GROUNDWATER AND RELATED ISSUES

A Continuing Education Series in Geology
At UC Riverside Extension
March 10, 2007

Sponsored by
Inland Geological Society
&
Association of Engineering and Environmental Geologists, Inland Chapter

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TOPICAL SUMMARIES

1. Computation of Groundwater Quality Objectives for the Basin Plan Update (Santa Ana Region)

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The 2004 Basin Plan Amendment. The Porter-Cologne Water Quality Control Act (Division 7 of the California Water Code), and the Federal Clean Water Act both mandate periodic review of water quality control plans. Section 13240 of the Water Code requires that "Each regional board shall formulate and adopt water quality control plans for all areas within the region… Such plans shall be periodically reviewed and may be revised."

In the early 1990s, during consideration of adoption of the updated Basin Plan for the Santa Ana Region, watershed stakeholders questioned the validity of the groundwater quality objectives for TDS and nitrate-nitrogen and the Regional Board’s Nitrogen/TDS management plan that implemented those objectives. A principal underlying concern was that the updated Basin Plan resulted in inappropriate constraints on wastewater recycling opportunities. Reuse of recycled water is a critical component of many agencies’ plans to meet rapidly increasing water demands in the region. In response to these concerns, the Regional Board agreed to a review of the TDS and nitrate objectives.

The Nitrogen/TDS Task Force (Task Force) was formed in 1995-96 to conduct the Santa Ana Watershed-wide TDS and Nitrogen Investigation. The Task Force was comprised of 22 water supply and wastewater agencies throughout the Region. The Task Force effort was coordinated by the Santa Ana Watershed Project Authority, and Regional Board staff was active participants.

Updated Groundwater Quality Objectives. The primary purpose of this investigation was to develop scientifically-based TDS and nitrate-nitrogen objectives for groundwater sub-basins. The objectives were to be based on the State Water Resources Control Board Executive Order 68-16 which requires that the Regional Boards develop water quality objectives based on ambient water quality conditions that were present at the time that the first Basin Plan was developed (1973). Such objectives are referred to as anti-degradation objectives. Wildermuth Environmental, Inc. (WEI) developed and executed the scientifically-based methods to compute ambient TDS and nitrate concentrations in 1973 (corresponding to the anti-degradation objectives) and in 1997 (corresponding to the then current ambient concentration).

In this effort, the groundwater sub-basins of the Santa Ana River watershed were redefined based on updated hydrogeologic knowledge. These redefined sub-basins are now called "management zones." Groundwater quality objectives for each management zone were re-computed based on (1) a robust historical data set of water quality at wells and (2) rigorous and highly-reviewed scientific methodologies. These methodologies included mapping and hand-contouring of water quality at wells followed by a sequence of GIS processes that result in volume-weighted, regional estimates of TDS and nitrate in groundwater. ArcView 9.1, the Geostatistical Analyst extension, a digitizing tablet, and MS Excel were the primary software tools used in this effort. This presentation will explain these methodologies in detail.

Objectives Based on "Maximum Benefit." The new objectives for the management zones in the northern portions of Chino Basin ranged from 260 to 290 mg/L for TDS and 4 to 5 mg/L for nitrate-nitrogen. Current ambient TDS and nitrate concentrations were 300 mg/L and 7.4 mg/l – implying no assimilative capacity for TDS or nitrate.

> Note: If the current quality of a management zone is the same as or poorer than the specified water quality objectives, then that management zone does not have assimilative capacity. If the current quality is better than the specified water quality objectives, then that management zone has assimilative capacity. In the later case, the difference between the objectives and current quality is the amount of assimilative capacity available. Within management zones that have assimilative capacity, the Regional Board, at its discretion, can permit discharges at concentrations higher than the objectives.

The implication of no assimilative capacity is that the TDS and nitrate mass added to groundwater from the use of recycled water for irrigation and recharge would have to be mitigated at great cost.

