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A RIVERBANK FILTRATION DEMONSTRATION PROJECT ON THE KALI RIVER, DANDELI, KARNATAKA, INDIA

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A RIVERBANK FILTRATION DEMONSTRATION PROJECT
ON THE KALI RIVER, DANDELI,
KARNATAKA, INDIA

BY

PAMELA CADY

THESIS SUBMITTED IN PARTIAL FULFILLMENT
OF THE REQUIREMENTS FOR THE DEGREE OF

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2011

ABSTRACT

A small scale RBF system was installed in a village near the Kali River in the state of Karnataka to evaluate the performance of riverbank filtration (RBF) under the hydrogeological and climatological conditions of southern India. A series of hydraulic and tracer tests were carried out along with periodic biological and geochemical monitoring of various water sources in the study area.

Hydrogen and oxygen isotopes highlight the impact of evaporation and irrigation at nearby rice paddies on the RBF production well. Dissolved silica data used to determine the relative contributions of surface and groundwater indicate that this RBF system derives approximately 28% of its water from the river. Even with nearly $\frac{3}{4}$ of the RBF water coming from groundwater, bacteria and metals data indicate that groundwater dilution does not appear to play a major role in pollutant reduction. Instead, other RBF removal processes, such as biodegradation and redox chemistry, are at work in the system.

Bacteria levels demonstrate at least 88% to >99% removal over currently used source waters. Despite this, Indian drinking water standards for *E. coli* are not consistently met and total coliform standards are never met in the RBF system. Bacteria levels are higher during the three month monsoon season. Average dissolved metal levels meet Indian standards for all metals analyzed. A community survey carried out before and after RBF installation shows significantly improved health indicators amongst RBF water users. In summary, this pilot-scale project demonstrates an RBF system that is welcomed by the host community and provides water of higher quality than other water sources in this study area.

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* Note: See soft copy for full Appendices 11, 12, 27, and 30.

LIST OF ABBREVIATIONS

AOC	Assimilable Organic Carbon
APHA	American Public Health Association
BCM	billion cubic meters (10^9 m^3)
bgs	below ground surface
BIS	Bureau of Indian Standards
BW	Bore Well
CPCB	Central Pollution Control Board
DI	DeIonized water
DOC	Dissolved Organic Carbon
<i>E. coli</i>	<i>Escherichia coli</i> bacteria
EC	Electrical Conductivity
GW	groundwater
HP	Hand Pump
IAEA	International Atomic Energy Agency
IC	Ion Chromatography
ICP-MS	Inductively Coupled Plasma - Mass Spectrometry
INR	Indian Rupees
KKR	Kariyampalli Kali River
KOW	Kariyampalli Open Well
KR	Kali River
MBW	Mainal Bore Well
meq/L	milliequivalents per liter
mg/L	milligrams per liter
MOW	Mainal Open Well
MPN	Most Probable Number
n	number of samples
ORP	Oxidation Reduction Potential
OW	Open Well
RBF	Riverbank Filtration
SW	surface water
TC	Total coliform bacteria
TDS	Total Dissolved Solids
TERI	The Energy and Resources Institute
TT	Town Tap
UV	Ultra Violet light
W1, 2, 3...	RBF Well 1, 2, 3...
WHO	World Health Organization

Note on village names: Village names in the study area are not codified in English, so spellings are variable. Examples of variations are as follows:

Mainal = Mayanala

Bommanahelli = Bommanahalli

INTRODUCTION:

This project investigates the suitability of a small River Bank Filtration (RBF) system for providing improved water to rural communities in developing countries. The RBF study site is located in the tropical monsoon climate of rural southern India near the perennial Kali River, which receives polluted effluent from many sources, including municipal discharge and a large paper mill. At the beginning of the project, for drinking water, local residents relied on the polluted river water, unprotected and unimproved dug wells (Open Wells), Bore Wells, or water delivered from upstream of industrial and municipal inputs. These established water supply systems provide unsafe water and are unreliable, sometimes breaking down for months at a time (Patil, 2009).

This study characterizes basic chemical constituents in the local groundwater, Kali River water, and the RBF water. Measurements of metal and bacteria concentrations are used to determine RBF's capacity to alleviate contamination and to determine whether RBF treatment under these conditions can meet the Bureau of Indian Standards limits for drinking water. As well, water chemistry is used to determine the percentages that groundwater and surface water contribute to the RBF water to further understand to what degree the treatment mechanisms of RBF, such as groundwater mixing, biodegradation, or redox chemistry, are at work. Dissolved silica (Hooper and Shoemaker, 1986; Wels, Cornett and Lazerte, 1991) and environmental isotopes (Sklash and Farvolden, 1979) of hydrogen and oxygen are used for this purpose.

SIGNIFICANCE OF THE PROJECT:

Safe Drinking Water: More than one billion people in the world - 18% of the global population - do not have access to safe drinking water (UN, 2006). India is included in the group of countries with the maximum percentage of citizens who experience health problems due to unsafe water (Figure 1) (Nature, 2000). As a result of unsafe drinking water, the World Health Organization reports that 4,000 children under the age of five die daily from diarrheal diseases worldwide. This is 90% of the total deaths due to diarrhea in the developing world (WHO, 2005; WHO, 2010).

Figure 1: Map of total disease burden caused by unsafe water by country in 2000
India is in the highest tier, with 4 to 7.9% of its total disease burden due to unsafe water (Nature, 2000)

The CIA World Factbook ranks India 51st out of 224 countries for infant mortality rate, with 51 infants dying by their first year of age per 1,000 live births. This is more than eight times the reported rate in the United States (CIA, 2009). Some common water-related diseases are those caused by infection from hepatitis A, typhoid, *giardia*

lamblia, cryptosporidiosis, poliomyelitis, cholera, amebic dysentery, cyclosporiasis, and *Escherichia coli* (*E. coli*) (Centers for Disease Control and Prevention, 2003).

These diseases can cause gastro-intestinal infections, which in weak populations, such as the very young, can lead to death. Additionally, repeated diarrheal episodes can impair health by causing chronic malnutrition, increased infections, and reduced growth and development (Ejemot et al, 2009).

Many of India's perennial rivers are heavily polluted by the discharge of untreated sewage and effluents from industrial facilities. This water should not be used without treatment, even for irrigation. However, due to lack of other options and weak enforcement of existing water quality regulations, contaminated surface water serves many uses, including drinking.

Access to improved drinking water is estimated to reduce the occurrence of diarrhea by 25% (WHO, 2005). Others, when reviewing 38 studies on the topic, have found a 15 - 43% reduction in diarrheal diseases due to hygiene, sanitation, water supply, and water quality interventions (Fewtrell et al, 2005). Therefore, the reduction of diarrheal diseases in the developing world requires a multi-pronged approach including availability of sanitary toilet facilities, access to safe drinking water, hand-washing education, and safe storage of water (WHO, 2005). Low cost treatment such as RBF can be a part of this effort as it can potentially provide a clean and affordable source of drinking water to thousands of people in rural India.

Total coliforms are a group of bacteria that can survive and grow in both aerobic and anaerobic settings in warm-blooded hosts as well as in water and soil (WHO, 2006). Presence of total coliform indicates incomplete treatment or potential

contamination of drinking water (Feng, Weagant and Grant, 1998). *E. coli* are a subset of total coliforms that are adapted to the higher temperatures of human and animals' intestines (WHO, 2006). Therefore, *E. coli* are used as indicators of recent fecal contamination because they are unable to grow and reproduce outside of their host. In temperate environments their survival half-life outside of their hosts ranges from 1 day (in water) to 3 days (in soil). But in moist, warm, high-nutrient settings in tropical environments, *E. coli* can maintain free-living populations (Winfield and Groisman, 2003). The RBF field site is in a moist, warm tropical environment, but highly leached soils such as laterites have naturally low fertility (Baligar et al, 2004). For this reason, *E. coli* is used as an indicator of recent fecal contamination at the RBF field site. Fecal contamination is a concern in drinking water supplies because it can carry pathogens causing diarrhea, meningitis, and other health problems (WHO, 2006).

Industrial Pollutants: Bacteria are not the only indicator for unsafe drinking water.

Water contaminated with heavy metals can cause stomach cramps (copper and zinc); anemia (chromium and zinc); diarrhea (copper); damage to the kidneys (cadmium and mercury), the nervous system (lead), brain functioning (manganese and mercury); and death (copper and lead) (Agency for Toxic Substances and Disease Registry, 2008).

One industry that may affect the research site is integrated pulp and paper mills, which produce many waste products, including heavy metals (US EPA, 2006).

Groundwater Depletion: Because surface water sources are often unreliable and unsafe for human consumption, as much as one third of the world population now relies on groundwater for drinking (Worldwatch Institute, 2000). Most groundwater, though, is used for irrigation, such as in northern India where 95% of groundwater used is for irrigating crops (Schiermeier, 2009). As a result of both agricultural and domestic uses, depletion of aquifers is an increasing threat to this water supply source. The World Health Organization states that water usage has increased at twice the rate of population growth for the last 100 years (WHO, 2008).

The World Resources Institute's Pilot Analysis of Global Ecosystems (PAGE) predicts that the majority of the Indian subcontinent, as well as many other parts of the globe, will be experiencing water scarcity by 2025 (World Resources Institute, 2001) (Figure 2). Here, water scarcity is defined as less than 2,500 m³ of water/person/year. By another measurement, per person annual water needs are 1 m³ for drinking, 100 m³ for other domestic use such as washing, and 1000 m³ for food production, totaling approximately 1,100 m³ of water/person /year (Allan, 2001). Even by this smaller measure, India's Krishna River basin—the second largest in India, covering nearly 260,000 km², and neighbor to the Kali River basin—still falls short in WRI's estimated future supply (Bouwer et al, 2006).

The map illustrates the global distribution of major river basins. The basins are color-coded: yellow for major river basins, green for land, and blue for oceans. The basins are labeled as follows:

- Colorado
- Rio Grande
- Panuco
- Grande de Santiago
- Balsas
- Volta
- Niger
- Nile
- Orange
- Limpopo
- Galana
- Jubba
- Tigris and Euphrates
- Kura-Araks
- Volga
- Rhine
- Meuse
- Elbe
- Odra
- Vistula
- Danube
- Dnieper
- Black Sea
- Caspian Sea
- Amu Darya
- Syr Darya
- Indus
- Ganges
- Brahmaputra
- Yangtze
- Hai He
- Huang He
- Fuchun Jiang
- Hong Kong
- Chao Phraya
- Godavari
- Mahanadi
- Cauveri
- Pennar
- Krishna
- Narmada
- Tropic of Cancer

Outlined basins are projected to have a population of more than 10,000,000 people in 2025. These basins are also in or approaching water scarcity, with less than 2,500 cubic meters of water per person per year. Unlabeled, outlined basins in Africa and the Middle East have no perennial river flowing through them.

Excessive pumping from aquifers can lead to declining water tables, which can lead to problems such as well failure or changes in water chemistry. Excessive drawdown can also lead to irreversible compaction of the aquifer and land subsidence, which inhibits aquifer recharge. In addition, groundwater withdrawal can impact surface water levels which can become too low to provide habitat for aquatic life. Beyond health and environmental effects, the greater cost of drilling deeper wells in the search for groundwater is an economic burden. Tushaar Shah, with the International Water Management Institute, states that over 25% of the farms in India are in danger of pumping their wells dry within the next few decades (Pearce, 2004). In the state of Tamil Nadu, which borders Karnataka (the host state of the study site), 95% of small farmers' wells have already gone dry (Pearce, 2004). Additionally,

recent satellite imagery shows evidence of severe drawdown rates in northern India (Rodell, Velicogna and Famiglietti, 2009). High pumping and drilling costs can force small farmers, especially in India where many live at the subsistence level, to rely on rainfall to irrigate their crops. This can lead to diminished crop returns. The dramatic rise in Bore Well development in India that accompanied the 'Green Revolution' of the latter half of the 20th century has led to the current groundwater crisis. This has caused researchers to claim that "for the short term, drastic measures may have to be taken to ameliorate crisis conditions" (Narasimhan, 2006) and that there are "massive needs for investment in water supply systems for growing cities and for underserved rural populations" (Briscoe and Malik, 2006).

Proposed Solution: Riverbank Filtration (RBF) is one solution to the combined problems of contaminated surface water supplies and of aquifer depletion. RBF technology reduces withdrawal of groundwater, instead tapping into surface water which is currently underused in the research area due to contamination problems. RBF draws infiltrating river water through the alluvium of a riverbed towards a well which is located up to a few hundred meters from the river (Figure 3).

Figure 3: Theoretical riverbank filtration (RBF) system diagram
Map and cross-sectional views show path of infiltrating river water to RBF production wells (Kim, Corapcioglu and Kim, 2003)

Similar to slow sand filtration systems, but with fewer ongoing labor needs, RBF uses the natural processes of sorption, ion exchange, redox reactions, precipitation, filtration, dilution, predation, and biodegradation to pre-treat drinking water (Hiscock and Grischek, 2002; Kelly and Rydlund, 2006; Vogel et al, 2005a). RBF wells are best sited in sandy soils such as alluvial aquifers (Hubbs, Ball and Caldwell, 2006). Much of the biological activity occurs within a few meters of the surface water interface. Here a biofilm of bacteria, fungi, algae, and protozoa embedded in a granular matrix lies just beneath the riverbed (Schmidt et al, 2003). Via this biologically active layer, referred to by its German name "schmutzdecke," RBF greatly reduces levels of pathogens, particles, and biodegradable compounds (Tufenkji, Ryan and Elimelech, 2002; Ray, 2004).

Studies show RBF treatment lowers heavy metals concentrations such as zinc (82%), copper (51%), lead (75%), chromium (94%), and cadmium (75%) (Schmidt et al, 2003). Others have found chromium removal between 89-100% in bench experiments with sand columns ranging in lengths from 0.4 m to 1.2 m (Baig,

Mehmood and Matin, 2003). RBF sites have seen *E. coli* bacteria reduced >99.96% (3.4 log removal) (Boving et al, 2010; Vogel et al, 2005b) (Appendix 1).

RBF systems have been used in European countries such as Germany, Holland, Hungary, France, Switzerland, and Finland for decades, and in some sites for over a century (Tufenkji, Ryan and Elimelech, 2002; Ray, Melin and Linsky, 2002).

Historically, RBF has been used mostly along rivers in temperate and cold climates such as Germany (Peel, Finlayson and McMahon, 2007). RBF is, however, relatively untested in monsoon climates, i.e. locations dominated by strong seasonal rains followed by a prolonged dry season. Because of the lack of studies on RBF's performance in these settings, municipalities in developing countries are reluctant to adopt this water treatment technology (Boving, 2007). As a response to extensive dysentery-related deaths (WHO, 2005) and increasing groundwater demand from population pressure —especially in the developing world— RBF is a well-suited low-cost, sustainable approach for producing safe drinking water in developing countries such as India.

OBJECTIVE:

This study's principal objective was to test the performance of a small community-sized RBF system under monsoon conditions in a rural settlement of southwestern India. This thesis reports on bacterial and metals contamination in this pilot RBF system and discusses how these concentrations changed over the observation period of approximately one year. Dissolved silica and stable isotope levels were examined to determine the percentage of contaminant change that can be attributed to groundwater dilution versus other RBF processes. This data set was supplemented with a pre- and post-installation survey of households in the Kali River watershed served by RBF. A major goal of this study was to provide a template that shows how to assess the performance of a small RBF system in a developing country.

LOCATION:

Geography: The study area is located in a rural area of the south Indian state of Karnataka, along the Kali River (Figure 4). This westward-flowing, relatively short river drains a portion of the Western Ghats range and passes four dams en route to the Arabian Sea. It is a 185 km perennial river which lies early in the path of India's southwest monsoon and has a drainage area of 3,376 km² (Manjunatha et al, 2001). Rainfall in the Western Ghats exceeds 5,000 mm annually (Manjunatha et al, 2001). The uppermost dam, which creates the Supa Reservoir, is approximately 10 km upstream from the field site. This 4.12 billion cubic meter (BCM) reservoir has a 1,057 km² catchment area and was completed in 1984. Its maximum flood discharge is 7,663 m³/s. The Bommanahelli Reservoir constitutes the lower bound of the sampling area. This 0.097 BCM reservoir has a 1683 km² catchment area with a maximum flood discharge of 9,622 m³/s (Figure 5) (Birasal, Nadkarni and Gouder, 1987; Karnataka Power Corporation, 2005).

Geology: The Kali River watershed is located in the late Archean Dharwar Schist Belt of the Precambrian South Indian Shield. This greenstone terrain is rich in iron and manganese ore bodies. The Shimoga Basin of the Chitradurga Group, which encompasses the study site, consists of schists of sandstones, conglomerates, limestones, greywackes, and mangiferous and ferruginous cherts. Overlying these meta-sedimentary rocks are the laterites found commonly in tropical climates. These porous, clay-like, soft soils are produced by intense weathering and leaching of parent material. Lateritic soils are reddish colored and rich in hydrated oxides of iron,

manganese, and aluminum. These soils are composed mostly of gibbsite ($\text{Al}(\text{OH})_3$), goethite ($\text{FeO}\cdot\text{OH}$), kaolinite ($\text{Al}_2\text{Si}_2\text{O}_5(\text{OH})_4$), and quartz (SiO_2). In Karnataka, laterites can reach thicknesses of up to 60 m (Radhakrishna and Vaidyanadhan, 1997). Along river courses, alluvial soils are also found.

Figure 4: Study area within India
Inset map shows the Kali, or Kalinadi, River before dam construction in Karnataka state's Uttara Kannada district. Star indicates the city of Dandeli. Map sources: (Geology.com, 2007; mapsofindia.com, 2007)

Field Site: The RBF wellfield was installed along the Kali River near the town of Dandeli (population 53,290), in northwestern Karnataka. Dandeli has several satellite villages (Figure 6) which tend to have a single dirt road bordered by a few dozen houses, a small school, and surrounding cropland. The host village of the RBF wellfield, Kariyampalli, differs from other villages in this study in that it has a health clinic. One commonality of these small villages is the lack of secure sources of safe drinking water. Results from the household survey indicate that the village of

Kariyampalli has less reliable water supply, villagers must walk further to get water, and residents rely more heavily on the local Open Well and the Kali River as water supply sources than in neighboring villages (Appendix 2). Additionally, self- and proxy-reported family health was significantly worse in Kariyampalli than in other villages surveyed (Appendix 2). These findings indicate that Kariyampalli was an ideal site for a pilot RBF system. Additionally, Dandeli's largest employer is the West Coast Paper Mill that, along with a number of other industries and the city's sewage system, discharges effluent into the Kali River around Dandeli, upstream of Kariyampalli.

The distance from Moulangi, the sampling site furthest upstream, to Bommanahelli, the site furthest downstream, is about 7 km. The three bore well sites which were used for comparison with RBF samples, were approximately 1 km (Mainal), 2 km (Harnouda), and 2.5 km (Bada Khanshera) from the RBF well field.

Figure 5: Kali River and its dams
Dam IV: Supa Dam;
Dam III: Bommanahelli Dam

Figure 6: Map of sampling locations (in river order: Moulangi, Dandeli, Halmaddi, Kerwad, Kariyampalli, Mainal, Bada Khanshera, Harnouda, Saksali, Bommanahelli). Maps created by Tom Boving.

PREVIOUS STUDIES:

Kali River Water Quality: The Bureau of Indian Standards (BIS) has desirable (ideal) regulatory goals and, frequently, permissible (less ideal) regulatory goals (Appendix 3). Previous studies on the water quality of the Kali River and its tributaries (Manjunatha et al, 2001; Bharati and Krishnamurthy, 1990; Bharati and Krishnamurthy, 1992; Chavadi and Gokhale, 1986; Krishnamurthy and Bharati, 1994; Krishnamurthy and Bharati, 1996; Subramanian, Biksham and Ramesh, 1987) have found pH levels ranging from 6.8 to 10.9 (BIS desirable goal: 6.5 – 8.5). Major anion and cation concentrations reported in these studies were below the BIS desirable limits for Cl^- , SO_4^{2-} , and Ca^{2+} (Appendix 3). Kali River metal concentrations for Mn^{2+} and Fe^{2+} are above the BIS permissible levels. Cd^{2+} , Cr^{2+} , Cu^{2+} , and Zn^{2+} levels fall within permissible levels. Lead exceeds the standards in some years. None of these studies reported on bacterial loads in the Kali River.

Riverbank Filtration Sites: Previous studies were conducted mainly in sand and gravel alluvial aquifers in the temperate climates of Germany and the US (Kelly and Rydlund, 2006; Schmidt et al, 2003; Tufenkji, Ryan and Elimelech, 2002; Boving et al, 2010; Vogel et al, 2005b; Schubert, 2002; Hoppe-Jones, Oldham and Drewes, 2010; Sontheimer, 1980; Grischek et al, 2010; Trettin et al, 1999; Kuehn and Mueller, 2000) and have shown successful RBF water treatment using wells 5 – 250 meters away from surface waters sources. Travel times for these systems are from under 1 day to 270 days and were determined through various means, including temperature (Kelly and Rydlund, 2006; Schmidt et al, 2003; Vogel et al, 2005b; Grischek et al,

2010), dissolved oxygen (Vogel et al, 2005b; Hoppe-Jones, Oldham and Drewes, 2010), chloride (Boving et al, 2010; Sontheimer, 1980; Trettin et al, 1999), TOC (Hoppe-Jones, Oldham and Drewes, 2010), and groundwater modeling (Grischek et al, 2010). By dividing the distance of each study's RBF well to its adjacent river by the travel time reported, travel velocities were calculated. These velocities typically ranged from around 0.5 to 18 meters/day but in one case was as high as 250 meters/day (Trettin et al, 1999) (Appendix 1). Percentage of groundwater in these systems ranged from 25 – 87% (or 13 - 75% surface water). These systems achieved bacterial removal percentages of 99.2% - 99.999% (2.1 - 5 log) for total coliform and 99.9% - 99.994% (3 - 4.2 log) for *E. coli*. Metal data showed 82% zinc, 51% copper, 75% lead, 94% chromium, 75% cadmium, and 40.5% nitrate removal percentages, while manganese in the study by Hoppe-Jones et al. (2010) increased up to 2300% (Appendix 1). Change in iron content was not assessed in these studies. Note, though, that none of the studies reported on all of these compounds, so this listing is a combination of results. Also, particular removal efficiencies and surface / ground water mixing ratios are highly site specific and cannot easily be extrapolated to other settings.

METHODS / PROCEDURES:

FIELD METHODS:

RBF Wellfield: In October 2008, four RBF wells were drilled in a line perpendicular to the Kali River near the village of Kariyampalli 4 km downstream from the city of Dandeli. Wellfield distances range from 29 - 79 m from the Kali River (Figure 7). All RBF wells were drilled with air hammer rotary method to 22.9 m (75 ft) except Well 1, which was drilled to 18.3 m (60 feet). The wells have 15.24 cm (6 inch) diameter steel screens of 6.1 m length and 19.05 cm (7.5 inch) diameter steel casing. At the time of drilling, water was encountered in Wells 1, 2, and 3 at 12.2 m (40 ft) below ground surface and 12.8 m (42 ft) bgs in Well 4. By January 2009, water levels in the wells were at approximately 4 m (13 ft) bgs in all wells. Soils are brownish-red silty loam for the top 8 - 10.5 meters below ground surface, progressing to a more clayey layer of about 2 meters, to 1 - 3 meters of weathered bedrock, and ending in 3.5 - 9 meters of solid greywacke (Appendix 4). Submersible (electrical) pumps and water meters were purchased locally and pumping rates were determined in the field to be about 7,000 L/hr. The pump used is 2HP 1Q ST 54 H-5, single pulse 230 volt, with approximately 8 m³/hr capacity at 100 m head.

Field Parameters:

All samples were spatially referenced by latitude and longitude using a handheld Garmin GPS 12 XL receiver unit. The following basic field parameters were also collected: pH, temperature (T), electrical conductance (EC), total dissolved solids (TDS), and oxidation-reduction potential (ORP) using portable Hanna Instruments

Combination pH & EC and pH & ORP meters. Nitrites (as N, 1-10 ppm), nitrate (as N, 1-50 ppm), alkalinity (as CaCO₃, 1-180 ppm), total hardness (50-800 ppm), total ammonia (0-6 ppm), iron²⁺ and iron³⁺ (0-100 ppm), and chloride (1-10 ppm) content were determined using test strips (NO₂, NO₃: Industrial Test Systems *Sensafe* strips; alkalinity, total hardness: LaMotte *Insta-Test5* pool and spa strips; NH₃: Hach *Aquachek* strips; Fe: Orion Research *Aquafast* strips). Test strips have limitations, but with reasonable accuracy provide an indication of the general water quality characteristics at each location.

Temperature, pH, EC, and ORP field parameters were again collected in 2009 with the same instruments used the previous year. All meters were calibrated daily. Test strips were used again on RBF Wells 3 and 4 from February to August of 2009 to assess the same parameters (NO₂, NO₃, alkalinity, Total Hardness, NH₃, Fe, and Total Cl) as well as the pesticides atrazine (at or below 3 ppb) and simazine (at or below 4 ppb) (pesticides: *PurTest*; all others were the same strip tests from 2008). These two pesticides are among those most commonly found in US surface waters (Gilliom et al, 2006). Additionally, one five liter water sample from the Kali River was sent to an independent laboratory in Bangalore, India, for analysis of dioxin, pesticides, petroleum hydrocarbons and a number of other compounds suspected to be potentially present in the Kali River water (Appendix 5). This analysis was also used to corroborate our lab results.

Bacteria: The RBF wells were sampled periodically for bacteria levels from January to November 2009. In preparation for this, all four wells were sanitized in early January

with a solution of 1 part 5% sodium hypochlorite (NaOCl) bleach to 3 parts water. The solution was left in the well overnight and then pumped out continuously for at least one day (Minnesota Department of Health, 2006).

For total coliform and *E. coli* bacteria testing, raw unfiltered water samples were collected in 100 mL sterile bottles and kept in coolers in the shade until analysis in the lab. Because the submerged pump could not be easily moved, the wells without the pump were sampled with bailers dedicated to each well to reduce the possibility of cross contamination. In village Open Wells and the Kali River, a plastic bucket on a rope was used to collect samples (Figure 8). At each new water source, the bucket was submerged underwater, effectively pre-rinsing it before sample collection. Bacteria tests were carried out with Idexx brand's Colilert MPN (Most Probable Number) defined substrate technique, which included individual snap packs of powdered growth media added to 100 mL of sample water. These were then loaded into 100 cell Quanti-trays® and kept at $35\text{ }^{\circ}\text{C} \pm 0.5\text{ }^{\circ}\text{C}$ for 24 hours in incubators at the Dandeli College Microbiology lab (Idexx Laboratories, 2010). Positive (spiked with *E. coli*) and negative (distilled water) controls were run with each batch in the first month to verify the technique. There were insufficient supplies to run controls with every batch or to run progressive dilutions of those samples which exceeded the upper method detection limit. These factors reduced the accuracy of the bacteria results. Incubator temperature settings were verified with iButton brand thermochron readers. After incubation, positive Quanti-tray cells were detected with a long wave UV lamp (365 nm) for *E. coli* and with sunlight for total coliform.

Figure 7: RBF well field profile, Kariyampalli, Karnataka, India
RBF W1, 2, 3 = RBF Well 1, 2, 3

Sample Collection: For reconnaissance around Dandeli, water samples were collected from groundwater (Hand Pumps, Bore Wells, and Open Wells), untreated surface water (Kali River), treated surface water (Town Taps) and the RBF wells (Figure 8). During the 2008 field season, samples for ions and metals analysis were collected in 20 mL clear glass VOA vials with silicone-lined caps and preserved with 35% concentrated laboratory grade hydrochloric acid (Rankem, RFCL Ltd, New Delhi, India. Maximum limit of impurities: residue on ignition (as SO₄) 0.01%, free chlorine 0.0005%, sulfate (SO₄) 0.001%, sulfite (SO₃) 0.001%, ammonium (NH₄) 0.001%, iron (Fe) 0.0001%, and heavy metals (as Pb) 0.0005%). These samples were filtered in the lab back in the US over a year after collection. Due to a mistake in field procedures, cation samples were acidified before filtration. There were concerns that suspended cations and metals may have been dissolved by the acid and therefore show artificially elevated dissolved concentrations. Because of this possibility, these samples were used to assess the upper end of the range of potential metal concentration. After analysis, anion samples were acidified (having already been filtered) and run as cation samples to get the lower bound of the metals range. As such, metals concentrations reported here are an average level seen here between these two methodologies.

