

REPORT OF ANALYTICAL RESULTS

Sample Description	Sampled By	Sampled Date @ Time	Matrix
MB-3	Spencer Harris	08/22/07@11:35	Drinking Water

Analyte	Result	DLR	Dilution Factor	Units	Method	Date Analyzed	Date Prepared	Batch
Total Alkalinity as CaCO3	370	2	1	mg/L	SM 2320B	08/30/07		8014
Chloride	100	10	10	mg/L	EPA 300.0	08/27/07		7892
Electrical Conductance	1,100	1	1	umhos/cm	SM 2510	08/22/07		7721
Nitrate as N	12	0.1	1	mg/L	EPA 300.0	08/23/07		7751
Nitrate as NO3	52	0.4	1	mg/L	EPA 300.0			
pH	7.5	0.1	1	pH units	SM 4500-H B	08/22/07		7721
Sulfate	91	0.5	1	mg/L	EPA 300.0	08/23/07		7751
Total Dissolved Solids	700	10	1	mg/L	SM 2540 C	08/29/07		8049
Boron	0.15	0.05	1	mg/L	EPA 200.7	09/04/07		8195
Calcium	85	0.03	1	mg/L	EPA 200.7	09/04/07		8195
Hardness	540	1	NA	mg/L CaCO3	EPA 200.7			
Sodium Adsorption Ratio	1.0	0.1	1		EPA 200.7	09/06/07		8255
Copper	0.09	0.05	1	mg/L	EPA 200.7	09/04/07		8195
Iron	0.85	0.02	1	mg/L	EPA 200.7	09/04/07		8195
Potassium	0.6	0.1	1	mg/L	EPA 200.7	09/04/07		8195
Magnesium	81	0.03	1	mg/L	EPA 200.7	09/04/07		8195
Manganese	0.07	0.02	1	mg/L	EPA 200.7	09/04/07		8195
Sodium	51	0.05	1	mg/L	EPA 200.7	09/04/07		8195
Zinc	Not Detected	0.05	1	mg/L	EPA 200.7	09/04/07		8195

DLR = Detection Limit for Reporting. Results of "Not Detected" are below DLR.

CREEK ENVIRONMENTAL LABORATORIES

Lab Director, Michael Ng

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Spencer Harris
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Log Number: 07-C10663
Order: 04377
Project: Morro Bay Nitrate Study
Received: 08/22/07
Printed: 09/06/07

REPORT OF ANALYTICAL RESULTS

Sample Description	Sampled By	Sampled Date @ Time	Matrix
MB-4	Spencer Harris	08/22/07@11:30	Drinking Water

Analyte	Result	DLR	Dilution Factor	Units	Method	Date Analyzed	Date Prepared	Batch
Total Alkalinity as CaCO3	360	2	1	mg/L	SM 2320B	08/30/07		8014
Chloride	92	1	1	mg/L	EPA 300.0	08/23/07		7751
Electrical Conductance	1,000	1	1	umhos/cm	SM 2510	08/22/07		7721
Nitrate as N	11	0.1	1	mg/L	EPA 300.0	08/23/07		7751
Nitrate as NO3	49	0.4	1	mg/L	EPA 300.0			
pH	7.4	0.1	1	pH units	SM 4500-H B	08/22/07		7721
Sulfate	88	0.5	1	mg/L	EPA 300.0	08/23/07		7751
Total Dissolved Solids	650	10	1	mg/L	SM 2540 C	08/29/07		8049
Boron	0.16	0.05	1	mg/L	EPA 200.7	09/04/07		8195
Calcium	88	0.03	1	mg/L	EPA 200.7	09/04/07		8195
Hardness	570	1	NA	mg/L CaCO3	EPA 200.7			
Sodium Adsorption Ratio	1.0	0.1	1		EPA 200.7	09/06/07		8255
Copper	Not Detected	0.05	1	mg/L	EPA 200.7	09/04/07		8195
Iron	0.06	0.02	1	mg/L	EPA 200.7	09/04/07		8195
Potassium	0.8	0.1	1	mg/L	EPA 200.7	09/04/07		8195
Magnesium	85	0.03	1	mg/L	EPA 200.7	09/04/07		8195
Manganese	Not Detected	0.02	1	mg/L	EPA 200.7	09/04/07		8195
Sodium	56	0.05	1	mg/L	EPA 200.7	09/04/07		8195
Zinc	Not Detected	0.05	1	mg/L	EPA 200.7	09/04/07		8195

DLR = Detection Limit for Reporting. Results of "Not Detected" are below DLR.

CREEK ENVIRONMENTAL LABORATORIES

Lab Director, Michael Ng

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Spencer Harris
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1390 Oceanaire Drive
San Luis Obispo, CA 93405

Log Number: 07-C10662
Order: 04377
Project: Morro Bay Nitrate Study
Received: 08/22/07
Printed: 09/06/07

REPORT OF ANALYTICAL RESULTS

Sample Description	Sampled By	Sampled Date @ Time	Matrix
MB-14	Spencer Harris	08/22/07@11:25	Drinking Water

Analyte	Result	DLR	Dilution Factor	Units	Method	Date Analyzed	Date Prepared	Batch
Total Alkalinity as CaCO3	350	2	1	mg/L	SM 2320B	08/30/07		8014
Chloride	77	1	1	mg/L	EPA 300.0	08/23/07		7751
Electrical Conductance	1,000	1	1	umhos/cm	SM 2510	08/22/07		7721
Nitrate as N	11	0.1	1	mg/L	EPA 300.0	08/23/07		7751
Nitrate as NO3	48	0.4	1	mg/L	EPA 300.0			
pH	7.2	0.1	1	pH units	SM 4500-H B	08/22/07		7721
Sulfate	84	0.5	1	mg/L	EPA 300.0	08/23/07		7751
Total Dissolved Solids	640	10	1	mg/L	SM 2540 C	08/29/07		8049
Boron	0.17	0.05	1	mg/L	EPA 200.7	09/04/07		8195
Calcium	75	0.03	1	mg/L	EPA 200.7	09/04/07		8195
Hardness	480	1	NA	mg/L CaCO3	EPA 200.7			
Sodium Adsorption Ratio	1.0	0.1	1		EPA 200.7	09/06/07		8255
Copper	Not Detected	0.05	1	mg/L	EPA 200.7	09/04/07		8195
Iron	1.1	0.02	1	mg/L	EPA 200.7	09/04/07		8195
Potassium	0.9	0.1	1	mg/L	EPA 200.7	09/04/07		8195
Magnesium	70	0.03	1	mg/L	EPA 200.7	09/04/07		8195
Manganese	0.15	0.02	1	mg/L	EPA 200.7	09/04/07		8195
Sodium	48	0.05	1	mg/L	EPA 200.7	09/04/07		8195
Zinc	Not Detected	0.05	1	mg/L	EPA 200.7	09/04/07		8195

DLR = Detection Limit for Reporting. Results of "Not Detected" are below DLR.

