COW NUMBERS AND WATER QUALITY – IS THERE A MAGIC LIMIT? A GROUNDWATER PERSPECTIVE

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ABSTRACT

The question of how many cows are too many cows begs the question: too many for what? Certainly there are water quality and air quality issues, but there are also animal health, herd health, and food safety issues that relate to dairy size. In this presentation, I focus on water quality issues, particularly groundwater quality issues related to waste management on dairies. More cows means more animal waste, and more animal waste means either higher or more widespread risk of water and air pollution – or so common wisdom has it. Is that indeed the case and if so, how can that risk be minimized? Before answering this question, we have to ask what constitutes water pollution, what drives the potential risk for groundwater pollution on dairies (the nutrient and salt balance), and what source management and monitoring efforts would lead to an acceptable minimal risk within the currently evolving legal framework.

WATER POLLUTION: LEGAL FRAMEWORK

Until the late 1960s, there was little regulatory enforcement of pollutant discharges into either surface water or groundwater. In 1972, Congress passed the Clean Water Act, which regulates pollutant discharges into streams, rivers, and lakes (surface water). It primarily regulates direct discharges into surface water but also those activities that indirectly affect surface water quality through groundwater pollution that eventually reaches a river or lake. In California, the provisions of the Clean Water Act were incorporated into the framework of the Porter-Cologne Act of 1969, which established the nine Regional Water Quality Control Boards (RWQCBs) and the State Water Resources Control Board (SWRCB) as the primary regulatory agencies in charge of overseeing the state's water quality issues. For each of the large watersheds in California, the status of water quality in the state's rivers, streams, lakes, and aquifers are described in a so-called "Basin Plan". The Basin Plan outlines existing or potential water quality problems in a basin and sets forth water quality goals for a basin. Basin Plans provide the backdrop to the RWQCBs and SWRCBs regulatory power and provide the framework within which these boards manage water quality.

Over the first thirty years, most of the regulatory enforcement under the Clean Water Act focused on controlling direct point-source discharges of pollutants to streams and lakes, for example discharge from municipal wastewater treatment plants and from industrial processing facilities. Each point-source discharger must apply for a so-called "NPDES permit" (NPDES stands for National Pollutant Discharge Elimination System). The permit defines the level of

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In: Proceedings, National Alfalfa Symposium, 13-15 December 2004, San Diego, CA; UC Cooperative Extension, University of California, Davis 95616. (See http://alfalfa.ucdavis.edu for this and other proceedings).

wastewater treatment and the monitoring requirements that must be put in place by the discharger.

As a result of the introduction of the Clean Water Act, the discharge of animal waste, especially liquid animal waste, into streams or lakes was also prohibited. Beginning in the 1970s, California dairies were required to contain their wastewater in ponds that were lined with soil containing at least 10% clay. The pond design was driven by the requirement that the largest 24-hour rainfall amount that would likely occur over a 25 year time-span can be contained in the pond. Pond size therefore depended in large part on the size of the facility. The regulatory framework established in the 1970s also required dairies to apply manure and wastewater to croplands at ‘agronomically reasonable rates”. No permit was needed to either construct a pond or discharge waste and wastewater to cropland. There were no reporting or monitoring requirements.

In contrast, point source discharges under the NPDES permit system impose specific pre-discharge treatment practices, pollutant discharge limits, and monitoring requirements. Despite the limitations imposed under NPDES permits, water quality objectives have not been achieved in many watersheds, often due to unregulated sediment and nutrient discharges from non-point sources, such as agricultural runoff. In response, the portions of the Clean Water Act that deal with non-point sources have recently received increased attention. “Total Maximum Daily Load” (TMDL) limits are now being enforced in watersheds with continued water quality degradation in their streams. The principle idea of the TMDL process is to better control discharge from non-point sources and to tackle surface water quality management from a watershed-based approach that includes both point sources and non-point sources. Many watersheds have formed watershed groups that coordinate the implementation of improved land management practices and required water quality monitoring (self-monitoring).

The federal Clean Water Act focuses on water quality in streams and lakes. In contrast, the California Porter-Cologne Act also includes provisions for protecting groundwater. Groundwater quality objectives are defined in the individual Basin Plans. All Basin Plans require that landuse activities and waste discharges which may result in a change of groundwater quality be managed in ways that prevent groundwater degradation. Degradation is defined as any impact that will change groundwater quality to levels that would be inadequate for the “beneficial uses” of groundwater. Beneficial uses of groundwater throughout most of California include the use of groundwater for domestic and municipal water supply and for irrigation water supply.