In 2009, samples for ions, metals, and silica analysis were collected in 100 mL plastic sample bottles and for isotope analysis in 50 mL bottles. Isotope samples were collected raw, with no field filtering or acidification. All other samples were field filtered with glass microfiber and then 0.45 micron filters. Metals samples were then acidified with 2 drops of the same 35% concentrated hydrochloric acid used in 2008.

Bore Well

Town Tap
in Kerwad

Kali River at Dandeli

Hand Pump in Moulangi

Kariyampalli Open Well

Kariyampalli Open Well

Dedicated bailer used at RBF Well
Note: concrete protection is in place

RBF
Well 3

RBF Well 3 with pump in it (before
concrete protection structure was built)

Figure 8: Different types of water sources referred to in this study

Aquifer Tests: In January, 2009, programmable Solinst Levellogger Gold (model 3001 LT F15/M5) and In-Situ LevelTroll 500 and BaroTroll 500 pressure transducers were suspended in the RBF wells and the river to measure water level fluctuations in response to pumping, rainfall, and dam releases. Additionally, one logger measured electric conductance for use during a salt tracer test in which 5 kg of NaCl was mixed in a 16 L bucket of water and poured down Wells 2 and 4 while the EC logger was suspended down Well 3. The estimated concentration of NaCl in the tracer is 190,000 mg/L and in the well is 2,200 mg/L. RBF Well 3 was pumped for over 7 days but was occasionally interrupted by power outages. A second tracer test was performed by other team members in May - June 2009.

Additional Data: Team members met with West Coast Paper Mill officials in Dandeli to gather information on previous tests of the paper mill effluent. Data about population and statistics on current water usage were gathered from visits to local government offices. Drill log data from wells in the area were obtained from government engineering offices (Panchayat Raj Engineering).

LAB METHODS:

One in ten samples tested were duplicates or standards for quality assurance and quality control. Due to difficulties transporting water samples overseas, sample quantities for silica analysis were conserved by using half of all constituents in the APHA method. For the metals analysis, titanium was examined to check for interference with ^{66}Zn . Ti levels were too low to interfere with the zinc readings.

Table 1: Lab methods for isotopes, silica, ions, and metals analyses

	Instrument	Method	Location	Quantity	Standards	Sample Range	Precision
Isotopes (%)	Los Gatos Research Laser Mass Spectrometer		Northern Arizona University's Colorado Plateau Stable Isotope Laboratory (CPSIL)	15 mL	δD : -121.08 – -4.65 $\delta^{18}O$: -16.57 – -1.73	δD : -10.98 - 3.49 $\delta^{18}O$: -1.99 – -0.10	δD : ± 0.6 $\delta^{18}O$: ± 0.2
Silica (mg/L)	Shimadzu UV-Visible 1601 Spectrophotometer	APHA molybdosilicate method # 3113C (Eaton et al, 2005)	University of Rhode Island Department of Geosciences	25 mL	Si: 0 - 50	Si: 8 - 46	< 10% error
Ions (mg/L)	Dionex DX-120 Ion Chromatograph (IC)	APHA method # 4110 B/C (Eaton et al, 2005)	University of Rhode Island Department of Geosciences	0.5 mL	F ⁻ : 0.3 - 5 Cl ⁻ : 6.3 - 400 Br ⁻ : 0.3 - 15 NO ₃ ⁻ : 0.6 - 20 SO ₄ ²⁻ : 2.5 - 120 Ca ²⁺ : 1.3 - 250 Mg ²⁺ : 0.3 - 300 K ⁺ : 0.5 - 45 Na ⁺ : 1.9 - 200	F ⁻ : <0.3 - 0.5 Cl ⁻ : 6.3 - 350.5 Br ⁻ : <0.3 - 5.2 NO ₃ ⁻ : <0.6 - 20 SO ₄ ²⁻ : <2.5 - 118 Ca ²⁺ : 2 - 249.3 Mg ²⁺ : 0.8 - 81.1 K ⁺ : 0.5 - 15.4 Na ⁺ : 4.1 - 166.8	F ⁻ < 20% error; all others: < 10% error
Metals (ppb)	Thermo Electron Corporation X-Series II Quadrupole Inductively Coupled Plasma – Mass Spectrometer (ICP-MS)	APHA ICP-MS method #3125 (Eaton et al, 2005)	University of Rhode Island Graduate School of Oceanography Narragansett Bay Campus	5 mL	Fe ²⁺ : 3.6 - 36,000 Mn ²⁺ : 0.5 - 4,900 Pb ²⁺ : 0.09 - 890 Cr ²⁺ : 0.07 - 750 Cd ²⁺ : 0.08 - 820 Cu ²⁺ : 0.09 - 920 Ti ⁴⁺ : 0.08 - 800 Zn ²⁺ : 1 - 9700	Fe ²⁺ : <3.6 - 25,000 Mn ²⁺ : <0.5 - 2,400 Pb ²⁺ : <0.09 - 22 Cr ²⁺ : <0.07 - 16 Cd ²⁺ : <0.08 - 1 Cu ²⁺ : <0.09 - 83 Ti ⁴⁺ : <0.08 - 7 Zn ²⁺ : <1 - 6,000	Linear Dynamic Range of 10 orders of magnitude

DATA PROCESSING:

Field Data:

Aquifer Test Data: Hydraulic conductivity values were estimated using visual matching via the Bouwer-Rice and Cooper-Jacob solutions in Aqtesolv (Duffield, 2000). Three data segments from pump testing in May and June of 2009 as well as a slug test in January of 2009 were used for this analysis. The data segments were used rather than the entire data log as numerous power outages shut down the pump for hours at time. Two segments were chosen from time periods when power stayed on long enough for water level in Well 3 to reach steady-state. Besides these two draw-down observations (at datapoints 2925-3731 and 5042-5891), the rebound of the aquifer (at datapoints 4158-4995) was evaluated for hydraulic conductivity. Hydraulic conductivities were then used to compute the travel time of the river water to the RBF well (Eqn 4). To do this, Darcy's law (Eqn 1) was applied, where Q is discharge. Dividing Q by the unit cross sectional area (A) generates the specific discharge (q) (Eqn 2). The specific discharge divided by the porosity (n) results in the pore velocity (v) (Eqn 3). The travel time is derived from the distance of the RBF well to the Kali River (L) divided by the pore velocity (Eqn 4).

$$Q = -K * A * \left(\frac{\partial h}{\partial L}\right) \quad (\text{Eqn 1})$$

$$q = -K * i \quad (\text{Eqn 2})$$

$$v = \frac{q}{n} \quad (\text{Eqn 3})$$

$$\text{Travel Time} = \frac{L}{v} \quad (\text{Eqn 4})$$

where

- Q = discharge (L^3 / T)
- K = hydraulic conductivity (L / T)
- A = cross sectional area (L^2)
- i = hydraulic gradient: $(\frac{\delta h}{\delta L})$ (dimensionless)
- h = drawdown in well (L)
- L = distance to river (L)
- n = porosity (dimensionless)
- q = specific discharge (L/T)
- v = pore velocity (L/T)

As well, the semi-logarithmic curve of drawdown versus time graphed in Aqtesolv was examined for evidence of the river as a recharge boundary to the RBF well (Fetter, 1994).

Bacterial Data: The IDEXX system's detection range is <1 to >2,419.6 MPN per 100 mL. All bacteria data are reported to two significant digits. Minimum values were converted to 0.9 MPN / 100 mL and maximum values to 2500 MPN / 100 mL (Costa, 2010; US FDA, 2007; Eaton et al, 2005). These altered end points were used when plotting and averaging data for each sampling site. Coliform data were averaged by water source and these averages were compared across categories. Geometric means rather than arithmetic means were used because coliform data commonly range over many orders of magnitude and geometric means minimize the effect of outliers in the data set (Costa, 2010; Herron, 2007).

Ideally progressive dilutions would have been performed on samples from sites which routinely showed bacteria concentrations above the upper reporting limit (including the Kali River). Unfortunately, limited supplies prevented routine progressive dilution in the field and previous studies on the Kali River do not report bacteria data. As such, the bacteria concentrations presented here likely underestimate

the actual concentrations. Further, 2006 data from the states of Andhra Pradesh, Orissa, Pondicherry Tamil Nadu, and Karnataka's medium and small rivers range from 11 - 37,000 MPN / 100 mL total coliform and 3 - 5,000 MPN / 100 mL fecal coliform (Central Pollution Control Board, 2006). Those upper levels are from 2 to 15 times greater than the upper detection limit of the method used in this study. This also implies that any percent change reported here show minimum removals from Kali River water whereas the actual removal percentage is likely at least an order of magnitude greater.

This supplemental CPCB bacteria data from 2006 cited above is used for comparison with the RBF system. A total of 8 analyses of total coliform carried out by the Dharwad District Health Lab (Appendix 6) in 2003 and 2004 were also combined with the CPCB 2006 data and the data set from this study in reporting groundwater bacteria levels in Bore Wells (Appendix 7). No supplemental *E. coli* data from the Dharwad District Health Lab exists.

Percent change was calculated as follows:

$$\% \text{ change} = \frac{(\text{Kali River water}) - (\text{well water})}{(\text{Kali River water})} * 100 \quad (\text{Eqn 5})$$

From this data, log removal values were calculated as follows:

$$\text{Log Removal} = \text{Log}_{10} \frac{(100)}{(100 - \% \text{ change})} \quad (\text{Eqn 6})$$

Additionally, average and maximum percent changes were also calculated as follows:

$$\text{Avg \% Change} = 1 - \frac{\text{Geometric Mean of that sampling site}}{\text{Geometric Mean of the Kali River}} \quad (\text{Eqn 7})$$

$$\text{Max \% Change} = 1 - \frac{\text{minimum Coliform level of that sampling site}}{\text{maximum Coliform level of Kali River}} \quad (\text{Eqn 8})$$

Significance testing with SPSS software (IBM, 2010) was performed on the bacteria levels in RBF Wells 3 and 4, the Kariyampalli Open Well, and the Kali River at the RBF wellfield sampling site. These sample sets did not all pass normality testing of skew $< |2|$ and kurtosis $< |4|$, so non-parametric significance testing was used (Fernandez, 2010). Results from Mann-Whitney U tests using 2-tailed asymptotic significance test statistics are shown in Table 5. Water sources to the left of '<<' are significantly less contaminated than those the right, and water sources to the left of '<' are less contaminated than those on the right, but not significantly so.

Supplemental Data: Data on local population numbers and current water usage was used for general information and not analyzed per se. Data from previous tests of Kali River water (Appendix 3) were used for comparison and to assess possible changes with time. Existing well logs were used for understanding the geology and water table of the surrounding area.

GIS Data: All suitable data, including household survey, water quality, and hydrogeology data was spatially referenced with Global Positioning System (GPS) readings. Spatial data was supplemented with maps and pictures taken in the field. Qualitative parameters for each sampling location were tabulated and linked to internet-accessible maps of the study area in Google. This will provide a central place to store and access periodic updates from future monitoring of the RBF water.

Lab Data:

Isotope Data: Data on stable isotopes of oxygen ($^{18}\text{O}/^{16}\text{O}$) and hydrogen (D/H) were examined to identify surface water and groundwater signatures as evidence for the origins of the RBF water. It was predicted that the Kali River water would have a heavier isotopic signature due to evaporation at the Supa Reservoir 10 km upstream and that the local groundwater, derived from infiltrated rainfall that had not been subjected to evaporative stress, would be isotopically lighter than the river water. The proportion of these two source waters in the RBF well would give an isotopic signature of the production well between these two end members.

Silica Data: It was hypothesized that the river water's silica concentration is lower than the Bore Well water, as the local groundwater has had more time for dissolution of silica during water-rock interaction. A mixing model was set up with the river water and local groundwater (approximated by the 88 meter deep Bore Well in Mainal) as end-members. Samples from the RBF wells and the Kariyampalli Open Well were compared with this mixing model to determine approximate percentages of Kali River water contributions. The equation for calculating percentage of river water in water samples is as follows:

$$\% \text{ river water} = \frac{(\text{silica concentration of sample (mg/L)} - \text{silica concentration of KR water (mg/L)})}{(\text{Si concentration of MBW (mg/L)} - \text{Si concentration of KR (mg/L)})} \quad (\text{Eqn 9})$$

where silica concentration is calculated from absorbance on the spectrophotometer and MBW and KR concentrations are averages of samples from the Mainal Bore Well and the Kali River, respectively.

Samples collected in January 2009 were averaged and compared with later date samples from December 2009 to evaluate change with time. Dixon's Q test was used for statistical evaluation because this test is designed for small sample sizes (Rorabacher, 1991; Alfassi, Boger and Ronen, 2005). Test results were used to determine if the December samples qualified as outliers to the January data sets, i.e. if the relative contribution of surface and groundwater had changed over the 11 months of well operation.

Ion Data: Anion and cation percentages were tabulated and compared with other sample sets from around the world of impacted and unimpacted waters as well as previous studies on the Kali River.

Metals Data: Dissolved metals concentrations were tabulated and outliers were identified using Dixon's Q significance testing. Data with outliers removed was then used for comparisons between the RBF well water and the Kali River. Percent change was looked at as well as comparisons with water quality criteria laid out by the BIS.

RESULTS:

In all graphs of data from this study, there each water source is represented in a consistent manner. In bar or line graphs, the colors remain consistent. In scatterplot graphs, the colors and shapes remain consistent. Samples from the Kali River are shown as yellow triangles. RBF Wells 1, 2, 3, and 4 are shown as lavender, turquoise, black, and dark green squares. The Open Well in Kariyampalli is shown as maroon circles. The Mainal Bore Well and Local Bore Wells are shown as royal blue squares or diamonds. Indian Groundwater is shown in light blue.

STABLE ISOTOPES: In total, 18 samples were collected from the study area, including the RBF wellfield (n = 11) the Kali River (n = 3), the Kariyampalli Open Well (n = 3), and the Mainal Bore Well (n = 1). The range of these data points was -1.99 to -0.1‰ $\delta^{18}\text{O}$ and -10.98 to 3.49‰ δD . Samples from the study area correlate closely with the meteoric water line from Belgaum (Kumar et al, 2010) (approximately 70 km NNW of the study area), with data points from the Kariyampalli Open Well deviating the most from the regional average precipitation (Appendix 8).

Figure 9: Isotope data from this study with the local meteoric water line
 BMWL in green is the regional Belgaum Meteoric Water Line from Kumar et al., 2010
 KR = Kali River; W1, 2, 3 = RBF Well 1, 2, 3; MBW = Mainal Bore Well

SILICA: Aqueous silica concentrations were calculated based on 4-point absorbance calibration curves. Silica concentrations ($n = 46$) ranged from 8 to 46 mg/L with an overall average of 28 mg/L (Appendix 9). Average dissolved silica levels from the field site show, as expected, a generally increasing trend of silica with distance from the river. The only exception was the Kariyampalli Open Well sampled in January 2009. At that time, this well had less dissolved silica than any of the other samples except those from the Kali River. After 11 months of routine pumping at the RBF wellfield, silica results show a pattern similar to the January data except that RBF Well 4 displays an unusually low reading (Table 1).

Table 2: Dissolved silica data for January and December 2009
n = number of samples

Dissolved Silica Concentrations (mg/L)	January 2009				December 2009	
	n	min	max	avg	n	Value
Kali River	5	8	11	9	1	10
RBF Well 1	5	24	28	25	1	21
RBF Well 2	8	30	34	32	1	25
RBF Well 3	11	28	39	34	1	36
RBF Well 4	6	28	38	34	1	20
Kariyampalli Open Well	3	21	23	22	1	27
Mainal Bore Well	1	n/a	n/a	44	1	46

AQUIFER TESTS:

Table 3: Aqtesolv results for aquifer tests at the RBF well field
(See Appendix 10 for additional graphs)

Test Type	Date	Solution	Match	Saturated Thickness	Results
Slug	Jan, 2009	Bouwer-Rice	visual	820 cm	K = 6.9 m/day
Pump	May, 2009	Cooper-Jacob	visual	730 cm	T = 7.6 cm ² /sec K = 9.0 m/day
Pump	May, 2009	Cooper-Jacob	visual	730 cm	T = 11.5 cm ² /sec K = 13.6 m/day
Recovery	May, 2009	Cooper-Jacob	visual	730 cm	T = 12.8 cm ² /sec K = 15.1 m/day

Results from a slug test performed on January 15, 2009 at Well 3 and analyzed using the Bouwer-Rice solution in the Aqtesolv program (Duffield, 2000) yielded a hydraulic conductivity value of 6.9 m/day via visual matching. In addition, recovery data were collected when pumps shut down during electricity outages during the May 15 – June 17, 2009 aquifer test. Three subsets of this dataset (broken down as one recovery test and two pump tests – Appendix 10) were analyzed using the Cooper-

Jacob method in the Aqtesolv program and yielded hydraulic conductivities of 9.0, 13.6, and 15.1 m/day) via visual matching (Figure 9 and Appendix 10).

Figure 10: Pump test results from 5/09 yield a hydraulic conductivity of 13.6 m/day
Data drawn from datapoints 5042-5891 using visual matching. Obs W3 = RBF Well 3

FIELD PARAMETERS: pH values of the water samples in the study area, including the RBF wellfield, were generally neutral, ranging from 5.9 to 7.6. The more acidic samples were associated with the RBF wellfield and the Hand Pumps. Temperatures of groundwater samples ranged from 22.0 to 28.6°C. Kali River samples from sites other than Halmaddi ranged in temperature from 23.1 to 27.1°C. Higher surface water temperatures were observed in the treated paper mill effluent at the Halmaddi confluence (31.6 to 32.2°C). ORP ranged from -149 to 434 mV. The most negative (reducing) values were measured at the Halmaddi confluence, the Hand Pumps, and the RBF Wellfield. Electrical conductivity and total dissolved solids (TDS)

concentrations of water samples in the region of research ranged from 34 to 2,327 $\mu\text{S}/\text{cm}$ (EC) and 17 to 1,162 ppm (TDS) with the highest levels from the Halmaddi confluence and the Hand Pumps. Lowest levels were from the Kali River upstream of the Halmaddi confluence (Appendix 13).

Disposable test strips showed total chlorine levels ranging from 0 to 1 ppm, nitrite from 0 to 3.3 mg/L, total ammonia from 0 to >6 ppm, alkalinity from 0 to 240 ppm, and total hardness from 0 to 800 ppm (Appendices 12 and 13). On four separate days in February and March of 2009, strip tests for the pesticides atrazine and simazine came out negative in RBF Well 3 samples (Appendix 12). Additionally, a sample sent out to an independent laboratory in Bangalore, Karnataka did not find any pesticides present and found dioxin and chlorinated phenols to be less than the 0.01 ppm detection limit (Appendix 5).

BACTERIA: Total coliform and *E.coli* data are presented in three ways. ‘Aggregate annual data’ compares average (geometric mean) bacteria levels. The ‘percent change’ for each of the sampling stations (RBF wells, Kariyampalli Open Well (KOW), Mainal Open Well (MOW), Mainal Bore Well (MBW)) relates the (1) average and (2) maximum bacteria concentrations in a water source to that of the Kali River at Kariyampalli. In addition, the bacteria data were examined for possible seasonal changes during the dry season (October - May) and the monsoon (June – September).

Figure 11: Total coliform levels and rainfall data versus time
Shaded area represents rainy season, points: MPN / 100 mL, columns: mm. See Appendix 14 for same graph with standard error bars. Open well = Kariyampalli Open Well; Local Bore Wells = 8 Dharwad District Health Lab samples (District Health Laboratory, 2003) plus 1 Mainal Bore Well sample; MPN = Most Probable Number

Total coliform: The data set ($n = 95$), along with rainfall distribution over the study period, is shown in Figure 10. Of all samples, 25 (26%) were at or beyond the upper detection limit of the method. Most of these highly contaminated samples were taken from the Kali River, where the actual total coliform concentration was at or greater than the detection limit of 2500 MPN / 100 mL in 11 out of 15 samples (73%). Four data points were removed from the data set due to various reasons. These reasons include high readings attributed to the pump probably coming into contact with bacteria while being moved from Well 3 to Well 4, possible data transcription errors, and suspicion of outside contamination of samples. Removing these four data points did not dramatically affect the results (Appendix 15). Eight Bore Well samples analyzed by the Dharwad District Health Lab were included for comparison. In

figures and tables here, these are included when the phrase ‘Local Bore Wells’ is used. Five of these showed total coliform concentrations at the minimum detection limit, which did not correlate with the measurements we took. Additionally, data from India’s Central Pollution Control Board show total coliform concentrations ranging up to 15,000 MPN / 100 mL in all water sources and up to 6,000 MPN / 100 mL in water sources whose labels specify bore wells or groundwater (Table 4). This indicates that the finding of 2500 MPN / 100 mL at the Mainal BW is not as unusual as might seem from comparison with the Dharwad District Health Lab data. Rather, the Dharwad District Health Lab data appears to be uncharacteristically low for Indian wells of this type.

Table 4: Total coliform ranges in Indian waters
 BW = Bore Wells; GW = Groundwater; HP = Hand Pumps; OW = Open Wells; MPN = Most Probable Number (Central Pollution Control Board, 2006; Central Pollution Control Board, 2005)

	Specifically cite BW or GW only			All data – includes HP, OW, etc.		
	MPN / 100 mL		# of Sites	MPN / 100 mL		# of Sites
	Low	High		Low	High	
2005	4	6,000	21	1	15,000	133
2006	7	2,500	16	1	9,301	70

In the figures and tables in this section (total coliform: Figures 11-15, Table 6; *E coli*: Figures 16-20, Table 7), where the term ‘Indian Groundwater’ is used, the data is drawn from Appendix 7. Data in this appendix is a combination of the CPCB 2006 data in Table 4 plus Dharwad District Health Lab Data from 2003 and 2004 and Mainal BW data from this RBF study. CPCB 2005 data was not included because the resulting data set was too large to calculate the geometric mean. Fifteen suspect data points were removed from the CPCB data set. These were data that were clearly marked as coming from open wells and a mine pit as well as one site which had nearly equal total coliform and *E coli* data (9301 MPN / 100 mL and 9300 MPN / 100 mL).

This near equivalence of total coliform and *E. coli* concentrations is not seen anywhere else in data from this or other studies and the *E. coli* data was therefore deemed suspect. In order to match the methodology used in this study, three data points that were above 2,500 MPN / 100 mL were changed to 2,500 MPN / 100 mL. These were Andhara Pradesh 2006 data with minimum, maximum, and average data listed as 2550, 2550 and 2550 MPN / 100 mL; Assam 2006 data listed as 9301, 9301, 9301 MPN / 100 mL; and Assam 2006 data listed as 33, 34000, and 17017 MPN / 100 mL (Appendix 7).

Figure 12: Total coliform % change relative to the Kali River
OW = Open Well; BWs = Bore Wells; GW = groundwater

Aggregate Annual Data: Considering the entire total coliform data set from this RBF study, the average percent change from the Kali River's geometric mean of 1700 MPN / 100 mL ranged from -44% (at KOW, MOW, and MBW) to 95% (RBF Well 3). The data are graphically summarized in Figure 12. Note that negative percentages indicate a bacteria concentration that is higher than the Kali River water, whereas positive numbers are indicative of bacterial loads lower than the Kali River. Because the

KOW and MOW had total coliform levels that were worse than the river, their maximum percent changes are zero. Again, because the actual total coliform concentration in the river exceeded the upper detection limit in 11 of 15 samples, the actual removal percentage calculated based on the aggregate annual data is underestimating the performance of the RBF system.

Results from non-parametric Mann-Whitney U tests on the total coliform and *E. coli* levels in RBF Wells 3 and 4, the Kariyampalli Open Well, and the Kali River at the RBF wellfield sampling site are shown in Table 5. In all instances, water from RBF Well 3 was the least contaminated. For the wet season, there was only enough data to perform Mann-Whitney U tests on the bacteria concentrations of the Kali River and Well 3 (see Appendices 16, 17, and 18 for greater detail).

Table 5: Significance testing results for RBF field site bacteria concentrations from Mann-Whitney U test (a water source to the left of '<<' is significantly less contaminated than that on the right, and a water source to the left of '<' is less contaminated than that on the right, but not significantly so.) W3, W4 = RBF Wells 3 & 4; KKR = Kali River at Kariyampalli village; KOW = Open Well at Kariyampalli village

	less contaminated ----- more contaminated					
Total coliform (all year)	W3	<<	W4	<<	KKR	<< KOW
Total coliform (dry season)	W3	<<	W4	<<	KKR	< KOW
Total coliform (monsoon)	W3			<<		KKR
<i>E. coli</i> (all year)	W3	<	W4	<<	KOW	< KKR
<i>E. coli</i> (dry season)	W3	<<	W4	<<	KOW	< KKR
<i>E. coli</i> (monsoon)	W3			<<		KKR

Seasonal Data: The total coliform data set was divided into two seasonal data sets for the dry (n = 75) and wet (= Monsoon; n = 20) seasons (Table 6). Overall, the Kali River showed almost twice as much total coliform concentration during the dry season relative to the monsoon (2100 versus 1200 MPN/100 mL). The opposite trend is seen at the production well. The total coliform concentration at Well 3 was less than half as much during the dry season relative to the monsoon (66 versus 140

MPN/100 mL). The removal efficiency of RBF Well 3 was 97% during the dry season and 88% during the monsoon. Independent of the season, the Kariyampalli Open Well (the principal water supply for the villagers prior to the RBF installation) was always equally polluted or more polluted than the Kali River.

Figure 13: Total coliform - aggregate annual data

Percent change relative to the Kali River is shown above each column. Error bars show upper and lower range of geometric mean standard deviation. KR = Kali River, W1 = RBF Well 1; KOW = Kariyampalli Open Well; LBWs = Local Bore Wells; IGW = Indian Groundwater

Figure 14: Total coliform - dry season data

Percent change relative to the KR is shown above each column. Error bars: geometric std deviation. KR = Kali River, W1 = RBF Well 1; KOW = Kariyampalli Open Well; LBWs = Local Bore Wells

Figure 15: Total coliform - monsoon data

Percent change relative to the Kali River is shown above each column. Error bars show upper and lower range of geometric mean standard deviation. n/a = not analyzed, KR = Kali River, W1 = RBF Well 1; KOW = Kariyampalli Open Well; LBWs = Local Bore Wells

Table 6: Total coliform concentrations and removals

Shown are all data combined and organized by dry and wet seasons. Note that whenever ≥ 2500 is used, the upper detection limit has been exceeded. As such, the average and maximum RBF removals versus the river are underestimated. Indian groundwater ("Indian GW") data is a combination of CPCB 2006 data (n = 127), Dharwad District Health Lab data (n = 8) and data from this study (n = 1). MPN = Most Probable Number; OW = Open Well

Site	N	Range		Geometric Mean	Max. % Change vs. Kali River	Avg. % Change vs. Kali River	Log Removal of Avg % Change
		Low	High				
		(MPN / 100 mL)					
All data (January - November, 2009)							
Kali River	15	370	≥2500	1700	n/a	n/a	
Well 1	4	1300	≥2500	1800	48%	-6.1%	-0.026
Well 2	4	170	520	360	93%	79%	0.7
Well 3	43	4.1	920	85	>99%	95%	1.3
Well 4	13	38	≥2500	230	99%	87%	0.87
Kariyampalli OW	7	n/a	≥2500	≥2500	-44%	-44%	-0.16
Indian GW	136	0.9	≥2500	33	>99%	98%	1.7
Dry season (January - May and October - November, 2009)							
Kali River	10	400	≥2500	2100	n/a	n/a	
Well 1	4	1300	≥2500	1800	48%	11%	0.053
Well 2	4	170	520	360	93%	83%	0.76
Well 3	29	4.1	920	66	>99%	97%	1.5
Well 4	13	38	≥2500	230	99%	89%	0.95
Kariyampalli OW	6	n/a	≥2500	≥2500	0%	-20%	-0.081
Rainy season (June – September, 2009)							
Kali River	5	370	≥2500	1200	n/a	n/a	
Well 1	No Data						
Well 2	No Data						
Well 3	14	7.5	580	140	>99%	88%	0.93
Well 4	No Data						
Kariyampalli OW	1	n/a	≥2500	≥2500	0.0%	-110%	-0.32

E. coli: The range of *E. coli* concentration for all samples (n = 84) is from 0.9 MPN / 100 mL to 1700 MPN / 100 mL. No samples were at or beyond the upper detection limit of the method, while 10 (12%) samples, all from the RBF production well (Well 3), were at the minimum detection limit. Percent change compared to the Kali River (at 460 MPN / 100 mL) ranged from 57% (KOW) to 99% (RBF Well 3 on ten different days throughout the sample period) (Figure 17 and Appendix 19). Seven *E. coli* data points were removed because the samples were possibly mislabeled or

contaminated. Similar to the total coliform data, removing these data points did not change the data interpretation (Appendix 19).

