RETURN FLOW TO GROUND WATER FROM ONSITE WASTEWATER SYSTEMS

Dennis McQuillan[1] and Eugene Bassett[2]

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Abstract

Ground water pumped for potable supply is often beneficially used only once, discharged into a centralized sewer system, and released after treatment into a different hydrologic system such as a river that flows into an ocean. These and other anthropogenic transfers of water from continental aquifers into oceans are resulting in ground-water depletion and a small contribution to rising sea levels. Ground-water depletion can cause saline intrusion, water quality degradation, decreased production or drying up of water supply wells, and subsidence which can damage property and permanently reduce aquifer porosity and storage capacity. In New Mexico, for example, water levels are declining in many aquifers, many wells and springs are decreasing in production or have dried up, and some aquifers are projected to be completely dewatered within decades.

Onsite wastewater dispersal systems can be a significant, but often unmanaged, source of return flow to ground water. The potential benefits of returning treated wastewater to the aquifer from which it was withdrawn should be considered in any comprehensive water resources management program. Ground water recharge from an onsite dispersal system depends on the volume of effluent discharged, depth and configuration of the system, hydraulic conductivity of the soil and other intervening geologic material above the water table, depth to ground water, climate and evapotranspiration (ET) rates. The current paradigm is to construct shallow dispersal systems to enhance treatment by natural processes in the soil. This configuration also is beneficial if the goal is to deliver treated effluent to vegetation or to enhance water losses to ET. If the goal is to maximize return flow to ground water, however, a better paradigm would be to install deeper dispersal systems in areas where site conditions provide a high potential for natural attenuation, or when advanced wastewater treatment systems are utilized. In areas with limited saturated thickness and where ground-water depletion is severe, however, water-quality issues may be of secondary concern to the prospect of complete aquifer dewatering.

For gravity systems, seepage pits or dispersal trenches installed deeper than the zone of greatest influence from evapotranspiration would maximize return flow to ground water. Pressurized distribution to dispersal trenches could further enhance return flow. Another option to maximize return flow would be to locate dispersal systems in areas of known recharge or where the geologic media have a high hydraulic conductivity. Dispersal systems could also be clustered or shared at these strategic locations.

1 New Mexico Environment Department, 525 Camino de los Marquez, Suite 1, Santa Fe, NM 87505, 505-476-8607 dennis.mcquillan@state.nm.us
2 E.C. Bassett Construction, P.O. Box 100, Edgewood, NM 87015, 505-264-5626, BassettEC@aol.com

Introduction

Ground water is an important source of potable, agricultural and industrial water supply. In many areas of the world, ground-water resources are being depleted because withdrawal rates significantly exceed recharge. Increasing demands for water supply, prolonged drought conditions in some regions, and the relocation of ground water outside the immediate watershed are contributing factors to ground-water depletion. Ground water can be transferred to the oceans by the evaporation of irrigation water followed by precipitation and runoff into an ocean, and by the discharge of wastewater into rivers or directly into the ocean. The relocation of ground water into the ocean is estimated to be responsible for a sizeable amount of the observed rise in mean sea level (Konikow and Kendy, 2005; Milly et al., 2003; Sahagian, 2000).

Ground-water depletion can result in water-table declines, saline intrusion, water quality degradation, diminished production from water-supply wells and springs, and land-surface subsidence which can damage property and permanently reduce aquifer porosity and storage capacity (Johnson, 2001; Bartolino and Cunningham, 2003). The water table in some areas of New Mexico has been declining for decades, with total declines of approximately 300 feet in Santa Fe (Bartolino and Cunningham, 2003), 120 feet in Albuquerque (Bexfield and Anderholm, 2002) and 100 feet in the High Plains (McGuire, 2007). Concerns about ground-water sustainability are particularly acute in the High Plains area of Curry and Roosevelt Counties where water levels are declining at rates of more than two feet per year (Stephens, 2007). The average saturated thickness of the aquifer in this region is predicted to be reduced to 25 feet by 2020, with many areas being completely dewatered for all practical purposes by 2050 (ibid). Relocation of water from the High Plains Regional Aquifer, which includes portions of Colorado, Kansas, Nebraska, New Mexico, Oklahoma, South Dakota, Texas and Wyoming, into the ocean is estimated to have resulted in a sea level rise of 1.1 mm (Sahagian, 2000).