CREEK ENVIRONMENTAL LABORATORIES

Lab Director, Michael Ng

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Spencer Harris
Cleath & Associates
1390 Oceanaire Drive
San Luis Obispo, CA 93405

Log Number: 07-C10661
Order: 04377
Project: Morro Bay Nitrate Study
Received: 08/22/07
Printed: 09/06/07

REPORT OF ANALYTICAL RESULTS

Sample Description	Sampled By	Sampled Date @ Time	Matrix
MB-15	Spencer Harris	08/22/07@11:20	Drinking Water

Analyte	Result	DLR	Dilution Factor	Units	Method	Date Analyzed	Date Prepared	Batch
Total Alkalinity as CaCO3	400	2	1	mg/L	SM 2320B	08/30/07		8014
Chloride	160	10	10	mg/L	EPA 300.0	08/27/07		7892
Electrical Conductance	1,300	1	1	umhos/cm	SM 2510	08/22/07		7721
Nitrate as N	8.6	0.1	1	mg/L	EPA 300.0	08/23/07		7751
Nitrate as NO3	38	0.4	1	mg/L	EPA 300.0			
pH	7.2	0.1	1	pH units	SM 4500-H B	08/22/07		7721
Sulfate	79	0.5	1	mg/L	EPA 300.0	08/23/07		7751
Total Dissolved Solids	760	10	1	mg/L	SM 2540 C	08/29/07		8049
Boron	0.29	0.05	1	mg/L	EPA 200.7	09/04/07		8195
Calcium	100	0.03	1	mg/L	EPA 200.7	09/04/07		8195
Hardness	640	1	NA	mg/L CaCO3	EPA 200.7			
Sodium Adsorption Ratio	1.1	0.1	1		EPA 200.7	09/06/07		8255
Copper	Not Detected	0.05	1	mg/L	EPA 200.7	09/04/07		8195
Iron	0.86	0.02	1	mg/L	EPA 200.7	09/04/07		8195
Potassium	0.9	0.1	1	mg/L	EPA 200.7	09/04/07		8195
Magnesium	93	0.03	1	mg/L	EPA 200.7	09/04/07		8195
Manganese	Not Detected	0.02	1	mg/L	EPA 200.7	09/04/07		8195
Sodium	65	0.05	1	mg/L	EPA 200.7	09/04/07		8195
Zinc	Not Detected	0.05	1	mg/L	EPA 200.7	09/04/07		8195

DLR = Detection Limit for Reporting. Results of "Not Detected" are below DLR.

CREEK ENVIRONMENTAL LABORATORIES

Lab Director, Michael Ng

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ZymaX FORENSICS

REPORT OF ANALYTICAL RESULTS

Client:	Bill Boucher City of Morro Bay 955 Shasta Morro Bay, CA	Lab Number:	40650
		Received:	8/22/2007
		Matrix:	Water
Project:	Morro Bay Nitrate Study	Sample Description:	See Below
Project Number:		Analyzed:	Sept. 26, 2007
Collected by:	S. Harris	Method:	CF-IRMS

$\delta^{15}N$ $\delta^{18}O$

LAB NUMBER	SAMPLE DESCRIPTION	$\delta^{15}N$ ‰	$\delta^{18}O$ ‰
40650-1	MB-15	7.9	16.0
40650-2	MB-14	7.1	12.9
40650-3	MB-4	8.8	13.1
40650-4	MB-3	10.0	13.6
40650-5	Ferilizer	0.7	13.8
Analytical Precision (1-sigma)		0.3	0.2

Submitted by,
Zymax Forensics, a DPRA company

40650-1d15n.xls
RH

River He, PhD
Isotope Lab Manager

APPENDIX F

Well Field Nitrate Concentrations and Chemographs

Nitrate Concentration in Morro Valley Wells

City of Morro Bay

All Values in mg/l NO_3

Date	25C02 (MB-3)	25C03 (MB-4)	25F05 (MB-14)	25F06 (MB-15)
09/01/55	13.8			
03/05/57				
05/29/57	12.5			
08/29/57	12.5			
09/30/58	7.6			
12/03/59	13			
12/22/59				
01/04/60	16			
03/22/60	6			
06/27/60				
08/08/60	1.8			
08/16/60	8.2			
09/20/60	11			
08/18/61	5.7			
09/28/61				
11/01/61	20			
07/12/62				
10/30/62	13	3		
12/11/62	14.3	4.8		
03/07/63		1		
04/30/63				
07/08/63				
09/19/63	11			
10/15/63				
07/14/64				
09/11/64	10.5			
10/06/64				
04/06/65				
07/21/65	14			
08/03/65				
10/04/65	23			
12/09/65				
10/14/66				
07/21/66	14			
09/27/66	16			
10/14/66	20	11.6		
05/24/67		3.5		
11/07/67	4			
03/20/70	11	7		
03/23/70				
05/16/72	10.5	4		
02/15/73				
07/16/74	18	10	8	9
11/13/75	23	22	11	10
05/25/76				