Figure 16: *E. coli* levels and rainfall data versus time
Shaded area represents rainy season; points: MPN / 100 mL, columns: mm. See Appendix 14 for same graph with standard error bars. Open well = Kariyampalli Open Well; MPN = Most Probable Number

Aggregate Annual Data: As with the total coliform data, geometric means of *E. coli* data were used for comparisons of the wells to the river. Geometric means for each of the 7 sampling sites in this study are shown in Table 7. The average percent change relative to the Kali River ranged from 57% (KOW) to 99% (RBF Well 3). Compared to the maximum *E. coli* concentration detected in the river (870 MPN / 100 mL on October 10, 2009), maximum percent changes ranged from 75% (KOW) to >99% (RBF Wells 2, 3, and 4) (Figures 17 and 18 and Table 7).

Figure 17: *E. coli* % change relative to the Kali River
 Well 1, 2, 3 = RBF Well 1, 2, 3; OW = Open Well; BW = Bore Well; GW = Groundwater

Figure 18: *E. coli* - aggregate annual data

Percent change relative to the Kali River is shown above each column. Error bars show upper and lower ranges of geometric mean standard deviation. KR = Kali River, W1 = RBF Well 1; KOW = Kariyampalli Open Well; MBW = Mainal Bore Well; IGW = Indian Groundwater

Figure 19: *E. coli* - dry season data

Percent change relative to the Kali River is shown above each column.

Figure 20: *E. coli* - monsoon data

Percent change relative to the Kali River is shown above column. n/a = not analyzed

Table 7: *E. coli* concentrations and removals

Shown are all data combined and organized by dry and wet seasons. Indian groundwater data is a combination of CPCB 2006 data (n = 95) and data from this study (n = 1). MPN = Most Probable Number; Well 1, 2, 3 = RBF Well 1, 2, 3; OW, BW, GW = Open Well, Bore Well, Groundwater (Central Pollution Control Board, 2006)

Site	N	Range		Geometric Mean	Max. % Change vs. Kali River	Avg. % Change vs. Kali River	Log Removal of Avg % Change
		Low	High				
		(MPN / 100 mL)					
All data (January - November, 2009)							
Kali River	12	120	870	460	n/a	n/a	n/a
Well 1	3	16	140	42	99%	91%	1.0
Well 2	4	1.0	12	4.7	>99%	99%	2.0
Well 3	44	0.9	64	3.6	>99%	99%	2.1
Well 4	13	1.0	12	4.0	>99%	99%	2.1
Kariyampalli OW	7	27	1700	200	97%	57%	0.4
Mainal BW	1	n/a	39	39	96%	91%	1.1
Indian GW	96	1.0	610	10	>99%	98%	1.7
Dry season (January - May and October - November, 2009)							
Kali River	8	120	870	470	n/a	n/a	n/a
Well 1	3	16	140	42	98%	91%	1.2
Well 2	4	1.0	12	4.7	>99%	99%	2.0
Well 3	29	0.9	18	1.8	>99%	>99%	2.4
Well 4	13	1.0	12	4.0	>99%	99%	2.1
Kariyampalli OW	6	27	1700	200	97%	58%	0.4
Rainy season (June – September, 2009)							
Kali River	4	140	790	440	n/a	n/a	n/a
Well 1	No Data						
Well 2	No Data						
Well 3	15	0.9	64	13	>99%	97%	1.5
Well 4	No Data						
Kariyampalli OW	1	n/a	200	200	75%	55%	0.35

Seasonal Data: During the dry season, geometric means (n = 64) of *E.coli* bacteria concentration ranged from 1.8 MPN / 100 mL (RBF Well 3) to 470 MPN / 100 mL (Kali River) (Table 7). Removal percentages relative to the Kali River geometric mean ranged from 58% (KOW) to >99% (RBF Well 3) (Figure 17, Table 7, Appendix 19). Rainy season geometric means (n = 20) ranged from 13 MPN / 100 mL (RBF Well 3) to 440 MPN / 100 mL (Kali River). Note that during the wet season, only the

Kali River, Kariyampalli Open Well, and RBF Well 3 were tested. Average wet season percent changes from the Kali River range from 55% (KOW) to 97% (RBF Well 3) (Figure 17, Table 7, and Appendix 19).

In contrast to the total coliform data, the *E.coli* concentration did not change as much by season. The Kali River maintained approximately the same total coliform concentration during the dry season relative to the monsoon (470 versus 440 MPN / 100 mL). The total coliform concentration at Well 3 did not change substantially between the dry season relative to the monsoon (1.8 versus 13 MPN / 100 mL).

IONS: Cation (n = 80) and anion (n = 63) analyses of samples from the wellfield and the surrounding region are summarized in Table 4 with supplemental information provided in Appendices 12 and 20. Summaries of previous studies on the Kali River (Bharati and Krishnamurthy, 1990; Krishnamurthy and Bharati, 1994; Department of Mines & Geology, 2004; Department of health and family welfare services, 2004; Panchayat Raj Engineering, 2006; Birasal et al, 1985), at local Open Wells (Department of health and family welfare services, 2004; Panchayat Raj Engineering, 2006), and from this study are shown below.

Previous Studies:

Anions: The lowest concentrations of fluoride, nitrate, bicarbonate, chloride, and sulfate in all previous work on both the Kali River and local Open Wells were all observed in Kali River samples. In addition, the Dandeli Open Well in 1999 also tied

for lowest fluoride with the Kali River in Kariyampalli in 2003. Highest concentrations were at the Halmaddi Kali River site and the Dandeli Open Well.

Table 8: Range of anion concentrations from previous studies

KR = Kali River; KKR = Kali River at Kariyampalli village; OW = Open Well; DOW = Open Well #190304 in Dandeli (Appendix 21) (Krishnamurthy and Bharati, 1994; Department of Mines & Geology, 2004; Department of health and family welfare services, 2004; Panchayat Raj Engineering, 2006; Birasal et al, 1985)

	Location of lowest reading	Low (mg/L)	High (mg/L)	Location of highest reading
Fluoride	KKR & DOW 1999	0	0.6	Halmaddi KR 2004
Nitrate	Moulangi KR 1985	0.02	33	Dandeli OW 2000
Bicarbonate	Moulangi KR 1985	7.95	397	Halmaddi KR 2004
Chloride	KKR 2003	12	334	Dandeli OW 2001
Sulfate	Moulangi KR 1985	0.2	96.6	Halmaddi KR 1990

Cations: The lowest concentrations for sodium, potassium, magnesium, and calcium were all found in Kali River samples. In addition, the Kariyampalli Open Well in 2003 also tied for the lowest potassium level with the Kali River in Kariyampalli in 2003. Highest concentrations were generally seen at the Halmaddi Kali River site, although the Dandeli Open Well had the highest magnesium level in 2001.

Table 9: Range of cation concentrations from previous studies

KR = Kali River; KKR = Kali River at Kariyampalli village; KOW = Open Well at Kariyampalli village; Dandeli OW = Open Well #190304 in Dandeli (Appendix 21) (Krishnamurthy and Bharati, 1994; Department of Mines & Geology, 2004; Department of health and family welfare services, 2004; Panchayat Raj Engineering, 2006; Birasal et al, 1985)

	Location of lowest reading	Low (mg/L)	High (mg/L)	Location of highest reading
Sodium	Moulangi KR 1985	2.8	192	Halmaddi KR 1990
Potassium	KKR & KOW 2003	0	37.2	Halmaddi KR 1990
Magnesium	Moulangi KR 1990 & 1994	1	53	Dandeli OW 2001
Calcium	Moulangi KR 1994	5.12	96	Halmaddi KR 2004

Figure 21: Schoeller diagram of ions from previous studies in the research area (Bharati and Krishnamurthy, 1990; Department of Mines & Geology, 2004; Panchayat Raj Engineering, 2006)

This Study:

All ions evaluated were below BIS levels except chloride and calcium.

Chloride exceeded BIS desirable guidelines (250 mg/L), but not BIS permissible guidelines (1,000 mg/L), in the Hand Pumps (Bada Khanshera and Harnouda sites) and the Kali River (Halmaddi site only) categories. Calcium concentrations exceeded BIS desirable guidelines (75 mg/L) in most sample categories (Mainal HP, Mainal BW, Harnouda BW, Kerwad OW, Halmaddi KR). Permissible BIS guidelines for calcium (200 mg/L) were exceeded only in the Hand Pumps category (Bada Khanshera and Harnouda sites) (Appendices 12 and 20).

Figure 22: Schoeller diagram of ions from Kali River and RBF well samples

Figure 23: Schoeller diagram of ions from HP, OW, and BW / TT samples

Figure 24: Schoeller diagram of ions from KKR, W3, KOW, and BKaBW

Cation : Anion Balance: Ion analyses of samples from this study indicate that cation levels are 80% to 470% greater than anions (Appendix 22). This strong discrepancy between anion and cation levels is likely indicative of an underestimation of alkalinity concentrations due to test strip measurements (error: $\pm 20 - 30$ mg/L), instead of the more accurate bicarbonate titration method (error: ± 5 mg/L (Eaton et al, 2005). Titration measured bicarbonate anions ranged from 48.8 to 245.2 mg/L (avg: 147 mg/L) in two previous studies of the Kali River at Dandeli (Bharati and Krishnamurthy, 1990; Krishnamurthy and Bharati, 1994), whereas this study found 0 to 60 mg/L using test strips (avg: 20 mg/L). Hence, previous studies showed more than 7 times greater alkalinities than reported here. Further, comparison of electrical conductivity readings from this study with the sum of the anions and cations (Lenntech BV, 2011) shows wide variability in comparisons, with 39% with lower ion

totals and 48% with higher ion totals than expected (Appendix 12). This suggests also that the $\pm 20 - 30$ mg/L error for the bicarbonate test strips is evident in data from this study. Altogether, the potentially underreported anion (alkalinity) concentrations limited the usefulness of this data set.

Cations:

Dixon's Q tests were performed to measure if the cation levels in Moulangi, Halmaddi, and Kariyampalli from this study qualified as outliers when compared with previous studies. None of this study's cation data qualified as outliers. Note that Kariyampalli data from this study is compared with Kerwad data from previous studies as they refer to the same sampling location on the Kali River. Dixon's Q tests were also performed on chloride levels. Other anions were not uniformly reported in previous studies. None of this study's anion data qualified as outliers (Appendix 23).

Table 10: Range of cation concentrations from this study
KR = Kali River; KKR = Kali River at Kariyampalli village; HP = Hand Pump (Appendix 12)

	Location of lowest reading	Low (mg/L)	High (mg/L)	Location of highest reading
Sodium	KKR 2009	4.1	170	Halmaddi KR
Potassium	KKR 2009	0.5	15	Halmaddi KR
Magnesium	Moulangi KR	0.8	81	Bada Khanshera HP
Calcium	Moulangi KR	2.0	250	Harnouda HP

Previous Studies – Kali River: Due to insufficient bicarbonate data, only cations could be plotted on ternary Piper diagrams. These are shown below.

When graphed in a trilinear diagram, cations from previous studies were generally neutral, except for Halmaddi and Kerwad samples from 1990, which were Na/K type waters, as would be expected for impacted waters (Duh et al, 2008) (Figure 25).

Figure 25: Cation ternary diagram of previous studies on the Kali River (Bharati and Krishnamurthy, 1990; Department of Mines & Geology, 2004)

Local government analysis of an Open Well in Dandeli from 1999 – 2006 were all neutral cation waters except for one of the 11 samples. The unusual case was a Na/K type water from April, 2000 (Figure 26).

Figure 26: Cation ternary diagram of previous studies on Dandeli Open Well #190304, 1999 - 2006 (Panchayat Raj Engineering, 2006)

This study: On Piper plots, samples from this study ($n = 47$) showed a broad range of compositions while staying at or below 30% magnesium. Most samples (76%) are calcium to neutral cation type waters, while 24% were Na/K type waters, including 2008 Kali River samples ($n = 9$) and Moulangi and Kerwad Town Tap.

Kali River samples were neutral to Na / K type waters in the cation field (Figure 27).

Figure 27: Cation ternary diagram of Kali River samples from this study

Bore Well samples from this study were predominantly neutral to Na/K type in the cation field. Hand Pumps are calcium (Harnouda and Bada Khanshera) to neutral type waters in the cation field. Open Wells were calcium to neutral cation type waters (Figure 28). Harnouda Bore Well and RBF Wells 1 and 2 have incomplete data and cannot be plotted on ternary diagrams.

RBF wellfield: RBF Well 3 samples are near neutral water types in the cation field.

RBF Well 4 samples are calcium to neutral type waters (Figure 28).

Figure 28: Cation ternary diagram of BW / TT, HP, KOW, and RBF Well samples

Briefly, the cation data from samples in this study can be synthesized as follows:

Ca²⁺ Type Waters   >   >   Na⁺ / K⁺ Type Waters
OW > RBF Wells > HP > KR > BW

METALS:

Overall, 59 water samples from around Dandeli were tested for 8 different dissolved metals, yielding 420 analyses. Dixon's Q outlier tests were performed within the five sample categories (BW / TT, HP, OW, KR, and the RBF Wellfield) for each metal. With this test, 19 of the 420 samples were deemed to be outliers of their category. Outliers were not included in the category averages. In those samples where dissolved metals levels were only reported as a range of concentrations, the average from that range was used. Dissolved metals at the Halmaddi confluence account for all of the outliers in the Kali River category. Other sample categories had outliers from multiple site locations.

Table 11 shows the Bureau of Indian Standards (BIS) and the World Health Organization (WHO) limits for dissolved metals in drinking water and whether sample categories from this study exceeded those standards. The majority of cases that exceeded WHO drinking water standards were above aesthetic rather than health standards (Table 11).

Table 11: Dissolved metals regulatory standards and their occurrence in this study

* = aesthetic guideline; BIS = Bureau of Indian Standards; WHO = World Health Organization; All Categories = Hand Pumps, Kali River, Open Wells, Bore Wells, Town Taps, and RBF Wells (WHO, 2006; Bureau of Indian Standards, 1991)

	BIS Desirable Levels	BIS Permissible Levels	WHO standards	Above BIS desirable levels	Above WHO standards
Cadmium	10 ppb	-	3 ppb	None	None
Chromium	50 ppb	-	50 ppb	None	None
Copper	50 ppb	1,500 ppb	2,000 ppb	Town Tap	None
Lead	50 ppb	-	10 ppb	None	Town Tap, Hand Pumps, and Open Wells
Manganese	100 ppb	300 ppb	500 ppb (100 ppb*)	All categories	Town Tap, Hand Pumps, Open Wells and RBF Wells
Zinc	5,000 ppb	15,000 ppb	3,000 ppb*	Hand Pumps	Hand Pumps
Iron	300 ppb	1,000 ppb	300 ppb*	Hand Pumps, Kali River, Open Wells, and RBF Wells	Hand Pumps, Kali River, Open Wells, and RBF Wells

For sample averages (without outliers) from the RBF wellfield area, Figure 29 shows the water quality relationships between the Kali River in Kariyampalli, the Kariyampalli Open Well, local Bore Wells, and the RBF production well (note that chromium data for KKR and KOW are from 2008 only).

Figure 29: Schoeller diagram of field site average dissolved metals concentrations
The production well has the lowest concentrations for all metals analyzed except iron and manganese. KKR = Kali River at Kariyampalli village; W3 = RBF Well 3; KOW = Open Well at Kariyampalli village; BWs = Bore Wells in Harnouda, Mainal, and Bada Khanshera

These data indicate that the Bore Wells have the highest average for each of the seven dissolved metals analyzed (note that chromium concentrations are from Bada Khanshera and Harnouda Bore Wells only; there is no data from the Mainal Bore Well). The RBF pumping well show the lowest average concentrations of all water sources sampled for Cu, Cd, Zn, Pb, and Cr.

Specific Metals: The statistically relevant data from the local Bore Wells, Kariyampalli Kali River, and RBF Well 3 were used for calculating percent change at RBF Well 3 from the groundwater and surface water inputs (Appendix 27). RBF Well 3's average metal concentrations are then compared with the worst of the currently used drinking water sources. These currently used drinking water sources consist of all Bore Wells and Town Taps, all Kali River sites (except Halmaddi), and all Open Wells (except Mainal).

Overall, the metal data shows that, except for iron and manganese, the RBF water met the BIS and WHO drinking water standards for zinc, lead, chromium, cadmium, and copper.

In all water samples, metals concentrations were as follows. Zinc concentrations in water samples collected in the study area ranged from <1 to 6,000 ppb (Appendix 25). Zinc was detected above the BIS desirable level in one Hand Pump sample (Bada Khanshera HP). Zinc concentrations at the Halmaddi confluence ranged from 43 to 230 ppb (not shown in figures in Appendix 25).

Cadmium concentrations ranged from <0.08 to 1 ppb (Appendix 25). These concentrations were well below the BIS standard (Table 13). The cadmium concentration at the Halmaddi confluence was 1 ppb (not shown in figures in Appendix 25).

Lead levels ranged from <0.09 to 22 ppb (Appendix 25). There were 4 samples that met the BIS lead standard, but did not meet the more stringent World Health Organization standard for drinking water (Moulangi and Kerwad TT, Moulangi HP, and Mainal OW; Table 13). Lead concentrations at the Halmaddi confluence ranged from 2 to 7 ppb.

Copper levels range from <0.09 to 83 ppb with levels found beyond the BIS desirable limit in two tap water samples (Moulangi and Dandeli TT; Table 13) (Appendix 25). Copper concentrations at the Halmaddi confluence ranged from 3 to 4 ppb.

The range of titanium levels was <0.08 to 7 ppb. There are no BIS or WHO limits for titanium. Titanium concentrations at the Halmaddi confluence ranged from 4 to 5 ppb.

Chromium ranges from 0 to 16 ppb (Appendix 25). All Chromium concentrations are below both the BIS and WHO standards. Chromium concentrations at the Halmaddi confluence ranged from <0.07 to 3 ppb (not shown in figures in Appendix 25).

Manganese concentrations range from <0.5 to 2,400 ppb (Appendix 25). Out of 56 total samples, 24 samples from all categories were found above the BIS desirable level for manganese. Manganese concentrations at the Halmaddi confluence ranged from 4 to 340 ppb.

Iron concentrations ranged from <3.6 to 25,000 ppb (0.0036 to 25 mg/L) (Appendix 25). As with manganese, there were 24 out of 56 samples (43%) that exceeded the BIS desirable standard for iron. Iron concentrations at the Halmaddi confluence ranged from 330 to 1,030 ppb (not shown in figures in Appendix 25).

DISCUSSION:

Results from this study can be broadly categorized as contributing understanding to two questions concerning this RBF system. The first question is where the water in the production well originates. Isotope, silica, and aquifer test data was used to address this research question. These results are discussed in the section ‘Source of Water in the RBF Well.’ The second major question asked during this study is the degree to which the RBF production well delivers high quality drinking water. This is approached by analyzing field parameters and bacterial, metals, and ions data and elaborated on in the section ‘Performance of the RBF System.’

Source of Water in the RBF Well:

Stable Isotopes: Isotopic variation amongst the samples was not great enough to use these values for distinguishing surface water from groundwater inputs to the RBF water. The slope of the local meteoric water line (BMWL) recorded in Belgaum by Kumar et al., (2010) is 7.78. Two out of three Kali River samples plot close to the BMWL meteoric line, indicating that the river is fed by precipitation water. Closely paralleling this is the best fit line for data points from this study that are not impacted by evaporation (KR, MBW, RBF W 1, 2, 3; $n = 13$). That slope is 5.43 (Figure 9).

In contrast, data points ($n = 7$) from the Kariyampalli Open Well and the nearest RBF well (Well 4) form a line with shallower slope (2.93). These data show the effect of isotopic fractionation due to evaporation at the rice paddies surrounding the Kariyampalli Open Well (Kendall and McDonnell, 1998). All of these lines are shown in Figure 9.

The isotopic signature of groundwater not influenced by precipitation, evaporation, or river recharge could not be determined. Although the isotopic data could not be used for the originally intended purpose - distinguishing between surface and ground water inputs - it did prove useful when combined with the dissolved silica data to show the source of water in the RBF production well.

Silica: A two-end member mixing model was created using silica concentrations as a proxy for groundwater percentage in the samples. In this model, the Kali River water was set at 0% groundwater and the Mainal Bore Well at 100% groundwater, under the assumption that it is entirely fed by groundwater. Based on that, the dissolved silica levels, which ranged from 21 to 39 mg/L, corresponded to 38% groundwater (KOW) to 72% groundwater (RBF W3) in January. After 11 months of pumping in which the pump was running approximately four hours per day, another set of samples was taken. These showed 27% (RBF W4) to 73% (RBF W3) groundwater contributions. With particular reference to RBF Well 3, the mixing model shows an average of 28% river water contribution (Table 12). This falls within the range seen in other studies of RBF systems, which show 13 - 75% surface water (Appendix 1). Silica concentration demonstrates that the percentage of Kali River water drawn into RBF Wells 1, 2 and 4 increased with time pumping, whereas Well 3 (the pumping well) shows a constant percentage of the ratio of river water to groundwater. Results from Dixon's Q testing show the December increase in RBF Well 2 to be significant at the 95% confidence level. None of the other wells show a statistically significant change between the January and the December silica data at the 95% confidence level (Appendix 24). The change at Well 2 is hypothesized to be the result of more river water being drawn into

the RBF wellfield during the 11 months of pumping. This mixing model would benefit from a greater number of samples to give greater confidence to its results.

Table 12: Percentage of Kali River water (derived from silica data)

KR = Kali River

	% KR water 1/09	% KR water 12/09	% change	Avg % KR water 2009
Kali River	100%	100%	-	100%
RBF Well 1	53%	70%	17%	62%
RBF Well 2	33%	59%	27%	46%
RBF Well 3	28%	27%	-1%	28%
RBF Well 4	29%	73%	44%	51%
Kariyampalli Open Well	62%	54%	-8%	58%
Mainal Bore Well	0%	0%	-	0%

When isotope data are combined with silica concentration data, effects from evaporation at the rice paddies is corroborated. In theory, samples would have increasing silica concentrations with distance from the river because groundwater has more time for water-rock interaction. Instead, as Figure 38 shows, only RBF Wells 1 and 2 fall on a mixing line between river water and groundwater and the evaporative effect of the rice paddies is shown on the Kariyampalli Open Well and RBF Well 4. Additionally, the rice paddies around the Kariyampalli Open Well were sometimes irrigated with Kali River water and the effect of this is seen in the silica data in which RBF Wells 3 and 4 as well as the Kariyampalli Open Well begin to reverse the trend seen along mixing line A such that mixing line B trends back towards the silica signature of the Kali River (Figure 30). Thus evaporative enrichment and irrigation with Kali River water of the rice paddies are influencing shallow groundwater in that area and acting as a secondary surface water source to the RBF system. This leads to a three-end member model of effects on the samples in this study rather than a two-

end member model that was originally conceived between the surface waters of the Kali River and the 88 meter deep groundwater of the Mainal Bore Well.

Figure 30: Silica (mg/L) versus $\delta^{18}\text{O}$ (‰)
W1, 2, 3 = RBF Well 1, 2, 3

Aquifer Test Data: Analysis of the January, 2009 slug test generates a 6.9 m/day hydraulic conductivity and a travel time of 30 days. Given the imprecision of slug tests in general, it seems likely that this travel time is slower than should be expected at this field site. A second tracer test was performed by Boving et al. (2010a) in May – June 2009 and yielded 9 – 15.1 m/day hydraulic conductivities at Well 3 and more realistic travel times ranging from 14 to 23 days (Appendices 1 and 10). Moment analysis of the same dataset in Boving et al. (2010a) gave a travel time of 8.7 days from the Kali River to RBF Well 3.

Semi-logarithmic drawdown versus time graphs of data from the May 2009 pump tests on Well 3 suggest the existence of a recharge boundary (Fetter, 1994). The existence of a recharge boundary further supports the idea that the RBF production well is receiving water from the Kali River and, possibly, the nearby rice paddies (Figure 10 and Appendix 10).

Performance of the RBF System:

Field Parameters: pH levels at the production well ranged from 6.1 to 7.3 with the average being 6.6. Nearly a quarter (12 of 50) of the readings registered below the BIS guideline of 6.5. These lower pH levels may account for one third of respondents who reported a bitter taste (US EPA, 2011) in the post-installation survey in 2010 (Appendix 2). Average electrical conductivity (324.8 us/cm) and total dissolved solids (161.2 ppm) at RBF Well 3 are lower than the average of each of the other water source categories in the area except the Kali River (averages: 188.7 us/cm and 93.8 ppm). There are no BIS guidelines for electrical conductivity. The BIS guidelines for TDS are 500 ppm (desirable) and 2000 ppm (permissible). All samples meet the desirable BIS guidelines for TDS except for the Kali River at the Halmaddi confluence and the Bada Khanshera and Harnouda Hand Pumps, although these do fall within the permissible guidelines.

Suslow (2004) indicates that increasing ORP levels result in decreasing survival of *E. coli* and that measurements above 665 mV result in a dramatic drop in survival for many pathogenic bacteria and fungi, which tend to die in that setting within a few minutes. In these oxidizing conditions, electrons are pulled away from

cell membranes, ruining cell walls and killing the microbes (Suslow, 2004). In this study, the highest ORP value seen was at the Kerwad Town Tap, with a value of 434 mV. The lowest value seen was -149 mV at the Halmaddi Hand Pump. RBF Well 3's average ORP reading was 207 mV. ORP values within the RBF Wellfield mimic the bacteria levels, with Well 3 showing the highest and Well 1 the lowest levels (Figure 31 and Appendices 12 and 13). Nevertheless, these values are all below Suslow's cut off and therefore ORP values indicate that the wellfield conditions are not oxidizing enough to suppress pathogen concentrations in the well water. Bacteria reductions are therefore likely the result of biological activity in the biofilm at the riverbed rather than the redox conditions in the wellfield.

Figure 31: Average ORP values in the RBF wellfield while Well 3 was the pumping well correlate to distance to closest surface water (i.e. Kali River or the rice paddies around the Kariyampalli Open Well). Standard error shown with error bars. ORP = Oxidation Reduction Potential; KR = Kali River at Kariyampalli village; W1, 2, 3 = RBF Well 1, 2, 3; KOW = Open Well at Kariyampalli village

The relationship between redox conditions and distance to the nearest surface water is corroborated by Figure 32. This figure demonstrates that ORP levels in Well 4 are much lower when Well 3 is the pumping well rather than Well 4. During these times, Well 4 is in the reducing zone.