The authors have personal knowledge of many wells and springs in New Mexico that have either decreased in production or dried up. The economic impacts of having to drill deeper wells, pump ground water up from greater depths, and from having to develop new sources of water supply to replace depleted sources can be significant, especially for private domestic well owners and small public water systems. The New Mexico National Guard has been mobilized to deliver truck tankers of potable water to some communities when their ground-water sources either dried up or became insufficient to meet basic demands. Communities affected by depletion of the High Plains Aquifer in Curry and Roosevelt Counties are developing plans to import water via a pipeline from Ute Reservoir. A number of communities in New Mexico are exploring the possibility of constructing desalinization plants to develop saline aquifers for water supply, and the City of Alamogordo has already secured required permits from the State Engineer to do so.

Some fresh water aquifers in New Mexico are underlain by bodies of brackish and saline ground water that are increasingly being drawn into pumping wells as the fresh water is depleted. This saline intrusion has caused deterioration of the quality of water produced by public and private water supply wells in the Estancia Basin (White, 1993) and in other areas of the state.

Land-surface subsidence induced by ground-water pumping has been documented in the

Albuquerque (Leake, 2004), Deming (Contaldo and Mueller, 1991) and Santa Fe (Thomsen and Fialko, 2005) areas.

Consequently, wastewater is increasingly being viewed as a resource that should be beneficially used rather than as a waste which needs to be disposed. Irrigation systems using gray water or sewage effluent treated to secondary or tertiary levels have been installed at residential, municipal and commercial facilities. A number of golf courses in New Mexico, for example, are irrigated with treated effluent. Irrigating with gray water or treated wastewater, rather than with drinking water, reduces the demand for ground-water withdrawals for those water systems that are supplied by aquifers.

The City of El Paso, Texas has recharged approximately 20 billion gallons of reclaimed wastewater into the Hueco Bolson aquifer (Sheng, 2004). The Village of Cloudcroft, New Mexico has experienced serious water supply shortages caused by depletion of their fractured bedrock aquifer, and is constructing a state-of-the-art wastewater treatment system that will recycle highly treated effluent back into their drinking-water system (Thomson and Thomas, 2006).

Return Flows from Onsite Wastewater Systems

"Return flow" is defined by New Mexico Administrative Code (NMAC, 2004) as "That amount of diverted water returned to the available water supply." The return flow addressed by this paper consists of ground water used for potable supply that is returned to an aquifer through onsite wastewater dispersal systems. Based on the widespread impacts that onsite wastewater systems have had on ground-water quality in some areas of New Mexico (McQuillan, 2004, New Mexico Environment Department, 2006), there is little doubt that they are a significant source of return flow in those areas.

The magnitude of return flow from an onsite wastewater system can be influenced by the volume of effluent discharged, depth and configuration of the dispersal system, hydraulic conductivity of the soil and other intervening geologic material above the water table, depth to ground water, climate and ET rates. Options for quantifying deep percolation and return flow to ground water include rules of thumb, lookup tables and empirical equations, soil-water balance calculations, Darcian flux calculations, application of soil temperature to estimate the downward flux of water, application of geochemical tracers, and unsaturated flow models (Stephens et al., 2006).

In New Mexico, water-rights credits have been approved for the portion of water originally pumped from a well that is returned to an aquifer from onsite wastewater systems. In approving a water-rights permit for the diversion of ground water in Roswell that included credit for return flow from septic tanks, the New Mexico State Engineer (2001) found that 50 percent of the water delivered to households in a public drinking-water system was discharged to the consumers' septic system leach fields, and that 85 percent of the water discharged to the leach fields percolated through the vadose zone to the shallow aquifer. The return flow from septic systems in the Roswell case, therefore, was estimated to be 42.5 percent of the water delivered to the consumers.