In practice, the enforcement of these guidelines has been limited to those dischargers that are subject to some written permitting process such as the NPDES permit or the so-called waste discharge requirements (WDR) or Waivers of WDR, also a form of permit issued under state regulations. Until 2002, agricultural landuses have not been subject to regulatory permitting since application of nutrients and waste to cropland and the application of irrigation water have been categorically exempt from needing written permits. Only in areas that are vulnerable to pesticide contamination of groundwater, certain pesticide and runoff management practices have been required as part of a groundwater protection program implemented by the California Department of Pesticide Regulations.

In 2003, agricultural runoff into streams and lakes lost their categorical exemption and became regulated waste discharges. New requirements for all runoff from agricultural lands to surface waters (but not to groundwater) are currently being put in place. The new regulations affect all growers with land adjacent to or nearby creek beds, stream channels, and lakes. The so-called "agricultural discharge waiver" permitting process is specifically concerned with surface water contamination although it is likely that it will also address groundwater impacts at some future point.

Also in 2003, federal guidelines took effect that broadened the scope of the NPDES permit to specifically include all large confined animal farming operations (so-called CAFOs). In California, these are primarily dairies. "Large" is any dairy with 700 or more adult cows. Under these new regulations, large dairies (and other CAFOs), including their crop-land receiving any animal waste, are now defined as "point sources" and therefore have to apply for a NPDES permit. With the introduction of the NPDES permitting process to dairies, dairies will not only have to comply with discharge requirements to surface water (the main goal of the federal NPDES), but also with existing provisions in the Basin Plans that deal with groundwater protection (Porter-Cologne Act). Guidelines are currently being developed by the Central Valley RWQCB, which will apply to approximately 1,000 of the 1,700 dairy facilities within the Central Valley. Separate guidelines are proposed by the Santa Ana RWQCB that will apply to the approximately 250 dairies in the Chino Basin. Unlike in the Central Valley, the Chino Basin has a declining herd-size, already existing significant groundwater contamination problems due to large amounts of salt and nutrient leaching from dairies since the 1950s, and an almost complete ban of land-application of dairy wastes.

For dairies in the Central Valley, the new NPDES permit will bring the first major change in the regulatory framework since the introduction in the 1970s of the retention pond requirement and "reasonable agronomic rate" land application requirements. Under proposed new regulations, dairies would be required to put in place certified waste management plans for the production area (corral, pond, feed and solid waste storage areas) and certified nutrient management plans for the land application area. Surface water discharges continue to be prohibited. Dairies will be required to file annual reports documenting the implementation of the plan requirements and install groundwater monitoring wells to demonstrate compliance with groundwater quality goals.

What are the groundwater quality goals? The use of groundwater for domestic and municipal water supply and for irrigation water supply is the primary beneficial use of California's aquifers. Hence, groundwater quality goals are primarily driven by drinking water quality standards and by irrigation water. Whatever would cause significant harm to those uses, would be considered an undesirable degradation of this resource. Historically, nitrate, salinity, and pathogens have been the primary potential groundwater pollutants related to waste management of animal farming operations.

BEYOND POINT SOURCE: POTENTIAL POLLUTION SOURCES IN DAIRIES

New regulations classify (large) dairies as a "point source" for purposes of the NPDES permit. However, the term is somewhat misleading in that a dairy is a significantly larger and more complex potential pollution source than most NPDES permittees (A typical permittee is a discharger with a single piped or channeled outlet to a stream). With respect to groundwater, large dairies with land application areas that measure from several hundred to several thousand acres are in a league of their own as a potential pollution "point"-source, when compared to groundwater pollution sources with a history of regulation, such as dry cleaners, gas stations, industrial spill-sites, and food waste generators.