All Values in mg/l NO_3

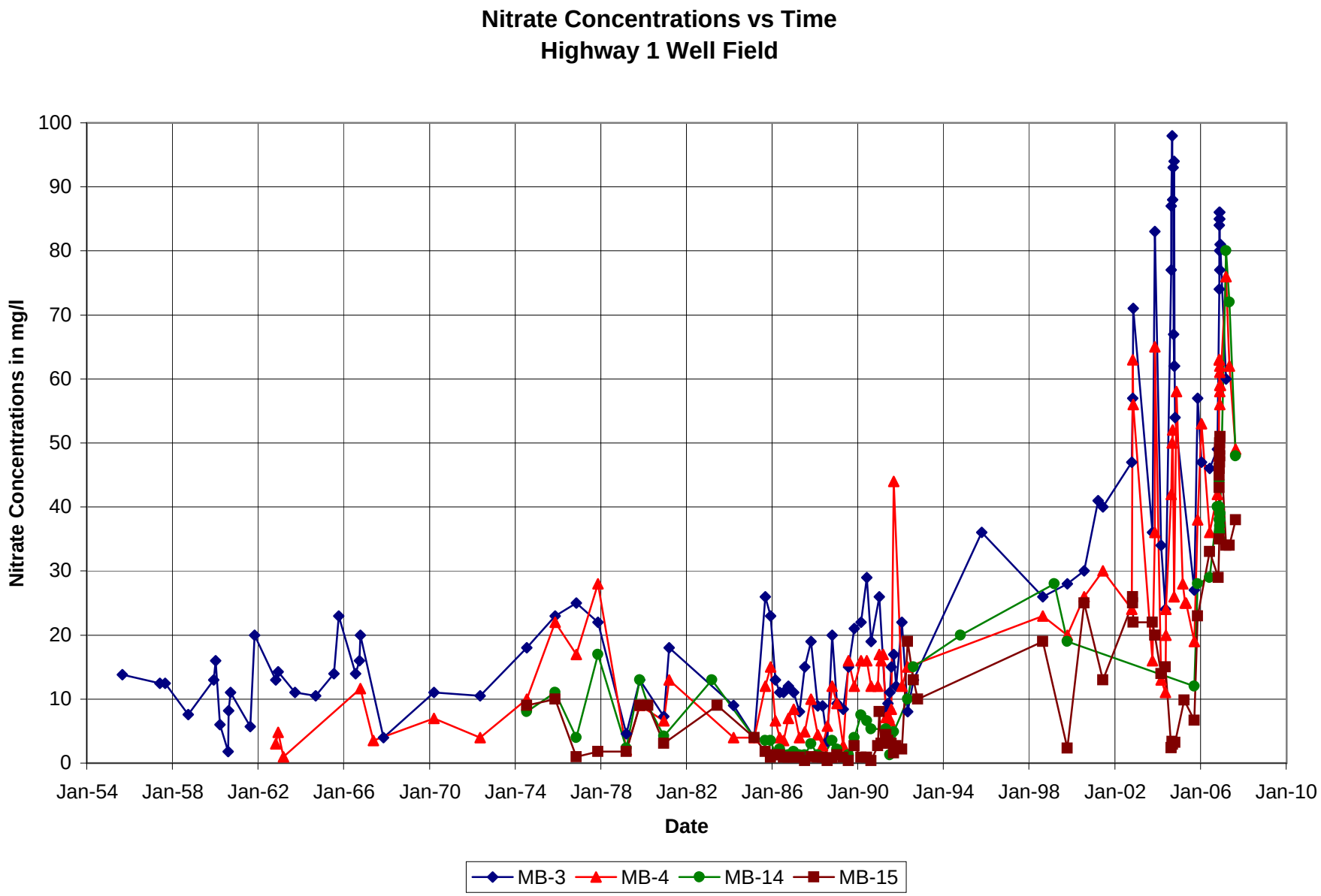
Date	25C02 (MB-3)	25C03 (MB-4)	25F05 (MB-14)	25F06 (MB-15)
11/09/76	25	17	4	1
11/15/77	22	28	17	1.8
03/14/79	4.6	2	2.3	1.8
09/19/79				
10/31/79	13	9	13	9
03/14/80			9	9
12/10/80	7.3	6.6	4.2	3.1
03/16/81	18	13		
03/12/82				
03/14/83			13	
06/14/83				9
03/13/84	9	4		
10/25/84				
11/12/84				
02/25/85				
03/06/85	4	4	4	4
05/06/85				
09/06/85	26	12	3.5	1.8
12/09/85	23	15	3.5	0.9
02/24/86	13	6.6	1.3	1.3
05/13/86	11	4	2.2	1.3
07/15/86	11	3.5	1.3	0.9
10/06/86	12	7	1.3	0.9
01/05/87	11	8.4	1.8	0.9
04/09/87	8	4	1.3	0.9
07/15/87	15	4.9	1.3	0.4
10/26/87	19	10	3	1
02/17/88	8.9	4.4	1.3	0.9
05/13/88	8.9	2.7	0.9	0.9
07/29/88	3.4	5.8		0.4
10/21/88	20	12	3.5	0.8
01/11/89	9.3	9.3	2.2	1.3
05/02/89	8.4	2.7	0.9	0.9
07/31/89	15	16	1.3	0.4
10/31/89	21	12	4	2.7
03/26/90				
02/27/90	22	16	7.5	0.9
06/04/90	29	16	6.6	0.9
07/02/90				
08/15/90	19	12	5.3	0.4
12/11/90		12		2.7
01/03/91	26	17		8
02/07/91		16		3.1
03/06/91		17		
04/30/91	8	7.1	5.3	4.4
05/28/91	9.3	7.1	4.9	3.5
06/18/91	8.4	7.1	4.4	3.1
07/02/91	11	6.6	1.3	