Blandford (2006) conducted a field investigation of return flow from septic systems at another site near Roswell. The study involved the review of well logs and other hydrogeologic data for the region, installation of seven test borings adjacent to active septic leach fields, collection and analysis of water and soil samples from the test borings and laboratory testing of soil hydraulic properties. The amount and timing of return flow was estimated using numerical simulation of several representative subsurface geologic configurations. The study estimated that an average return flow of 0.37 ac-ft/yr per household, which is 47 percent of the average amount of water delivered per household, reached the water table within a period of several months to 2 years.

A number of regional water budgeting and planning efforts in New Mexico have used a rule-of-thumb assumption that approximately 50 percent of the water pumped from onsite domestic wells is returned to the aquifer through septic systems (Stephens and Lewis, 2003; Wilson et al., 2003). As discussed by Stephens et al. (2006), however, rule-of-thumb assumptions for return flow can involve a high degree of uncertainty. Wastewater return flows greater than 50 percent may occur in shallow water-table areas of New Mexico where residents do little or no gardening or landscape irrigation. Conversely, return flows could be small or zero when liquid waste systems are installed in fine grained soil overlying a geologic formation that acts as a capillary barrier in a deep water-table area. Given the geologic complexity of New Mexico (Figure 1) a wide range of return flow percentages can be expected to occur.

The question of how much recharge onsite septic systems provide to ground water also has arisen in northern Georgia which is experiencing extreme drought conditions and water-supply shortages. A hydrologic study in this region discovered that ground-water fed streams in watersheds with a large density of septic systems had a greater specific conductance and greater baseflow than did streams in watersheds with a small density of septic systems (Landers, 2008). The source of elevated conductance and baseflow was attributed to ground-water recharge from septic systems that eventually discharged into the streams. The increase in baseflow was estimated to be 83 percent of water delivered to consumers for indoor use during the fall of 2007 (ibid).

Water Quality Considerations

Domestic wastewater contains total dissolved solids (TDS), nitrogen, chloride, organic carbon, and microbes, and can contain organic compounds including surfactants, solvents and pharmaceuticals, at concentrations greater than in the potable water supplied to the home. When site conditions provide adequate natural attenuation of these constituents, conventional onsite septic tanks and drain fields are a suitable means of wastewater treatment and dispersal (McQuillan, 2004). The ability of natural soil to attenuate suspended solids, biodegradable organic matter and fecal coliform bacteria is well documented (USEPA, 2002). Depending on soil and/or ground-water conditions, natural attenuation of nitrogen by denitrification or other mechanisms also may occur (USEPA, 2002). Evidence of natural denitrification in the Middle Rio Grande Basin, New Mexico is provided by Plummer et al. (2004, p. 88) who detected dissolved nitrogen gas, at concentrations in excess of what would be derived from diffusion and equilibrium with atmospheric nitrogen, in 30 percent of ground-water samples tested. Plummer et al. (2004, p. 71) also mapped extensive regions of shallow inner valley ground water that contained <0.5 mg/L dissolved oxygen and identified these areas as having potential for denitrification (p. 209).