WEI developed a proposal to the Regional Board on behalf of the Chino Basin stakeholders to establish higher TDS and nitrate objectives that would allow the recharge of recycled water without direct mitigation. The proposal was consistent with California Water Code section 13241 which provides criteria to be used in establishing water quality objectives. One of the keys to using this section of the water code was the extraordinary groundwater management program being implemented by the Chino Basin stakeholders, which includes groundwater desalination facilities at the down-gradient end of the basin, artificial recharge programs in the forebay areas, comprehensive groundwater-level and groundwater-quality monitoring programs, and forward-projecting computer-simulation modeling. A key element of the maximum benefit proposal was for the desalination facilities to create hydraulic isolation of the Chino Basin to prevent adverse impacts to downstream groundwater basins (e.g. Orange County).

The Chino Basin stakeholders were successful in raising the TDS and nitrate objectives to 420 and 5 mg/L for TDS and nitrate, respectively. WEI was able to demonstrate through technical, financial and institutional analyses that raising the objectives would promote maximum beneficial use of State waters and still be protective of beneficial uses. WEI also was successful in working with other stakeholders in the watershed in obtaining similar maximum benefit–based objectives in the Beaumont, San Timoteo and Yucaipa basins. Currently, WEI is assisting Eastern Municipal Water District with their maximum benefit proposal for the San Jacinto basin.

To date, the Chino, Beaumont, San Timoteo and Yucaipa basins are the only basins in California with TDS and nitrate objectives based on maximum benefit criteria. But the maximum benefit model can be (and probably should be) applied to other groundwater basins in the arid southwest, where the large-scale use of recycled water for irrigation and recharge is crucially important for meeting current and future water demands.

2. Perchlorate Issues in the Santa Ana River Watershed

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Perchlorate salts, such as ammonium perchlorate, are highly soluble and dissociate in water to form perchlorate ions. The production of ammonium perchlorate in large quantities began in the 1950s at a facility in Nevada. Ammonium perchlorate is an oxidizer used in the manufacture of solid rocket propellants and explosives and has been used extensively in this country's space program. Perchlorate salts are also used in the manufacture of fireworks and flares. It is now known that past practices at various facilities has resulted in the discharge of perchlorate to groundwater. Recent research and groundwater isotope analyses have determined that sodium nitrate imported from Chile since the early 1900s is also a source of perchlorate in groundwater.

Prior to 1997, perchlorate had not been detected in low concentrations in groundwater anywhere in the United States because an analytical method did not exist to detect perchlorate at low concentrations. In 1997, an improved perchlorate detection method was developed that was sensitive to 4 parts per billion. The California Department of Health Services then directed the sampling of drinking water wells throughout California.

Since that time, perchlorate has been detected in groundwater throughout the United States; especially in California.

In California, about 340 municipal drinking water wells have been found to contain perchlorate. Approximately 175 of these wells are located in the Santa Ana River Basin, largely in the Riverside and San Bernardino County areas of the Inland Empire. Since perchlorate was first detected in groundwater in the Santa Ana Region in 1997, the Regional Board has undertaken investigations to identify the sources of perchlorate, issued enforcement orders to compel the responsible parties to address the problem, and took other actions to assist water purveyors that were impacted by perchlorate. An effective method for removing low concentrations of perchlorate from groundwater did not exist when perchlorate was first determined to be widespread in groundwater in 1997. However, effective, but expensive, methods have since been developed, and wellhead treatment systems for the removal of perchlorate are now in place on a number of municipal supply wells in the Inland Empire.

Several industrial sources of perchlorate have been identified in areas of the Santa Ana Region where the highest concentrations of perchlorate have been found in groundwater. In the Redlands area, a former Lockheed rocket motor facility was found to be the source of perchlorate that had impacted 45 municipal drinking water wells. Lockheed took responsibility for this contamination and provided mitigation to the five water purveyors that were affected. To date, Lockheed has spent over $100 million on trichloroethylene and perchlorate investigation and cleanup.

Also, the Regional Board is devoting a level of resources to address perchlorate contamination in the Rialto area that is unprecedented by any other case in the region. These efforts include complex technical investigations and prolonged litigation. Multiple facilities have been identified as the sources of perchlorate that resulted in the closure of many wells in the Rialto area, prompting a potential water supply shortage situation in 2002. These sources include former aerospace, fireworks and other facilities.

