SCAVENGER WELLS FOR GROUNDWATER REMEDIATION AND PROTECTION ON DAIRY FARMS

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Introduction

Food production depends upon the efficient management of large quantities of nutrients in rural areas. This is true for both crop and livestock production areas. Nutrients which are not utilized by crops and/or livestock may find their way into surface or groundwater, be retained in the soil, or even find their way into the atmosphere as gases, aerosols, or particulates.

In some cases the excess nutrients may exist in very low concentrations over large areas, or they may be present in higher concentrations in rather small areas. Thus, concentration of a nutrient is not necessarily a good indicator of the relative impact on the environment, even though it may cause a problem in a small area. It is important that best management practices be implemented to reduce nutrient loadings to surface and groundwaters for both situations.

There are several sources of potential groundwater contamination on dairy farms. They include pastures, high intensity areas, spray fields, and lagoons or storage ponds. Although nitrate-nitrogen is usually the nutrient of concern in groundwater, phosphorus concentrations in groundwater may also be important, particularly if the groundwater enters surface waters through springs or some other pathway. However, phosphorus concentrations are usually very low in groundwater because the phosphorus is adsorbed in the soil profile. Nitrate-nitrogen is not fixed in the soil and moves very readily with water moving through the soil. Thus, it is responsible for most cases of excess nutrients in groundwater. The source of nitrate-nitrogen can be natural or the result of human activities. There are no substitutes for nitrogen in plant nutrition, so the most practical way to approach nitrogen in the environment is through careful management.

Nitrogen Cycle

The nitrogen cycle is the interaction of all processes which involve nitrogen in its different forms. Simplified, it is the cycling of nitrogen to and from the atmosphere and between organic and inorganic compounds. The primary processes are fixation, mineralization, immobilization,

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nitrification, and denitrification. Fixation is the binding of nitrogen into a slowly available form, as in fixation of nitrogen gas by certain legumes or fixation of ammonium by clays. Mineralization is conversion of nitrogen from organic forms to inorganic. Immobilization is the reverse path of mineralization. Nitrification is the oxidation of ammonium to nitrate and nitrite. Denitrification is the reduction of nitrates to nitrogen gas.

Nitrogen Fate and Transport in Groundwater

Nitrogen in leachate from ponds, lagoons and high intensity areas consists primarily of organic and ammonium nitrogen. In the absence of oxygen, the nitrogen may persist in these forms, with the organic compounds being slowly mineralized and the ammonium form moving down gradient. When ammonium moves into oxidizing environments, it may be converted into nitrate. Nitrate is highly mobile and is generally quite persistent. However, it is readily denitrified in reducing environments with sufficient organic carbon or appropriate chemical reducing agents. Due to the generally slow movement of groundwater and lack of vertical mixing, groundwater nitrate levels tend to be highest near the top of the surficial aquifer. Local groundwater nitrate concentrations in this upper oxygenated layer can be quite high, but may represent a low total mass loading if the depth interval is sufficiently small.

Principles of Operation

Groundwater interception by well extraction, or scavenger well, is a well established technology which has been successfully applied to a variety of scenarios involving surficial aquifer contamination. The method is based upon creating a capture zone by pumping one or more wells within a contaminant plume. In a rural area, the plume would be a volume of groundwater which has a high concentration of nitrogen or other nutrient. The capture zone is formed by the water table depression developed as water is produced from the well field. While less effective in some hydrogeologic settings such as highly developed karst areas with prominent limestone outcroppings and numerous sinkholes, interception is attractive as an alternative to retroactively fitting dairies with lined ponds for a variety of reasons.

The method is particularly well suited to the capture of pond leachate, since the location and extent of the plume source is well known, and the plume should be near the water table surface in the vicinity of the pond. The aquifer-well system interaction may be conveniently modeled using potential theory. The assumptions necessary for a reasonably accurate approximation by this method are steady flow, a homogeneous conductivity field, relatively small mounding due to seepage from the pond, and that the drawdown required to create a sufficient cone of depression be a small fraction of the aquifer saturated thickness. The width of a well capture zone is a function of aquifer transmissivity, well production rate, and regional groundwater gradient. Multiple extraction well networks have been implemented, but they probably would not be necessary due to the relatively limited extent of plume spreading that would be expected in the vicinity of the pond.

