MINE WATER MANAGEMENT BY AQUIFER INJECTION ENGINEERING

Dr Len Drury

Senior Principal,
Coffey Geosciences Pty Ltd.,
142 Wicks Road, North Ryde,
Sydney, Australia 2113.

ABSTRACT

The practice of disposing of waste water by injection to the subsurface is quite common in the USA and Europe, and is increasingly being practiced in Australia, particularly in the mining industry. Due to stringent environmental regulations and controls on surface disposal, interest in this method has developed rapidly. Many mine water related management problems, particularly in environmentally sensitive locations, can be successfully solved by aquifer injection engineering. In addition, government legislation and regulations can be changed by the demonstration of innovative techniques, such as aquifer injection.

This paper reviews the present practices of aquifer injection in Australia and the criteria recommended in site selection of waste water borehole injection systems. Examples of mine waste disposal by aquifer injection in Australia and India will be given in this conference.

MINE WASTE WATER DISPOSAL BY AQUIFER INJECTION

To date the most common use of aquifer injection (artificial recharge) in Australia has been to artificially increase the safe yield of alluvial aquifers. In Queensland, surface trenches and weirs are used to impound water and induce infiltration to aquifers in the Lockyer and Callide Valleys; Proserpine River; and the Burdekin River. In New South Wales, the alluvial aquifers supplying water for Kempsey and Bega town water supplies are recharged by pumping water from rivers into abandoned palaeochannels which traverse the extraction wellfield area. The Mt Newman Iron Ore Mine wellfield in Western Australia is also recharged by surface water sources.

Liquid waste disposal by injection to groundwater via boreholes has recently been developed in Australia, and already incorporates a large range of liquid types. Injection into the groundwater system is practiced for a number of purposes, not always for waste disposal. The possible consequences and criteria to be observed in site selection and operation are discussed in this paper. The purposes for which borehole injection are, or could be carried out in Australia, include:

Urban Industrial Wastes. This is typified by injection into deep boreholes of liquid waste from wool scouring operations and chemical plants near Perth, Western Australia.

Rural Industrial Wastes. Important examples are the disposal of cheese and butter factory wastes in South Australia and Victoria; washing water from sultana drying in Victoria; starch factory wastes in New South Wales.

Storm Water Excess. Stormwater is discharged to the groundwater system at Warnambool, Victoria and for municipal councils in Adelaide, South Australia. Treated sewage has been discharged to groundwater in parts of South Australia, eg Adelaide's Bolivar treatment plant and towns along coastal New South Wales.

Mine Waste Disposal. Development of mines with excessive and poor quality water (Oaklands and Ingomar Coal Projects) or mines located in environmentally sensitive locations (Heathcote Gold Mine) can be made economically viable by aquifer engineering.

Insitu Leaching as a Mining Method. In-situ mining is a process in which a liquid, usually an oxidising leach solution, is pumped through an orebody via a series of injection bores. The leaching solution migrates through the orebody (aquifer), mobilising the target mineral into a soluble complex. The pregnant liquor is then recovered through one or a number of pumping bores. The method can be used to leach economic minerals (e.g. gold, copper, silver, potash or uranium). After extraction of the metal, the technique produces a large volume of liquid waste which is usually reused by injection into the same or similar deep aquifers. There are a number of in-situ leaching projects commencing in Australia, including the Honeymoon and Beverly Uranium Deposits.

Oilfield Brine Injection. Brine injection is a common procedure used worldwide for both disposal of brine, and for secondary hydrocarbon recovery.

Construction Sites. Water injection is sometimes carried out at construction sites where dewatering of excavations is necessary. The injection is designed to maintain groundwater conditions in the vicinity of the excavation at their pre-construction level, to minimise subsidence and possible consequent damage to buildings and services.

Brine Disposal, Murray Basin. Saline water is a hazard in much of the Murray Basin, and large volumes require disposal wherever shallow water tables have been lowered by groundwater pumping. Studies have been conducted into evaporation, concentration and subsurface disposal of the resulting brine and the technique has now been put into practice in South Australia.

Groundwater Barriers. In some parts of the world, injection of water has been used to create a groundwater pressure mound to protect a valuable groundwater resource from incursion by adjacent poor quality water. Most notably, such schemes have been constructed to protect coastal aquifers from seawater encroachment. A number of schemes have been examined in Australia, but none have yet been implemented. Hydrocarbon contamination has been contained and recovered by artificially induced groundwater pressure mounds around the pollution plume.