In the Santa Ana Region, many municipal wells contain perchlorate at low concentrations in areas that were historic citrus growing areas. Regional Board staff research found that Chilean nitrate, which contained about 0.2% perchlorate, was used as fertilizer on many citrus groves in these areas between at least the early 1900s through the 1940s. Recent perchlorate isotope analyses performed on groundwater samples collected from an historic citrus growing area in the Inland Empire confirmed that the perchlorate isotopes matched that of perchlorate in Chilean fertilizer and not the synthetic perchlorate used by industry. This provides further substantiation to the premise that the widespread occurrence of perchlorate in low concentrations in the Inland Empire is from the historic use of Chilean nitrate fertilizer.

3. Numerical Groundwater Flow and Contaminant Transport Modeling

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Numerical simulations employ computer programs to represent field conditions and then stress those conditions to study system dynamics and/or to predict the effect of new or altered stresses. The modeling process typically includes developing a conceptual model of the flow system, selecting computer codes, and performing calibration and sensitivity analysis of the computer model. The conceptual model is a simplified representation of the flow system that is based on available field data and the geology and hydrogeology of the study area. This information is used to discretize, or design, the model domain and grid, which divides a three-dimensional study area into cells defined by a series of rows, columns, and layers. Modeling may be performed in one, two, or three dimensions, and modelers may employ various types of numerical models (e.g., finite element, finite difference) or use analytical solutions for simpler problems. A steady-state calibration assumes that the modeled conditions are permanent. Transient models incorporate temporal variations in stresses such as pumping and recharge, and may also be calibrated to match head and flux values that vary over a span of time. Contaminant transport calculations are also generally performed assuming transient conditions, and are calibrated to measured concentrations.

The recent detection of perchlorate in groundwater at the Stringfellow Hazardous Waste Site in Riverside County has necessitated additional evaluation of the extent and distribution of impacts downgradient of the site. Additional analyses are also necessitated by the startup and imminent expansion of the Chino Desalter Projects near the Stringfellow site, which may potentially affect the plume, increasing its size and/or altering transport pathways and thereby impacting additional groundwater supplies. Considering these conditions, the California State Department of Toxic Substances Control directed development of a three-dimensional, numerical, groundwater flow and contaminant transport model of the Stringfellow site and vicinity to evaluate perchlorate transport behavior and to assess the impact on the perchlorate plume of pumping at the Desalter.

To perform these simulations, an area of approximately 45 square miles in the eastern portion of the Chino Basin was extracted from an existing groundwater flow model that was created to simulate the effects of the Desalter in the Chino Basin. The new, smaller model domain was refined and reconstructed, based on available data, into three layers, consisting of alluvium overlying weathered bedrock, which, in turn, overlies unweathered bedrock. The initial modeling effort consisted of three phases: 1) calibration of a steady-state model; 2) contaminant fate and transport modeling of perchlorate; and 3) creation of a transient model, projecting current and planned expanded Desalter pumping approximately 20 years in the future to test the effect on groundwater flow and contaminant transport near Stringfellow.

Modeling of the Stringfellow site is now continuing after submittal of an interim report, with additional field data collected since the interim submittal being incorporated into the model and further evaluation of remediation scenarios and transient modeling to be performed.

4. Natural and artificial recharge in the western Mojave Desert

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Areal recharge from infiltration of precipitation does not occur under present-day climatic conditions in arid areas, but focused recharge in small stream channels where water is concentrated, however briefly after stormflow, does occur in some areas. More than 60 miles of streambed along Oro Grande, Sheep Creek, and Big Rock Creek Washes near Victorville and Quail Wash near Joshua Tree were instrumented using specialized drilling techniques. Boreholes installed as part of the study were as deep as 670 feet and equipped with state-of-the-art instrumentation to continuously measure changes in matric potential and temperature associated with streamflow. Carefully preserved core material from the boreholes were analyzed for physical properties and chemical and isotopic tracers of the movement of water.