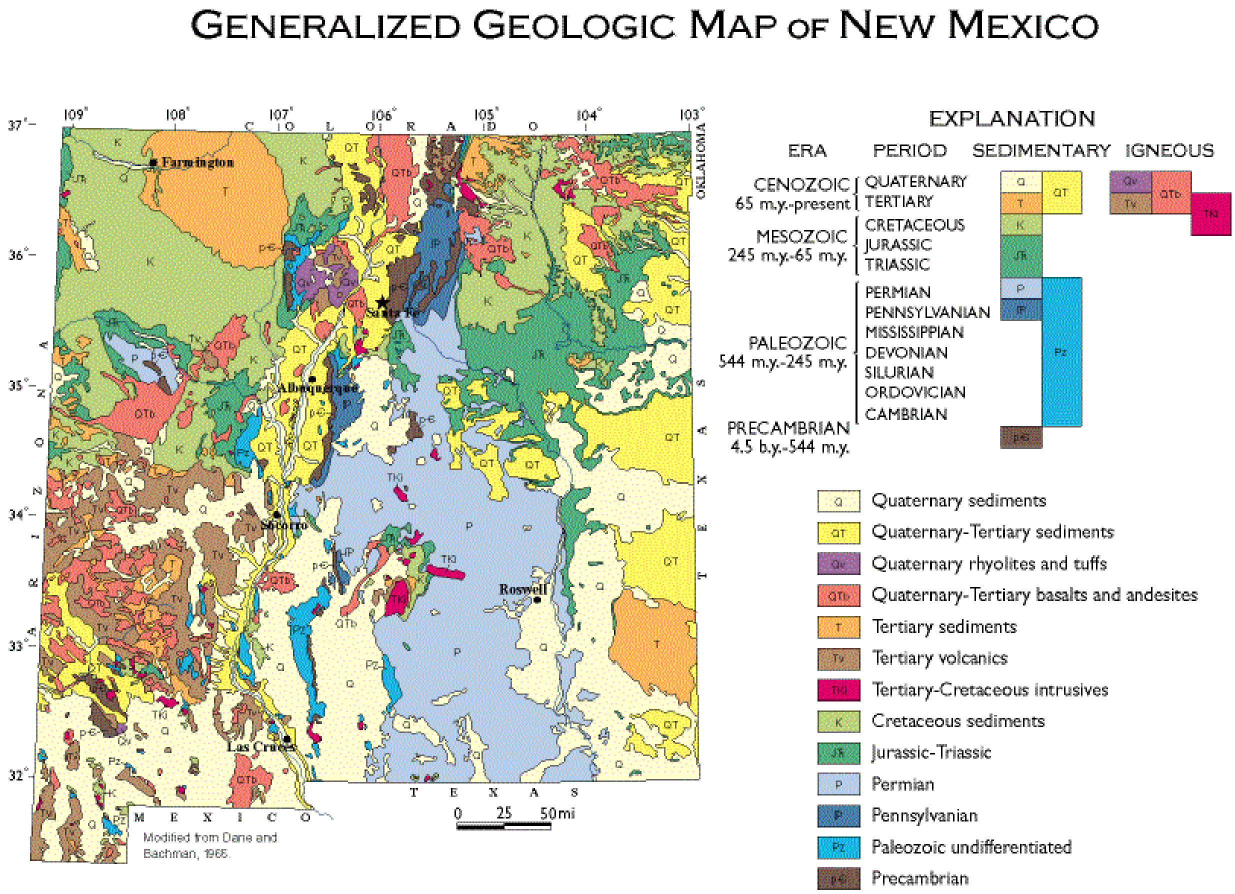

Fig. 1. Generalized Geologic Map of New Mexico (simplified version of New Mexico Bureau of Geology and Mineral Resources, 2003).

Widespread ground-water contamination, however, has occurred in many rural areas utilizing onsite wells and septic systems when the capacity of the soil and site to attenuate wastewater constituents to concentrations within allowable standards is exceeded (McQuillan, 2004). Ground water impacted by septic tank effluent typically contains elevated TDS and chloride. In oxic conditions the ammonia in sewage can oxidize to nitrate and contaminate ground water. In anoxic conditions, however, ammonia does not undergo nitrification, and is not detected in ground water at appreciable levels, suggesting that it is removed by cation exchange or by volatilization. Organic carbon in the effluent can be oxidized by ground-water bacteria, which will increase the demand for, and consumption of, available electron acceptors used for respiration. Ground-water bacteria will preferentially respirate, and chemically reduce, dissolved oxygen, nitrate (denitrification), geologic manganese and iron oxide minerals, sulfate and carbon (methanogenesis), in that order, based on decreasing energy yield to the organism. Reduction of manganese and iron oxides releases soluble metal ions into ground water, and sulfate reduction creates hydrogen sulfide gas. Concentrations of these anaerobic respiration byproducts in ground water have been increased by discharges of septic system effluents in anoxic aquifers (Anderholm, 1987; Gallaher et al., 1985; McQuillan and Misseri, 2007). In potable water supply, these anaerobic respiration byproducts can create aesthetic and economic problems, and manganese at mg/L concentrations may pose neurological risks.