Although disposal of the liquid waste into a groundwater system usually involves relatively small quantities of fluid, any injection into groundwater requires careful prior study and analysis. The waste liquid may be toxic and/or aggressive, and stringent conditions are required to ensure successful disposal. These conditions relate both to the design and construction of the injection facilities and to the effects on the local and regional groundwater system. In a successful disposal scheme, the injected fluid should totally reside in the target formation, and there should be no leakage to ground surface of either the injected fluid or of any other fluid displaced by its injection.

Criteria For Site Evaluation

Criteria used by Coffey Geosciences Pty Ltd for the evaluation of sites for subsurface waste water disposal are outlined below-

Regional Geological and Hydrogeological Considerations: In evaluating the feasibility of subsurface waste water injection, the initial requirement is for suitable hydrogeological conditions to be available.

An areally extensive, thick, sedimentary or highly fractured hard rock sequence should be present to provide a suitable repository for the injected liquid. The target aquifer preferably should be overlain by a confining layer and geological structure should not be complex, with little cross faulting and folding. Complex geological structures with multiple structural lineations complicate the prediction and monitoring of waste water movement and provide avenues for escape of waste water. The region should not be an area of groundwater discharge for the aquifer interval being considered and the target aquifer should contain either saline water or water of similar quality to that being injected. There should be an absence of mineral resources (e.g. gold, copper, oil, gas, coal) so that degradation or possible dissolution of natural resources is minimised and sterilisation of the deposit avoided. Since deep aquifer, high pressure injection may stimulate seismic activity, the injection site should not be located in potentially seismically active fault areas.

Local Evaluation of Aquifer and Disposal Water Injection: Hydrodynamic, physical, chemical and biological factors must be studied in assessing the suitability of aquifer injection. Clogging, erosion or fracturing of aquifers may have deleterious consequences on the long term performance of the injection wellfield system. Chemical compatibility of waste water with the aquifer receptor water needs to be assessed to avoid chemical precipitation, fissured formation dissolution, or swelling and dispersion of clay minerals. Introduction of micro-organisms in the injection system may lead to clogging of the well/aquifer interface.

Waste water repositories should have sufficient borehole exposure, porosity and permeability to accept the quantity of injected fluid without necessitating excessively high injection pressures. The injection bores should be designed so that there is slow lateral movement of fluid into the aquifer. A homogeneous aquifer is preferred to prevent excessive "fingering" of the waste water/formation water contact. Overlying and underlying confining beds should be present. No unplugged or improperly abandoned bores penetrating the disposal site should be present as this may lead to cross aquifer contamination.

Hydrodynamic Criteria: Numerous reviews of the hydrodynamic criteria of waste water injection have been carried out in the USA and Europe, e.g. Bear (1972, 1979), Huisman (1970), Witherspoon & Neuman (1972), and Olsthoom (1982). Basically, the hydraulic relationships developed for groundwater extraction and for aquifer injection are diametrically opposite. Modelling techniques developed for regional hydrogeological assessments and wellfield extraction can be applied analogously to pressure interference effects at the injection wellfield.

The injected water flows from the well into the aquifer by raising the head of water in the hole. The injection bore can be sealed and pressure applied to the well and thus high injection rates can be achieved. The thickness and permeability of the receptor aquifer and the viscosity of the injected fluid control the differential pressure required per unit rate of injection. The porosity and thickness of the porous receptor determines the volume of fluid to be stored per unit area. Differential pressures and injection rates are also controlled by geological constraints, such as the areal extent of the aquifer, destruction of confining horizons at high differential pressure, and/or fracturing of the aquifer structure due to high inflow velocities and pressure.

The local and regional hydrogeological regime must be understood in sufficient detail to enable confident prediction of the route and time frame of injected water through the aquifer, and to be sure that there will be no return of the injected waste water to the surface.

Physical Criteria: The clogging of an aquifer by the presence of particulate matter in the injection water is an obvious and serious consideration that needs to be addressed. Plugging by iron compounds, organic debris, silica or clay minerals and colloidal particles occurs by the formation of a semi-impermeable filter cake on the well screen or filter pack/aquifer interface, or by deep aquifer penetration (Figure 1). Treatment of the well screen at the interface is relatively easy using standard well remediation techniques, but successful removal of particulates once they penetrate the aquifer pore structure is difficult to achieve. In addition, entrained gas in the aquifer may significantly reduce permeability in a similar manner to plugging by solid particles (Figure 2).