As part of this work the recharge process was divided into four components including: 1) streamflow availability 2) infiltration into the streambed, 3) deep infiltration to depths below the root zone, 4) movement of water through the thick, heterogeneous unsaturated zones underlying alluvial basins. Streamflow along study washes ranged from perennial in some washes near the mountain front to brief flows of less than an hour duration occurring only several times a year along the downstream reaches of the study washes. Streamflow frequency decreased downstream from the mountain fronts but increased downstream from urbanized areas. Total infiltration along the 11.6 mile reach of Sheep Creek Wash was about 470 acre-feet and only about 80 acre-feet along the 14 mile reach of Oro Grande Wash. Deep infiltration to depths below the root zone did not occur along some wash reaches where annual infiltration was less than 2 ft/y. This value may represent a threshold below which deep infiltration and subsequent ground-water recharge does not occur. However, deep infiltration was greater along reaches where local geomorphology controlled the location of the stream channel and infiltration occurred repeatedly in the same spot repeatedly year after year. Movement of water through thick, heterogeneous unsaturated zones decreased with depth as water spread laterally away from the stream channel. Isotopic data and numerical model results suggest that in some settings as much as 300 years may be required for water to reach the water table about 100 m below land surface. Given the timescale of the recharge process, short-term changes in climate, such as El Nino or the Pacific Decadal Oscillation, are unlikely to effect average ground water recharge values along the study reaches.

Frequency and infiltration of streamflow are important components of the hydrologic budget that sustain ecosystems along small intermittent stream channels. However, the results of this study are primarily important for water supply. This work demonstrated that ground-water recharge from a single large source, such as the Mojave River which averages about 56,000 acre feet, is larger than the aggregated recharge from numerous small streams draining the San Gabriel, San Bernardino, and Little San Bernardino Mountains. In addition, surface flows and subsequent ground water recharge from the Mojave River are distributed along the entire reach of the river 100 miles from the mountain front.

Local water agencies are using the techniques developed as part of this study to develop artificial recharge in areas along washes where small amount of ground-water recharge occurs naturally. Instrumented boreholes have been installed at two artificial recharge sites near Victorville, CA to monitor the movement of imported water downward through the thick, heterogeneous unsaturated zones at these sites. Although water from the ponds initially required more than 3 years to infiltrate through the 400 ft thick unsaturated zone to the underlying water table; once wetted, water from the ponds can infiltrate to the water table in about 1 year. The ponds provide a new source of water to recharge aquifers away from the Mojave River that would not have been possible without this work.

5. HYDROLOGY, DESCRIPTION OF COMPUTER MODELS, AND EVALUATION OF SELECTED WATER-MANAGEMENT ALTERNATIVES IN THE SAN BERNARDINO AREA, CALIFORNIA

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The San Bernardino area of southern California has complex water-management issues. As an aid to local water managers, this report provides an integrated analysis of the surface-water and ground-water systems, documents ground-water flow and constrained optimization models, and provides seven examples using the models to better understand and manage water resources of the area. As an aid to investigators and water managers in other areas, this report provides an expanded description of constrained optimization techniques and how to use them to better understand the local hydrogeology and to evaluate inter-related water-management problems.

In this report, the hydrology of the San Bernardino area, defined as the Bunker Hill and Lytle Creek basins, is described and quantified for calendar years 1945–98. The major components of the surface-water system are identified, and a routing diagram of flow through these components is provided. Annual surface-water inflow and outflow for the area are tabulated using gaged measurements and estimated values derived from linear-regression equations. Average inflow for the 54-year period (1945–98) was

146,452 acre-ft/yr; average outflow was 67,931 acre-ft/yr. The probability of exceedance for annual surface-water inflow is calculated using a Log Pearson Type III analysis. Cumulative surface-water inflow and outflow and ground-water-level measurements indicate that the relation between the surface-water system and the ground-water system changed in about 1951, in about 1979, and again in about 1992. Higher ground-water levels prior to 1951 and between 1979 and 1992 induced ground-water discharge to Warm Creek. This discharge was quantified using streamflow measurements and can be estimated for other time periods using ground-water levels from a monitoring well (1S/4W–3Q1) and a logarithmic-regression equation. Annual wastewater discharge from the area is tabulated for the major sewage and power-plant facilities.