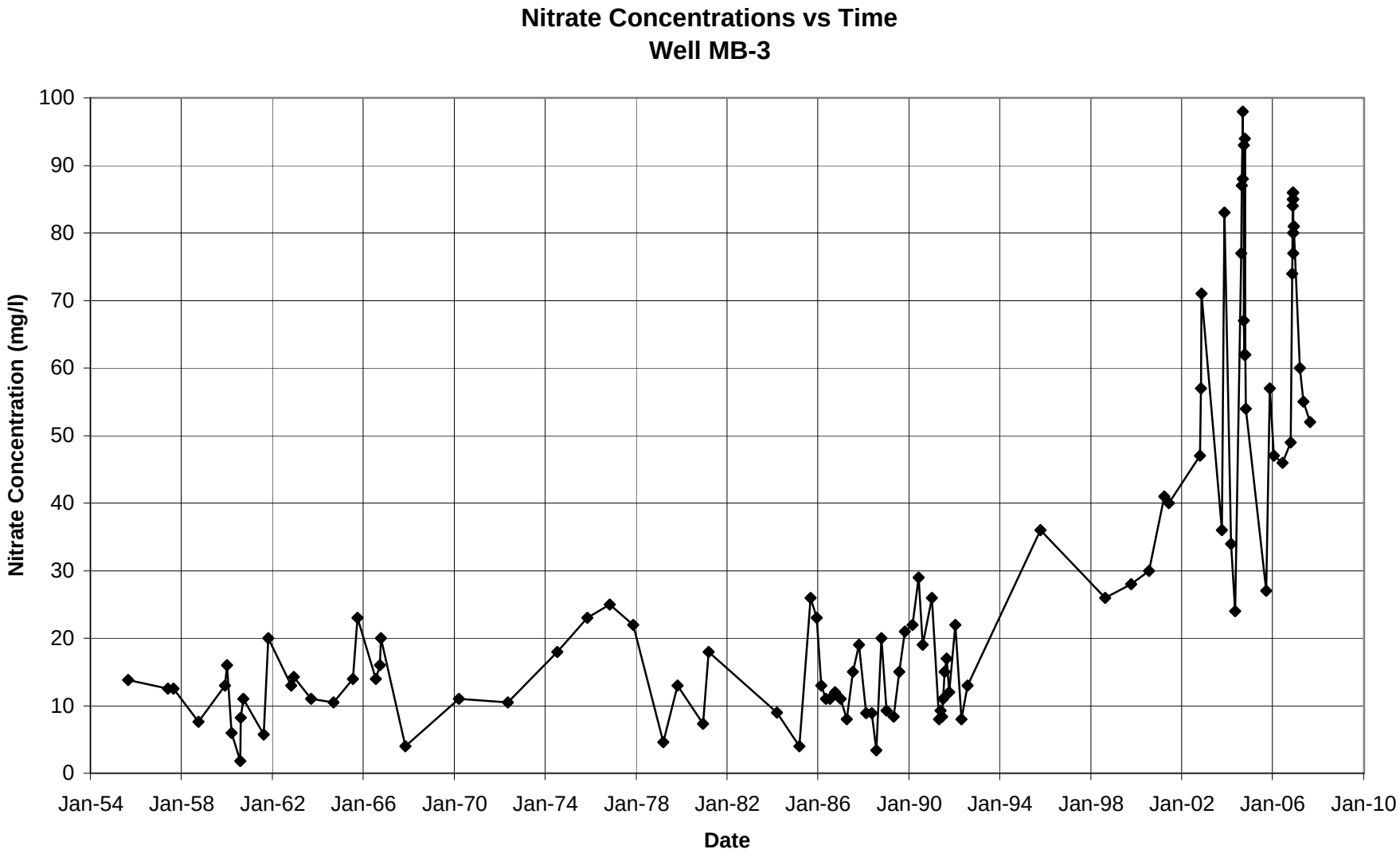
All Values in mg/l NO_3

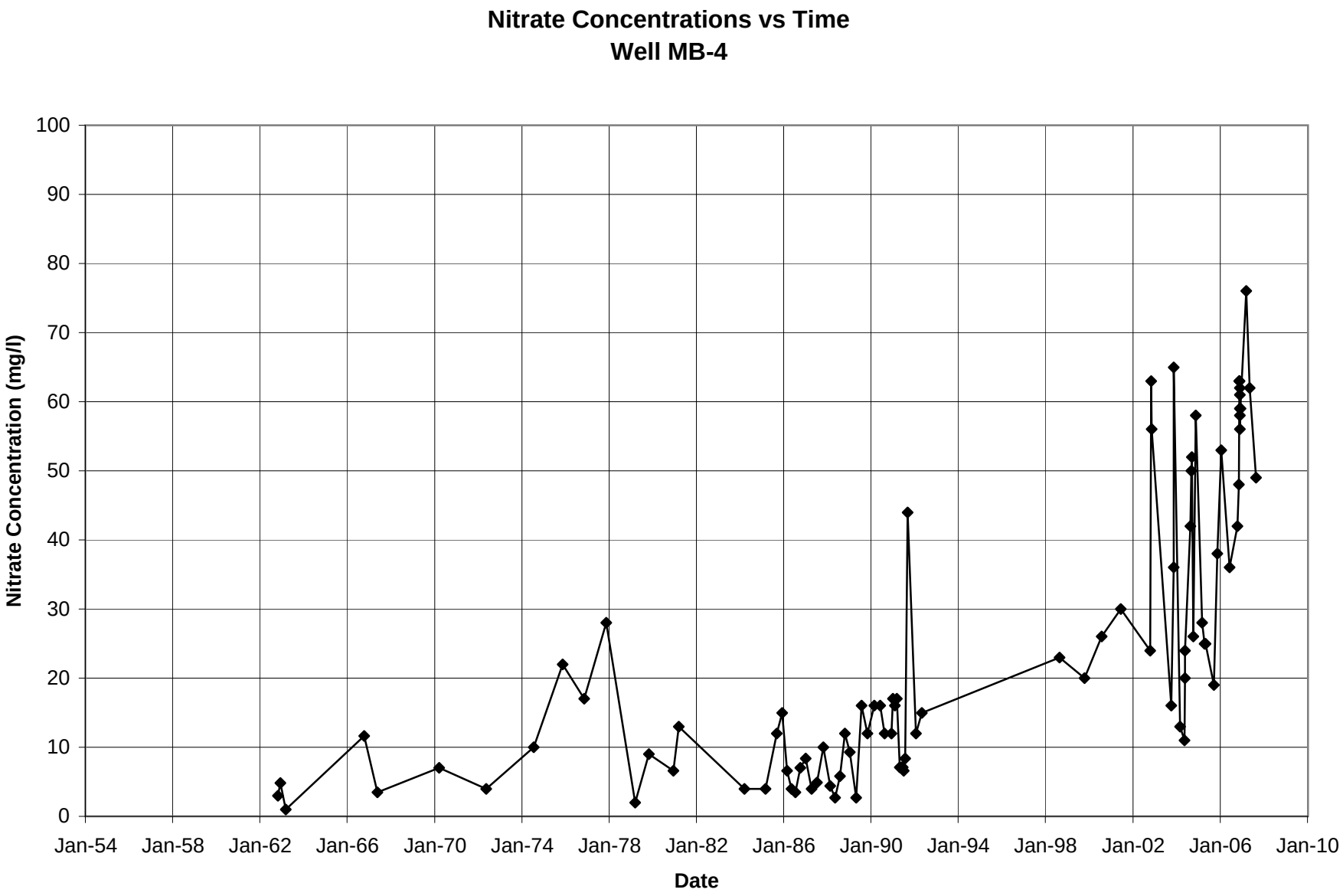
Date	25C02 (MB-3)	25C03 (MB-4)	25F05 (MB-14)	25F06 (MB-15)
07/30/91	15	8.4	4.4	3.1
08/05/91				
09/03/91	17	44	4.9	1.6
10/15/91	12			
01/21/92	22	12		
04/28/92	8	15		
08/04/92	13			
10/18/95	36			
08/20/98	26	23		
03/04/99			28	
10/14/99	28	20	19	
01/17/00				
07/27/00	30	26		
03/26/01	41			
06/13/01	40	30		
10/21/02	47	24		
11/07/02	57	63		
11/12/02	71	56		
10/07/03	36	16		
11/12/03		36		
11/19/03	83	65		
03/03/04	34	13		
05/12/04	24	11		
05/21/04		20		
05/25/04		24		
08/19/04	77			
08/24/04	87	42		
09/08/04	98	50		
09/13/04	88	52		
09/22/04	93			
09/28/04	67			
10/05/04	62			
10/12/04	94	26		
10/19/04	62			
10/26/04	54			
11/16/04		58		
03/08/05		28		
04/19/05		25		
05/03/05		25		
09/20/05	27	19	12	7
11/15/05	57	38	28	23
01/18/06	47	53		
06/06/06	46	36	29	33
10/17/06	49	42	40	
11/01/06				29
11/07/06		48	40	
11/15/06	74		44	35
11/16/06				43