Figure 32: Average ORP values at Well 4 varies depending on which well was being pumped. Standard error shown with error bars. ORP = Oxidation Reduction Potential; W3, 4 = RBF Well 3, 4

Bacteria: The BIS standard for total coliform bacteria is zero MPN / 100 mL for 95% of samples collected throughout the year. The remaining 5% of samples can be up to 10 MPN / 100 mL, but no two consecutive samples are allowed to have any detectable coliform bacteria. *E. coli* levels are required to be zero MPN / 100 mL at all times (Bureau of Indian Standards, 1991).

A two year study in northwestern India in 2007 and 2008 found that 45.4% of taps, 29.2% of Bore Wells, and 72.0% of Open Wells were unsafe for human consumption (Malhotra, Arora and Devi, 2009). Government documents reported water in the Dandeli area to be unsafe for drinking in 46% of samples tested in 2003 and 2004 (District Health Laboratory, 2003). Some Hand Pumps and Bore Wells were deemed safe for consumption, but, despite this, unsafe water was found at all water sources (Hand Pumps, Open Wells, Bore Wells, and the Kali River). Those data agree with findings from this study, which found bacteria concentrations at unsafe levels in the Kariyampalli Open Well, the Mainal Bore Well, and the Kali River at

Kariyampalli. No Hand Pumps were tested for bacteria in this study. As an example of potential maximum bacteria levels, monitoring results from India's Inland Water Quality Monitoring Network show that the Yamuna River, which passes through the cities of Delhi and Agra in northern India, had total coliform levels of 2.3×10^8 MPN / 100 mL and fecal coliform levels of 1.3×10^8 MPN / 100 mL in 2006 (Central Pollution Control Board, 2006). The same report listed maximum total and fecal coliform levels in the Kali River downstream of Dandeli as 1,800 MPN / 100 mL and 560 MPN / 100 mL, respectively, in 2006. In contrast, our study found repeated total coliform levels above the method detection limit of 2,500 MPN / 100 mL and maximum *E. coli* levels at 870 MPN / 100 mL. The same CPCB report showed the highest bacteria levels in tributaries of the neighboring Krishna River basin to be much higher than the Kali River, at 420,000 MPN / 100 mL and 22,000 MPN / 100 mL for total and fecal coliform levels in 2006 (Central Pollution Control Board, 2006). These statistics from this study at the Kali River and from the CPCB at rivers other than the Kali River support the idea that, had progressive dilutions allowed for actual quantification of total coliform levels, the percent removals of the RBF system would have been much greater than those reported here. In comparison, the pumping well (RBF W3) concentrations are lower than KR and KOW for total coliform bacteria and lower than all other theoretical source waters (KR, KOW, and MBW) for *E. coli* (Figures 13 and 18). However, BIS standards for total coliform are regularly exceeded while *E.coli* standards are met most the time.

Total coliform: The dilution levels calculated with the silica data were used to predict the total coliform bacteria levels at the research site. This was done to distinguish reductions in bacteria due to dilution versus removal due to other RBF processes. Compared to the actually measured concentration (Figure 33), the predicted total coliform values were lower at Well 1, the Kariyampalli Open Well, and the Mainal Bore Well. RBF Well 1 probably shows a higher level of total coliform than expected due to a livestock holding area within 3 meters of the wellhead. The Kariyampalli Open Well most probably had higher coliform levels because users dip into that well with buckets that have been placed on the ground or have otherwise come into contact with contaminated surfaces. The well is unprotected and anything may fall into it. Additionally, the rice paddies surrounding the Kariyampalli Open Well are plowed with cattle and water buffalos whose manure could contribute to bacteria levels in the Open Well.

The Mainal Bore Well had had the highest total coliform bacteria concentrations (≥ 2500 MPN / 100 mL). Interestingly, in an earlier survey by the District Health Lab, the total coliform bacteria concentration found at the Mainal Bore Well was 9 MPN / 100 mL (Appendix 6). Eight other bore well samples in the area by the District Health Lab ranged from five samples with total coliform levels below the detection limit up to one at 46 MPN / 100 mL (Appendix 6). For the 2005 CPCB groundwater data set referenced earlier, there is only one point at the lowest end of the range (1 MPN / 100 mL) from Himachal Pradesh (Central Pollution Control Board, 2005; Petrassi, Thomas and Gommers, 1999). When looking at the number of stations reporting total coliform levels at or below 10 MPN / 100 mL, 44% of sites (58 of 133

sites) in the 2005 CPCB data set qualify (Central Pollution Control Board, 2005). In the 2006 CPCB data set, 2 sites (3%) report minimum total coliform levels of 1 MPN / 100 mL, 13 sites (19%) report levels at or below 10 MPN / 100 mL, and 7 sites (10%) report levels at 2500 MPN / 100 mL or above (Central Pollution Control Board, 2006) (Appendix 7). These data imply that the 63% of samples in the Dharwad District Health Lab data that found total coliform levels below the minimum detection limit and 75% at or below 10 MPN / 100 mL is unusual in comparison to other data sets in India. Therefore it is perhaps less surprising that this study found such high total coliform levels at Mainal Bore Well than that the local health lab found such low levels in this and nearby bore wells. In 2008, the Mainal residents considered the Mainal Bore Well to be a good water source and the only reason they didn't use it at that point was that the pump was broken. In 2009 when the pump was working and samples were collected, it was presumably in use by local residents. Because of the discrepancies in bacteria concentration in the local groundwater, the models used in this study set these levels at 0 MPN / 100 mL.

On the other hand, dilution calculations predict higher levels of total coliform than were actually seen in RBF Wells 2, 3, and 4 (Figure 33). At the production well (RBF W3), actual total coliform removal was more than five times greater than that attributed to dilution alone (dilution prediction of 490 MPN / 100 mL versus actual mean of 85 MPN / 100 mL). This indicates that factors beyond dilution, such as biological activity and filtering, are at work in removing bacteria in the RBF process.

Table 13: Relation of silica analysis to total coliform data

According to silica data, an average of 23% of total coliform reduction at W3 is due to factors other than dilution. SW = Surface Water; GW = Groundwater; MPN = Most Probable Number; OW = Open Well; BW = Bore Well

Columns	1	2	3	4	5
	Observed Geometric Mean of SW (MPN / 100 mL)	Estimated % river water (from Silica data)	Estimated Geometric Mean after GW dilution (MPN / 100 mL)	Observed Geometric Mean (MPN / 100 mL)	Estimated % due to other RBF processes
Kali River	1700	100%	1700	1700	n/a
Well 1		53%	900	1800	-53%
Well 2		33%	550	360	11%
Well 3		28%	480	85	23%
Well 4		29%	490	230	15%
Kariyampalli OW		62%	1050	≥2500	-85%
Local BWs		0%	0		n/a

Table 13 demonstrates that at least 23% of the bacteria reduction seen at RBF Well 3 can be attributed to these other factors. Mean total coliform detected at the Kali River (column 1) is multiplied by the percentage of river water (column 2) to produce the geometric mean predicted by dilution with groundwater at 0 MPN / 100 mL (column 3). In contrast, column 4 shows the actual coliform levels at each sample site. Column 5 quantifies the other RBF processes, such as filtering and predation, at work in the system. Column 3 minus column 4 then divided by column 1 (the source water) yields column 5. Table 13 underestimates the non-dilution processes because it sets the groundwater at 0 MPN / 100 mL of total coliform, which is lower than the data indicate. As there was some discrepancy in what the actual bacteria level is of the local groundwater, this absolute minimum level was used here. Figure 33 gives a graphical display of columns 3 and 4 from Table 13.

Figure 33: Total coliform - observed annual data versus dilution predictions
 MPN = Most Probable Number; Well 1, 2, 3 = RBF Well 1, 2, 3; OW = Open Well; BW = Bore Well

E. coli: Dilution levels calculated with dissolved silica data predict from 1.4 times (at KOW) to 36 times (at W3) more *E. coli* than is actually seen in the data, indicating that dilution is not the only factor at work in *E. coli* removal (Figure 34). Again, evidence of livestock holding near RBF W1 is seen in the data, as this well has a notably higher level of bacteria than the more distant RBF wells and even the river itself.

The geometric average of *E. coli* bacteria level in the production well (RBF W3) is at 3.6 MPN / 100 mL over 10 months of data collection. Although this is slightly above the BIS level of <1 MPN / 100 mL, it is greatly improved from the levels of the other local water sources in the area. Therefore, minimal disinfection will be required to get the RBF water to BIS standards, but it will be much easier to achieve treatment with water starting at 3.6 MPN / 100 mL than with Kali River levels

(Schmidt et al, 2003; Kuehn and Mueller, 2000). As an example, studies have shown that nanofiltration treatment membranes had to be replaced every 8 days when used with conventionally pre-treated surface water and replaced every 62-75 days when used with water pre-treated via RBF (Ray et al, 2002). Further, water with approximately 1-10 MPN / 100 mL is occasionally allowable according to BIS total coliform regulations, but may increase in contamination level due to regrowth during storage in the home. RBF-treated water, though, tends to have low assimilable organic carbon (AOC) content and therefore inhibits bacterial regrowth when compared with raw river water and water treated via ozonation or activated carbon (Schmidt et al, 2003). Finally, it is suspected that at least some of the bacteria originate from livestock manure inside the RBF well catchment area. This assumption is based on the observed higher bacteria concentrations at RBF W3 during the wet season (Tables 6 and 7), which indicate possible influx of bacteria contaminated seepage from the surface. Based on the results of this study, the owner of the cattle was advised to move the livestock away from the RBF wellfield.

Table 14: Relation of silica analysis to *E. coli* data
According to Silica data, an average of 27% of *E. coli* reduction at W3 is due to factors other than dilution. SW = Surface Water; GW = Groundwater; MPN = Most Probable Number; OW = Open Well; BW = Bore Well

Columns	1	2	3	4	5
	Observed Geometric Mean of SW (MPN / 100 mL)	Estimated % river water (from Silica data)	Estimated Geometric Mean after GW dilution (MPN / 100 mL)	Observed Geometric Mean (MPN / 100 mL)	Estimated % due to other RBF processes
Kali River	460	100.0%	460	460	n/a
Well 1		53.2%	240	42	44%
Well 2		32.6%	150	4.7	32%
Well 3		28.1%	130	3.6	27%
Well 4		28.7%	130	4.0	28%
Kariyampalli OW		62.0%	290	200	19%
Mainal BW		0%	0.0	39	-8.5%

Table 14 demonstrates that at least 27% of the *E. coli* bacteria reduction seen at RBF Well 3 can be attributed to RBF factors other than dilution. Mean *E. coli* detected at the Kali River (column 1) is multiplied by the percentage of river water (column 2) to produce the geometric mean predicted by dilution with groundwater at 0 MPN / 100 mL (column 3). In contrast, column 4 shows the actual bacteria levels at each sample site. Column 5 quantifies the other RBF processes, such as filtering and predation, at work in the system. Column 3 minus column 4 then divided by column 1 (the source water) yields column 5. Table 14 underestimates the non-dilution processes because it sets the groundwater at 0 MPN / 100 mL of *E. coli* bacteria, which is lower than the data indicate. Because there was only one data point for the local groundwater, this absolute minimum level was used here as a precaution against possibly erroneous data.

Figure 34 gives a graphical display of columns 3 and 4 from Table 14.

Figure 34: *E. coli* – observed annual data versus dilution predictions
MPN = Most Probable Number; Well 1, 2, 3 = RBF Well 1, 2, 3

IONS:

Previous Studies – Kali River:

Kali River samples from previous studies show similar trends to samples from this study. Samples from upstream of the Halmaddi paper mill effluent are lower in ions and similar to rivers in rural areas or to a global average river (Duh et al, 2008; Hem, 1985). Samples from Halmaddi and downstream are higher in ion concentrations, with Halmaddi samples generally higher than or equivalent to the British industrial river studied by Duh et al. and the road runoff samples of other researchers (Bharati and Krishnamurthy, 1990; Department of Mines & Geology, 2004; Duh et al, 2008; Gobel, Dierkes and Coldewey, 2007; Harrison and Wilson, 1985). Previous studies of an Open Well in Dandeli show higher ions concentrations than the Kariyampalli Open Well in this study. The Dandeli Open Well samples are similar to the Kerwad Open Well ion concentrations in this study (Panchayat Raj Engineering, 2006) (Figure 21).

This study: Dixon's Q test results indicate that analytical errors associated with determining alkalinity in the field explains the apparent cation : anion imbalance shown in Appendices 12 and 22. Overall, the RBF production well delivers water with an ion content that falls between the river and local groundwater (Figure 24). The RBF water, in comparison to the Kali River water, is more closely related to 'unimpacted waters,' such as groundwater, rural river water, and precipitation, seen in studies from other parts of the world (Duh et al, 2008; Hem, 1985; Gobel, Dierkes and Coldewey, 2007; Barber et al, 2006; Safai et al, 2004; Lee and Fetter, 1994).

METALS:

Table 15: Comparison of dissolved metals at RBF Well 3 to the Kali River at the field site and to the worst drinking water source in the area

RBF W3 = RBF Well 3; KKR = Kali River at Kariyampalli village; TT = Town Tap; OW = Open Well

	% improvement of RBF W3 over:		
	KKR	Worst currently used local drinking water	
			Location
Zn	49%	95%	Kerwad TT
Cd	-13%	79%	Kerwad OW
Pb	-28%	98%	Moulangi TT
Cu	57%	99%	Moulangi TT
Cr	92%	95%	Saksali OW
Mn	-60%	86%	Kerwad OW
Fe	-18%	77%	Kerwad OW

Table 15 compares the dissolved metals levels at the production well with those found at the Kali River at the field site and with the levels at the most contaminated sources of drinking water in the area that were in use by villagers at the time of the sampling (Appendices 25, 26, and 27). Overall, the average RBF water quality is superior to the alternatives and all applicable drinking water standards for metals were met. Based on the silica mixing model data, the improvement of the RBF water quality must be caused by processes other than just dilution.

Table 16: Comparison of metals concentration ranges on the Kali River and at RBF Well 3 from this study and previous studies

Levels from this study include outliers from the Halmaddi KR sample site (Appendix 3)

Metal	Range of Concentration (ppb)					
	Previous Studies		This Study			
	Kali River		Kali River		RBF Well 3	
	Low	High	Low	High	Low	High
Chromium	3	34	<0.07	3.3	<0.07	0.1
Manganese	4	1,635	<0.5	340	<0.5	270
Iron	270	3,650	<3.6	1,030	49	14,000
Copper	9	37	<0.09	5.3	<0.09	0.9
Cadmium	0	5	0.1	1.0	<0.08	1.4
Zinc	29	843	<1	230	<1	29
Lead	2	76	0.1	8.0	0.1	0.9

Table 17: Change in metals concentration at W3 over the expected SW / GW mixture
SW = surface water; GW = groundwater; W3 = RBF Well 3; KKR = Kali River at Kariyampalli village;
BW = Bore Well

Column	1	2	3	4	5	6
	Observed Average conc. of KKR (ppb)	Observed Average conc. of BW's (ppb)	Estimated % river water at W3 (via Silica data)	Expected W3 conc. via KKR / BW's mixture (ppb)	Observed RBF W3 conc. (ppb)	Average % change over KKR / BW's mixture
Cr	0.5	0.7	28%	0.74	0.07	90%
Pb	0.2	1.6	28%	1.2	0.2	82%
Cu	0.8	2.1	28%	1.8	0.4	80%
Zn	25	30	28%	29	13	56%
Mn	45	170	28%	140	73	47%
Cd	0.1	0.3	28%	0.24	0.13	47%
Fe	74	170	28%	140	87	40%

Table 17 shows that RBF processes other than dilution were at work in dissolved metals removal at the research site. Data used for this calculation have had outliers removed via Dixon's Q analysis as described earlier. Bore Well data is the average of concentrations seen at the in Mainal, Bada Khanshera, and Harnouda sites. One exception to this is the chromium Bore Well value, which lacks data from Mainal. Dissolved metals concentration at the Kali River sampled at the RBF wellfield site (column 1) is multiplied by the percentage of river water (column 3) and dissolved metals concentration at the nearby Bore Wells (column 2) is multiplied by the percentage of groundwater (100 minus column 3). The concentration of dissolved metals expected at the production well from dilution of the surface water and groundwater (column 4) results from the addition of these two products. In contrast, column 5 shows the actual metals concentrations at RBF W3. Column 6 quantifies the other RBF processes, such as sorption and precipitation, at work in the system. Column 4 minus column 5 then divided by column 4 yields Column 6 (the percent change at W3 over the concentrations expected via dilution alone) (see Appendix 27 for complete calculations). From Table 17 we see that, as with the bacteria data,

dilution itself (here, surface water is diluting groundwater) accounts for a portion, but not the entirety, of pollutant removal at the RBF wellfield.

Dissolved metal concentrations in all water sources are below BIS Desirable levels in all but 26 (6%) of 448 sample tests in this study. The majority of exceedances are for iron and manganese levels. This is presumably because of the climate and geology of the area, which retains high proportions of Fe and Mn during the formation of lateritic soils. The high content of these metals in soils is exemplified by this region's rich iron and manganese mining history. During drilling and pumping of new wells, the soils are temporarily disturbed. For instance, at RBF Well 4, the highest iron concentrations were measured after moving the pump from Well 4 to Well 3 on January 15, 2009 (13,000 mg/L). Shortly thereafter, the iron concentration decreased to 96 mg/L. This suggests that disturbances in the flow field and geochemistry caused by moving the pump resulted in temporarily higher iron concentrations, as well as manganese, which both diminished over time as the flow field stabilized again and less iron was flushed into the well water. In comparison, the 300 ppb standard for iron used by the WHO is an aesthetic standard, due to objectionable taste.

The highest overall iron levels seen in the study are found in Hand Pump samples (Appendices 25 and 26). At the RBF wellfield, iron concentrations ranged from 49 to 24,000 mg/L and generally decreased with time pumping. The lowest Fe concentrations were observed in Bore Wells and Town Tap water samples. With Bore Well depths around 90 meters, water from these sources is likely more characteristic

of the underlying metasedimentary rocks, rather than the laterized soils overlying them which are enriched in oxidized, and therefore soluble, iron and manganese.

Since this study limited sampling to less than a year, it is recommended to take additional samples for iron to determine if lower concentrations remain stable over time.

Figure 35: Average Fe levels in the RBF wellfield show an inverse relationship to distance to closest surface water (i.e. Kali River or the rice paddies around the Kariyampalli Open Well). Columns represent average dissolved iron concentration in ppb. Error bars show standard error. KR = Kali River at Kariyampalli village; W1, 2, 3 = RBF Well 1, 2, 3; KOW = Open Well at Kariyampalli village

As shown in Figure 35, there is an inverse relationship between iron concentration in water and distance to the nearest surface water bodies (i.e. Kali River and irrigated rice paddies). A less obvious, but similar trend can be observed in the case of Mn (Figure 36). Kuehn and Mueller (2000) stress the importance of redox conditions on the performance of RBF systems. Most bacterial reduction, facilitated by dissolved iron and manganese, occurs earlier on in the RBF process, in the reduced zone, while later, in the aerated zone, dissolved manganese and iron precipitate out of solution (Tufenkji, Ryan and Elimelech, 2002). Although this study's data set is small,

both the manganese and the iron levels in the RBF wellfield suggest that Well 1 is in a reducing zone, with another, less pronounced, reducing zone in the area where the irrigation water from the rice paddies flow towards Well 4 (Figures 7). Oxidation Reduction Potential readings support this hypothesis (Figure 31). ORP data from the RBF wellfield while Well 3 was the pumping well show reducing conditions (negative ORP values) at Well 1 (average ORP: -71 mV, n = 2, range: -72mV to -69 mV) which become more oxidizing at Well 3 (average ORP: 218 mV, n = 48, range: 46mV to 366 mV) and then less oxidizing again at Well 4 (average ORP: -70 mV, n = 6, range: -87mV to -35 mV) (Figure 31, Appendix 12).

Figure 36: Average Mn levels in the RBF wellfield show an inverse relationship to distance to closest surface water (i.e. Kali River or the rice paddies around the Kariyampalli Open Well). Columns represent average dissolved manganese concentration in ppb. Error bars show standard error. KR = Kali River at Kariyampalli village; W1, 2, 3 = RBF Well 1, 2, 3; KOW = Open Well at Kariyampalli village

As mentioned above, decreasing trends in iron content seen in previous studies since the early 1990's, as well as processing upgrades at the West Coast Paper Mill, imply that improved dissolved oxygen levels in the Kali River may lead to decreased iron levels at RBF Well 3 in the future, as more oxygen-rich river water leads to lower levels of dissolved iron and manganese in source waters. Similar results were seen in

RBF systems along Germany's Rhine River in response to improved water quality leading to higher dissolved oxygen levels in the river after environmental protection measures in the 1970's (Schmidt et al, 2003; Kuehn and Mueller, 2000).

Table 18: Comparison of BIS guidelines and concentrations at the RBF production well
BIS = Bureau of Indian Standards; RBF W3 = RBF Well 3; MPN = Most Probable Number

	BIS guideline		RBF W3 concentration		
	Desirable	Permissible	Average	Min	Max
Total coliform bacteria (MPN / 100 mL)	0.9 (95% of the time) 10 (5% of the time – cannot be consecutive samples)		85 (dry season: 66 wet season: 143)	4.1	920
<i>E. coli</i> bacteria (MPN / 100 mL)	0.9 (100% of the time)		3.6 (dry season: 1.8 wet season: 13)	0.9	64
Chromium (ppb)	50	-	<0.07	<0.07	0.08
Manganese (ppb)	100	300	72.8	<0.5	270
Iron (ppb)	300	1,000	87.2	49	14,000
Copper (ppb)	50	1,500	0.35	<0.09	0.86
Cadmium (ppb)	10	-	0.13	0.1	(1.4)
Zinc (ppb)	5,000	15,000	13	<1	29
Lead (ppb)	50	-	0.22	<0.09	0.89

In summary, total coliform BIS guidelines were never met during the study period because although levels did dip below 10 MPN / 100 mL, they never did so on consecutive days. *E. coli* bacteria BIS guidelines were met 10 days out of the 46 sampling days (22% of the time). These occurred in both the dry (9 days or 29% of the time) and the monsoon (1 day or 7% of the time) seasons. BIS standards were met 100% of the time for chromium, copper, cadmium, zinc, and lead readings. Manganese and iron concentrations, as mentioned above, met the BIS guidelines once the flow field stabilized at the research site.

FUTURE STUDIES:

There are many processes at the field site that warrant further research. Some involve strengthening the current data set by continued sampling and analysis. Others involve looking into topics that have not yet been covered in this study.

A more robust data set for all parameters collected in this study would allow for greater confidence in the conclusions. This includes a larger number of samples collected over longer time periods. Specifically, dissolved metals data would help with understanding the trends in iron and manganese levels in each well and whether metals concentrations in RBF water are affected by a monsoon climate. Continued bacteria testing would clarify whether the effects of moving the livestock away from the RBF wellfield resulted in a lasting decrease of bacterial concentration in the well water. Also, another full year of bacteria sampling without moving the pump would remove some of the suspicion regarding spikes in bacteria levels. Additionally, progressive dilutions of samples from the Kali River, the Kariyampalli Open Well, and the Mainal Bore Well would allow determination of the actual removal percentages of the RBF system with greater accuracy. Similarly, because villagers report less usage of the Kariyampalli Open Well (Appendix 2), that changed behavior might mean lower coliform counts in the Open Well due to fewer contaminated buckets being introduced into that water source. This might further lower bacteria levels in the RBF wells, particularly in the well closest to the Kariyampalli Open Well (RBF 4). Additionally, other water quality indicators including coliphages and pathogens such as *Legionella pneumophila*, *Helicobacter pylori* could be studied to further determine the safety of the RBF water (US EPA, 2008). A stronger and longer

lasting partnership with RBF users, the local clinic in Kariyampalli, and the hospital in Dandeli could reveal more accurate water quality and health data if more careful records are kept and analyzed. Repeating the exact questions asked in the pre-implementation survey would allow for significance testing of a greater number of responses in the post-implementation survey. A non-RBF user control group would also bolster the validity of the survey results.

It would be interesting to investigate the effects of varying the pumping schedule on water quality at RBF Well 3. This information could be used if minimum in-stream flow requirements necessitate pumping interruptions, for instance, during the driest Indian summer months just before the monsoon begins. This could be a problem, despite the existence of the dam upstream, if another drought occurs like the one in 2001 mentioned by villagers (Appendix 28). This knowledge would enable tandem use of RBF with other drinking water supplies, such as bore wells, to create a sustainable drinking water strategy for Kariyampalli and beyond.

CONCLUSIONS:

Kariyampalli village, south of Dandeli, Karnataka was in need of a reliable, safe drinking water supply and an ideal candidate for a riverbank filtration system. When looking at the overall picture of both bacterial and metals concentrations, RBF water is safer than any of the other drinking water sources in the area. Additionally, using RBF water instead of Bore Wells reduces groundwater depletion.

Ion analyses support the observation that the Kali River upstream of the research site is impacted by municipal and industrial inputs.

Bacterial pollution appears to be a larger problem in this area than metal pollution of the drinking water as all water samples exceeded BIS standards more frequently for bacteria levels than for metals levels. Samples indicate average removal at RBF Well 3 from the Kali River of 95% (maximum >99%) for total coliform and 99% (maximum >99%) for *E. coli* bacteria. The actual removal percentages are even higher, but could not be precisely determined in the field. Silica data indicate that water from RBF Well 3 is 28% river water. Yet dilution with groundwater by itself does not explain the reduction in metals and pathogen concentrations. Of the total coliform change, 23% is attributable to processes other than dilution by groundwater. As well, 27% of the change in *E. coli* concentration is due to non-dilution processes in the RBF wellfield. Stable isotope data indicate that the removal of both total coliform and *E. coli* levels by riverbank filtration could become even greater if the Kariyampalli Open Well is retired, as this might reduce the amount of bacteria introduced into the RBF wellfield. Additionally, if this project is replicated elsewhere in India in locations where the wellfield can be protected from irrigation water and

livestock manure, better pollutant removal can be expected, especially if the wells are set back further from the river, leading to travel times greater than the range of 8.7 - 23 days seen at this site. Although bacteria levels seen in the production well are generally slightly above BIS regulations, the levels are a great improvement over currently used water supplies. Data gathered during the monsoon season indicates increased bacteria levels during this season, but further protection of the wellfield from surface contamination by livestock manure may improve this problem. As Bore Wells are associated with groundwater depletion, RBF provides water that best addresses the combined issues of both groundwater depletion and surface water contamination.

Average RBF production well concentrations of metals, like most other sampled sources, are all below BIS standards, although the data for iron and manganese did temporarily range above BIS aesthetic guidelines.

This study, including a community survey, demonstrated that RBF-treated water is welcomed by local residents, and, through dilution and other processes, reduces pollutants found in source waters by up to >99%, producing water that is near or below BIS standards and leading to significantly improved self- and proxy-reported family health by RBF users.

Additionally, sanitation systems and hand-washing need to be combined with water quality efforts in addressing public health. Lastly, the problems with attaining BIS regulatory limits for bacteria show that RBF needs to be considered a pre-treatment method and combined with final finishing of the water via solar disinfection, chlorination, or other methods.