The ground-water system consists of a valley-fill aquifer and a much less permeable bedrock aquifer. The valley-fill aquifer, which is the focus of this study, is composed primarily of highly transmissive unconsolidated and poorly-consolidated deposits. The bedrock aquifer is composed of faulted and fractured igneous and metamorphic rock. The valley-fill aquifer is underlain by the bedrock aquifer and and is bounded laterally by the bedrock aquifer and by faults with varying capabilities to transmit ground water. Some underflow occurs across faults in the valley-fill sediment, particularly beneath the Santa Ana River. Essentially no underflow occurs from the surrounding bedrock. Hydrogeologic units were defined for the valley-fill aquifer using driller's logs, geophysical logs, and hydrographs from multiple-depth piezometers. These units are shown on a detailed hydrogeologic section constructed along Waterman Canyon Creek. A large-scale aquifer test demonstrated the continuity of the hydrogeologic units and their hydraulic properties in the center of the Bunker Hill basin. Gross annual pumpage from the valley-fill aquifer for 1945–98 was compiled from reported and estimated data, and then used to estimate extraction from the upper and lower layers of the valley-fill aquifer and return flow to the upper layer. Annual values of the major components of recharge and discharge for the valley-fill aquifer are calculated for 1945–98. Average recharge occurs primarily from gaged streamflow (67 percent), ungaged mountain-front runoff (9 percent), and pumpage return flow (16 percent); average discharge occurs primarily as pumpage (88 percent).

Computer models, including a ground-water flow model and a constrained optimization model, are described. The ground-water flow model includes the Bunker Hill and Lytle Creek basins and simulates three-dimensional ground-water flow in the valley-fill aquifer using finite-difference techniques. The model consists of an upper layer representing the upper unconfined/semi-confined hydrogeologic unit and a lower layer representing a combination of several lower confined hydrogeologic units. The vertical connection between the model layers is approximated by Darcian flow. The flow-impeding effect of faults within the valley-fill aquifer is simulated by a horizontal flow-barrier package. The model also includes a streamflow-routing package that simulates the interaction of a complex network of streams with the valley-fill aquifer. Calibration of the flow model was for 1945–98.

The constrained optimization model uses linear programming to calculate the minimum quantity of recharge from imported water and pumpage from wells necessary to solve various water-management problems. A description of linear-programming techniques and a simplified example problem are provided. The optimal quantity of recharge or pumpage is determined by their availability and by constraints on ground-water levels and ground-water quality. The response of ground-water levels to recharge and pumpage is calculated by the ground-water flow model. The mathematically optimal solutions derived from the optimization model, in concert with field data and hydrogeologic concepts, can be used to guide water-management decisions.

Selected water-management alternatives for the San Bernardino area were evaluated with the aid of the ground-water flow and constrained optimization models. Seven scenarios were designed to answer specific water-management questions and to demonstrate key hydrogeologic characteristics of the area. A 32-year simulation period, 1999–2030, with annual values of recharge and pumpage, was used for each scenario. The scenarios include: (1) average historical conditions; (2) annually varying historical conditions; (3) additional artificial recharge provided by construction of Seven Oaks Dam; (4) increased ground-water pumpage; (5) optimal pumpage from barrier wells designed to prevent further spread of contamination from the Newmark U.S. EPA superfund site; (6) optimal pumpage needed to control ground-water levels in an area with potential liquefaction and land subsidence; and (7) optimal recharge and pumpage to control ground-water levels and to prevent migration of the Newmark contamination.

Results of the evaluation include the following conclusions. Additional pumpage in the vicinity of the former marshland is needed to prevent a reoccurrence of dangerously high ground-water levels similar to those experienced in 1945 and 1980. High ground-water levels are a water-management concern because they indicate soil is saturated near land surface and is susceptible to liquefaction during an earthquake. The optimal location of additional pumpage is near Warm Creek in an area of historically rising ground water. The high ground-water levels occur primarily during short periods following abundant natural recharge. About 15,000 acre-ft per year of additional, areally distributed pumpage are needed to control the high ground-water levels.

Demand for water in the San Bernardino area is projected to increase during the next 25 years by as much as 50,000 acre-feet per year. Part of this increased demand can be met by additional pumpage needed to prevent a rise in ground-water levels (15,000 acre-feet per year) and part by increased local supply (3,000 acre-feet per year) resulting from construction of a conservation pool behind Seven Oaks Dam. As much as 70,000 acre-feet of additional pumpage is theoretically available from existing wells using excess pumping capacity. However, additional pumpage greater than about 15,000 acre-feet per year likely will result in a longterm decline in ground-water levels such as occurred during the 1960's, a decline which prompted land subsidence. To meet future demand for water in excess of about 15,000 acre-feet per year and to prevent a reoccurrence of land subsidence, imported water probably will need to be used, either for direct delivery or for recharge of the ground-water system.