Lot size influences the regional nitrogen loading rate, and the cumulative increase in ground-water nitrate that can be caused by multiple residential septic systems in oxic conditions (McQuillan, 2007). Two residential areas in basin-fill terrain where onsite septic systems caused an increase in nitrate levels in private domestic wells are compared in Figures 2 and 3. The Albuquerque West Mesa site (Figure 2) was developed with platted lots of about 0.5 acre. Each house had a well in the front yard and a septic system in the back yard. As ground water flowed through the West Mesa subdivision, nitrate-N levels increased from a background of about 1 or 2 mg/L to levels in excess of 20 mg/L. The Eldorado site near Santa Fe (Figure 3) was developed with platted lots averaging about 1.3 acre with significant greenbelt areas between the lots. Septic system effluent increased ground-water nitrate-N in Eldorado from a background of 1 or 2 mg/L to a maximum of 7 mg/L. In basin-fill hydrogeologic terrain in New Mexico, some residential areas developed with septic systems on lots of 0.5 acre or smaller have caused ground-water nitrate contamination in excess of the drinking water standard of 10 mg/L as N (McQuillan, 2007). Septic systems in basin-fill areas developed with lots of 1 acre or larger, however, have not been found to increase ground-water nitrate in excess of the standard (ibid). Fractured bedrock terrain was found to be a significant risk factor for nitrate contamination, even with large lot size (ibid).

A regional nitrogen loading rate for an area developed with onsite wastewater systems can be estimated with the following formula:

$$\frac{Q\ \text{gal}}{\text{day}} * \frac{365\ \text{day}}{\text{year}} * \frac{3.78\ \text{L}}{\text{gal}} * \frac{C\ \text{mg}}{\text{L}} * \frac{2.2\ \text{lbs}}{10^{6}\ \text{mg}} * \frac{A}{LS} = \text{lbs N/acre/year}$$

Where:

A = percent of total area consisting of platted lots/100
C = total nitrogen concentration (mg/L)
LS = lot size (acre)
Q = wastewater flow (gallons per day)

A wastewater flow of 375 gallons per day, an effluent concentration of 60 mg/L total nitrogen, and 85 percent of surface area consisting of platted lots (15 percent surface area consisting of roads, easements, greenbelts etc.) a residential area developed with 0.5 acre lots would generate a regional nitrogen loading rate of 116 lbs N/acre/year. A residential area developed with 1 acre lots would generate a regional nitrogen loading rate of 58 lbs N/acre/year.

Fig 2. Residential Area in the Albuquerque West Mesa.

Fig 3. Residential Area in the Eldorado community near Santa Fe.

Anoxic conditions occur in shallow ground water along the Rio Grande valley (Plummer et al., 2004, p. 71) and in other alluvial aquifers in New Mexico (McQuillan and Misseri, 2007). Anoxic conditions do not typically extend outside of the inner valley where depths to ground water increase to 30 feet and greater. The concern that septic system effluents may increase the concentration of anaerobic respiration byproducts appears to be limited to inner valley aquifers where the depth to ground water is less than 30 feet.

Design Considerations for Wastewater Dispersal Systems

The current paradigm is to construct shallow dispersal systems to enhance the delivery of oxygen to the infiltration zone which in turn enhances wastewater treatment by natural processes in the soil (USEPA, 2002, p. 4-6). A shallow configuration also is beneficial if the goal is to deliver treated effluent to vegetation or to enhance ET. Enhancing soil treatment and the loss of water to ET would tend to reduce the risk of ground-water contamination, but would also have the effect of reducing the amount of water returned to the aquifer.