APPENDICES

Appendix 1: Previous Studies of Riverbank Filtration

Authors	Location	Climate	Aquifer Materials	Distance to River	% Groundwater
Boving et al., 2010	Zarqa River, Jordan	semi-arid	sand	5 m	
Grischeck et al., 2010	Neisse River, & Lakes Gottwitz and Dollnitz, Germany	temperate	sandy	Gottwitz: 200 m; Neisse: 50-150 m	Gottwitz: 87% GW
	S Platte, Cedar, and Ohio Rivers, US	temperate	sand & gravel	20-120 m	? 45% GW
Hoppe-Jones et al., 2010	Missouri River, US	temperate	sand and gravel	18.3 m vertical	10 - 50% GW
Kelly and Rydlund, 2006	Rhine River, Germany	temperate			
Kuehn and Mueller, 2000	Rhine River, Germany	temperate			
Schmidt et al., 2003	Rhine River, Germany	temperate			roughly 50%
Schubert, J in Ray et al., 2002	Rhine River, Germany	temperate		50-250 m	25% GW @ 50 m from river
Sontheimer, 1980	Rhine River, Germany	temperate			
Trettin et al., 1999	Elbe River, Germany	temperate	med sand to gravel w/ loam overburden	250 m	
Tufenkji et al., 2002	Rhine and Meuse Rivers, Netherlands	temperate		Rhine: 30 m; Meuse: 25 m	
Vogel et al., 2005	Platte River, US	temperate	sand & gravel w/ some silt & clay	< 40 m vertical	

Ranges for all studies: semi-arid & temperate Germany, US, and Jordan sand and gravel 5 - 250 m 25 - 87% GW

Appendix 1: Previous Studies of Riverbank Filtration

Travel Velocity

Travel Time	Travel Velocity (meters/day)	Bacteria Reduction	Metals Reduction
<1 day	5 m/d	E. coli: 99.95-99.96% (3.3-3.4 log)	
Gottwitz: 60 - 120 days; Neisse: 8 - 24 days	1.7 - 18.8 m/d		
7 - 25 days	0.8 - 17.1 m/d		Mn: increase by 2 - 24x; Nitrate: 40.5% removal
30 - 270 days	0.4 - 2.0 m/d	Total Coliform: 99.998% (4.61 log)	
5 - 100 days		Total Coliform: 99.99% (4.0 log)	
1 - 80 days			Zn 82%, Cu 51%, Pb 75%, Cr 94%, Cd 75%
14 days	3.6 - 17.9 m/d	E coli: 99.9% - 99.99% (3-4 log) avg	
20 - 30 days			
flooding: <1-160 days; receding: 1-200 days	1.3 - 250 m/d		
Rhine: 15 days; Meuse: 63 days	0.4 - 2 m/d	Total Coliform: both sites: 99.999% (5 log)	
30 - 60 days	0.7 - 1.3 m/d	Total Coliform: 99.2% (2.1 log); E coli 99.96% (3.4 log)	

1 - 200 days   0.4 - 250 m/d   Total Coliform: 99.2% - 99.999% (2.1 - 5 log);
E. coli: 99.9% - 99.994% (3 - 4.2 log)   Zn 82%, Cu 51%, Pb 75%, Cr 94%,
Cd 75%, Mn -2300%, NO3-: 40.5%

Appendix 2: HOUSEHOLD SURVEYS

METHODS:

Our non-profit study partner, TERI, conducted a survey of 110 households in 7 of Dandeli's satellite villages in 2008, before the RBF system was installed. De-identified data from 16 of the 34 questions from the survey are reported in this study. These questions covered water sources and supply (questions 5-9 and 14), water quality (questions 15-17), access to water (question 18), costs (question 22), usage of Kali River water (question 26), and health (questions 28-31) (see below).

Additionally, a post-implementation survey was conducted among nine households using the RBF water in Kariyampalli in 2010. De-identified data from 19 of the 28 questions from that survey are reported in this study. These questions covered water sources and supply (questions 3-4 and 6-8), water quality (questions 9-12), access to water (questions 13-15), costs (question 16), usage of Kali River water (question 19), health (questions 20-22), and workshop information (questions 23-24) (see below). In accordance with anonymity requirements, no data was analyzed from the socio-economic profiles of respondents. Those survey questions that passed normality testing of skew $<|2|$ and kurtosis $<|4|$ were evaluated for significance with independent samples t-tests in SPSS software (IBM, 2010) to correlate village location with water supply, water treatment, and villagers' health (five survey questions). These parameters (three survey questions) were also tested in the same fashion for significant changes before and after RBF installation in Kariyampalli.

RESULTS

2008 Household Survey:

The populations of the seven villages surrounding Dandeli were surveyed before the RBF system was installed. The baseline 2008 survey results from Kariyampalli were compared with those from the other 6 villages. Survey results from Kariyampalli represent 19 households out of a possible 37 (51.4% coverage) and in the other villages, results are from 91 households out of a possible 356 (25.6%). Kariyampalli had an average of 10 people per household. The average from the other 6 villages was 9.4 members per household. Thus, survey results from Kariyampalli represent approximately 190 people (out of roughly 370 people) and results from the rest of the villages represent approximately 855 people (out of a possible 3,350 people, approximately). Statistics from the local government show that 2.2% of households in Kariyampalli qualify as middle or upper income (above INR 12,000 per year (approximately USD 260)). This value is slightly higher than the 1.6% of households in the other 6 villages combined. These percentages range from 0 - 2.2% per village.

Water: The people of Kariyampalli experienced greater water shortages than those of other villages, although the Kariyampalli villagers reported a greater number of public taps in their village. This tap water was reported to be less reliable than those of other villages. Perhaps due to this problem, Kariyampalli residents showed a greater desire for private wells and taps than residents of surrounding villages. In contrast to their dissatisfaction with water supply, Kariyampalli villagers give a better rating to their water's quality than residents of other villages. The color and taste of water used for

drinking and cooking in Kariyampalli was reported as better than that of other areas in the survey. Perhaps because of the existence of a small health clinic in Kariyampalli, a greater proportion of these residents reported boiling, straining, or using mud or clay filters to purify their water. A disproportionately high percentage of people in Kariyampalli reported that their water supply was a 10 minute walk or more from their house compared with results from all villages. Water in Kariyampalli was reported to be free of charge to a greater extent than in the sister villages. Residents of Kariyampalli relied more on the combined usage of Kali River and Open Well water for drinking and domestic uses (63%) than all other villagers (33%) (Table 28, Figure 48).

Health: A greater percentage of Kariyampalli survey respondents than respondents from other villages said that their family's health was average or bad. Additionally, more people from Kariyampalli felt that their drinking water quality was related to their health. A smaller percentage of Kariyampalli residents (37% versus 60% of all other villagers) reported never having gastrointestinal distress at all during the year. More Kariyampalli residents report seeing a doctor if they have diarrhea (Table 28, Figure 48).

Results from Kariyampalli (n = 16 - 19) and all other villages (n = 62 - 91) in the 2008 survey were compared to determine if Kariyampalli residents showed significant differences regarding the following parameters:

- Usage of Kali River water for household purposes in the wintertime;

(Q5 and Q26), Kariyampalli (n = 19), all other villages (n = 83(Q26), n = 89(Q5))

- Water shortages experienced for household uses in the wintertime;

(Q6), Kariyampalli (n = 16), all other villages (n = 80)

- Water treatment techniques (divided into 3 categories of: boil, filter/strain/sedimentation, and no treatment);

(Q17), Kariyampalli (n = 19), all other villages (n = 62)

- Overall family health (good, average, and bad);

(Q28), Kariyampalli (n = 19), all other villages (n = 91)

- Occurrence of diarrhea (never, sometimes, always);

(Q30), Kariyampalli (n = 19), all other villages (n = 84)

Independent samples t-tests found no significant differences for any of these questions except family health. Kariyampalli villagers reported significantly worse health than families in other villages (Table 32).

2010 Household Survey: After the RBF system was operational for about one year, a follow up survey was conducted in Kariyampalli village. Nine Kariyampalli households who were RBF water users took the post-implementation survey in 2010.

These represent 24.3% of the 37 total households (both RBF users and non-users) in the village.

Water: Survey respondents use the RBF water for household uses such as drinking and cooking. None reported using it for agricultural purposes. One third of RBF users reported water shortages that are “not too bad” for household use and the rest stated that they have no water shortage concerns. Similarly, one third of respondents claim that the RBF water supply is irregular, and the rest that the supply comes regularly every day. 89% of RBF users also use other water sources. There is incomplete data on which water sources are referred to in this question. The RBF water is reported to be ‘clear’ by 100% of users and to taste either sweet (11%), normal (56%), or bitter (33%). None of the RBF users reported purifying the RBF water before using it, with 56% being “satisfied” and 44% “very satisfied” with the water quality. Two thirds of users say that the water supply is within a 10 minute walk from their house. As a consequence, 78% state that they spend less than half an hour per day collecting water for the household. 33% pay nothing for the water and 67% pay between INR 30 - 50 per month for the RBF water. 58% of those surveyed use Kali River water for agricultural purposes, but none use the river water within their household.

Health: Two thirds of surveyed residents describe their family’s health as “good” and one third as “average,” with none reporting “bad” health. Only 11% feel that the RBF water affects their health. Two thirds state they do not experience gastrointestinal distress. 11% state that they sometimes have episodes of diarrhea and 22% said that

they don't know. 56% of these users attended the water hygiene and sanitation workshops held the previous year. Of those that attended, they claimed these workshops were either "good" or "very good."

Results comparing Kariyampalli residents' responses in 2008 (n = 16 - 19) and 2010 (n = 9) were compared for the following parameters, which met normality standards:

- Water shortages experienced for household uses in the wintertime;

Q6, 2008 (n = 19); Q6, 2010 (n = 9)

- Overall family health (good, average, and bad);

Q28, 2008 (n = 16); Q20, 2010 (n = 9)

- Occurrence of diarrhea (never, sometimes, always);

Q30, 2008 (n = 19); Q22, 2010 (n = 9)

Independent samples t-tests found that self-reported family health in Kariyampalli was significantly better in 2010. The other questions did not reveal significant differences. Question 8, concerning the usage of Kali River water for household purposes by Kariyampalli residents in the wintertime did not meet requirements for normal distribution, and therefore could not be compared with 2008 data for statistical relevance. Other questions in the 2010 survey could not be tested for significance

with the 2008 questions because the wording or meaning of the questions did not match.

DISCUSSION:

2008 Household Survey:

Health: Higher usage of river water may be related to the greater percentage of Kariyampalli survey respondents that said their family's health was average or bad. The larger proportion of Kariyampalli residents (compared to other villages) who felt that their drinking water quality was related to their health could be explained by the higher usage of the suspect water sources and/or greater education due to the existence of the health clinic. Again, the existence of the health clinic may explain the greater likelihood that Kariyampalli residents will see a doctor if they have diarrhea. The significance finding of villagers' self-reported family health may also be a reflection of the exposure to the health clinic in the village. Education at the health clinic may make residents more aware of outside standards of family health than residents of other villages who may not visit health clinics as often (Table 28, Figure 48).

Answers to questions 5 ("Which sources of water do you use for household purposes during the year?") and 26 ("Do you presently use Kali River water? If so, do you use it for drinking, agriculture, domestic purposes, or no opinion?") (see below, also Figure 48) from the household survey cast some doubt on the reliability of the survey results, at least for those two questions. Options for water sources include tap at home, public tap, private well, public well, tankers, river water, bottled water, and

other. An additional space was provided in question 5 to check if the water is used for drinking/cooking. These two questions should give a similar result for drinking and domestic usage of river water in the season that the survey was conducted (winter). This is not the case. 32% of Kariyampalli residents reported using Kali River water in the winter for drinking and cooking (Q5) and 74% said they used Kali River water ‘presently’ (Q26). Among residents of the other 6 villages, 29% said that they used Kali River water in the winter for drinking and cooking (Q5) and 62 - 65% reported using Kali River water ‘presently’ for domestic and drinking purposes (Q26). It is unclear why the results within villages are near complements of each other. There may have been ambiguity introduced into these questions via translation into Kannada or transcription errors. Additionally, respondents may have been distracted by the time they had gotten to the 26th question in the survey. Since the same survey was used in all the villages in 2008, it seems valid to compare these questions between Kariyampalli and the other villages. Nevertheless, whether 32% or 74% of Kariyampalli residents drank Kali River water before the RBF project was installed, none of the RBF users in Kariyampalli reported river water usage for domestic purposes in the follow-up survey a year later.

2010 Household Survey:

Water: Cost considerations may explain why none of the survey respondents reported using the RBF water for agricultural purposes. Another reason may be that the water tank is too far away from their fields. The report of bitter-tasting water may not necessarily be a negative attribute as bitter flavor is considered to be one of the six

basic flavors in a well-rounded Indian meal. In traditional Indian Ayurvedic medicine, bitter flavor is used to purify the body and aid in digestion (Gupta,). The minimal concern for water shortage by RBF users implies that there is enough water in the house to use for hand washing, a crucial element in family health (WHO, 2005; Ejemot et al, 2009; Fewtrell et al, 2005).

Hand washing education was a component of the overall project in which this study was conducted. (Fewtrell et al, 2005) found, in reviewing 38 articles on various techniques for reducing diarrhea in developing countries, that a 15% reduction could be attributed to water quality improvements and a 33-42% reduction from hand washing education, although they do state that possible publication bias may lead to inflated numbers (Fewtrell et al, 2005). Another meta-analysis of five trials found a 30-32% reduction in diarrhea attributable to hand washing education (Ejemot et al, 2009). The World Health Organization has stated that a 25% reduction in diarrhea can be expected from water quality interventions and a 45% reduction from hygiene improvements (WHO, 2005). Therefore we can expect that approximately 15-25% of the diarrhea reduction seen in this study was attributable to the RBF system and 30-45% to the hand washing education workshops. Combined, these two factors then account for 45-70% of the reduction in diarrhea.

QUESTIONS USED FROM 2008 BASELINE SURVEY:

WATER SOURCE/SUPPLY

5. Which sources of water do you use for household purposes during the year?
(Write 1= for Yes and 2= No in the relevant columns)

Source	Mar-May	June-Sept	Oct-Feb	Check if used for drinking / cooking
a. Tap at home				
b. Public tap				
c. Private Well				
d. Public Well				
e. Tankers				
f. River water				
g. Bottled water				
h. Other				

6. Do you face any shortage of water for **household use** during the year?
- i. No
  - ii. Yes - Mar to May (1) severe (2) not too bad (3) no problem
  - iii. Yes – June to Sept (1) severe (2) not too bad (3) no problem
  - iv. Yes – Oct – Feb (1) severe (2) not too bad (3) no problem
7. Are there public taps in your village?
1. Yes
  2. No
  3. Don't know
8. How would you describe the water supply from public taps? Do you consider it regular (does it come everyday) or irregular?
- a) March-May 1.Regular 2. Irregular 3. No water at all 4. Don't know
  - b) June-Sept 1.Regular 2. Irregular 3. No water at all 4. Don't know
  - c) Oct-Feb 1.Regular 2. Irregular 3. No water at all 4. Don't know
9. How many hours a day is the supply from public taps?
- A) Mar-May _____
  - B) June – Sept _____
  - C) Oct – Feb _____

Write the appropriate number in the space provided

1. no water at all
2. less than 2 hours
3. 2-5 hrs a day
4. 6-12 hr s
5. 24hrs

14. If you had a choice which kind of drinking water source would you pick (circle one):

A. Tanker	B. Public well	C. Private Well
D. Public tap	E. Private tab	F. Stream

WATER QUALITY

15. What is generally the colour of the water you use for drinking and cooking?

1. Clear
2. Cloudy
3. Brownish/ orangish
4. Brackish

16. What is generally the taste of water you use for drinking and cooking?

1. Sweet
2. Salty
3. Bitter
4. Metallic (taste of rust)
5. Chemical
6. Normal
7. Other

17. How do you purify water for drinking?

1. Boil
2. Tap filter / strain through cloth
3. Water filter
4. Mud / clay pot
5. Sedimentation
6. Other method (specify)

ACCESS TO WATER

18. How far away is your drinking water source?

- a. I have tap water at home
- b. Right outside the house
- c. less than a 10 min walk to and from
- d. between 10 and 20 min walk to and from
- e. about 30 min walk to and from
- f. about 1 hour walk to and from
- g. more than 1 hour walk to and from (Specify: ____ hours)

COSTS/WILLINGNESS TO PAY

21. Roughly how much is your monthly water bill?

- a. Nothing
- b. Less than Rs.50
- c. Between Rs. 51 to 75
- d. Between Rs. 76 to 100
- e. Between Rs.100- 150
- f. More than Rs. 150

KALI RIVER WATER

24. Do you presently use Kali River water?

1. Yes

If yes, what do you use it for

- 1. Drinking purpose
- 2. Agriculture purpose
- 3. Domestic propose
- 4. No opinion

2.No

If No, Why not?

- 1. Not accessible
- 2. Bad quality
- 3. Others (specify).....

HEALTH

26. How would you describe health of your family members?

1.Good

2.Bad

3.Average

27. Do you feel that your drinking water quality has something to do with your health?

- a. Yes
- b. No
- c. Don't know

28. Do you have stomach problems or episodes of diarrhea? If yes, then when are the most likely episodes of diarrhea that you have observed?

- a. Always
- b. Sometimes (maybe they cannot pin-point when in the year)
- c. Only in June – September
- d. Only in Oct. – Feb.
- e. Only March - May
- f. Never
- g. Don't know

29. If you have diarrhea, do you see the doctor?

a. Yes

b. No

QUESTIONS USED FROM 2010 FOLLOW-UP SURVEY:

8. Do you use RBF water for household purposes?
 1. Yes   2. No   3. Don't know

9. What purpose do you use RBF water
(Write 1= for Yes and 2= No in the relevant columns)

All purpose	Drinking	Cooking	Agriculture

30. Do you still face any shortage of water for household use?
 i. No
 ii. Yes   (1) severe   (2) not too bad   (3) no problem
31. How would you distinguish between RBF water supply from other sources (public taps)? Do you consider it regular (does it come everyday) or irregular?
 1.Regular   2. Irregular   3. No water at all   4. Don't know

32. Do you still depend on water supply from sources other than RBF?
 i. No (if no, no more questions)
 ii. Yes   1. Daily   2. Alternate days   3. Only when needed
 Please describe the other water source (es): _____

33. What is generally the colour of the RBF water?
 a. Clear
 b. Cloudy
 c. Brownish/ orangish
 d. Brackish

34. How do you feel the taste of RBF water?
 a. Sweet
 b. Salty
 c. Bitter
 d. Metallic (taste of rust)
 e. Chemical
 f. Normal
 g. Other

35. Do you purify RBF water for drinking?
- No
  - Yes
- Boil
  - Tap filter / strain through cloth
  - Water filter
  - Mud / clay pot
  - Sedimentation
  - Other method (specify)
36. Overall, how satisfied are you with RBF water quality?
- Very Satisfied
  - Satisfied
  - Unsatisfied
37. How far away is the RBF water supply from your house?
- Right outside the house
  - Less than a 10 min walk to and from
  - Between 10 and 20 min walk to and from
  - About 30 min walk to and from
  - More than 30 min walk to and from (Specify: ____ hours)
38. How much time per day do you spent on obtaining RBF water for your household?
- No time
  - Less than ½ hour
  - Less than 1 hr
  - Between 1 and 2 hours
39. Do you still have to miss your jobs or other work to be around your house when the water comes?
- YES
  - NO- this is not a problem
  - NO- there are others at home to help fill the water
40. Roughly how much do you pay monthly for RBF water?
- Nothing
  - Less than Rs.30
  - Between Rs. 30 to 50
  - More than Rs. 50
42. Do you still use Kali River water?
- No, not any more for household purpose
  - Yes, only for agriculture purpose
  - Others (specify) .....
43. How would you describe health of your family members?
- Good
  - Bad
  - Average

44. Do you feel that RBF water quality is affecting your health?
- a. Yes
  - b. No
  - c. Don't know
45. Do you still have stomach problems or episodes of diarrhea? If yes, then when are the most likely episodes of diarrhea that you have observed?
- a. Everyday
  - b. Sometimes
  - c. Only after drinking RBF water
  - d. Only after drinking water other than RBF water
  - e. No more
  - f. Don't know
46. Did you participate in workshops that taught about water hygiene and sanitation practices conducted by RBF team?
- a. Yes
  - b. No
47. Did the workshops conducted on water hygiene and sanitation useful? How would you rate these workshops?
- a. Yes
    - 1. Very Good
    - 2. Good
    - 3. Average
    - 4. Not up to the mark
  - b. No

Appendix 3: Previous Studies on the Kali River

Study	Manjunatha et al., 2001	Bharati and Krishnamurthy, 1990	Bharati and Krishnamurthy, 1992	Krishnamurthy and Bharati, 1994
Location	Kadsali to Karwar	Dandeli	Dandeli	Dandeli
Date	2001	1985 - 1986	1987 - 1988	1987 - 1988
pH		7.6 - 7.7	6.78 - 10.92	7.03 - 8.51
Temp (°C)		25.4 - 26.4		25.75 - 30.16
EC (uS/cm)				64.25 - 640.58
TDS		75.0 - 359.5 (total solids)		2.79 - 35.33 (Turbidity)
Turbidity				
free chlorine				
Ammonia - Nitrogen (NH ₃)		0.222 - 0.373		0.220 - 0.450
Oxidized Nitrogen (NO ₃ + NO ₂)		0.560 - 2.184		0.630 - 1.720
Og Nitrogen (O-N)		0.341 - 0.566		0.330 - 0.820
Total Ammonia		0.222 - 0.373		
NO ₃ -				
F-				
Cl-		18.1 - 83.4		17.66 - 117.97
PO ₄ -		0.015 - 0.070		0.022 - 0.090
SO ₄ -		3.0 - 96.6		
Bicarbonate		97.6 - 245.2		48.81 - 203.02
Carbonate		18.0 - 36.0		30.50 - 79.00
Alkalinity				
Total Hardness		19.0 - 45.0 (as CaCO ₃)		16.89 - 208.56
Calcium Hardness as CaCO ₃		14.5 - 126.9		
Ca ²⁺	0.8 - 6.3	5.6 - 50.9		5.12 - 59.18
Mg ²⁺	0.9 - 1.7	1.0 - 5.1		1.00 - 13.3
Na ⁺	2.8 - 5.4	4.6 - 192.0		8.17 - 63.61
K ⁺	0.5 - 0.7	1.0 - 37.2		1.28 - 10.33
Mn (ppb)	1.1 - 11.1	3000-4500	4 - 1635	4 - 635
Fe ²⁺				
Fe ³⁺				
Fe	13 - 104	1.8 - 3.65	0.270 - 3.299	0.270 - 3.299
Al				
Silica		4.0 - 12.0		5.11 - 8.83 (Silicates)

Study	Manjunatha et al., 2001	Bharati and Krishnamurthy, 1990	Bharati and Krishnamurthy, 1992	Krishnamurthy and Bharati, 1994
Location	Kadsali to Karwar	Dandeli	Dandeli	Dandeli
Date	2001	1985 - 1986	1987 - 1988	1987 - 1988
Cr (ppb)			3 - 34	3 - 34
Co (ppb)	0.1 - 1		3 - 32	3 - 32
Ni (ppb)	0.1 - 1.6		5 - 32	12 - 32
Cu (ppb)	0.2 - 3.3		9 - 37	9 - 37
Zn (ppb)	0.3 - 26.8		29 - 843	29 - 843
Rb (ppb)	0.3 - 1.3			
Sr (ppb)	7.1 - 20			
Mo (ppb)	0.00 - 0.1			
Cd (ppb)	0.1 - 0.2		0 - 5	0 - 5
Ba (ppb)	0.9 - 7.6			
Hg (ppb)				
Pb- (ppb)	0.1 - 3		2 - 76	2 - 76
DO		4.1 - 7.8		2.8 - 7.67 (Oxygen)
COD		13.8 - 113.8		4.94 - 131.89
Free CO2		2.1 - 6.1		2.33 - 4.27
Dissolved Og Matter		1.4 - 27.3		0.830 - 36.05
Total Residue				87.78 - 626.27

All values in mg/L unless otherwise noted

Krishnamurthy and Bharati, 1996	Subramanian et al, 1987	Chavadi and Gokhale, 1986			
Dandeli	Kadra, below lowest dam	Tattihalla Tributary	Dandeli	Halmaddi	Kadra, 35 km from coast
1987 - 1988	1978, 1984	1983-1984	1983- 1984	1983-1984	1983- 1984
7.03 - 8.51	7.2	7.6 - 9.2	7.5 - 9.1	6.9 - 9.4	8.0 - 9.6
	141 (mS?)	185 - 370	52 - 125	150 - 1200	59 - 260
	99	40 - 160	30 - 90	100 - 1070	70 - 1040
17.66 - 117.97	16				
0.022 - 0.090					
3.66 - 52	3.8				
	26				
16.89 - 208.56					
	11.2				
	4				
	2.2	43 - 94	53 - 207	57 - 312	67 - 200
	0.7	6.0 - 73	1.0 - 22	1.0 - 72	1.0 - 37

BIS 10500 Indian Standards Desirable (permissible) Limit in mg/L	WHO Guideline (or aesthetic) Values in mg/L	Study
		Location
1991	2006	Date
6.5 - 8.5		pH
		Temp (°C)
		EC (uS/cm)
500 (2000)		TDS
5 (10) NTU		Turbidity
≥ 0.2	≥ 0.5	free chlorine
		NH ₃
		NO ₃ + NO ₂
		Og N
		Total Ammonia
45 (100)	50 (short term exposure)	NO ₃ -
1 (1.5)	1.5	F-
250 (1000)		Cl-
		PO ₄ -
200 (400)		SO ₄ -
		Bicarbonate
		Carbonate
200 (600)		Alkalinity
300 (600)		Total Hardness
		Ca Hardness
75 (200)		Ca ²⁺
		Mg ²⁺
		Na ⁺
		K ⁺
100 (300)	100 (500)	Mn (ppb)
		Fe ²⁺
		Fe ³⁺
0.3 (1.0)		Fe
0.03 (0.2)		Al
		Silica

BIS 10500 Indian Standards Desirable (permissible) Limit in mg/L	WHO Guideline (or aesthetic) Values in mg/L	Study
		Location
1991	2006	Date
50	50	Cr (ppb)
		Co (ppb)
	70	Ni (ppb)
50 (1,500)	2,000	Cu (ppb)
5,000 (15,000)	(3,000)	Zn (ppb)
		Rb (ppb)
		Sr (ppb)
	70	Mo (ppb)
10	3	Cd (ppb)
	700	Ba (ppb)
1	6	Hg (ppb)
50	10	Pb- (ppb)
		DO
		COD
		Free CO ₂
		Dissolved Og Matter
		Total Residue

Depth (m)	Well Construction	Water Level	Graphic Log	Description
	Cap			ground surface
1	6" Steel Pipe in 7 1/2" Hole	max water level 1/09		top soil, dark reddish-brown, damp (grass-covered)
2				brown-red silty loam, damp
3				
4				
5				
6				
7				
8				
9				light brown fine sand to silt, damp
10				
11				gray-brown silty sand, dry - weathered rock
12				
13				
14	6 1/2" Open Borehole	water level 10/08		
15				solid bedrock (graywacke)
16				
17		well depth 1/09		
18				
19				
20				

Appendix 4:
Drill Log for
RBF Well #1

**Appendix 4:
Drill Log for
RBF Well #1**

Depth	Well	Levels	Graphic Log	Description
	Cap			ground surface
1 m	6" Steel Pipe in 7 1/2" Hole	max water level 1/09		1 top soil, dark reddish-brown, damp (grass covered)
2 m				2 brown-red silty loam, damp
3 m				3
4 m				4
5 m				5
6 m				6
7 m	6" Steel Screen in 7 1/2" Hole			7
8 m				8
9 m				9
10 m				10
11 m				11
12 m	6 1/2 " Open Borehole	water level 10/08		12 light brown, weathered bedrock
13 m				13
14 m				14
15 m				15 solid bedrock (graywacke)
16 m				16
17 m				17
18 m				18
19 m				19
20 m				20
21 m				21
22 m				22
23 m		well depth 1/09		23
24 m				24
25 m				25

**Appendix 4:
Drill Log for
RBF Well #2**

**Appendix 4:
Drill Log for
RBF Well #2**

Depth (m)	Well	Levels	Graphic Log	Description
	Cap			ground surface
1	6" Steel Pipe in 7 1/2" Hole			1 top soil, dark reddish-brown, damp, (grass covered)
2				2 brown-red silty loam, damp
3				3
4				4
5	6" Steel Screen in 7 1/2" Hole	max water level 1/09		5
6				6
7				7
8				8
9				9
10				10 brown loam and clay, damp
11	6 1/2 " Open Borehole			11
12				12 light brown, weathered bedrock
13				13
14		water level 10/08		14
15				15 solid bedrock (graywacke)
16				16
17				17
18				18
19				19
20				20
21				21
22				22
23				23
24				24
25				25