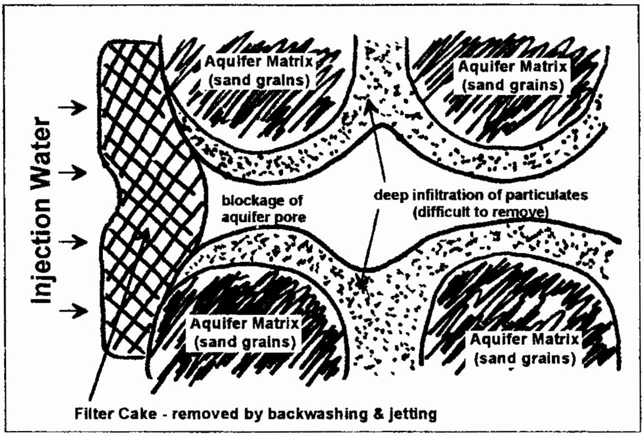

Figure 1. Aquifer blockage by sediment content in injection water.

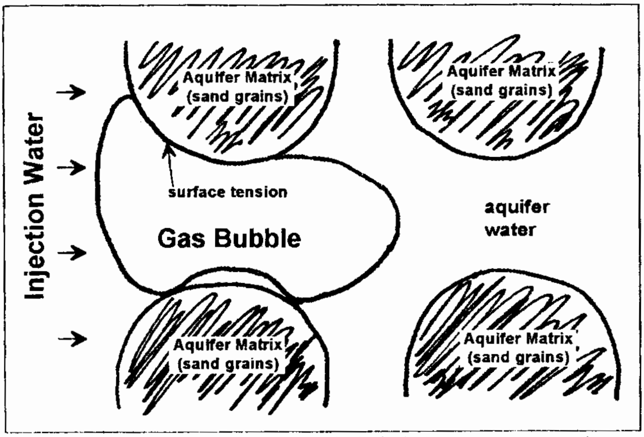

Figure 2. Aquifer blockage by gas bubble held by surface tension.

Suspended particulates can be removed before aquifer injection by surface filtration. There appears to be no proven relationship between the concentration of particulates in injection water and the clogging of the wells. The Modified Fouling Index (MFI, Schippers & Verdouw, 1980) is used in Coffey studies to assess fouling potential to injection wells in aquifers with intergranular permeability. Olsthoom (1982) developed an empirical relationship between MFI and clogging rates which indicated that clogging due to particulate concentration is proportional to the injection velocity. Injection velocities greater than 1m/hour (0.3mm/sec) can be avoided by proper well construction and wellfield design.

Elimination of entrainment of air and gas may be achieved by operating a closed pressurised system from water source to injection wellfield. Correct design and pressure control in the transport conduit and injection pipework can reduce the release of dissolved gases from solution.

Fracturing and Erosion of Aquifer Structure: Hydraulic fracturing of a rock formation occurs by the injection of water at sufficient pressure to overcome confining stresses. Hydraulic fracturing, caused by waste water injection into the aquifer system should be avoided, as escape of the injected fluid to other aquifer systems or to the surface may occur. Excessive entry velocity of the injection fluid and the dissolution of the intergranular cement by radical differences in aquifer chemistry could erode the granular structure of an unconsolidated aquifer and reduce its permeability.

Chemical Criteria: Injection of waste water may disturb the steady state chemical equilibrium of ambient groundwater. Mixing of different water types may lead to precipitation or dissolution of minerals depending on their stability and ionic solubility. Low pH water will dissolve calcareous cements and high pH may remove siliceous cements. In fractured carbonate aquifers permeability may increase due to dissolution of the aquifer. However, in granular aquifers, permeability will be reduced if precipitation of minerals (e.g. calcium and magnesium carbonates, iron, aluminium, manganese) occurs. Iron precipitation is particularly serious due to the abundance of iron in some natural groundwater systems.

Exposure to waters of different chemical composition can induce clays within the aquifer to swell or disperse. The montmorillonite clays are prone to swelling which, if it occurs, will restrict the flow of the injected fluid. The non-swelling clays (illite and kaolinite) may disperse and move with the injected fluid through the aquifer to be captured by drag forces at pore constrictions.

Biological Criteria: A variety of bacteria, fungi and algae occur in groundwater. Algae require sunshine to grow and fungi require oxygen for their metabolism; both can be excluded in an injection wellfield if a closed pipeline system is installed. Bacteria in groundwater are found under various salinity, temperature, pressure and oxidation/reduction states and can occur in injection systems where the natural equilibrium is disturbed. Most problems of this type relate to the production of hydrogen sulphide gas and clogging at the well screen or filter pack/aquifer interface. Cleaning of the injection well clogging due to bacterial growth can be achieved by using strong oxidising agents such as chlorine or hypochlorites.

CONCLUSIONS

The disposal of waste water by aquifer injection is still in its infancy in Australia and only a few examples of this disposal system option are known. An understanding of the regional and local hydrogeological regime into which the water is to be injected is essential. The services of experienced hydrogeologists who have a proven record of such projects is critical. Bores should be designed and constructed appropriately based on the aggressiveness and toxicity of the waste water being injected.

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