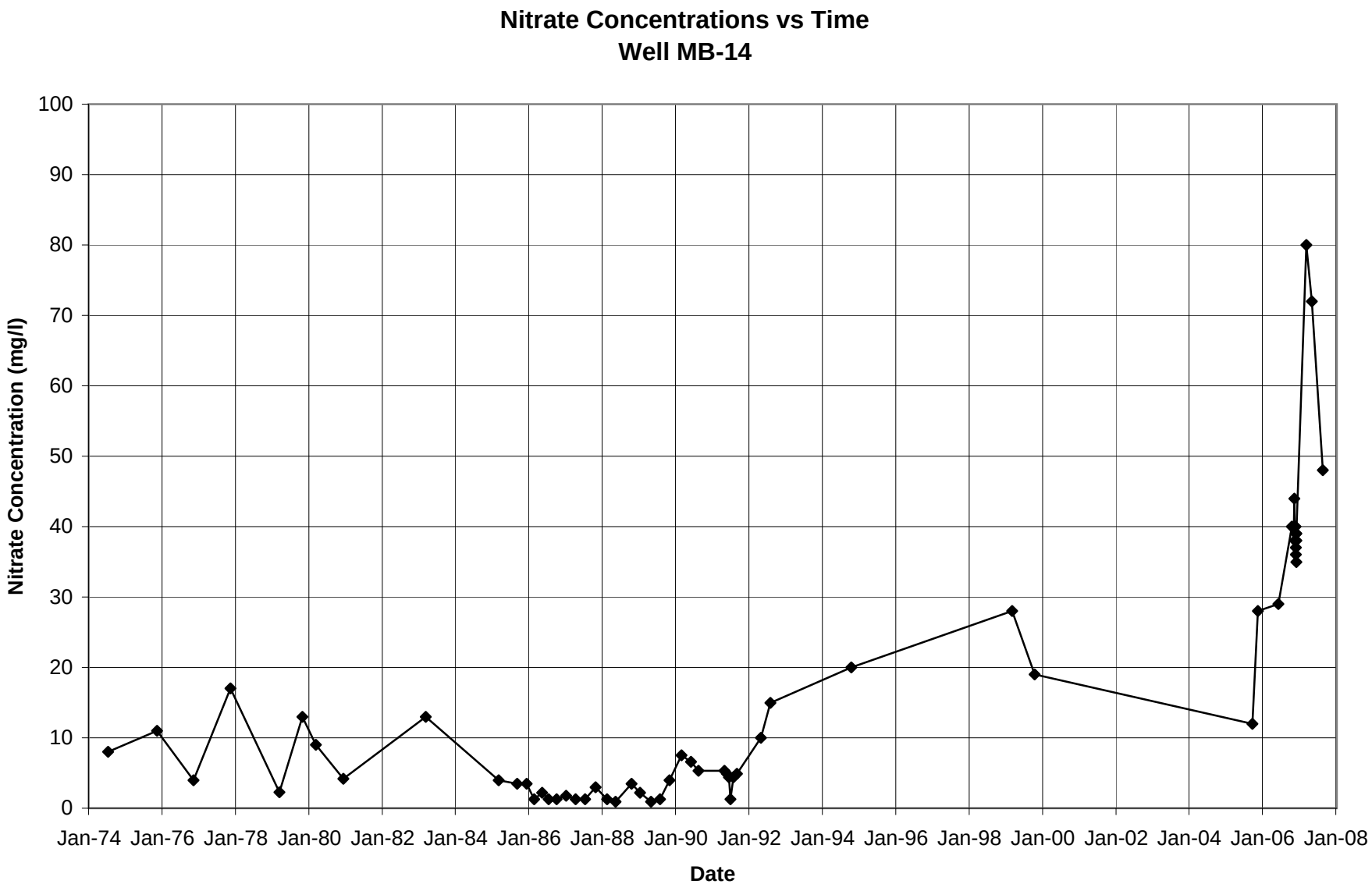
All Values in mg/l NO_3

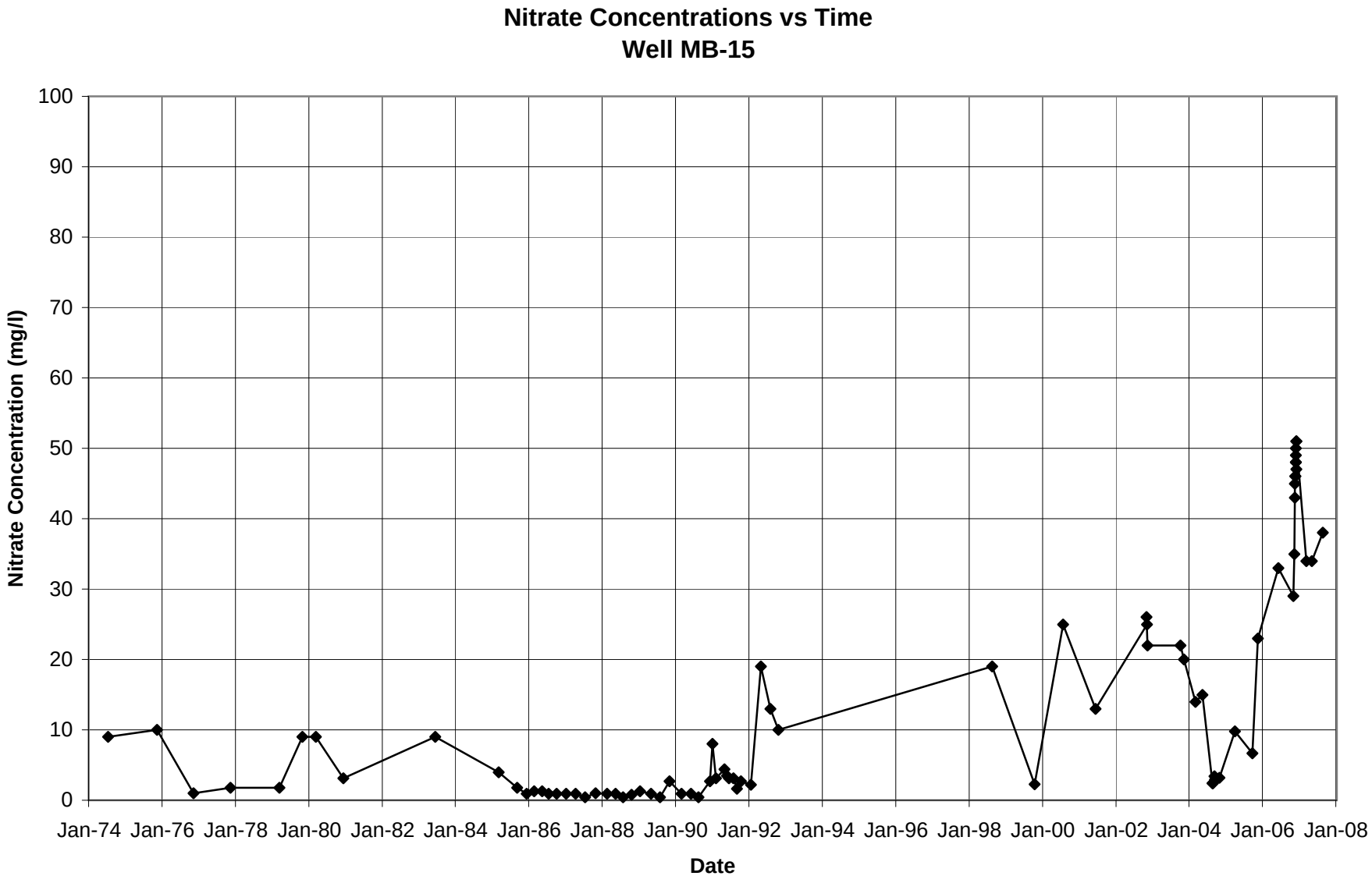
Date	25C02 (MB-3)	25C03 (MB-4)	25F05 (MB-14)	25F06 (MB-15)
11/20/06	84	63	38	45
11/21/06	86	63	40	46
11/22/06	85	63	40	46
11/27/06	86	62	39	50
11/28/06	85	61	39	49
11/29/06	80	58	37	48
11/30/06	80	59	36	48
12/01/06	77	56	35	47
12/04/06	81	59	38	51
12/05/06	81	59	39	51
03/13/07	60	76	80	34


Nitrate Concentrations vs Time
Highway 1 Well Field
Nitrate Concentrations in mg/l
100
90
80
70
60
50
40
30
20
10
0
Jan-54
Jan-58
Jan-62
Jan-66
Jan-70
Jan-74
Jan-78
Jan-82
Jan-86
Jan-90
Jan-94
Jan-98
Jan-02
Jan-06
Jan-10
Date
MB-3
MB-4
MB-14
MB-15


Nitrate Concentrations vs Time
Well MB-3
Nitrate Concentration (mg/l)
100
90
80
70
60
50
40
30
20
10
0
Jan-54
Jan-58
Jan-62
Jan-66
Jan-70
Jan-74
Jan-78
Jan-82
Jan-86
Jan-90
Jan-94
Jan-98
Jan-02
Jan-06
Jan-10
Date


Nitrate Concentrations vs Time
Well MB-4
Nitrate Concentration (mg/l)
100
90
80
70
60
50
40
30
20
10
0
Jan-54
Jan-58
Jan-62
Jan-66
Jan-70
Jan-74
Jan-78
Jan-82
Jan-86
Jan-90
Jan-94
Jan-98
Jan-02
Jan-06
Jan-10
Date