Much of the recharge to the valley-fill aquifer occurs during years with unusually abundant runoff, which occur on average about once every 5 to 10 years. Maintaining and enhancing capabilities to artificially recharge native runoff are likely to be necessary to meet increased demand for water from the valley-fill aquifer. Since 1945, significant fluctuations in ground-water storage have become common because of the abundant, but highly variable, recharge combined with relatively constant ground-water pumpage. Annual fluctuations in ground-water storage from 50,000 to 100,000 acre-feet are common. Cumulative fluctuations in ground-water storage greater than 500,000 acre-feet in a 10-year period also are common, but this magnitude will not significantly affect the availability of ground water, as long as historic recharge capacities are maintained or enhanced.

Hydraulic control of the Newmark contamination site is unlikely to occur using only the five planned extraction (barrier) wells; another four wells may be needed, each with a capacity of about 3.5 cubic feet per second. Without additional extraction wells, contaminated ground water tends to migrate around the barrier wells, especially to the west. Minimum total pumpage at nine barrier well sites, located across the leading edge of the contamination, needs to be at least 14,000 acre-feet per year, based on results from the optimization model.

Control of maximum and minimum ground-water levels in the vicinity of the former marshland does not require significant additional recharge of imported water, but does require additional pumpage. Additional pumpage from as many as 29 potential production wells located along the proposed eastern and southern extensions of the Baseline feeder pipeline is unlikely to sufficiently control high ground-water levels. Additional pumpage needs to be areally distributed in the vicinity of Warm Creek, just north of the San Jacinto fault. Extraction needs to occur from the highly permeable deposits of the upper water-bearing unit to prevent an upward hydraulic gradient and from the less permeable near-surface deposits that remain saturated even as hydraulic head in the underlying production zone is declining.

The high probability of a major earthquake on either the San Jacinto fault or San Andreas fault in the San Bernardino area makes control of high ground-water levels a pressing economic concern. Significant mitigation of this threat by additional extraction of ground water is possible, especially if a use can be found for the surplus water. Reoccurrence of land subsidence is a continuing concern and can be monitored with multiple-depth piezometers, extensometers, and satellite-borne interferometry, particularly if pumpage near the former marshland is increased. Contamination of the valley-fill aquifer is widespread both areally and vertically. Plans for cleanup will be aided by continued mapping of the hydrogeologic units, which strongly influence ground-water flow paths. The large magnitude of proposed ground-water extraction to cleanup several areas of contamination suggests that these plans need to be coordinated with plans to prevent liquefaction and land subsidence.

6. WELL SITING AND DESIGN

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In the Southwest, ground water development is a key aspect of water supply, not only for primary supply but for drought management. In order to more fully develop the ground water resources of an area, potential new well sites need to be identified and prioritized for future exploration. Evaluation and ranking of potential well sites typically considers: Geohydrology; Existing Production Wells in the Area; Relationship to Topography and Drainage; Water Quality; Land Ownership; Drilling Rig Access; Proximity to Infrastructure, and Relative Potential for Environmental Issues. Design of municipal water supply wells relies on both proven experience and sound science. Most all deep high capacity municipal water supply wells are constructed using reverse rotary drilling and the “two pass” method involving both a pilot borehole and an enlarged (reamed) hole. Selection of the various aquifer zones for completion incorporates “aquifer zone testing” whereby both water quality and yield estimates can be measured to prevent completion (screening) in zones with undesirable water quality. Design of the well screen and filter pack employs the fundamental principle of well design – that is: “the purpose of the filter pack is to stabilize the aquifer; and the purpose of the well screen is to stabilize the filter pack”. The fundamental principle of well design uses the Terzaghi migration and permeability factors to ensure a properly designed well. Development consists of both preliminary and final phases to complete the well construction process. Proper siting, design, construction and development have proven to result in high capacity, efficient and sand free wells yielding high quantities of water with acceptable water quality.