**Appendix 4:
Drill Log for
RBF Well #3**

Depth	Well	Levels	Graphic Log	Description
	Cap			ground surface
1 m	6" Steel Pipe in 7 1/2" Hole	max water level 1/09	1	top soil, dark reddish-brown, damp (grass covered)
2 m			2	brown-red loam, damp
3 m			3	
4 m			4	
5 m			5	
6 m			6	
7 m	6" Steel Screen in 7 1/2" Hole		7	
8 m			8	
9 m			9	
10 m			10	brown-red, silty-sandy clay, damp
11 m			11	
12 m			12	coffe brown , silty sandy, dry weathered bedrock
13 m			13	
14 m			14	
15 m	6 1/2 " Open Borehole	water level 10/08	15	dark rock flower, graywacke, solid bedrock, rock sample (#4)
16 m		16		
17 m		17		
18 m		18		
19 m		19		
20 m		20		
21 m		21		
22 m		22		
23 m		23		
24 m		24		
25 m		25		

Appendix 4:
Drill Log for
RBF Well #4

**Appendix 4:
Drill Log for
RBF Well #4**

Appendix 4: Drill Log Data for RBF Wells

Drill Log Data

University of Rhode Island
Department of Geosciences
Kingston, RI 02881

Project World Bank DM 2008
Location Kariampalli, Karnataka, India
Date Drilled Oct. 26, 2008

Drilling Company Rani Fast Drilling
Log by Boving
Drilling Method Air hammer rotary
Sampling Composite samples

#	Total Depth of Hole	Water level	Steel Screen		Steel Casing Diameter	Screen Slot	Screen Length	Screen Interval (bgs)
			Diameter	Diameter				
1	60 ft (20 m)	43.6 ft (13.3 m)	6" (15.25 cm)	7.5" (19 cm)	Welded holes	No screen	(n/a)	
2	75 ft (22.9 m)	43.6 ft (13.3 m)	"	"	"	20 ft (6.1 m)	20 ft (6.1 m) - 40 ft (12.2 m)	
3	"	40 ft (12.2 m)	"	"	"	"	18 ft (5.5 m) - 38 ft (11.6 m)	
4	"	45.9 ft (14 m)	"	"	"	"	22 ft (6.7 m) - 42 ft (12.8 m)	

Appendix 5: Independent Chemical Laboratory Data

ANALYTICAL SOLUTIONS
WORLDWIDE

SHIVA ANALYTICALS (INDIA) LIMITED

Plot No. 24D [P] & 34D, KIADB Industrial Area,
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Mobile : +91-99002 42040/41/42/43
Web : www.shivatec-india.com, Email : info@shivatec-india.com

Test Certificate

SAIL No.: 03149

Issued To :

The Energy & Resources Institute.,
Western Regional Centre,
House No. 233 / GH - 2, Vasudha Housing Colony
Alto-St, Cruz, Bambolim, Goa - 403 202

Ref : Letter

Date : 12.06.2008

CA No. : 00509062881

Date of Receipt : 18.06.2009

Date of Report : 29.06.2009

Matrix : Water Sample

....Page : 1 of 2

Customer ID :

Sl.No.	Parameters	Results	Limits as per IS : 10500-1991	Protocol
A. Essential Characteristics				
1.	Colour, Hazen Units	10	5 max	IS : 3025 (P - 4) 1983
2.	Odour	Unobjectionable	Unobjectionable	IS : 3025 (P - 5) 1983
3.	Taste	*	Agreeable	IS : 3025 (P - 7) 1984
4.	Turbidity, NTU	8	5 max	IS : 3025 (P - 10) 1984
5.	pH Value	6.6	6.5 - 8.5	IS : 3025 (P - 11) 1983
6.	Total Hardness (as CaCO ₃), mg/l	144	300 max	IS : 3025 (P - 21) 1983
7.	Iron (as Fe), mg/l	< 0.05	0.3 max	IS : 3025 (P - 2) 2004
8.	Chlorides (as Cl), mg/l	37	250 max	IS : 3025 (P - 32) 1988
9.	Residual free chlorine, mg/l	< 0.1	0.2 min	IS : 3025 (P - 26) 1986
10.	Fluoride (as F), mg/l	0.4	1 max	APHA 21 st Edition (P 4500D) 2005
B. Desirable Characteristics				
1.	Total Dissolved Solids, mg/l	206	500 max	IS : 3025 (P - 16) 1984
2.	Calcium (as Ca), mg/l	38.8	75 max	IS : 3025 (P - 40) 1991
3.	Magnesium (as Mg), mg/l	11.4	30 max	IS : 3025 (P - 40) 1991
4.	Copper (as Cu), mg/l	< 0.05	0.05 max	IS : 3025 (P - 2) 2004

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Note: 1. The results listed above pertain only to the tested samples and applicable parameters.

2. Samples which are degradable will be disposed immediately after testing and others will be disposed after one month from the date of issue of test certificate unless otherwise specified.

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Ref : Letter

Date : 12.06.2008

CA No. : 00509062881

Date of Receipt : 18.06.2009

Date of Report : 29.06.2009

Matrix : Water Sample

Customer ID :

Sl.No.	Parameters	Results	Limits as per IS : 10500-1991	Protocol
1.	Pesticides, mg/l	Absent	Absent	GC - MS

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SAIL No.: 03149

Ref : Letter

Date : 12.06.2008

CA No. : 00509062881

Date of Receipt : 18.06.2009

Date of Report : 29.06.2009

Matrix : Water Sample

....Page : 2 of 2

Customer ID :

Sl.No.	Parameters	Results	Limits as per IS : 10500-1991	Protocol
5.	Manganese (as Mn), mg/l	< 0.05	0.1 max	IS : 3025 (P - 2) 2004
6.	Sulphates (as SO ₄), mg/l	6	200 max	IS : 3025 (P - 24) 1986
7.	Nitrate (as NO ₃), mg/l	< 1	45 max	APHA 21 st Edition (P 4500B) 2005
8.	Phenolic Compounds (as C ₆ H ₅ OH), mg/l	< 0.001	0.001 max	APHA 21 st Edition (P5530D) 2005
9.	Mercury (as Hg), mg/l	< 0.001	0.001 max	IS : 3025 (P - 2) 2004
10.	Cadmium (as Cd), mg/l	< 0.01	0.01 max	IS : 3025 (P - 2) 2004
11.	Selenium (as Se), mg/l	< 0.01	0.01 max	IS : 3025 (P - 2) 2004
12.	Cyanide (as CN), mg/l	< 0.01	0.05 max	APHA 21 st Edition (P4500E) 2005
13.	Arsenic (as As), mg/l	< 0.01	0.01 max	IS : 3025 (P - 2) 2004
14.	Lead (as Pb), mg/l	< 0.05	0.05 max	IS : 3025 (P - 2) 2004
15.	Zinc (as Zn), mg/l	< 0.05	5 max	IS : 3025 (P - 2) 2004
16.	Anionic detergents (as MBAS), mg/l	< 0.1	0.2 max	APHA 21 st Edition (P5540C) 2005
17.	Polynuclear Aromatic Hydrocarbons (as PAH), mg/l	< 0.01	Not Specified	APHA 21 st Edn 2005
18.	Chromium (as Cr ⁺⁶), mg/l	< 0.05	0.05 max	APHA 21 st Edition (P3500B) 2005
19.	Mineral Oil, mg/l	Absent	0.01 max	IS : 3025 (P - 39) 1991
20.	Alkalinity (as CaCO ₃), mg/l	135	200 max	IS : 3025 (P - 23) 1986
21.	Aluminium (as Al), mg/l	< 0.03	0.03 max	IS : 3025 (P - 2) 2004
22.	Boron, mg/l	< 0.05	1 max	IS : 3025 (P - 2) 2004
C Bacteriological Tests				
1.	Total Coliforms (MPN Coliforms) / 100ml	7	10 max	IS : 1622 : 2003
2.	E. Coli / 100ml	Absent	Absent	IS : 1622 : 2003

Note : Residual Free Chlorine test is applicable only when water is chlorinated.

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Ref : Letter

Date : 12.06.2008

CA No. : 00509062881

Date of Receipt : 18.06.2009

Date of Report : 29.06.2009

Matrix : Water Sample

Customer ID :

Sl.No.	Parameters	Results	Protocol
Dioxins, ppm			
1.	2,3,7,8 Tetrachloro dibenzo-p-dioxin	< 0.01	GC - MS
2.	1,2,3,7,8 Pentachloro dibenzo-p-dioxin	< 0.01	
3.	1,2,3,4,7,8 hexachloro dibenzo-p-dioxin	< 0.01	
4.	1,2,3,4,6,7,8 heptachloro dibenzo-p-dioxin	< 0.01	
5.	Octa chloro dibenzo dioxin	< 0.01	
Chlorinated phenols, ppm			
7.	Penta Chlorophenol	< 0.01	GC - MS
8.	2,4-Dichlorophenol	< 0.01	

- Note :
1. The results listed above pertain only to the tested samples and applicable parameters.
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Appendix 6: Dharwad District Health Lab Bacteria Data

Government of Karnataka, Office of the Senior Specialist, District Health Lab, Dharwad
Report on Bacteriological Analysis of Water and Effluent Samples

	K. Well	near B. school	B. Village Center	Havgi Village near College	Mainal	Mainal	H.	K.	H. Gram	K. Gram	Mainal	B.	Unknown	Total Min	Total Max	Bore well avg
Location Type	K. BW	Hand Pump	Hand Pump	BW	KR	BW	BW	BW	BW	BW	Kali River	BW	unknown	all	all	BW
Village	K. B.	B.	B.	Havgi	Mainal	Mainal	H.	K.	H.	K.	Mainal	B.	unknown			
Date									Jan 19 2004	Jan 19 2004	Jan 19 2004	Jan 19 2004	Aug 22 2003	8/03	1/04	
MPN / 100	46	1600	0	0	60	9	42	0	0	0	25	0		0	1600	12.13
mL																
Water deemed safe for drinking?	No	No	Yes	Yes	No	Yes	No	Yes	Yes	Yes	No	Yes	No	7/13 =	54 %	
E coli found	Yes	Yes	No	No	Yes	No	Yes	No	No	No	Yes	No	*		1/7 =	25%

* "shows evidence of recent fecal contamination" [letter from Hubli to Haliyal Community Health Center, in packet with Dandeli area tests]

All of these data were collected on October 8, 2003 unless otherwise noted

B.: Bommanahalli, K.: Kariyampalli, H.: Harnouda; highlighted columns are bore well data

Appendix 7: Indian Groundwater bacteria data

CPCB 2006 Data plus Dharwad Health Lab and RBF All GW data (+ CPCB unspecified well types) but not OW + suspect data	Fecal Coliform (MPN/100 ml)			Total Coliform (MPN/100 ml)		
	Min	Max	Mean	Min	Max	Mean
2006 Andhra Pradesh				7	7	7
2006 Andhra Pradesh	2	2	2	21	21	21
2006 Andhra Pradesh	2	2	2	480	480	480
2006 Andhra Pradesh	3	3	3	80	80	80
2006 Andhra Pradesh	2	2	2	11	11	11
2006 Andhra Pradesh	2	2	2	7	7	7
2006 Andhra Pradesh				43	43	43
2006 Andhra Pradesh	3	3	3	100	100	100
2006 Andhra Pradesh	3	3	3	150	150	150
2006 Andhra Pradesh	2	2	2	70	90	80
2006 Andhra Pradesh	2	2	2	75	75	75
2006 Andhra Pradesh	2	2	2	2500	2500	2500
2006 Andhra Pradesh	2	2	2	2500	2500	2500
2006 Andhra Pradesh	2	2	2	2500	2500	2500 +
2006 Andhra Pradesh	1	1	1	2500	2500	2500
2006 Andhra Pradesh	4	4	4	12	12	12
2006 Andhra Pradesh	4	4	4	12	12	12
2006 Andhra Pradesh	2	2	2	110	110	110
2006 Andhra Pradesh				110	110	110
2006 Andhra Pradesh				25	25	25
2006 Andhra Pradesh				500	500	500
2006 Assam				72	72	72
2006 Assam				360	360	360
2006 Assam				60	60	60
2006 Assam				1	1	1
2006 Assam				360	360	360
2006 Assam				1	1	1
2006 Assam				2500	2500	2500 +
2006 Assam	73	73	73	210	210	210
2006 Assam	36	36	36	280	280	280
2006 Assam	8	8	8	23	23	23
2006 Assam	27	94	61	34	140	87
2006 Assam	22	22	22	33	2500	2500 +
2006 Assam	13	17	15	21	26	24
2006 Assam	490	500	495	550	580	565
2006 Assam	610	610	610	690	690	690

2006 Assam	610	610	610	690	690	690
2006 Himichal Pradesh, Punjab	3	3	3	14	14	14
2006 Himichal Pradesh, Punjab	4	4	4	16	16	16
2006 Himichal Pradesh, Punjab	20	20	20	225	225	225
2006 Himichal Pradesh, Punjab				7	7	7
2006 Himichal Pradesh, Punjab				5	5	5
2006 Himichal Pradesh, Punjab	9	9	9	34	34	34
2006 Himichal Pradesh, Punjab				2	2	2
2006 Himichal Pradesh, Punjab	4	4	4	16	16	16
2006 Himichal Pradesh, Punjab	4	4	4	17	17	17
2006 Himichal Pradesh, Punjab				2	2	2
2006 Himichal Pradesh, Punjab				2	2	2
2006 Himichal Pradesh, Punjab	31	31	31	158	158	158
2006 Kerala	60	500	201	100	890	354
2006 Kerala				80	80	80
2006 Kerala	110	110	110	140	140	140
2006 Kerala	12	12	12	140	140	140
2006 Kerala	13	13	13	23	23	23
2006 Kerala	80	80	80	100	100	100
2006 Kerala	200	200	200	420	420	420
2006 Kerala	180	180	180	380	380	380
2006 Kerala	60	60	60	100	100	100
2006 Kerala	170	170	170	280	280	280
2006 Kerala	100	100	100	160	160	160
2006 Kerala	40	40	40	300	300	300
2006 Kerala	40	40	40	140	140	140
2006 Kerala	80	80	80	170	170	170
2006 Kerala				110	110	110
2006 Tamil Nadu	170	170	170	330	330	330
2006 Tamil Nadu	14	14	14	33	33	33
2006 Maharashtra & Gujarat	27	27	27	140	140	140
2006 Maharashtra & Gujarat	2	2	2	5	5	5
2006 Maharashtra & Gujarat	2	2	2	5	5	5
2006 Maharashtra & Gujarat	2	2	2	5	5	5
2006 Maharashtra & Gujarat	2	2	2	5	5	5
2006 Maharashtra & Gujarat	2	2	2	11	11	11
2006 Rajasthan	7	14	11	20	150	85
2006 Rajasthan	3	4	4	14	150	82
2006 Rajasthan	3	4	4	7	20	14
2006 Rajasthan	3	4	4	9	11	10
2006 Rajasthan	3	3	3	7	14	11
2006 Rajasthan	3	3	3	4	7	6

2006 Rajasthan	4	4	4	20	28	24
2006 Rajasthan	3	3	3	11	21	16
2006 Rajasthan	3	3	3	4	11	8
2006 Rajasthan	3	4	4	4	14	9
2006 Rajasthan	3	3	3	7	7	7
2006 Rajasthan	4	4	4	14	75	45
2006 Rajasthan	3	3	3	4	7	6
2006 Rajasthan	3	3	3	4	7	6
2006 Rajasthan	3	7	5	7	20	14
2006 Rajasthan	7	11	9	28	210	119
2006 Uttar Pradesh	90	90	90	250	250	250
2006 Uttar Pradesh	80	80	80	210	210	210
2006 Uttar Pradesh	292	292	292			
2006 West Bengal				22	22	22
2006 West Bengal				4	4	4
2006 West Bengal	2	2	2	30	30	30
2006 West Bengal				30	30	30
2006 West Bengal				30	30	30
2006 West Bengal				2	2	2
2006 West Bengal	33	33	33	900	900	900
2006 West Bengal				4	4	4
2006 West Bengal	2	2	2	80	80	80
2006 West Bengal	8	8	8	17	17	17
2006 West Bengal				17	17	17
2006 West Bengal				17	17	17
2006 Bihar	1	1	1	2	2	2
2006 Bihar	1	1	1	2	2	2
2006 Bihar	1	1	1	2	2	2
2006 Bihar	1	1	1	2	2	2
2006 Bihar	13	13	13	23	23	23
2006 Bihar	30	30	30	80	80	80
2006 Bihar	50	50	50	70	70	70
2006 Bihar	23	23	23	30	30	30
2006 Bihar	17	17	17	22	22	22
2006 Bihar	70	70	70	140	140	140
2006 Bihar	30	30	30	50	50	50
2006 Bihar	2	2	2	4	4	4
2006 Bihar	50	50	50	110	110	110
2006 Bihar	13	13	13	22	22	22
2006 Bihar	2	2	2	4	4	4
2006 Bihar	1	1	1	2	2	2
2006 Bihar	30	30	30	50	50	50

2006 Bihar	8	8	8	11	11	11
2006 Chattisgarh & Madhya Pradesh				7	7	7
2006 Chattisgarh & Madhya Pradesh				11	11	11
2006 Chattisgarh & Madhya Pradesh				2	2	2
2006 Chattisgarh & Madhya Pradesh				2	2	2
2006 Chattisgarh & Madhya Pra	2	2	2	2	4	3
2003 Kariyampalli Well BW *				46	46	46
2003 Bommanahelli School HP *				1600	1600	1600
2003 Bommanahelli Village HP *				0.9	0.9	0.9
2003 Havgi BW *				0.9	0.9	0.9
2003 Mainal BW *				9	9	9
2003 Harnouda BW *				42	42	42
2003 Kariyampalli BW *				0.9	0.9	0.9
2004 Harnouda Gram BW *				0.9	0.9	0.9
2004 Kariyampalli Gram BW *				0.9	0.9	0.9
2004 Bommanahelli BW *				0.9	0.9	0.9
2009 Mainal BW (RBF Study)	39.3	39.3	39.3	2500	2500	2500

2003 - 2009	Fecal Coliform			Total Coliform		
	Min	Max	Mean	Min	Max	Mean
All Data - including CPCB unsp	1	610	47	0.9	2500	229
Geometric Mean	10	10	10.0	29	34	32.7
Total Count			96			136
Median			5			27.5
Count < 2 MPN	6			8		
Count > 50 MPN		19			57	
Count > 500 MPN		2			13	
Count > 1000 MPN		0			8	
Count ? 2500 MPN					7	

* = Dharwad District Health Lab Data

+ = values above 2500 changed to 2500

Suspect data:

Deleted data (8 Fecal Coliform datapoints, 7 Total Coliform datapoints):

2 sites in Madhya Pradesh described as 'open well / tube well'

E coli data from 1 site in Assam with 9300 MPN when TC was 9301

4 sites in Andhra Pradesh described as Open Wells

Mine pit data in West Bengal (1 site)

Appendix 8 - Isotopes raw data

Kariyampalli Samples: December 2009 Results			
Location	Sample Date	$\delta^{18}\text{O}$ (‰)	δD (‰)
Kali River	1/14/2009	-1.82	-3.08
	1/20/2009	-1.51	-2.34
	1/22/2009	-1.64	-1.63
RBF W1	1/14/2009	-1.75	-3.92
	1/14/2009	-1.69	-3.84
	1/20/2009	-1.83	-5.43
RBF W2	1/14/2009	-1.61	-3.25
	1/20/2009	-1.92	-5.20
	1/22/2009	-1.59	-4.28
RBF W3	1/14/2009	-1.50	-2.04
	1/20/2009	-1.59	-4.59
	1/22/2009	-1.19	-1.59
RBF W4	1/14/2009	-1.51	-1.03
	1/20/2009	-1.33	-2.42
	1/22/2009	-0.72	1.46
Kariyampalli Open Well	1/14/2009	-0.90	0.05
	1/20/2009	-0.36	0.61
	1/20/2009	-0.28	0.75
	1/22/2009	-0.10	3.49
Mainal Bore Well	1/21/2009	-1.82	-5.82
Mainal Open Well	1/21/2009	-1.99	10.98
		$\delta^{18}\text{O}$ (‰)	δD (‰)
Range: min		-1.99	-
Range: max		-0.10	3.49

Appendix 9 - Silica raw data

Equation from Calibration Curve (with R2 = 0.9999): $y = 44.837x - 0.1582$
11/10/2009

Sample Name	Absorbance (=x)	Calculated Si mg/L (=y)	precision:	
tap water	0.399	17.7	+/- 0.4 mg/L Silica	
DI purge	0.001	-0.1	low range	high range
Kali 1/14	0.186	8.2	7.8	8.6
W3 1/16	0.818	36.5	36.1	36.9
OW 1/12	0.511	22.8	22.4	23.2
Kali 1/12	0.183	8.0	7.6	8.4
Kali 1/17	0.179	7.9	7.5	8.3
W3 1/19	0.818	36.5	36.1	36.9
W3 1/18	0.819	36.6	36.2	37.0
W3 1/24	0.771	34.4	34.0	34.8
Mainal Bore 1/2	0.978	43.7	43.3	44.1
W3 1/22	0.624	27.8	27.4	28.2
Kali 1/19	0.244	10.8	10.4	11.2
W4 1/17	0.638	28.4	28.0	28.8
W4 1/22	0.693	30.9	30.5	31.3
Kali 1/22	0.223	9.8	9.4	10.2
W3 1/18	0.792	35.4	35.0	35.8
W1 1/12	0.545	24.3	23.9	24.7
W2 1/17	0.709	31.6	31.2	32.0
W3 1/12	0.702	31.3	30.9	31.7
W2 1/12	0.685	30.6	30.2	31.0
W2 1/22	0.759	33.9	33.5	34.3
W4 1/24	0.720	32.1	31.7	32.5
OW 1/22	0.463	20.6	20.2	21.0
W2 1/24	0.725	32.3	31.9	32.7

Equation from Calibration Curve (with R2 = 0.999): $y = 47.031x - 0.6226$
11/13/2009

Sample Name	Absorbance (=x)	Calculated Si mg/L (=y)	precision:	
DI	0.001	-0.6	+/- 1.8 mg/L Silica	
DI	0.001	-0.6	low range	high range
W3 1/20	0.835	38.7	36.9	40.5
OW 1/14	0.504	23.1	21.3	24.9
W2 1/10	0.743	34.3	32.5	36.1
W4 1/12	0.806	37.3	35.5	39.1
W2 1/14	0.651	30.0	28.2	31.8
W1 1/10	0.549	25.2	23.4	27.0
W4 1/14	0.820	37.9	36.1	39.7
W2 1/10	0.736	34.0	32.2	35.8
W3 1/10	0.714	33.0	31.2	34.8
W1 1/14	0.552	25.3	23.5	27.1

W3 1/14	0.706	32.6	30.8	34.4
W1 1/17	0.598	27.5	25.7	29.3
W4 1/14	0.768	35.5	33.7	37.3
W2 1/10	0.696	32.1	30.3	33.9
W3 1/10	0.660	30.4	28.6	32.2
W1 1/14	0.516	23.6	21.8	25.4

Analysis Date: 1/27/2010 All these samples from 12-22-09:

Equation from Calibration Curve (with R2 = 0.9996): $y = 50.539x - 0.3247$

New Equation half way through = (R2 = 0.9999) $y = 47.692x - 0.2044$

Sample	Absorbance (=x)	Calculated Si mg/L (=y)	Notes	Notes
Well #3	0.7948	39.8	prob skewed hi re: 50 mg/L std	
Open Well	0.5383	26.9		
Mainal Bore Well	0.9224	46.3		
Mainal Hand Pump	0.7581	38.0	prob skewed hi re: Mainal BW	
Well #3	0.6615	33.1	15 min. mark	*
Mainal Hand Pump	0.7114	35.6		*
Mainal Hand Pump	0.7025	35.2		*
Well #2	0.5254	24.9	*New Equation*	
Kali River	0.2524	11.8		
Well #4	0.4231	20.0		
Well #1	0.4707	22.2		
Kali River	0.1779	8.3	15 min. mark	*
Well #1	0.4095	19.3		*

* = duplicate in same run

Dec 2009 samples:

Average of readings	Absorbance	Calculated Si mg/L
Kali River	0.215	10.1
RBF Well 1	0.440	20.8
RBF Well 2	0.525	24.9
RBF Well 3	0.728	36.5
RBF Well 4	0.423	20.0
Open Well	0.538	26.9
Mainal Bore	0.922	46.3
Mainal HP	0.724	36.3

DI = Deionized water; Kali = Kali River; OW = Open Well at Kariyampalli village;
W1, 2, 3 = RBF Well 1, 2, 3; HP = Hand Pump; Mainal Bore = Mainal Bore Well

Appendix 10 - Well test results - Aqtesolv

Slug test results from Jan 2009 yield a hydraulic conductivity of 6.9 m/day
 Data drawn from datapoints 1102 – 1282 using visual matching.

Recovery test results from May 2009 yield a hydraulic conductivity of 15.1 m/day
 Data drawn from datapoints 4158-4995 using visual matching.

Pump test results from May 2009 yield a hydraulic conductivity of 9.0 m/day
Data drawn from datapoints 2925-3731 using visual matching.