Nitrate Concentrations vs Time
Well MB-14
Nitrate Concentration (mg/l)
100
90
80
70
60
50
40
30
20
10
0
Jan-74
Jan-76
Jan-78
Jan-80
Jan-82
Jan-84
Jan-86
Jan-88
Jan-90
Jan-92
Jan-94
Jan-96
Jan-98
Jan-00
Jan-02
Jan-04
Jan-06
Jan-08
Date


Nitrate Concentrations vs Time
Well MB-15
Nitrate Concentration (mg/l)
100
90
80
70
60
50
40
30
20
10
0
Jan-74
Jan-76
Jan-78
Jan-80
Jan-82
Jan-84
Jan-86
Jan-88
Jan-90
Jan-92
Jan-94
Jan-96
Jan-98
Jan-00
Jan-02
Jan-04
Jan-06
Jan-08
Date

APPENDIX G

Laboratory Reports of Wastewater Samples

CREEK ENVIRONMENTAL LABORATORIES, INC.
A Minority-owned Business Enterprise
141 SUBURBAN ROAD, SUITE C-5 • SAN LUIS OBISPO, CA 93401 • (805) 545-9838 • FAX (805) 545-0107

Spencer Harris
Cleath & Associates
1390 Oceanaire Drive
San Luis Obispo, CA 93405

Log Number: 07-C12703
Order: 05162
Project: Morro Basin Nitrate Study
Received: 10/02/07
Printed: 10/12/07

REPORT OF ANALYTICAL RESULTS

Sample Description	Sampled By	Sampled Date @ Time	Matrix
Headworks at WWTP		10/02/07@10:30	Aqueous

Analyte	Result	DLR	Dilution Factor	Units	Method	Date Analyzed	Date Prepared	Batch
Total Alkalinity as CaCO3	330	2	1	mg/L	SM 2320B	10/11/07		9816
Chloride	440	10	10	mg/L	EPA 300.0	10/03/07		9504
Electrical Conductance	2,000	1	1	umhos/cm	SM 2510 B	10/02/07		9518
Organic Nitrogen Value	14	0.5	NA	mg/L	Calculated			
Total Nitrogen Value	42	0.5	NA	mg/L	Calculated			
Ammonia, Total, as N	27	0.3	1	mg/L	SM 4500-NH3 D	10/03/07		9481
Nitrate as N	1.3	0.1	1	mg/L	EPA 300.0	10/03/07		9504
Nitrate as NO3	5.7	0.4	1	mg/L	EPA 300.0			
Nitrite as N	Not Detected	0.1	1	mg/L	EPA 300.0	10/03/07		9504
pH	7.5	0.1	1	pH units	SM 4500-H B	10/02/07		9518
Sulfate	61	0.5	1	mg/L	EPA 300.0	10/03/07		9504
Total Dissolved Solids	1,100	10	1	mg/L	SM 2540 C	10/08/07		9718
Total Kjeldahl Nitrogen	41	0.5	1	mg/L	SM 4500-NH3 D	10/03/07	10/03/07	9490
Boron	0.36	0.05	1	mg/L	EPA 200.7	10/11/07		9851
Calcium	52	0.03	1	mg/L	EPA 200.7	10/11/07		9851
Hardness	300	1	NA	mg/L CaCO3	EPA 200.7			
Sodium Adsorption Ratio	6.5	0.1	1		EPA 200.7	10/12/07		9926
Copper	0.08	0.05	1	mg/L	EPA 200.7	10/11/07		9851
Iron	2.6	0.02	1	mg/L	EPA 200.7	10/11/07		9851
Potassium	20	0.1	1	mg/L	EPA 200.7	10/11/07		9851
Magnesium	42	0.03	1	mg/L	EPA 200.7	10/11/07		9851
Manganese	0.06	0.02	1	mg/L	EPA 200.7	10/11/07		9851
Sodium	250	0.05	1	mg/L	EPA 200.7	10/11/07		9851
Zinc	0.31	0.05	1	mg/L	EPA 200.7	10/11/07		9851

DLR = Detection Limit for Reporting. Results of "Not Detected" are below DLR.

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Spencer Harris
Cleath & Associates
1390 Oceanaire Drive
San Luis Obispo, CA 93405

Log Number: 07-C12704
Order: O5162
Project: Morro Basin Nitrate Study
Received: 10/02/07
Printed: 10/12/07

REPORT OF ANALYTICAL RESULTS

Sample Description	Sampled By	Sampled Date @ Time	Matrix
Cayucos Line 1st. MH Upstream of WWTP		10/02/07@10:40	Aqueous

Analyte	Result	DLR	Dilution Factor	Units	Method	Date Analyzed	Date Prepared	Batch
Total Alkalinity as CaCO3	500	2	1	mg/L	SM 2320B	10/11/07		9816
Chloride	230	10	10	mg/L	EPA 300.0	10/03/07		9504
Electrical Conductance	1,800	1	1	umhos/cm	SM 2510 B	10/02/07		9518
Organic Nitrogen Value	6.2	0.5	NA	mg/L	Calculated			
Total Nitrogen Value	57	0.5	NA	mg/L	Calculated			
Ammonia, Total, as N	35	0.3	1	mg/L	SM 4500-NH3 D	10/03/07		9481
Nitrate as N	8.9	0.1	1	mg/L	EPA 300.0	10/03/07		9504
Nitrate as NO3	39	0.4	1	mg/L	EPA 300.0			
Nitrite as N	7.6	0.1	1	mg/L	EPA 300.0	10/03/07		9504
pH	7.5	0.1	1	pH units	SM 4500-H B	10/02/07		9518
Sulfate	98	0.5	1	mg/L	EPA 300.0	10/03/07		9504
Total Dissolved Solids	940	10	1	mg/L	SM 2540 C	10/08/07		9718
Total Kjeldahl Nitrogen	41	0.5	1	mg/L	SM 4500-NH3 D	10/03/07	10/03/07	9490
Boron	0.28	0.05	1	mg/L	EPA 200.7	10/11/07		9851
Calcium	90	0.03	1	mg/L	EPA 200.7	10/11/07		9851
Hardness	420	1	NA	mg/L CaCO3	EPA 200.7			
Sodium Adsorption Ratio	3.5	0.1	1		EPA 200.7	10/12/07		9926
Copper	Not Detected	0.05	1	mg/L	EPA 200.7	10/11/07		9851
Iron	0.46	0.02	1	mg/L	EPA 200.7	10/11/07		9851
Potassium	16	0.1	1	mg/L	EPA 200.7	10/11/07		9851
Magnesium	48	0.03	1	mg/L	EPA 200.7	10/11/07		9851
Manganese	0.05	0.02	1	mg/L	EPA 200.7	10/11/07		9851
Sodium	160	0.05	1	mg/L	EPA 200.7	10/11/07		9851
Zinc	0.22	0.05	1	mg/L	EPA 200.7	10/11/07		9851

DLR = Detection Limit for Reporting. Results of "Not Detected" are below DLR.