The fact is that the dairy has no single outlet to groundwater, and that there is not one single spill-site, tank site, lagoon, or individual field that is the target of the regulation. A dairy is a collection of numerous potential groundwater pollution sources. For purposes of characterizing the potential impact on groundwater quality, a dairy can be divided into several "management units": the animal housing area (corrals, free-stalls), the milking barn, the wastewater storage pond, the solid waste processing and storage area, the feed storage area, and the fields that receive either liquid manure or solid manure or both. Each of these management units is a potential groundwater pollution source in its own right, because the processes by which water may recharge to groundwater and chemically react during the recharge process can be significantly different between these management units: the milking barn is often a paved or concrete lined area with little or no infiltration, the corral in most cases is an unlined earthen surface with a significant compaction layer, the storage pond by law should have a soil liner with 10% clay and it's floor is covered with an often dense matt of organic debris. It is the only area of the dairy that is continuously inundated with liquid waste. The fields surrounding the dairy and receiving land applications of manure are maintained to achieve agronomic crop yields, hence are typically kept to maintain good soil drainage.

Even within an individual management unit, there is potentially significant spatial variability in the pollutant loading and groundwater recharge process: certain areas of the corrals are preferably used by animals, certain areas of the corral are more prone to flooding and standing water; the manure application to fields can be highly non-uniform due to high irrigation non-uniformity, non-uniform crop yields, incomplete mixing with irrigation water, or due to variable soil conditions throughout the field. Hence, some parts of a field may contribute much larger amounts of, e.g., nitrate to groundwater recharge than other parts of a field (Harter et al., 2003).

The variability in potential salinity and nitrate groundwater loading rates across a dairy is a challenge both from a waste and nutrient management point of view and with respect to monitoring the effectiveness of waste and nutrient management to protect groundwater.

CONTROLLING GROUNDWATER POLLUTION: NUTRIENT AND SALT BALANCES

The most important tool for evaluating the potential nitrogen and salt losses to groundwater is to prepare a nutrient and salt mass balance for the farm as a whole and also individually for fields receiving manure (solid, liquid, or both). Preparing the nitrogen or salt mass balance is like running the annual totals on a checking account:

Daily: INPUT – OUTPUT – LOSSES = CHANGE IN ACCOUNT BALANCE

Losses include losses to the atmosphere, to groundwater, and to natural attenuation. Surface water losses are neglected here, because they are essentially prohibited.

For example, for a whole farm mass balance, the nitrogen (N) account looks like this:

> INPUTS: Purchased feed N + commercial fertilizer N + irrigation water N + atmospheric deposition N
>
> OUTPUTS: Milk sales N + Solid manure export N + Animal growth/sales
>
> LOSSES: Volatilization (of ammonia-N) + Denitrification (of nitrate-N) + groundwater loading (of nitrate-N)

For nitrogen (and similarly, for salt), the inputs and outputs can be measured using farm records. Atmospheric deposition of nitrogen is relatively small and adequately known from the literature. Similarly, animal growth and animal sales contribute only little to the overall farm N balance (unless there are significant changes in farm size).

On the other hand, the losses are all difficult to measure. How do we know how large the losses are and how much of it is in the “nitrate-N to groundwater” category?

This can be done by making a long-term assessment. Over the course of one year (sometimes a few years), the total amount of salts or nitrogen stored within a dairy in form of feed, stored manure, and retention in soils is in a quasi-equilibrium. This is much like someone’s checking account that always runs around $1000 even though there may be quite a change in the account balance between the beginning of the month and the end of the month. At the end of the year (hopefully), there is still about $1000 in the account. Hence, over the long run, there is a negligible change in the account balance:

Annually: INPUT – OUTPUT – LOSSES = 0

If I can measure all the inputs to the account and all the outputs from the account, the unknown losses from the account are simply obtained by taking the difference between inputs and outputs:

LOSSES = INPUT - OUTPUT

Once we have determined the nitrogen LOSSES using this mass balance method, we try to estimate volatilization and denitrification losses from literature values and then obtain the groundwater nitrogen losses by subtraction:

Nitrate-N to groundwater = LOSSES – ammonia-N volatilization – denitrification

Because of the uncertainties about the exact amount of ammonia-N volatilization and denitrification, this is not a precise method, but certainly a tool that will indicate if a farm is grossly out of balance with respect to nitrogen.

For salts, there are neither volatilization losses nor losses due to transformations (such as denitrification), hence the salt LOSSES computed from the whole farm salt mass balance all go towards groundwater loading.