Seepage pits would be expected to provide the greatest amount of return flow to ground water. Surface-application and shallow-drip dispersal systems would have the least potential for return flow since they maximize water loss to ET.

Discussion and Conclusions

Ground-water depletion is a critical issue in many areas of the world. In New Mexico, water levels are declining in many aquifers, many wells and springs are decreasing in production or have dried up, and some aquifers are projected to be completely dewatered within decades. Recycling of treated wastewater for beneficial uses such as irrigation and potable water supply can substantially reduce the demand for and withdrawal of ground water.

Return of treated wastewater to the aquifer from which it was originally withdrawn has obvious benefits for ground-water sustainability but is not a new or unique concept. Many thousands of septic systems in New Mexico have been providing return flow to ground water through soil-based dispersal systems for decades. The potential benefits of returning treated wastewater to the aquifer from which it was withdrawn should be considered in any comprehensive regional water resources management program.

The current paradigm favoring shallow dispersal systems minimizes the risk of ground-water contamination, but also minimizes the amount of treated effluent returned to ground water. In areas where ground-water depletion is occurring, a better paradigm would be to install deeper dispersal systems in areas where site conditions provide a high potential for natural attenuation, or when advanced wastewater treatment systems are utilized. Deeper dispersal would reduce or avoid losses from ET and maximize return flow to ground water. Since dispersal by deep trenches or seepage pits has been discouraged or prohibited by many regulatory agencies (USEPA, 2002, p. 4-4), exceptions to the shallow system philosophy may be controversial. However, many natural soils can provide wastewater treatment analogous to a single pass, aerobic sand filter even below the shallow zone that is favored by the current paradigm. The challenge is finding the appropriate balance between preventing excessive degradation of ground-water quality, and minimizing ET loss of the water that needs to be preserved. In shallow water-table areas where ground-water depletion has been minimal, for example, protecting the quality of the aquifer may be the most important issue. In areas with limited saturated thickness and where ground-water depletion is severe, however, water-quality issues may be of secondary concern to the prospect of complete aquifer dewatering.

Regional nitrogen loading rates from onsite septic systems of approximately 58 lbs N/acre/year or less have not been shown to cause ground-water nitrate-N contamination in excess of the allowable standard of 10 mg/L in New Mexico. Additionally, the concern that septic system effluents may increase the concentration of anaerobic respiration byproducts appears to be limited to inner valley aquifers where the depth to ground water is less than 30 feet. A 30 foot clearance to ground water or to fractured bedrock also would provide greater potential for the soil to provide wastewater treatment analogous to a single pass, aerobic sand filter. Therefore, if the decision is made to enhance the return flow of septic system effluent, beyond the amount that would normally occur from systems that are properly sited, constructed and permitted in accordance with NMAC (2005), the following criteria would minimize potential risks to ground-water quality:

1. Regional nitrogen loading rate should be less than or equal to 58 lbs N/acre/year, which corresponds with platted lot sizes of about one acre or greater;
2. Depth to ground water should be greater than 30 feet; and
3. Depth to fractured bedrock should be greater than 30 feet.

These criteria may not be appropriate, however, in an area of severe ground-water depletion and water-supply shortage. Allowing septic systems to contaminate an aquifer with 20 mg/L nitrate-N, for example, may be less deleterious to the affected community than having the aquifer become completely de-watered.

With regard to advanced (secondary or tertiary) wastewater treatment systems, the justification for shallow dispersal systems, on the basis of protecting ground-water quality, is greatly reduced since a high degree of treatment should occur before effluent enters the soil. The use of dispersal systems designed to maximize the return flow of effluent from advanced treatment systems should be less risky than from conventional septic tanks.

For gravity systems, seepage pits or dispersal trenches installed deeper than the zone of greatest influence from ET would maximize return flow to ground water. Pressurized distribution to dispersal trenches could further enhance return flow.

Another option to maximize return flow would be to locate dispersal systems in areas of known recharge or where the geologic media have a great hydraulic conductivity. Dispersal systems also could be clustered or shared at these strategic locations.

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