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Spencer Harris
Cleath & Associates
1390 Oceanaire Drive
San Luis Obispo, CA 93405

Log Number: 07-C12705
Order: 05162
Project: Morro Basin Nitrate Study
Received: 10/02/07
Printed: 10/12/07

REPORT OF ANALYTICAL RESULTS

Sample Description	Sampled By	Sampled Date @ Time	Matrix
Atascadero Road MH#13-47		10/02/07@10:50	Aqueous

Analyte	Result	DLR	Dilution Factor	Units	Method	Date Analyzed	Date Prepared	Batch
Total Alkalinity as CaCO3	290	2	1	mg/L	SM 2320B	10/11/07		9816
Chloride	190	10	10	mg/L	EPA 300.0	10/03/07		9504
Electrical Conductance	1,300	1	1	umhos/cm	SM 2510 B	10/02/07		9518
Organic Nitrogen Value	17	0.5	NA	mg/L	Calculated			
Total Nitrogen Value	45	0.5	NA	mg/L	Calculated			
Ammonia, Total, as N	28	0.3	1	mg/L	SM 4500-NH3 D	10/03/07		9481
Nitrate as N	Not Detected	0.1	1	mg/L	EPA 300.0	10/03/07		9504
Nitrate as NO3	Not Detected	0.4	1	mg/L	EPA 300.0			
Nitrite as N	Not Detected	0.1	1	mg/L	EPA 300.0	10/03/07		9504
pH	7.7	0.1	1	pH units	SM 4500-H B	10/02/07		9518
Sulfate	60	0.5	1	mg/L	EPA 300.0	10/03/07		9504
Total Dissolved Solids	810	10	1	mg/L	SM 2540 C	10/08/07		9718
Total Kjeldahl Nitrogen	45	0.5	1	mg/L	SM 4500-NH3 D	10/03/07	10/03/07	9490
Boron	0.60	0.05	1	mg/L	EPA 200.7	10/11/07		9851
Calcium	28	0.03	1	mg/L	EPA 200.7	10/11/07		9851
Hardness	160	1	NA	mg/L CaCO3	EPA 200.7			
Sodium Adsorption Ratio	6.4	0.1	1		EPA 200.7	10/12/07		9926
Copper	0.19	0.05	1	mg/L	EPA 200.7	10/11/07		9851
Iron	2.1	0.02	1	mg/L	EPA 200.7	10/11/07		9851
Potassium	23	0.1	1	mg/L	EPA 200.7	10/11/07		9851
Magnesium	21	0.03	1	mg/L	EPA 200.7	10/11/07		9851
Manganese	0.07	0.02	1	mg/L	EPA 200.7	10/11/07		9851
Sodium	180	0.05	1	mg/L	EPA 200.7	10/11/07		9851
Zinc	0.68	0.05	1	mg/L	EPA 200.7	10/11/07		9851

DLR = Detection Limit for Reporting. Results of "Not Detected" are below DLR.

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APPENDIX H

Management Goals and Practices
(UC Publication 8097)

PUBLICATION 8097 FWQP FACT SHEET 3.4

Management Goals and Management Practices:

Nutrient Management Goals and Management Practices for Cool-Season Vegetables

STUART PETTYGROVE is UC Cooperative Extension Soils Specialist, UC Davis; **TIM HARTZ** is UCCE Vegetable Crops Specialist, UC Davis; **RICHARD SMITH** is UCCE Farm Advisor, Monterey County; **TOM LOCKHART** is Watershed Coordinator, Cachuma Resource Conservation District; **BLAINE HANSON** is UCCE Irrigation and Drainage Specialist, UC Davis; **LOUISE JACKSON** is Professor, Plant Physiologist, and UCCE Specialist, UC Davis; and **STEVE GRATTAN** is UCCE Plant-Water Relations Specialist, UC Davis;

This Fact Sheet includes Management Goals and Management Practices for reduction of nutrient pollution in cool-season vegetables. For our purposes, we are defining a *Management Goal* (MG) as the best economically achievable technology or process for limiting the movement of nutrients, particularly nitrogen (N) and phosphorus (P), into ground or surface waters. Management Goals are general (for example, "Base the amount and timing of N fertilizer applied on crop needs").

As used here, a *Management Practice* (MP) is a specific practice to be used in accomplishing a Management Goal (for example, "Use plant tissue analysis to aid in fertilization decisions"). Growers and crop advisors have found these practices suitable for vegetable production in California's coastal region. Management Practices are not requirements and will not necessarily be feasible or necessary for pollution control in every situation. Rather, they are options for managing N and P fertilizers and water efficiently.

The development of a comprehensive farm plan for nutrient management on cool-season vegetable crops involves a series of ten Management Goals:

MG 1. Evaluate current irrigation and fertilization practices and plan improvements in management.

MG 2. Avoid fertilizer material spills during all phases of transport, storage, and application.

MG 3. Base the amount and timing of N fertilizer applications on crop needs and production goals.

MG 4. Place N fertilizer materials where maximum plant uptake will occur.

MG 5. Minimize leaching losses of nitrate during non-crop periods.

MG 6. Operate irrigation systems to minimize deep percolation and N losses.

MG 7. Improve the uniformity of existing furrow irrigation.

MG 8. Improve the uniformity of existing sprinkler irrigation.

MG 9. Improve the uniformity of existing drip irrigation.

MG 10. Evaluate and maintain nutrient management goals and recommended practices.

To implement the Management Practices, you may require specific technical information. Consult your local UCCE Farm Advisor or visit the UC Davis Vegetable Research and Information Center Web site for help with developing these practices.

UNIVERSITY OF CALIFORNIA
Division of Agriculture and Natural Resources
http://anrcatalog.ucdavis.edu

In partnership with
NRCS Natural Resources Conservation Service
http://www.nrcs.usda.gov

Farm Water Quality Planning
A Water Quality and Technical Assistance Program for California Agriculture
http://waterquality.ucanr.org

This Fact Sheet is part of the **Farm Water Quality Planning (FWQP)** series, developed for a short course that provides training for growers of irrigated crops who are interested in implementing water quality protection practices. The short course teaches the basic concepts of watersheds, nonpoint source pollution (NPS), self-assessment techniques, and evaluation techniques. Management goals and practices are presented for a variety of cropping systems.

UC PEER REVIEWED

MG 1. Evaluate current irrigation and fertilization practices and plan improvements in management

MP 1.1. Determine nitrate and salt contamination of ground water in existing wells; and assess the potential for transport of soluble contaminants such as nitrates and salts downward to the ground water and laterally to surface

MP 1.2. Develop and implement a system for keeping long-term records on each field for water and nutrient/soil amendment inputs, cultural operations, pest problems, land leveling or other improvements, and crop yield and quality. The Farm Water Quality Plan (ANR Pub 9002) gives one method for developing a long-term system.

MP 1.3. Review current cultural practices to develop improved nutrient and water management plans.

MG 2. Avoid fertilizer material spills during all phases of transport, storage, and application

MP 2.1. Have organized training sessions for field personnel.

MP 2.2. When transporting fertilizer, do not overfill trailers or tanks. Cover or cap loads properly and display appropriate placards on vehicles.

MP 2.3. When transferring fertilizer into on-farm storage or into a fertilizer applicator, take care not to allow materials to accumulate on the soil.

MP 2.4. Maintain all fertilizer storage facilities to meet government and industry standards and protect them from the weather.