The largest unknown in the above procedure is the amount of N volatilization in the animal production area and during manure storage, prior to land application. A field-by-field mass balance circumvents this issue. Also, a field-by-field assessment takes into account differences in the management of individual fields. For the nitrogen field mass balance, the inputs and outputs are:

> INPUTS: solid and liquid manure N + commercial fertilizer N + irrigation water N + atmospheric deposition N
>
> OUTPUTS: crop harvest N

The losses are the same as on the farm level (volatilization, denitrification, and nitrate loading to groundwater). However, since much of the ammonia volatilization occurs prior to the application of manure to the field, the uncertainty about the volatilization losses is significantly smaller. To obtain a field mass balance, detailed records are needed of irrigation water and manure applications and of chemical analyses of the nitrogen content in the individual manure applications. These types of data collection activities are only now beginning to appear on dairies, but are currently proposed to become standard tools as part of compliance with the NPDES permit.

UNDERSTANDING THE NUTRIENT BALANCING ACT, PART 1: GETTING THERE

In a recent research project, we found that a typical field nitrogen mass balance prior to targeted nutrient management may look like this (numbers are approximate lbs N/acre/year):

INPUTS	Commercial fertilizer N	250
	Liquid manure, organic N	450
	Liquid manure, ammonia N	350
	Atmospheric deposition	10
	Irrigation water N	10
	Total Inputs	**1070**
OUTPUTS	Crop removal – summer corn	300
	Crop removal – winter grain	200
	Total Outputs	**500**
LOSSES	**Total Losses (= Total Inputs – Total Outputs)**	**570**
	Volatilization (less than 10% of applied N)	0-100
	Denitrification (less than 10% of applied N	0-100
	Groundwater Nitrate-N loading (= Total Losses – Volatilization – Denitrification)	**370 – 570**

Table 1: Typical nutrient mass balance in an unmanaged field that receives from 4 – 6 diluted liquid manure applications each year, typically during spring and fall pre-irrigations and during winter pond releases. All numbers are in lbs N/acre per year.

How good or bad are groundwater nitrate-N loading rates that are on the order of 300 to 700 lbs/N/acre? To find an answer, recall that all groundwater in the Central Valley has “drinking water” designated as one of its beneficial uses (which must be protected by law) and that the drinking water limit for nitrate-N is 10 mg/l. The amount of nitrogen in 1 acre-foot of recharge with the maximum allowable concentration of 10 mg nitrate-N/l is 27 lbs. Typically, annual groundwater recharge rates underneath irrigated forage crops range from 1 acre-foot per acre to 2 acre-feet per acre (assuming irrigation efficiencies between 70% and 50%). Hence, average losses of N to groundwater should be limited to no more than approximately 27 – 54 lbs/acre/year at the most (after accounting for volatilization and denitrification). This amount is one-tenth of the amount to leach out of the field in the example above!

The above example shows that without nutrient management, actual nitrate losses to groundwater can be an order of magnitude higher than desirable, causing significant groundwater degradation. Indeed, we found that it is common to find shallow groundwater nitrate-N concentrations of 50 to over 100 mg/l underneath fields with frequent applications of liquid manure – that is 5 to 10 times above the drinking water limit. We recently determined that the average nitrate-N concentration in shallow groundwater recharged from fields with manure applications in the Hilmar-Modesto region averaged over 60 mg N/l (Harter et al., 2002). Similar average concentrations of total nitrogen were found in recharge from corrals and storage ponds. Because fields comprise between 80% - 90% of the land area of a dairy, more efficient utilization of the manure as a fertilizer and reduction of the nutrient and salt load in the cropping area of a dairy is key to addressing groundwater quality issues on dairies. This is not to say that improvements to waste containment are also needed in the corral and pond management areas of the dairy.

Campbell-Mathews (2004, this proceedings) demonstrates the results of a research project, where nutrient management was implemented using frequent flow metering and field testing of manure nitrogen content. Significant reductions were achieved on the INPUT side of the field mass balance in Table 1 (no use of commercial fertilizer, reduction of manure applications, manure applications only during crop growth stages), while no significant reductions occurred on the OUTPUT side (no crop yield losses). As a result, groundwater quality improved substantially underneath the research field (over 70% improvement). Importantly, significant adjustments in the infrastructure and management of an existing facilities were necessary to properly implement adequate nutrient management practices (e.g., Campbell-Mathews et al., 2001).

Farm and field-by-field nutrient and salt mass balances are an effective tool to check for large nitrogen and salt imbalances that pose an unacceptable risk for groundwater degradation. Where field nitrogen INPUTS exceed field nitrogen OUTPUTS by several hundred lbs N/acre, as in the above example, groundwater contamination is an almost inevitable consequence, unless there are strong nitrate-reducing conditions in the subsurface above or at the water level.