Travel time calculations:

$$\text{pore velocity} = v = \frac{\text{specific discharge}}{\text{porosity}} = \frac{-K * (\text{hydraulic gradient})}{\text{porosity}}$$

$$\text{hydraulic gradient: } \frac{3.3 \text{ m drawdown in RBF W3}}{52 \text{ m distance from RBF W3 to Kali River}} = 0.0635$$

$$\text{porosity} = 0.25 \text{ (estimate)}$$

$$\text{travel time: } \frac{\text{Distance from RBF W3 to Kali River}}{\text{pore velocity}}$$

Test Type	Date	Hydraulic Conductivity	Pore Velocity	Travel Time
Slug	Jan, 2009	K = 6.9 m/day	v = 1.8 m/day	30 days
Pump	May, 2009	K = 9.0 m/day	v = 2.3 m/day	23 days
Pump	May, 2009	K = 13.6 m/day	v = 3.5 m/day	15 days
Recovery	May, 2009	K = 15.1 m/day	v = 3.8 m/day	14 days

From complete dataset:

Elapsed Time (min):	849
Max Displacement (m):	2.46
Min Displacement (m):	0.29
Overall Change in Displacement (m):	2.17
Pump rate (L/min)	61.67

(25 equally spaced points from within 5042 to 5891

(5891 minus 5042 = 849 / 25 = 33)

with uncorrected Displacement

For pump period 5042 to 5891:

For Cooper-Jacob Solution:

count for Aqtesolv	Time (min)	Elapsed Time (min)	Displacement (cm)
1	6361	0	0.0
2	6394	33	153.3
3	6427	66	164.7
4	6460	99	171.6
5	6493	132	180.0
6	6526	165	181.1
7	6559	198	189.4
8	6592	231	191.1
9	6625	264	191.3
10	6658	297	198.5
11	6691	330	200.3
12	6724	363	200.5
13	6757	396	201.1
14	6790	429	195.4
15	6823	462	199.6
16	6856	495	201.8
17	6889	528	201.6
18	6922	561	209.3
19	6955	594	214.4
20	6988	627	205.9
21	7021	660	204.4
22	7054	693	202.0
23	7087	726	206.1
24	7120	759	207.1
25	7153	792	206.0

Elapsed Time (min):	792
Max Displacement (m):	214.4
Min Displacement (m):	153.3
Overall Change in Displacement (m):	61.1

From complete dataset:

Elapsed Time (min): 792
 Max Displacement (m): -35.12
 Min Displacement (m): -241.62
 Overall Change in Displacement (m): -206.5

Time (min) Pump rate (L/min)
 4244 61.67

Max Level: 921.077

with Uncorrected Displacement

For pump period 2925 to 3731:

For Cooper-Jacob Solution:

count for Aqtesolv	Time (min)	Elapsed Time (min)	Drawdown (Uncorrected)	Level	period #
1	4244	0	0.0	921.077	2928
2	4275	31	76.3	844.814	2959
3	4306	62	87.5	833.579	2990
4	4337	93	96.4	824.6541	3021
5	4368	124	101.0	820.032	3052
6	4399	155	110.1	810.929	3083
7	4430	186	115.8	805.2371	3114
8	4461	217	118.6	802.45	3145
9	4492	248	121.5	799.543	3176
10	4523	279	125.4	795.644	3207
11	4554	310	125.7	795.3491	3238
12	4585	341	128.6	792.4271	3269
13	4616	372	128.4	792.6771	3300
14	4647	403	133.5	787.574	3331
15	4678	434	130.6	790.511	3362
16	4709	465	126.9	794.213	3393
17	4740	496	127.7	793.387	3424
18	4771	527	128.8	792.278	3455
19	4802	558	129.2	791.8391	3486
20	4833	589	128.8	792.313	3517
21	4864	620	124.7	796.364	3548
22	4895	651	127.9	793.215	3579
23	4926	682	127.1	793.938	3610
24	4957	713	119.1	801.946	3641
25	4988	744	121.8	799.265	3672

Elapsed Time (min): 744
 Max Displacement (m): 133.5
 Min Displacement (m): 76.3
 Overall Change in
 Displacement (m): 57.2

50 points for Aqtesolv

Data points 4158-4995:

Elapsed Time (min): 780

Max Displacement (m) 102.3201

Min Displacement (m): -237.2179

Overall Change in Displacement (m): -134.8978

From complete dataset:

Elapsed Time (min): 837

Max Displacement (m): 105.9001

Min Displacement (m): -238.8129

Overall Change in Displacement (m): -132.9128

Time (min)	Level (cm)	Elapsed Time (min)	Displacement (cm)
5525	102.3201	0.1	0.1
5526	-37.6599	1	139.98
5542	-162.2258	17	264.5459
5558	-178.2078	33	280.5279
5574	-189.5579	49	291.878
5590	-193.3859	65	295.706
5621	-196.7479	96	299.068
5637	-199.3919	112	301.712
5653	-202.5559	128	304.876
5669	-209.7149	144	312.035
5685	-209.0019	160	311.322
5701	-210.4469	176	312.767
5717	-212.6179	192	314.938
5733	-213.5329	208	315.853
5749	-214.5358	224	316.8559
5765	-217.3639	240	319.684
5781	-220.6859	256	323.006
5797	-223.2288	272	325.5489
5813	-220.7519	288	323.072
5829	-219.0618	304	321.3819
5845	-223.7468	320	326.0669
5861	-222.2149	336	324.535
5877	-219.3389	352	321.659
5893	-220.7739	368	323.094
5909	-221.8118	384	324.1319
5925	-218.8319	400	321.152
5941	-221.6608	416	323.9809
5957	-224.6978	432	327.0179
5973	-223.9968	448	326.3169
5989	-227.3679	464	329.688
6005	-227.9088	480	330.2289
6021	-237.2179	496	339.538
6033	-54.7368	508	157.0569
6049	38.63	524	63.6901
6065	56.87	540	45.4501
6081	66.99	556	35.3301
6097	73.3401	572	28.98
6113	78.0901	588	24.23
6129	80.5601	604	21.76
6145	85.0301	620	17.29
6161	87.86	636	14.4601

6177	89.4401	652	12.88
6193	92.0301	668	10.29
6209	93.5401	684	8.78
6225	96.4501	700	5.87
6241	95.9701	716	6.35
6257	96.5701	732	5.75
6273	99.2801	748	3.04
6289	99.8101	764	2.51
6305	100.5801	780	1.74

Appendix 11 - Well test results overview

Boxes A and C show data segments used for pump tests analyzed with Aqtesolv (data points 2925-3731 and 5042-5891)

Box B shows data segment used for pump and recovery test analyzed with Aqtesolv (data points 4158-4995)

Appendix 13 - Field parameters data ranges by sample type

Parameter	Bore Wells and Town Taps			Open Wells			Hand Pumps		
	Min	Max	Average	Min	Max	Average	Min	Max	Average
# of samples	7			4			6		
Altitude (m)	443	473	460.43	438	463	446.25	441	464	452.17
Average pH	6.88	7.49	7.30	6.93	7.35	7.13	6.3	7.16	6.66
ORP (mV)	195	434	267.33	150	233	201.25	-149	140	34.5
Average Temp (°C)	22.6	26.5	23.70	23.3	26.2	24.8	26.1	27.5	27
TDS (ppm)	20	368	210.83	117	462	247.25	121	1162	557.83
EC (uS/cm)	42	736	422.5	235	922	490.25	243	2327	1119.67
Free Chlorine (ppm)	0	0	0						
Total Chlorine (ppm)	0	0.15	0.07	0	0.05	0.03	0	0.05	0.02
Total Ammonia	0	0.25	0	0	0.0.25	0	0	0.0.25	0
Sulfate (ppm)	0	250?	0						
Alkalinity (ppm)	0	>180	75	40-80	180	140	40-80	>180	120
Total Hardness	<50	250-450	125	50-100	450	450	<50	450-800	275
Fe2+ (ppm)	0	0-2	0	0	<2	0	2	50	14.4
Fe3+ (ppm)	0	2	1.5	<2	2	2	2	50	25.67
Total Nitrate (as N) (ppm)	0	5	0.125	0	5-10	0	0-0.5	20-50	20
Nitrite (as N) (ppm)	0	0	0	0	0	0	0	1	0.23
Bicarbonate* (as CaCO3 mg/L)	0	180	82	60	180		60	180	140
Bicarbonate (mEq/L)	0.0	3.0	1.0	1.0	3.0	2.0	1.0	3.0	2.3

* calculated from average Alkalinity

Appendix 13 - Field parameters data ranges by sample type

Parameter	Sample Type	2008 & 2009 Kali River			2008 & 2009 Kali River w/o Halmaddi			Overall (w/o RBF Wellfield)		
		Min	Max	Average	Min	Max	Average	Min	Max	Average
# of samples				9 - 14			8 - 13			32
Altitude (m)		427	448	437.6	427	448	437.1	438	473	448.9
Average pH		6.92	7.63	7.27	6.92	7.63	7.27	6.3	7.49	7.14
ORP (mV)		-47	284	179.9	85	284	197.4	-149	434	176.54
Average Temp (°C)		23.5	31.9	25.5	23.5	26.8	25.0	22.6	27.50	25.4
TDS (ppm)		17	758	93.8	17	84	42.7	20	1162	274.88
EC (uS/cm)		34	1518	188.7	34	168	86.5	42	2327	550.58
Free Chlorine (ppm)		0	0	0	0	0	0	0	0	0.00
Total Chlorine (ppm)		0	0.2		0	0.05		0	0.15	0.04
Total Ammonia		0	>6		0	<0.5		0	>6	0
Sulfate (ppm)		0	0	0	0	0	0	0	250?	0
Alkalinity (ppm)		0	40-80	20	0	<40	15	0	>180	86.25
Total Hardness		<50	450		<50	50-100		<50	450-800	250
Fe2+ (ppm)		0	<2		0	<2		0	50	4
Fe3+ (ppm)		0	2-5		0	<2		0	50	7.58
Total Nitrate (as N) (ppm)		0	<0.5		0	<0.5		0	20-50	3.38
Nitrite (as N) (ppm)		0	0	0	0	0	0	0	1	0.05
Bicarbonate* (as CaCO3 mg/L)		0	60	20	0	20	15	0	180	91
Bicarbonate (mEq/L)		0	1.0	0.3	0	0.3	0.3	0.0	3.0	1.4

* calculated from average Alkalinity

Appendix 13 - Field parameters data ranges by sample type

Parameter	Overall (w/o RBF, Halmaddi, or Hand Pumps)			Sample Type	2009 Kali River			RBF Well 1		
	Min	Max	Average		Min	Max	Average	Min	Max	Average
# of samples			25				1 - 6			3 - 4
Altitude (m)	427	473	447.94		6.92	7.42	7.12	6.42	6.77	6.65
Average pH	6.88	7.63	7.23		85	245	150	-107	-69	-86
ORP (mV)	85	434	221.99		23.5	26.8	24.7	25.1	28.3	26.4
Average Temp (°C)	22.6	26.80	24.6		29	84	53	190	234	208
TDS (ppm)	17	368	146.59		58	168	107	364	469	409
EC (uS/cm)	34	736	333.08							
Free Chlorine (ppm)	0	0	0.00							
Total Chlorine (ppm)	0	0.15	0.05							
Total Ammonia	0	0.25	0.00		0	0.25	0.125			
Sulfate (ppm)	0	250?	0.00							
Alkalinity (ppm)	0	>180	76.67		0	40	20			
Total Hardness	0	0	287.50		50	100	75			
Fe2+ (ppm)	0	<2	0.00							
Fe3+ (ppm)	0	2	1.75							
Total Nitrate										
(as N) (ppm)	0	5-10	0.06							
Nitrite (as N) (ppm)	0	0	0.00							
Bicarbonate* (as CaCO3 mg/L)	0	180	72.33		20	20	20			
Bicarbonate (mEq/L)	0.0	3.0	1.06		0.3	0.3	0.3			

* calculated from average Alkalinity

Appendix 13 - Field parameters data ranges by sample type

Parameter	RBF Well 2			RBF Well 3			RBF Well 4		
	Min	Max	Average	Min	Max	Average	Min	Max	Average
# of samples	8 - 9			8 - 50			12 - 20		
Altitude (m)	6.17	6.67	6.40	6.12	7.3	6.64	6.11	6.77	6.56
Average pH	-56	155	50	-50	366	207	-87	355	160
ORP (mV)	24	26.3	25.3	22.9	27.7	25.9	24.6	27.4	26.3
Average Temp (°C)	158	205	374	107	323	161	92	326	255
TDS (ppm)	313	409	748	213	628	325	181	659	506
EC (uS/cm)				0	1	0.4	0	0.5	0.29
Free Chlorine (ppm)				0	1	0.33	0	0.5	0.92
Total Chlorine (ppm)				0	0.25	0.13	0	0.25	0.17
Total Ammonia Sulfate (ppm)				<200	<200	<200			
Alkalinity (ppm)				0	240	172.63	40	120	93.33
Total Hardness				0	120	36.43	0	50	18.75
Fe2+ (ppm)				0	5	0.56	0	0.2	0.06
Fe3+ (ppm)									
Total Nitrate (as N) (ppm)				0	2	0.33	0	0.5	0.31
Nitrite (as N) (ppm)				0	0	0	0	0.15	0.01
Bicarbonate* (as CaCO3 mg/L)				20	240	173	60	100	93
Bicarbonate (mEq/L)				0.33	3.93	2.8	0	1.64	1.4

* calculated from average Alkalinity

Appendix 13 - Field parameters data ranges by sample type

2009 Kariyampalli Open Well				Overall (just RBF Wellfield)				Overall (including all sites)				Sample Type
Min	Max	Average		Min	Max	Average		Min	Max	Average		Parameter
3 - 4				35 - 93				67 - 125				# of samples
6.56	6.8	6.69		6.11	7.42	6.68		6.11	7.49	6.84		Altitude (m)
140	227	173		-107	366	108.97		-149	434	133.68		Average pH
23.1	23.7	23.4		22.9	28.3	25.33		22.6	28.30	58.39		ORP (mV)
97	126	116		29	374	194.61		20	1162	227.74		Average Temp (°C)
195	254	235		58	748	388.23		42	2327	455.05		TDS (ppm)
				0	1	0.35		0	1	0.17		EC (uS/cm)
				0	1	0.63		0	1	0.27		Free Chlorine (ppm)
				0	0.25	0.14		0	>6	0.07		Total Chlorine (ppm)
				<200	<200	<200		0	250?	0.00		Total Ammonia
				0	240	95.32		0	240	91.57		Sulfate (ppm)
				0	120	43.39		0	800	163.36		Alkalinity (ppm)
				0	5	0.31		0	50	3.00		Total Hardness
												Fe2+ (ppm)
												Fe3+ (ppm)
												Total Nitrate
				0	2	0.32		0	50	4.15		(as N) (ppm)
				0	0.15	0.01		0	1	0.04		Nitrite (as N) (ppm)
												Bicarbonate* (as
				20	240	95		0	240	93		CaCO3 mg/L)
				0	3.93	1.52		0	3.93	1.45		Bicarbonate (mEq/L)

Note: Max Nitrate = 220 mg/L NO3; Max Nitrite = 3.3 mg/L NO2 * calculated from avg Alkalinity

Appendix 14 – Bacteria and rainfall data with standard deviation bars

Total coliform levels and rainfall data versus time

Shaded area represents rainy season; columns: mm; points: MPN / 100 mL; MPN = Most Probable Number; geometric mean standard deviation shown with error bars; Open well = Kariyampalli Open Well; Local Bore Wells = 8 Dharwad District Health Lab samples (District Health Laboratory, 2003) and 1 Mainal Bore Well sample.

E. coli bacteria levels and rainfall data versus time

Shaded area represents rainy season; columns: mm; points: MPN / 100 mL; MPN = Most Probable Number; error bars: geometric mean standard deviation; Open well = Kariyampalli Open Well.

Appendix 15 - Total Coliform raw data

Date	Well 1	Well 2	Well 3	Well 4	Kariyampalli Open Well	Kali River	Mainal BW	Mainal OW
13-Jan-09	2500	460	280	1100	2500	2500		
15-Jan-09	1300	410	440	240	2500	2500		
22-Jan-09	2500	170	190	2500	2500	2500	2500	2500
24-Jan-09	1400	520	2500	2000	2500	2500		
02-Feb-09			19					
06-Feb-09			170					
09-Feb-09			31					
13-Feb-09			16					
16-Feb-09			4.1					
20-Feb-09			70					
27-Feb-09			24					
02-Mar-09			32					
06-Mar-09			20					
09-Mar-09			26					
13-Mar-09			19					
16-Mar-09				2500				
20-Mar-09				38				
23-Mar-09				39				
30-Mar-09				38				
3-Apr-09				248				
6-Apr-09				170				
13-Apr-09				370				
14-Apr-09				79				

20-Apr-09			86	
24-Apr-09			690	
14-May-09	66	2500		2500
14-May-09	82			
14-May-09	57			
15-May-09	100			
15-May-09	100			2500
15-May-09	140			
18-May-09	260	2500		2500
22-May-09	2500			
26-May-09	760			2500
29-May-09	160			
13-Jun-09	170			
17-Jun-09	48			
2-Jul-09	7.5	2500		2500
22-Jul-09	580			
24-Jul-09	100			440
27-Jul-09	81			
29-Jul-09	380			
31-Jul-09	150			
3-Aug-09	100			
7-Sep-09	330			2500
11-Sep-09	2500			
12-Sep-09	190			
14-Sep-09	160			
26-Sep-09	350			370
30-Sep-09	250			2500

10-Oct-09	600	2400						
13-Oct-09	20							
24-Oct-09	7.5							
27-Oct-09	920							
3-Nov-09	38							
6-Nov-09	20	400						
	Well 1	Well 2	Well 3	Well 4	Kariyampalli Open Well	Kali River	Mainal BW	Mainal OW
Range: min	1300	170	4.1	38	2500	370	2500	2500
Range: max	2500	520	2500	2500	2500	2500	2500	2500
Min % Removal	0	1	0	0	0	0	0	0
Max % Removal	48%	93%	99.8%	98%	0%	85%	0%	0%
	Well 1	Well 2	Well 3	Well 4	Kariyampalli Open Well	Kali River	Mainal BW	Mainal OW
Geometric Mean Overall	1836	359	85	231	2500	1730	2500	2500
Avg % Change from KR water	-6.1%	79%	95%	87%	-44%	0.0%	-44%	-44%
Avg % Change from KR worst water	27%	86%	97%	91%	0.0%	31%	0.0%	0.0%
% above is better than KR	-4.3%	55%	66%	60%	-31%	0.0%	-31%	-31%
% improvement rate of Well #3:	-95%	-76%	0%	-63%	-97%	-95%	-97%	-2835%
# of Readings Overall	4	4	46	14	7	15	1	1
# of Readings Jan - May	4	4	25	14	6	8	1	1
# of Readings Monsoon	0	0	15	0	1	5	0	0
# of Readings Post-Monsoon	0	0	6	0	0	2	0	0

Geo Mean Dry Season % Change Dry Season	1836 11%	359 83%	66 97%	231 89%	2500 -21%	2073 0.0%	2500 -21%	2500 -21%
Geo Mean Monsoon % Change Monsoon		n/a	143 88%	n/a n/a	2500 -107%	1205 0.0%	n/a n/a	n/a n/a
Including suspect data points: Geometric Mean Overall Geo Mean Dry Season Geo Mean Monsoon	Well 1	Well 2	Well 3	Well 4	Kariyampalli Open Well	Kali River	Mainal BW	Mainal OW
			106	274				
			84	274				
			173					

Appendix 16: Significance Testing Results on Aggregate Bacteria Levels

Water Source	U	W	Z	Exact Sig. # Asymp. [2*(1 - tailed Sig.)]	Sig. 2-tailed	<0.05	n	Mean Rank	Sum of Ranks	Median	Geometric Mean	Coliform Type	Resultant Rank (clean to dirty)	Sig Diff ?
W3							43	22.35	961	104.3	85.3		W3 (cleaner)	
KR	15	961	-5.479		0	yes	15	50	750	2500	1730.6	TC	KR (dirtier)	Yes!
KOW							7	13.5	94.5	2500	2500		KR (cleaner)	
KR	39	158.5	-1.467	0.332	0	yes	15	10.57	158.5	2500	1730.6	TC	KOW	Yes!
W3							43	26.23	1128	104.3	85.3		W3 (cleaner)	
W4	182	1128	-1.892		0.058	yes	13	36	468	238.2	230.5	TC	W4	Yes!
W3							43	22	946	104.3	85.3		W3 (cleaner)	
KOW	0	946	-4.214	0	0	yes	7	47	329	2500	2500	TC	KOW	Yes!
W4							13	7.27	94.5	238.2	230.5		W4 (cleaner)	
KOW	3.5	94.5	-3.439	0	0.001	yes	7	16.5	115.5	2500	2500	TC	KOW	Yes!
W4							13	8.42	109.5	238.2	230.5		W4 (cleaner)	
KR	19	109.5	-3.791	0	0	yes	15	19.77	296.5	2500	1730.6	TC	KR	Yes!
W3							44	22.5	990	2.0	3.6		W3 (cleaner)	
KR	0	990	-5.303		0	yes	12	50.5	606	568.6	459.0	E.coli	KR	Yes!
KOW							7	7.29	51	204.6	197.2		(cleaner)	
KR	23	51	-1.607	0.12	0.108	no	12	11.58	139	568.6	459.0	E.coli	KR	no

Appendix 17: Significance Testing Results on Dry Season Bacteria Levels

Test Statistics										
Water Source	Exact Sig. #			[2*(1 - Asymp. tailed Sig. Sig.)]			Mean Sum of Ranks			Coliform Type
	U	W	Z	<0.05	yes	no	n	Rank	Median	Resultant Rank (clean to dirty)
W3	4	439	-4.555	0	0	yes	29	15.14	66.3	TC
KR							10	34.1	2500	Dry Season
									66.5	W3 (cleaner)
									2073.7	KR
										Yes!
W3	101	536	-2.381	0.017	0.017	yes	29	18.48	66.3	TC
W4							13	28.23	238.2	Dry Season
									230.5	W3 (cleaner)
										W4
										Yes!
KOW	24	79	-1.131	0.562	0.258	no	6	9.5	2500	TC
KR							10	7.9	2500	Dry Season
									2500	KR (cleaner)
									2073.7	KOW
										no
W4	3	94	-3.238	0.001	0.001	yes	13	7.23	238.2	TC
KOW							6	16	2500	Dry Season
									2500	W4 (cleaner)
										KOW
										Yes!
W4	9	100	-3.581	0	0	yes	13	7.69	238.2	TC
KR							10	17.6	2500	Dry Season
									2073.7	W4 (cleaner)
										KR
										Yes!

Test Statistics

# Not corrected for ties	U: Mann-Whitney U Test	W: Wilcoxon W Test	Asymp. Sig.: Asymptotic Significance

Appendix 19 - E. coli raw data

Date	Well 1	Well 2	Well 3	Well 4	KOW	Kali River	MBW	MOW
13-Jan-09	140	12	5.2	12	120	870		
15-Jan-09	34	7.5	2.0	2.0	420	650		
22-Jan-09	2500	1.0	1.0	1.0	56	490	40	40
24-Jan-09	16	5.2	1.0	1.0	27	120		
02-Feb-09			2.0					
06-Feb-09			0.9					
09-Feb-09			1.0					
13-Feb-09			2.0					
16-Feb-09			1.0					
20-Feb-09			1.0					
27-Feb-09			0.9					
02-Mar-09			1.0					
06-Mar-09			0.9					
09-Mar-09			1.0					
13-Mar-09			0.9					
16-Mar-09				110				
20-Mar-09				3.1				
23-Mar-09				2.0				
30-Mar-09				6.3				
3-Apr-09				7.4				
6-Apr-09				8.6				
13-Apr-09				4.1				
14-Apr-09				4.1				
20-Apr-09				6.3				

24-Apr-09	9.8	
14-May-09	1.0	440 2500
14-May-09	1.0	
14-May-09	0.9	
15-May-09	5.2	
15-May-09	1.0	370
15-May-09	11	
18-May-09	18	1700 730
22-May-09	200	
26-May-09	220	310
29-May-09	12	
13-Jun-09	12	
17-Jun-09	9.7	
2-Jul-09	6.3	200 490
22-Jul-09	7.4	
24-Jul-09	36	140
27-Jul-09	54	
29-Jul-09	13	
31-Jul-09	11	
3-Aug-09	64	
7-Sep-09	8.6	790
11-Sep-09	0.9	
12-Sep-09	22	
14-Sep-09	14	
26-Sep-09	13	34
30-Sep-09	23	720
10-Oct-09	12	870

[illegible]

% Change Dry Season	91%	99%	99.6%	99%	58%	0.0%	92%	92%
Geo Mean Monsoon	n/a	n/a	13	n/a	200	444	n/a	n/a
% Change Monsoon	n/a	n/a	97.0%	n/a	55%	0.0%	n/a	n/a
Including suspect data points :								
Geometric Mean Overall	117		4.3	5.0		339		
Geo Mean Dry Season	117		2.5	5.0		382		
Geo Mean Monsoon			13			266		
	Well 1	Well 2	Well 3	Well 4	Kariyampalli Open Well	Kali River	Mainal BW	Mainal OW

Appendix 20: Anion and cation ranges by drinking water source												
		Average F- Amount (mg/L)	Average Cl- Amount (mg/L)	Average Br- Amount (mg/L)	Average NO3- Amount (mg/L)	Average SO4 -- Amount (mg/L)	Average HCO3- (as CaCO3 mg/L)	Average Na+ Amount (mg/L)	Average K+ Amount (mg/L)	Average Mg++ Amount (mg/L)	Average Ca++ Amount (mg/L)	
Hand Pumps anions n=6 cations n=11	Minimum	0.00	18.07	0.00	0.00	3.52	60.00	27.18	1.61	5.70	17.85	
	Maximum	0.36	350.53	224.66	72.76	190.94	180.00	98.80	9.13	81.09	271.10	
	Average	0.07	156.19	60.07	28.08	68.82	140.00	56.11	4.47	33.69	95.19	
Public & Private Taps + DI Water anions n=6 All Samples anions n=8 cations n=16	Minimum	0.18	6.88	0.11	0.25	1.88	0.00	10.08	1.00	0.87	2.07	
	Maximum	0.51	196.14	0.35	30.69	54.51	180.00	56.29	11.31	37.89	106.57	
	Average	0.38	74.19	0.23	7.40	21.67	82.00	33.34	3.04	14.20	40.24	
anions n=12 cations n=12	Minimum	0.18	3.40	0.11	0.25	0.76	0.00	6.23	0.52	0.02	0.04	
	Maximum	0.51	196.14	0.35	30.69	54.51	180.00	56.29	11.31	37.89	106.57	
	Average	0.38	57.89	0.23	8.01	16.67	71.67	28.05	2.63	10.80	31.35	
Open Wells w/o Kariyampalli anions n=2 cations n=4	Minimum	0.00	16.32	0.00	1.54	14.24	120.00	22.18	3.20	13.70	47.61	
	Maximum	0.44	91.52	0.42	30.18	115.56	180.00	54.17	6.90	30.18	92.73	
	Average	0.26	53.92	0.21	15.86	64.90	140.00	37.99	5.08	22.29	68.41	
Kariyampalli OW only anions n=5 cations n=6	Minimum	0.14	17.43	0.09	0.21	4.21	60.00	11.46	0.95	3.77	20.16	
	Maximum	0.38	20.95	0.09	4.66	8.46	60.00	20.50	3.27	6.05	31.40	
	Average	0.27	19.19	0.09	2.77	7.57	60.00	15.10	1.66	4.69	23.41	
All Open Wells anions n=7 cations n=10	Minimum	0.00	16.32	0.00	0.21	4.21	60.00	11.46	0.95	3.77	20.16	
	Maximum	0.44	91.52	0.42	30.18	115.56	180.00	54.17	6.90	30.18	92.73	
	Average	0.16	29.11	0.17	6.51	23.95	120.00	24.26	3.03	11.73	41.41	
Kali River No RBF Site 2008 only anions n=8 cations n=16	Minimum	0.00	6.57	0.00	0.77	1.82	0.00	9.49	0.98	0.84	1.96	
	Maximum	0.45	295.16	7.39	10.77	118.12	60.00	166.77	15.45	6.68	140.46	
	Average	0.12	58.54	4.21	3.86	22.51	20.00	49.23	5.33	2.43	37.75	

KR RBF Site 2008 + 2009 anions n=7 cations n=7	Minimum	0.00	6.32	0.51	0.33	2.67	20.00	4.13	0.49	1.02	3.42
	Maximum	0.36	12.39	0.51	2.41	4.79	20.00	11.18	4.78	1.85	8.18
	Average	0.07	9.83	0.51	1.42	3.66	20.00	6.69	1.56	1.28	5.33
KR all sites 2008 + 2009 anions n=15 cations n=24	Minimum	0.00	6.32	0.00	0.33	1.82	0.00	4.13	0.49	1.02	2.50
	Maximum	0.45	295.16	7.39	10.77	118.12	60.00	158.11	15.00	6.05	140.46
	Average	0.10	35.80	3.29	2.81	13.71	20.00	29.10	3.76	1.91	22.87
RBF W1 anions n=5 cations n=4	Minimum	0	19.77	0.11	0.22	1.63		11.93	4.80	9.87	26.12
	Maximum	0.36	47.56	0.24	1.44	9.75		25.21	5.67	10.52	27.58
	Average	0.19	28.92	0.17	0.83	7.58		16.00	5.35	10.28	26.99
RBF W2 anions n=6 cations n=6	Minimum	0.22	19.26	0.00	0.29	3.39		11.10	3.91	9.39	25.75
	Maximum	0.44	31.43	0.17	4.89	10.34		20.45	4.76	14.11	38.04
	Average	0.29	25.64	0.04	1.96	8.14		14.10	4.33	10.64	28.05
RBF W3 anions n=13 cations n=8	Minimum	0	16.45	0.00	0.30	6.12	0.00	11.53	1.21	9.51	26.62
	Maximum	0.44	25.77	1.38	3.55	9.31	240.00	14.93	1.86	11.39	32.39
	Average	0.27	21.31	0.14	2.15	7.67	172.63	12.90	1.60	10.84	29.81
RBF W4 anions n=5 cations n=5	Minimum	0.29	17.16	0.09	0.00	1.24	60.00	11.87	1.46	8.33	24.11
	Maximum	0.48	52.73	0.09	1.28	6.36	100.00	35.96	3.00	23.84	90.22
	Average	0.36	27.04	0.09	0.85	5.07	93.33	19.29	2.12	12.19	40.16
Overall all sites anions n=63 cations n=80	Minimum	0.00	6.32	0.00	0.00	1.24	0.00	4.13	0.49	0.87	2.07
	Maximum	0.51	350.53	224.66	72.76	190.94	240.00	158.11	15.00	81.09	271.10
	Average	0.23	49.77	8.02	6.32	19.58	104.66	25.64	3.46	13.19	40.59
Overall w/o RBF area anions n=34 cations n=57	Minimum	0.00	6.57	0.00	0.00	1.82	0.00	9.49	0.98	0.84	1.96
	Maximum	0.51	350.53	224.66	72.76	190.94	180.00	166.77	15.45	81.09	271.10
	Average	0.21	85.71	16.18	13.80	44.47	95.50	44.17	4.48	18.15	60.40
BIS Levels	Desirable	1	250	n/a	45	200	n/a	n/a	n/a	n/a	75
	Permissible	1.5	1000	n/a	100	400	n/a	n/a	n/a	n/a	200