MP 2.5. Clean up fertilizer spills promptly.

MP 2.6. Shut off fertilizer applicators during turns and use check valves on application equipment.

MP 2.7. Maintain proper calibration of fertilizer application equipment.

MP 2.8. Whenever injecting fertilizer into irrigation water, ensure that there is no backflow into wells or other water sources.

MP 2.9. Distribute rinse water from fertilizer application equipment evenly throughout the field.

MG 3. Base the amount and timing of N and P fertilizer applications on crop needs

MP. 3.1. Determine crop nutrient requirements and establish a crop nutrient budget.

MP 3.2. Measure nitrate levels in the irrigation water and adjust N fertilizer rate accordingly.

MP 3.3. Before applying N and P early in the growth cycle, assess the amount of nitrate and phosphorous already present through the use of soil sampling and analysis. For soils with pH > 6.2, the most appropriate soil test is the Olsen (or *bicarbonate*) procedure. The Olsen procedure is acceptable for soils with a lower pH, but some laboratories may recommend a different method.

MP 3.4. Use soil nitrate quick tests or plant tissue sampling to guide your decisions on N fertilization in the middle and late periods of the crop growth cycle.

MP 3.5. Make multiple small applications of N fertilizer.\

MP 3.6. Make efficient P fertilizer applications.

MP 3.6.1. When appropriate, apply injected bands of P fertilizer into the soil. P fertilizer is generally more available to the plants if it is injected in bands than if it is applied as a broadcast application.

MP 3.6.2. Apply P fertilizer as close to the time of planting as possible. The longer P fertilizer is in contact with the soil, the less accessible it is to plants.

MP 3.6. When applying manure before you plant a crop, determine the nutrient content and release rate of the manure and the amount of nitrate already present in the soil. Apply manure at a rate consistent with the crop nutrient requirements.

MP 3.7. When possible, avoid water-running N fertilizer in the furrows. If fertilizer N must be water-run, make sure to maximize the uniformity of the irrigation, inject the fertilizer during the last half of the irrigation set, and manage the tailwater.

MP 3.8. Do not apply fertilizer N or surface broadcast P less than 24 hours in advance of a predicted large storm event.

MG 4. Place N fertilizer materials where maximum plant uptake will occur

MP 4.1. Incorporate N fertilizer into the crop bed by placing fertilizer on the seed row and watering it in, by knifing fertilizer into the bed, or by broadcasting fertilizer and then listing it up into the bed.

MG 5. Minimize leaching losses of nitrate during non-crop periods

MP 5.1. If conditions permit, grow a cover crop rather than leave fields fallow during the rainy season.

MP 5.2. Use only low-N fertilizers (such as $N:P_2O_5:K_2O$ equal to 1:3:3) during bed preparation in the fall. Higher N materials may be appropriate if a crop is to be planted soon.

MG 6. Operate irrigation systems to minimize deep percolation and N and P losses (These practices apply to all system types.)

MP 6.1. Monitor soil moisture between irrigations and use that information to guide your irrigation timing decisions.

MP 6.2. Crop need should determine irrigation amount.

MP 6.3. Know the irrigation system flow rates and the time required to apply the desired inches of water.

MP 6.4. Use the minimum leaching fraction that will prevent stand establishment problems or yield reductions from salinity.

MP 6.5. When fertigating with a drip or sprinkler system, run the fertilizer in the later part of the set so as not to leach nutrients beyond the root zone. Avoid fertigating with furrow systems.

MP 6.6. Follow state regulatory requirements and industry guidelines for backflow prevention when injecting fertilizer into irrigation water (CCR Title 3). Schedule regular maintenance of backflow prevention devices.

MP 6.7. If irrigation uniformity remains low after all practical improvements have been made, consider converting to an irrigation system with a greater potential to improve uniformity in a way that minimizes deep percolation.

MP 6.8. Minimize the amount of tailwater leaving the farm during the irrigation season. Even tailwater from fields with only moderate soil nutrient levels can contain significant quantities of N and P that can lead to algal blooms and associated problems.

MG 7. Improve existing furrow irrigation uniformity

MP 7.1. Convert to surge irrigation.

MP 7.2. Where furrow runs are more than 1000 feet long, consider cutting the furrow run length in half with a corresponding decrease in set time.

MP 7.3. Use high irrigation flow rates initially to get water down the furrow and then cut the flow rates back to finish the irrigation.

MP 7.4. Reduce variations in slope when preparing irrigation furrows.

MP 7.5. Use practices that increase irrigation uniformity between furrows (e.g., by using torpedoes in furrows that don't get wheel traffic or by alternating wheel rows with each tractor pass, you can ensure greater uniformity in water advance time in all furrows).

MP 7.6. Recirculate, rechannel, or reuse surface water runoff.

MP 7.7. Keep records on a field-by-field basis of advance and recession times.

MP 7.8. Utilize the services of a mobile irrigation lab.

MG 8. Improve existing sprinkler irrigation uniformity

MP 8.1. Monitor flows and pressure variations throughout the system to detect non-uniform application.

MP 8.2. Maintain the irrigation system by repairing leaks, replacing malfunctioning sprinklers, monitoring nozzle performance for wear, and maintaining adequate water pressure through the entire set.

MP 8.3. Operate sprinklers during the least windy periods, whenever possible. When sprinkler irrigating under windy conditions, reduce the spacing between laterals when possible to optimize application uniformity.

MP 8.4. Use offset lateral moves on successive irrigations to improve distribution uniformity.

MP 8.5. Use flow-control nozzles when the pressure variation throughout the system is excessive.

MP 8.6. Make set times as short as possible during stand establishment.

MP 8.7. For very large blocks, consider converting to linear-move sprinkler systems.

MP 8.8. Utilize the services of a mobile irrigation lab.

MG 9. Improve existing drip irrigation uniformity

MP 9.1. Monitor flows and pressure variations throughout the system to detect non-uniform application.

MP 9.2. Use lateral hose lengths that ensure uniformity.

MP 9.3. Use drip tape that has a small emitter discharge exponent to reduce flow variations that result from pressure differences.

MP 9.4. Check for the potential for emitter clogging by conducting water analysis and fertilizer/water compatibility tests.

MP 9.5. Use filtration, chemical treatments, and flushing as needed to prevent or correct clogging problems.

MP 9.6. Maintain appropriate water pressure throughout the system.

MP 9.7. Utilize the services of a mobile irrigation lab.

MG 10. Evaluate and maintain nutrient management goals and recommended practices

MP 10.1. Periodically evaluate management goals and recommended practices implemented for nutrient management. Correct deficiencies as needed.

REFERENCE

Pettygrove, G. S., S. R. Grattan, B. R. Hanson, T. K. Hartz, L. E. Jackson, T. R. Lockhart, K. F. Schulbach, and R. Smith. 1998. Production guide: Nitrogen and water management for coastal cool-season vegetables. Oakland: University of California Division of Agriculture and Natural Resources, Publication 21581.

FOR MORE INFORMATION

You'll find detailed information on many aspects of field crop production and resource conservation in these titles and in other publications, slide sets, CD-ROMs, and videos from UC ANR:

Nutrients and Water Quality, slide set 90/104

Protecting Groundwater Quality in Citrus Production, publication 21521

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