The amount of volatilization and denitrification losses that would occur under specific soil and geologic conditions is difficult to assess precisely. In some areas, denitrification losses below the root zone may degrade significant amounts of nitrate before it enters groundwater, although such conditions would have to be investigated locally. We currently have little knowledge about the exact denitrification potential in the deeper unsaturated sediments of the eastern Central Valley dairy regions. But due to relatively good drainage and other geologic conditions in this region, denitrification is unlikely to be a means for degrading on the order of hundreds of lbs of nitrogen per acre each year. Our assessment of monitoring data in the Hilmar-Modesto area indicates that denitrification in that region does not account for significant losses in light of the overall imbalance between INPUTS and OUTPUTS in that region.

UNDERSTANDING THE NUTRIENT BALANCING ACT, PART 2: BEING THERE IS A HIGH RISK

Where nutrient management practices are in place and INPUTS and OUTPUTS are balanced, volatilization and denitrification rates by design are on the same order as the difference between INPUTS and OUTPUTS. Groundwater protection, however, is not guaranteed, even under tighter nutrient management practices as long as significant uncertainty exists about volatilization and denitrification losses. The uncertainty about these losses increases proportionally with the total INPUTS to a field. Reasonable estimates of volatilization and denitrification losses for conditions typical of the eastern San Joaquin Valley and Tulare Lake basin dairy areas range from 5% to 40% of total INPUTS – from a few ten to a few hundred lbs N/acre/year. In other words, the uncertainty about these losses is currently on the order of one to several hundred lbs N/acre/year – much larger than the targeted maximum groundwater nitrate losses.

If a farmer intends to achieve corn and winter forage crop yields equivalent to OUTPUTS of 600 lbs N/acre/year and is uncertain about whether the volatilization and denitrification losses in the root zone are a few ten or 300 lbs N/acre/year, how much N should (s)he apply? To insure good crop yields, (s)he would apply 600 + 300 = 900 lbs N/acre/year. But if it turned out at the end of the year that volatilization and denitrification only made up a loss of 50 lbs N/acre/year, the remaining 250 lbs N/acre/year of total LOSSES will leach into groundwater resulting in significant groundwater degradation (recall that the target for groundwater nitrate-N losses is much lower than 100 lbs N/acre/year). The problem of accounting for volatilization and denitrification losses is, of course, not unique to dairy farming, but is an underlying issue in nutrient management of other agricultural systems as well. However, modern dairy farms in California stand out relative to many other crops due to the high crop yields and the high turnover of nutrients. This applies to small dairy farms as much as to so-called mega-dairies. As in vegetable and other high nutrient yield crops, the nutrient management of these systems comes with significantly higher risks for groundwater contamination due to the increased uncertainties about losses, regardless of the number of cows in the herd.

UNDERSTANDING THE NUTRIENT BALANCING ACT, PART 3: THE RISKS OF ORGANIC FARMING ON A DAIRY

The difficulties of finding the proper long-term balance between INPUTS and OUTPUTS on a dairy system further stands out in one other way, not shared by other agricultural systems: in dairy cropping systems, large amounts of organic nitrogen are being applied to cropping systems. Unlike ammonia-N, urea-N, or nitrate-N, the organic nitrogen in manure is a complex mix of compounds, some of which will mineralize to plant-available ammonia-N and nitrate-N very quickly, and some of which will mineralize very slowly. Significant uncertainty is associated with predicting the rate at which organic nitrogen in manure will become plant-available. Effectively, a significant portion of the organic N in manure will act as a slow-release fertilizer that may release nitrogen at significant levels throughout the year. These slow-release dynamics are ill-matched with the large, fast, and short-lived nutrient uptake dynamics of many high-yielding feed cropping systems: the main uptake for a double-cropped corn/winter grain system is in June/July and in February/March. Nutrient requirements during the remaining year are relatively small.

Hence, the ability to properly balance INPUTS and OUTPUTS in a field is significantly hampered where large amounts of organic nitrogen (several hundred lbs/acre/year) are part of the INPUTS. Organic farmers share this problem with dairy farmers but with one significant difference: the total INPUTS and OUTPUTS of nitrogen in organic farming systems are typically much lower due to lower yields - and with that the risk for excessive N losses to groundwater is much lower.