Placement of the scavenger well or wells must be considered carefully. In general, placing the well further down gradient increases the likelihood of nitrification, and therefore nitrate would be the primary ion in the produced water. Once re-introduced into the highly reduced environment of the waste management stream, typically as flush water, nitrate should rapidly denitrify and be lost as nitrogen gas. However, the importance of accurate regional flow estimates increases with well distance from the pond, since the uncertainty in plume location and errors in the estimation of groundwater flow direction will increase with increasing distance. It is also important to select a pump which is designed to deliver water at the desired rate of extraction. Selecting pumps which deliver water at a greater capacity than well yield will tend to cycle more rapidly, which decreases pump life and increases operational costs.

Implementation

The practical aspects of leachate interception on a dairy farm was examined by installing a 10.2 cm scavenger well pumped by a 250 watt submersible pump. The well was installed to a depth of 13 m, with a 6.1 m screened interval. During operation, the water table intercepted the screened interval. The well was capable of producing approximately 40 m^3 water daily. The water was routed into the feed-cooling barn flush tank, and thus the well was integrated into normal dairy operations. The average total nitrogen concentration of the produced water was 140 mg/l, which corresponded to an average daily nitrogen extraction of 5.3 kg/d. Observation of water levels in adjacent monitoring wells showed a clear hydraulic connection and development of a capture zone of dimensions exceeding that which was predicted. The nitrogen species in the produced water was predominantly ammonium. However, nitrate concentrations were increasing in the extracted water, possibly indicating that nitrate-nitrogen away from the pond was beginning to reach the scavenger well.

Extensive groundwater quality improvement should not be expected to occur rapidly, as the actual amount of water being produced is relatively small, and travel times to the well may be quite long. Additionally, the extent of the leachate plume was not well defined. However, the relatively high nitrogen concentration indicated that a significant amount of nitrogen was being removed from the surficial aquifer.

Economics

There are many compelling reasons for the installation of concrete ponds and lagoons when a new dairy is being constructed, such as increased control over waste management and potentially enhanced groundwater protection. However, retrofitting existing dairy farms with lined ponds simply is not defensible as being cost effective in the protection of groundwater quality. The incremental cost of retrofitting existing ponds is substantially greater than the incremental cost of opting for a lined pond at time of dairy construction. Additionally, implementing a leachate interception well would provide acceptable protection at a lesser cost.

Assuming an installation cost of $150 per cubic yard of concrete and an average daily flush volume of 38 m^3 (10000 gallons), a 3 meter deep pond with 7 day storage would cost approximately $3500 per 100 cows. Additionally, other factors such as interruption of normal operations and the environmental impact of taking the old pond off line must be considered. Such a significant investment in pond construction precludes the application of that money to new management practices which would address potentially more substantial contributors to groundwater quality degradation, such as agronomically and environmentally unsound cropping practices and extensive high intensive areas. The scavenger well was installed and integrated into the waste management system of the project dairy for less than $3500. Installation was completed in two days. The annual cost of continuously operating the scavenger well was approximately $260, based upon 300 watt power consumption at $0.10 per kwh. However, a similar cost was previously incurred if the flush tank was routinely filled before scavenger well installation. Therefore, the net cost of operation would be considerably less than the actual cost of the power supplied to the pump. Maintenance would consist primarily of periodic replacement of the pump. When the cost of pump replacement is amortized over the expected lifetime of the pump, it would be less than $100 per year.

Summary

In appropriate hydrogeological settings, extraction of groundwater near seeping ponds may be far more cost effective than retroactive pond lining. The net cost benefit derived by the reduced expense of scavenger well installation and operation compared to that of new pond construction could be applied to the implementation of other beneficial management practices, such as the development agronomically sound cropping practices and the minimization of high intensity areas. Interception techniques derive the additional benefit of extracting residual nutrients from the surficial aquifer, including those introduced by other farm management practices.