UNDERSTANDING THE NUTRIENT BALANCING ACT, PART 4: BOTTOM-LINE

This brings me back to the original question: how many cows are too many cows? The answer is simple, but not useful: any number of cows that will not cause groundwater to be degraded (and that's just from a groundwater perspective. The number may be different from an air quality perspective).

The "number of cows per acre" game is a difficult one to play and one that does not provide the dairy industry with the flexibility that may be needed to do this the right way. Ultimately, the goal is to keep nitrate-N losses to groundwater to less than the 27 – 54 lbs N/acre/year number mentioned above. Until we can decrease the uncertainty about organic N mineralization rates, volatilization losses, and denitrification losses through better research data and through the development of appropriate management practices, the conversion to nutrient management with solely manure may have to be subject to some limitations, particularly with respect to the use of the organic N portion as "fertilizer". That could put a lid on expanding the "number of cows per acre" by increasing the per acre crop production and per acre crop N uptake, a remedy that has been proposed in recent dairy EIRs (Environmental Impact Reviews), which seek to maximize the number of cows on the available land. The "number" could be arbitrarily higher, if the industry manages to successfully convert and export its waste from the dairy as soil amendment, fertilizer, or otherwise. There is ample room for creative solutions. Ultimately, the salt loading may become the limiting factor, not only in closed groundwater basins such as the southern-most part of the San Joaquin Valley (Tulare Lake basin). Salts are not degraded or volatilized. Even after balancing the nutrient act, salts will be leaching to groundwater.

GROUNDWATER MONITORING

The first and most important step to groundwater monitoring on dairies is to compute the annual farm nitrogen and salt balance; and secondly, to compute field-by-field nitrogen and salt mass balances. These will indicate, whether a farm is grossly out of balance or within some desirable range for balancing INPUTS and OUTPUTS. Where these are grossly out of balance (for example, field nitrogen balances with INPUTS being twice as high or more than OUTPUTS), groundwater pollution is highly likely unless other locally mitigating factors come into play (e.g., strong denitrification).

Soil and plant tissue sampling will continue to be an important tool for day-to-day management of irrigation and nutrient applications in dairy cropping systems managed with manure. Because of uncertainties about organic N mineralization, it may become an even more important tool to ensure adequate crop yields without excessive applications of nutrients.

Given that nitrogen OUTPUTS on dairy cropping systems (400 – 600 lbs N/acre/year) will continue to be high relative to the desirable level of N losses to groundwater (30 – 50 lbs N/acre/year), neither farm and field-by-field nutrient and salt balances nor soil sampling will provide an absolute guarantee that groundwater is indeed protected. Current uncertainties about volatilization and denitrification and the vagaries of managing large amounts of organic nitrogen are in the way of using mass balances or soil sampling as the exclusive tools for groundwater protection – at least until a significant amount of research and on-the-ground experience will significantly reduce that uncertainty.

Groundwater monitoring at the water table, where recharge water from the dairy can be directly measured, is therefore difficult to argue away as an important tool to directly assess groundwater quality impacts from dairies. Groundwater monitoring is not the silver bullet, for it is itself associated with significant uncertainties, if we are to make an assessment of the overall groundwater nitrate and salinity contribution from a dairy: A groundwater monitoring well measures recharge water quality from but a small amount of land within the dairy (and, under some circumstances, beyond the dairy). In light of the large spatial variability in the nitrate and salt loading rates across the dairy (see discussion above), the question arises, how many wells it would take to allow for an adequate assessment of the groundwater quality impacts from a dairy facility (corrals, ponds, storage areas, and fields). We explored this question by analyzing nitrate and salt data from monitoring well networks with 8 – 25 monitoring wells per dairy on five dairies and compared data to those collected from tile-drains that drained entire dairy facilities (Harter et al., 2003). Average concentrations of nitrate in one to two dozen monitoring wells per facility (across all management units, see above) are found to be comparable to those from the tile-drain network, which is presumably the best indicator for whole farm impact on groundwater quality.

But is it practical and necessary to install that many monitoring wells on each dairy facility? Based on statistical analysis of our dataset, we have argued that 4-6 wells, located down gradient from the highest risk areas within a dairy (corral, pond, fields with the highest manure loading rates), is sufficient to determine, whether a dairy facility has significant compliance problems or not. If none of these 4-6 wells exceeded water quality objectives, the facility as a hole can be assumed with high certainty to not be detrimental to groundwater quality. If the majority of the wells indicate water quality problems, the facility is likely out of compliance.

The interpretation of data from such a small network of wells is most problematic, when just 1 well indicates a water quality problem. Is it significant or not? Such situations generally force installation of additional monitoring wells to aid the assessment.

GROUNDWATER MONITORING: ALTERNATIVES TO TRADITIONAL APPROACHES

The currently proposed requirement for groundwater monitoring in Central Valley dairies would constitute the first time that production agriculture will be required to use groundwater monitoring as part of running their business. No other agricultural commodity has, to date, been subject to such a requirement, although some production regions with high levels of fertilizer use, such as the Salinas Valley, have significantly stepped up education and monitoring efforts through central agencies (e.g., Monterey County Water Resources Agency).

Monitoring of groundwater quality impact from agricultural landuses as point source adds a substantially different dimension to traditional point source monitoring in groundwater. The two most significant differences to typical point sources to consider are land size and source size. A gas station or dry cleaner site has a single source and is limited in size to an acre or less. Perhaps the largest single source land area currently under monitoring requirements is the waste discharge from food processors on crop-land – typically on the order of a few tens to one hundred acres. In contrast, California's average sized dairy occupies several hundred to a few thousand acres of land, all of which are potential sources of groundwater contamination. A monitoring program that thoroughly scans discharges across the entire application area would be unprecedented. Such a monitoring program is not intended by currently proposed regulations due to its economic impacts and strong resistance to extensive groundwater monitoring by the dairy industry.

There exist opportunities here for the design of creative fixed monitoring networks with only a limited amount of monitoring wells per facility. The network would not be designed to catch each violation, rather it would ensure that the overall impact of dairy facilities within a region is not detrimental to groundwater. Most importantly, groundwater monitoring must be seen as part of a suite of monitoring tools. A complete monitoring program would primarily rely on accurate reporting of annual farm and field-by-field nutrient and salt mass balances. A groundwater monitoring network would be designed to minimize the number of monitoring wells needed per facility while providing a sufficiently accurate spot-check (not thorough scans) on groundwater quality. A key to the continued success of dairying will be that sufficient (but not really intensive) groundwater monitoring is implemented at key locations across multiple facilities that share similar hydrogeologic, pedologic, and agronomic management practices. The purpose of such a monitoring network must be to identify and quickly address problematic management practices maintained across these facilities as early as possible (Harter et al., 2003).

LONG-TERM OUTLOOK

In summary, dairies indeed pose a significant but manageable risk for groundwater pollution, primarily due to nitrate and salt loading. A number of research projects have also shown that pathogens are also a risk for domestic or municipal wells within the immediate vicinity of areas with land application of manure.

The dairy industry and other agricultural water users in California, not only urban and domestic water users have a high stake in maintaining good groundwater quality as it is their main source for drinking, wash, and irrigation water. To manage and protect basin groundwater quality in the long-run, it is necessary to eliminate the risk for unintended large-scale pollution by

- spreading the current risk factors across a larger land area,
- better understanding and monitoring the risk factors controlling groundwater pollution, and by
- reducing the risk through improved agronomic, engineering, and technical methods of nutrient and salt management.

Land values, market demands, and operational costs in the dairy industry are likely to continue to put pressure on allowing for and creating dairy systems

- with a larger amount of animals per (land application) acre, and
- with larger amounts of nutrient throughput in the cropping area to balance the larger number of animals.

Both will increase the risk of groundwater pollution unless they are matched with adequate technological and agronomic groundwater protection measures. Over the long term, I anticipate that most dairies will have to convert to completely lining animal production and manure storage areas (liquid and solid) with synthetic or other liners, similar to modern landfills; that they will have enclosed liquid manure storage facilities with digesters (new air pollution regulations); that manure storage facilities will have built-in or built-aside waste treatment systems that create a reliable, predictable, uniform fertilizer that can easily be managed to meet the dynamic, high nutrient demands in the land application area while minimizing the salt impact through salt exports; and that high precision irrigation and nutrient management techniques in the land application area will replace current practices (similar to developments in other high nutrient throughput crops such as vegetables). Meeting these challenges in an economically and agronomically viable fashion will require the visionary and cooperative initiative of industry, research and teaching institutions, and regulatory agencies. There is much room for innovation beyond current treatment, agronomic, and monitoring practices.

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