Appendix 21 - Cation : anion ratios from other studies

Study Authors		Subramanian, '87		Dept of Mines Analysis		Dept of Health and Family Welfare Report		Dept of Health and Family Welfare Report		Safai, 2004	
Paper Name		Envgeo peninsular river basins India		Halmaddi		Kariyampali		Kariyampali		Chem comp	
Village		Kadra, below lowest		treated effluent?		same in meq/L		Kali River		precip '84-'02	
Location Type		Kali River		2004?		2003		2003		Piper plots as meq/L)	
Date		1978, 1984		8.19		7		6.9		1984-2002	
pH		7.2									
Temp (°C)				1343							
EC (uS/cm)		141 (mS?)		765		149.5		45.5			
TDS (ppm)		99									
Turbidity (NTU)											
NO3-		0.00		0.5		3.81		1.65			
F-				0.6		0.12		0			
Cl-		16		193		50		12		32.64	
PO4-											
SO4-		3.8		67		8.4		3.44		16.32	
Bicarbonate		0.00		397						34.68	
Carbonate											
Alkalinity		26				36		16			
Total Hardness				448		80		24			
Ca Hardness as CaCO3											
Ca2+		11.2		96		32		8		65.88	
Mg2+		4		52						17.08	
Na+		2.2		97		33		16		34.16	
K+		0.7		0.3		0		0		2.44	
Cation:Anion Ratio		1.96		1.02		1.97		2.79		1.43	
* Incomplete Data Set		No HCO3-				*		*		%	

Study & interp chem characteristics natural water				Hem, 1985	
World Average					
meq/L	meq/L	1979	Avg '63 & '79		
1963					
0.02			0.02		
0.22	0.16		0.19		
0.17	0.13		0.15		
0.95	0.85		0.90		
0.75	0.67		0.71		
0.34	0.28		0.31		
0.27	0.22		0.25		
0.06	0.03		0.05		
His SO4 calc: 0.239, 0.172 = 0.99, 1.01 ratios					
1.06	1.05		1.05		
Avg '63 & '79					

Bharati and Krishnamurthy, 1990									
Effect of industrial effluents on River Kali around Dandeli, Karnataka									
Moulangi KR		Dandeli KR		Halmaddi KR		Kerwad KR			
Kali River	same in meq/L	Kali River	same in meq/L	Kali River	same in meq/L	Kali River	same in meq/L	Kali River	same in meq/L
Average between July, 1985 and July, 1986									
7.6 - 7.7									
25.4 - 26.4									
0.56	0.01	2.184	0.04	0.896	0.01	0.604	0.01	0.01	0.01
18.1	0.51	20.4	0.58	83.4	2.35	36	1.02		
3.2	0.05	3	0.05	96.6	1.51	16.8	0.26		
97.6	1.60	97.6	1.60	245.2	4.02	118.4	1.94		
5.6	0.28	6.6	0.33	50.9	2.54	11.8	0.59		
1	0.08	1.1	0.09	5.1	0.42	2.6	0.21		
4.6	0.20	5.2	0.23	192	8.35	96	4.18		
1	0.03	1.1	0.03	37.2	0.95	24.8	0.63		
(mg/L)	(meq/L)	(mg/L)	(meq/L)	(mg/L)	(meq/L)	(mg/L)	(meq/L)	(mg/L)	(meq/L)
0.27	0.30	1.56	1.74						

Bharati and Krishnamurthy, 1994 Studies on the metal pollution of the River Kali, around Dandeli (North Kanara district), Karnataka, India							
Moulangi KR		Dandeli KR		Halmaddi KR		Kerwad KR	
Kali River	same in meq/L	Kali River	same in meq/L	Kali River	same in meq/L	Kali River	same in meq/L
Average between June, 1987 and May, 1988 7.03 - 8.51 25.75 - 30.16							
1.13	0.02	1.72	0.03	0.63	0.01	1.08	0.02
17.66	0.50	18.61	0.52	117.97	3.33	51.94	1.47
48.81	0.80	51.9	0.85	203.02	3.33	116.5	1.91
5.12	0.26	5.63	0.28	59.18	2.95	24.27	1.21
1	0.08	1.21	0.10	13.3	1.09	3	0.25
8.17	0.36	9.28	0.40	63.61	2.77	23.61	1.03
1.28	0.03	1.67	0.04	10.33	0.26	2.89	0.07
(mg/L)	(mg/L)	(mg/L)	(mg/L)	(mg/L)	(mg/L)	(mg/L)	(mg/L)
0.56	0.60	1.06	1.06	0.76	0.76	0.76	0.76
NOTE: No Sulfate data available							

Panachayat Raj Engineering Observation Dug Well #190304									
Dandeli		Dandeli		Dandeli		Dandeli		Dandeli	
Open Well	Open Well	Open Well	Open Well	Open Well	Open Well	Open Well	Open Well	Open Well	Open Well
4/1999	4/1999	9/1999	9/1999	9/1999	4/2000	4/2000	4/2000	4/2000	4/2000
(mg/L?)	(mg/L?)	(mg/L?)	(mg/L?)	(mg/L?)	(mg/L?)	(mg/L?)	(mg/L?)	(mg/L?)	(mg/L?)
7.35 - 8.77									
23.1	0.37	30.8	0.50	33	0.53				
0.00	0.00	0.00	0.00	0.50	0.03				
87	2.45	62	1.75	53	1.50				
25	0.39	74	1.15	25	0.39				
206	3.38	172	2.82	172	2.82				
0	0.00	10	0.28	19	0.53				
48	2.40	48	2.40	32	1.60				
26	2.14	25	2.06	14	1.15				
43	1.87	49	2.13	121	5.26				
1	0.03	1	0.03	4	0.10				
1.03		1.15		1.72					
Apr-99		Sep-99		Apr-00					

	Panachayat Raj Engineering Observation Dug Well #190304									

Dandeli	Dandeli	Dandeli	Dandeli	Dandeli	Dandeli	Dandeli	Dandeli	Dandeli	Dandeli	Dandeli
Open Well	Open Well	Open Well	Open Well	Open Well	Open Well	Open Well	Open Well	Open Well	Open Well	Open Well
11/2000	11/2000	4/2001	4/2001	9/2001	4/2002	4/2002	4/2003	4/2003	4/2004	4/2005
(mg/L?)	(mg/L?)	(mg/L?)	(mg/L?)	(mg/L?)	(mg/L?)	(mg/L?)	(mg/L?)	(mg/L?)	(mg/L?)	(mg/L?)

12	0.19	13	0.21	15	0.24	10	0.16	10	0.16	11	0.18	4
0.20	0.01	0.10	0.01	0.20	0.01	0.20	0.01	0.30	0.02	0.50	0.03	0.25
67	1.89	334	9.42	64	1.81	76	2.14	64	1.81	56	1.58	62
37.8	0.59	94	1.47	95.2	1.49	65.2	1.02	70.9	1.11	42.5	0.66	62
206	3.38	198	3.24	101	1.66	240	3.93	221	3.62	196	3.21	206
14	0.39	14	0.39	10	0.28	0	0.00	5	0.14	0	0.00	10
48	2.40	80	3.99	48	2.40	48	2.40	48	2.40	40	2.00	37
27	2.22	53	4.36	26	2.14	28	2.30	24	1.97	21	1.73	21
35	1.52	55	2.39	82	3.57	64	2.78	64	2.78	47	2.04	72
1	0.03	6	0.15	5	0.13	3	0.08	3	0.08	3	0.08	4
1.05	0.77	1.66	1.11	1.07	1.11	1.07	1.11	1.11	1.07	1.07	1.07	
Nov-00	Apr-01	Sep-01	Apr-02	Apr-03	Apr-04							

Panachayvat Dug Well #190304															
Dandeli		Dandeli		Dandeli											
Open Well	Open Well	Open Well	Open Well	Open Well	Open Well	Open Well	Open Well	Open Well	Open Well	Open Well	Open Well	Open Well	Open Well	Open Well	
4/2005	5/2005	5/2006	5/2006	5/2006	5/2006	5/2006	5/2006	5/2006	5/2006	5/2006	5/2006	5/2006	5/2006	5/2006	
(meq/L?)		(mg/L?)		(mg/L?)		(mg/L?)		(mg/L?)		(mg/L?)		(mg/L?)		(meq/L?)	
0.06	0.06	5	0.08												
0.01	0.01	0.25	0.01												
1.75	1.75	57	1.61												
0.97	0.97	66	1.03												
3.38	3.38	205	3.36												
0.28	0.28	0	0.00												
1.85	1.85	40	2.00												
1.73	1.73	25	2.06												
3.13	3.13	54	2.35												
0.10	0.10	3	0.08												
1.12	1.12		1.08												

Birasal et al., 1985														
Chemical Changes in the Surface Waters During the Filling Phase of a Tropical Reservoir, on Kali River														
North Kanara District, Karnataka State														
Kali River above Supa Reservoir						Kali River below Supa Reservoir								
Min (mg/L?)	Max (mg/L?)	Min (meq/L)	Max (meq/L)	Min vs Max (meq/L)	Min (mg/L?)	Max (mg/L?)	Min (meq/L)	Max (meq/L)	Min vs Max (meq/L)	Min (mg/L?)	Max (mg/L?)	Min (meq/L)	Max (meq/L)	Min vs Max (meq/L)
6.9	8.1				5.4	7.7								
18.2	34.8				23.2	32.6								
58.3	269				38.8	99.8								
January, 1985 to August, 1985														
0	27				0.5	2								
1.8	4.2				0.02	0.5								
15	30.4	0.42	0.86	0.42	16.2	21.8	0.46	0.61	0.46	0.61	0.46	0.61	0.46	0.46
0.3	0.57	0.01	0.01	0.01	0.02	0.06	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
0.37	0.8	0.01	0.01	0.01	0.2	0.5	0.00	0.01	0.00	0.01	0.00	0.01	0.00	0.00
7.95	25	0.13	0.41	0.13	12.8	19	0.21	0.31	0.21	0.31	0.21	0.31	0.21	0.21
		0.00	0.00	0.00			0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
50	140				65	150								
18 (mg/L)	108 (mg/L)				50 (mg/L)	142 (mg/L)								
1.2	10.6	0.10	0.87	0.87	1.92	4.18	0.16	0.34	0.16	0.34	0.16	0.34	0.16	0.34
2.8	4.8	0.12	0.21	0.21	3.4	4.2	0.15	0.18	0.15	0.18	0.15	0.18	0.15	0.18
0.75	1.2	0.02	0.03	0.03	0.4	1	0.01	0.03	0.01	0.03	0.01	0.03	0.01	0.03
0.43	0.87	1.99			0.47	0.59	0.82							
NOTE: No Calcium data for this study														
Apr-05			May-06											

AVERAGES, etc.

Synopsis:			
No Incomplete datasets:			
Type	Rivers (3 studies)		
Parameter	Minimum	Maximum	Average
Value	0.27	1.74	1.00
Site	Moulangi KR	Kerwad KR	
Study	B & K, 1990	B & K, 1990	
Open Well (1 study)			
	Minimum	Maximum	Average
	0.77	1.72	1.17
	Dandeli OW Dandeli OW April, 2000		
	PRE	PRE	

No Incomplete Datasets included:											
Overall (4 studies)				Rivers (3 studies)				Open Well (1 study)			
Min	Max	Avg		Min	Max	Avg		Min	Max	Avg	
0.27	1.74	1.12		0.27	1.74	1.00		0.77	1.72	1.17	
(w/o precipitation) w/o Birasal or Kadra											
Overall (10 studies)				Kali River (4 studies)				Open Wells (2 studies)			
Min	Max	Avg		Min	Max	Avg		Min	Max	Avg	
0.27	2.79	1.10		0.27	2.79	1.07		0.77	1.97	1.23	

Appendix 22: Cation : anion comparisons

Kali River: Average anion and cation concentrations (meq/L)

Cations (labeled 'C') are shown in yellow and anions (labeled 'A') in green. All samples from 2008 unless otherwise indicated. Sites displayed in river order from top (upstream) to bottom (downstream). Site names abbreviated with first and last letter of site name, as follows: Mi – Moulangi, Hi - Halmaddi, Kd – Kerwad, Ki – Kariyampalli, Ml – Mainal, Ha – Harnouda, Si – Saksali, Bi – Bommanahelli. Duplicate Halmaddi site represents different sampling dates. Kariyampalli Kali River 2009 sample (Ki 09) is an average of 8 samples.

Cation : Anion ratios at RBF wellfield

Note W1 and W2 have no bicarbonate data incorporated into anion totals. Wtd Avg = weighted averages; W1, 2, 3 = RBF Well 1, 2, 3

	W1	W2	W3	W4	Wells 3 & 4
Min	2.3	2.5	1.9	2.9	1.9
Max	4.7	4.3	2.1	3.6	3.6
Avg	3.5	3.2	2.0	3.2	Wtd Avg: 2.5
# of counts	4	5	8	5	13

Cation : Anion ratios in the field area

Note W1 and W2 have no bicarbonate data incorporated into anion totals and were therefore not used for this ratio calculation. Wtd Avg = weighted averages

	Hand Pumps	Bore Wells / Town Taps	Open Wells	Kali River	RBF Wells 3 & 4		Overall
Minimum	0.9	1.3	1.3	0.8	1.9	Min:	0.8
Maximum	1.7	3.1	4.6	3.1	3.6	Max:	4.6
Average	1.3	1.8	2.8	1.5	2.5	Wtd Avg:	2.0
# of counts	7	6	7	15	13	Total:	48

Appendix 23 - Dixon's Q tests for ion data

Location	date	Source	Avg Na+	Amount (mg/L)	Dixon's Q Test for Outliers	n = 3
Moulangi KR	1985/1986	B&K '90	4.6		Q critical (95% Confidence Level)	
Moulangi KR	1987/1988	K&B, '94	8.2	0.355 <	0.97 = this study's data IS NOT an outlier	
Moulangi KR	Jan, 2008	(this study)	10.1			
Halmaddi KR	1987/1988	K&B, '94	63.6			
Halmaddi KR	Jan, 2008	(this study)	160.3			
Halmaddi KR	1985/1986	B&K '90	192.0			
This study's data is in the middle when the observations are arranged in ascending order so there is no need to do a Q Test						
Kariyampalli KR	14-Jan-09	(this study)	4.1			n = 8
Kariyampalli KR	22-Dec-09	(this study)	4.9			
Kariyampalli KR	17-Jan-09	(this study)	5.6			
Kariyampalli KR	12-Jan-09	(this study)	6.7			
Kariyampalli KR	22-Jan-09	(this study)	6.8			
Kariyampalli KR	19-Jan-09	(this study)	7.5			
Kariyampalli KR	Jan, 2008	(this study)	11.8			
Kerwad KR	1987/1988	K&B, '94	23.6	0.630 >	0.615 = K&B '94 data IS an outlier	
Kerwad KR	1985/1986	B&K '90	96.0			
Location	date	Source	Avg K+	Amount (mg/L)	Dixon's Q Test for Outliers	n = 3
Moulangi KR	1985/1986	B&K '90	1.0		Q critical (95% Confidence Level)	
Moulangi KR	1987/1988	K&B, '94	1.3	0.301 <	0.97 = this study's data IS NOT an outlier	
Moulangi KR	Jan, 2008	(this study)	1.4			

This study's data is in the middle when the observations are arranged in ascending order so there is no need to do a Q Test					n = 3
Halmaddi KR	1987/1988	K&B, '94	10.3		
Halmaddi KR	Jan, 2008	(this study)	15.0		
Halmaddi KR	1985/1986	B&K '90	37.2		
Kariyampalli KR	22-Dec-09	(this study)	0.5		
Kariyampalli KR	14-Jan-09	(this study)	0.6		
Kariyampalli KR	12-Jan-09	(this study)	0.8		
Kariyampalli KR	22-Jan-09	(this study)	0.9		
Kariyampalli KR	19-Jan-09	(this study)	1.5		
Kariyampalli KR	17-Jan-09	(this study)	1.9		
Kerwad KR	1987/1988	K&B, '94	2.9		
Kariyampalli KR	Jan, 2008	(this study)	3.3		
Kerwad KR	1985/1986	B&K '90	24.8		
Location	date	Source	Avg Mg++	Dixon's Q Test for Outliers	
Moulangi KR	Jan, 2008	(this study)	0.9	Q critical (95% Confidence Level)	
Moulangi KR	1985/1986	B&K '90	1.0		
Moulangi KR	1987/1988	K&B, '94	1.0	1.000 > 0.97 = this study's data IS an outlier	
Halmaddi KR	1985/1986	B&K '90	5.1		
Halmaddi KR	Jan, 2008	(this study)	6.3		
Halmaddi KR	1987/1988	K&B, '94	13.3		
This study's data is in the middle when the observations are arranged in ascending order so there is no need to do a Q Test					

Kariyampalli KR	14-Jan-09 (this study)	1.02	n = 8 n = 9
Kariyampalli KR	22-Dec-09 (this study)	1.04	
Kariyampalli KR	Jan, 2008 (this study)	1.12	
Kariyampalli KR	12-Jan-09 (this study)	1.21	
Kariyampalli KR	17-Jan-09 (this study)	1.24	
Kariyampalli KR	22-Jan-09 (this study)	1.43	
Kariyampalli KR	19-Jan-09 (this study)	1.85	
Kerwad KR	1985/1986 B&K '90	2.60	
Kerwad KR	1987/1988 K&B, '94	3.00	
0.481 < 0.615 = B&K '90 data IS NOT an outlier			n = 3
0.204 < 0.57 = K&B '94 data IS NOT an outlier			
Dixon's Q Test for Outliers			
Q critical (95% Confidence Level)			
Moulangi KR	Jan, 2008 (this study)	2.2	
Moulangi KR	1987/1988 K&B, '94	5.1	
Moulangi KR	1985/1986 B&K '90	5.6	
0.858 < 0.97 = this study's data IS NOT an outlier			
Halmaddi KR	1985/1986 B&K '90	50.9	
Halmaddi KR	1987/1988 K&B, '94	59.2	n = 8 n = 9
Halmaddi KR	Jan, 2008 (this study)	136.2	
0.903 < 0.97 = this study's data IS NOT an outlier			
Kariyampalli KR	14-Jan-09 (this study)	3.4	
Kariyampalli KR	22-Dec-09 (this study)	3.7	
Kariyampalli KR	Jan, 2008 (this study)	4.1	
Kariyampalli KR	17-Jan-09 (this study)	5.4	
Kariyampalli KR	12-Jan-09 (this study)	6.0	
Kariyampalli KR	19-Jan-09 (this study)	6.2	
Kariyampalli KR	22-Jan-09 (this study)	8.2	n = 8 n = 9
Kerwad KR	1985/1986 B&K '90	11.8	
Kerwad KR	1987/1988 K&B, '94	24.3	
0.446 < 0.615 = B&K '90 data IS NOT an outlier			
0.606 > 0.57 = K&B '94 data IS an outlier			

Appendix 23 - Dixon's Q tests for ion data

Location	date	Source	Avg Cl-	Amount (mg/L)	Dixon's Q Test for Outliers	n = 3
Moulangi KR	1/13/2008	(this study)	6.6		Q critical (95% Confidence Level)	
Moulangi KR		K&B, '94	17.7			
Moulangi KR		B&K '90	18.1	0.962 <	0.97 =	this study's data IS NOT an outlier
Halmaddi KR		B&K '90	83.4			
Halmaddi KR		K&B, '94	118.0	0.702 <	0.97 =	this study's data IS NOT an outlier
Halmaddi KR	1/10/2008	(this study)	199.2			
Kariyampalli KR	14-Jan-09	(this study)	6.3			n = 8
Kariyampalli KR	22-Dec-09	(this study)	8.6			n = 9
Kariyampalli KR	17-Jan-09	(this study)	9.7			
Kariyampalli KR	19-Jan-09	(this study)	10.2			
Kariyampalli KR	12-Jan-09	(this study)	11.6			
Kariyampalli KR	22-Jan-09	(this study)	12.4			
Kariyampalli KR	1/9/2008	(this study)	30.6			
Kerwad KR		B&K '90	36.0	0.198 <	0.615 =	B&K '90 data IS NOT an outlier
Kerwad KR		K&B, '94	51.9	0.368 <	0.57 =	K&B, '94 data IS NOT an outlier

Note: Kariyampalli data from this study is compared to Kerwad data because authors of previous studies refer to their Kerwad sampling site on the Kali River as being 4 km downstream of the Halmaddi confluence, which is considered Kariyampalli in this study.

Appendix 24 - Dixon's Q test results for silica data

Dixon's Q Test for Outliers
 If $3 \leq n \leq 7$, then $Q_{exp} = (X_2 - X_1) / (X_n - X_1)$
 If $8 \leq n \leq 10$, then $Q_{exp} = (X_2 - X_1) / (X_{n-1} - X_1)$
 If $11 \leq n \leq 13$, then $Q_{exp} = (X_3 - X_1) / (X_{n-1} - X_1)$

Dec datapoint is not on one end or the other when the observations are arranged in ascending order so there is no need to do a Q Test

December data IS NOT an outlier

Month	Absorbance	n
Kali	0.179	6
River	0.183	
	0.186	
	0.215	
	0.223	
	0.244	

Dixon's Q Test for Outliers
 n = 6
 Q critical (95% Confidence Level)
 $0.477 < 0.625 = \text{Dec. data IS NOT an outlier}$

RBF	0.440	6
W1	0.516	
	0.545	
	0.549	
	0.552	
	0.598	

Dixon's Q Test for Outliers
 n = 9
 Q critical (95% Confidence Level)
 $0.576 > 0.57 = \text{Dec. data IS an outlier}$

RBF	0.525	9
W2	0.651	
	0.685	
	0.696	
	0.709	
	0.725	
	0.736	
	0.743	
	0.759	

	Month	Absorbance	n	Dixon's Q Test for Outliers
RBF	1	0.624	12	
W3	1	0.660		
	1	0.702		
	1	0.706		
	1	0.714		
	2	0.728		
	1	0.771		
	1	0.792		
	1	0.818		
	1	0.818		
	1	0.819		
	1	0.835		

Dec datapoint is not on one end or the other
when the observations are arranged in ascending order
so there is no need to do a Q Test

December data IS NOT an outlier

RBF	2	0.423	7	Dixon's Q Test for Outliers
W4	1	0.638		n = 7
	1	0.693		Q critical (95% Confidence Level)
	1	0.720		0.542 < 0.568 = Dec. data IS NOT an outlier
	1	0.768		
	1	0.806		
	1	0.820		

KOW	1	0.463	4	Dixon's Q Test for Outliers
	1	0.504		n = 4
	1	0.511		Q critical (95% Confidence Level)
	2	0.538		0.363 < 0.829 = Dec. data IS NOT an outlier

CL: 95% Confidence Level

Appendix 25 – Overview of metals data

Overview of zinc concentrations

Note WHO standard is an aesthetic standard. Outliers are noted in parentheses. Averages are calculated without outliers. BIS = Bureau of Indian Standards; WHO = World Health Organization

ZINC	n	Low (ppb)	High (ppb)	Average (ppb)	Exceeds BIS 5,000 ppb limit	Exceeds BIS 15,000 ppb limit	Exceeds WHO 3,000 ppb limit
Bore Wells, Town Taps	6	7	450	110	-	-	-
Open Wells	8	3	(420)	21	-	-	-
Kali River	14	<1	(230)	32	-	-	-
Hand Pumps	6	5	(6,000)	230	1 sample	-	1 sample
RBF Wellfield	22	<1	41	15	-	-	-

Average zinc concentrations in each sample category.

Error bars show one standard deviation. Outliers are not shown. BIS = Bureau of Indian Standards; KKR = Kali River at Kariyampalli village; W3 = Well 3; KOW = Open Well at Kariyampalli village; All BWs = Bore Wells in Harnouda, Mainal, and Bada Khanshera villages; BW / TT = Bore Wells & Town Taps; HP = Hand Pumps; OW = Open Wells; all KR=all Kali River sites; all RBF=all RBF wells

Overview of cadmium concentrations

Outliers are noted in parentheses. Averages are calculated without outliers. BIS = Bureau of Indian Standards; WHO = World Health Organization

CADMIUM	n	Low (ppb)	High (ppb)	Average (ppb)	Exceeds BIS 10 ppb limit	Exceeds WHO 3 ppb limit
Bore Wells, Town Taps	6	(<0.08)	1	<0.08	-	-
Open Wells	8	<0.08	(1)	<0.08	-	-
Kali River	14	<0.08	(1)	<0.08	-	-
Hand Pumps	6	<0.08	1	<0.08	-	-
RBF Wellfield	22	<0.08	(1)	<0.08	-	-

Average cadmium concentrations in each sample category.

Error bars show one standard deviation. Outliers are not shown. BIS = Bureau of Indian Standards; KKR = Kali River at Kariyampalli village; W3 = Well 3; KOW = Open Well at Kariyampalli village; All BWs = Bore Wells in Harnouda, Mainal, and Bada Khanshera villages; BW / TT = Bore Wells and Town Taps; HP = Hand Pumps; OW = Open Wells; all KR=all Kali River sites; all RBF=all RBF wells

Overview of lead concentrations

Outliers are noted in parentheses. Averages are calculated without outliers. BIS = Bureau of Indian Standards; WHO = World Health Organization

LEAD	n	Low (ppb)	High (ppb)	Average (ppb)	Exceeds BIS 50 ppb limit	Exceeds WHO 10 ppb limit
Bore Wells, Town Taps	6	<0.09	17	4	-	2 samples
Open Wells	8	<0.09	(22)	1	-	1 sample
Kali River	14	<0.09	8	1	-	-
Hand Pumps	6	<0.09	14	4	-	1 sample
RBF Wellfield	22	<0.09	1	<0.09	-	-

Average lead concentrations in each sample category.

Error bars show one standard deviation. Outliers are not shown. BIS = Bureau of Indian Standards; KKR = Kali River at Kariyampalli village; W3 = Well 3; KOW = Open Well at Kariyampalli village; All BWs = Bore Wells in Harnouda, Mainal, and Bada Khanshera villages; BW / TT = Bore Wells and Town Taps; HP = Hand Pumps; OW = Open Wells; all KR = all 8 Kali River sites; all RBF = all 4 RBF wells

Overview of copper concentrations

Outliers are noted in parentheses. Averages are calculated without outliers. BIS = Bureau of Indian Standards; WHO = World Health Organization

COPPER	n	Low (ppb)	High (ppb)	Average (ppb)	Exceeds BIS 50 ppb limit	Exceeds BIS 1,500 ppb limit	Exceeds WHO 2,000 ppb limit
Bore Wells, Town Taps	6	<0.09	83	15	2 samples	-	-
Open Wells	8	<0.09	(28)	2	-	-	-
Kali River	14	<0.09	5	1	-	-	-
Hand Pumps	6	<0.09	(45)	2	-	-	-
RBF Wellfield	22	<0.09	(4)	1	-	-	-

Average copper concentrations in each sample category.

Error bars show one standard deviation. Outliers are not shown. BIS = Bureau of Indian Standards; KKR = Kali River at Kariyampalli village; W3 = Well 3; KOW = Open Well at Kariyampalli village; All BWs = Bore Wells in Harnouda, Mainal, and Bada Khanshera villages; BW / TT = Bore Wells and Town Taps; HP = Hand Pumps; OW = Open Wells; all KR = all 8 Kali River sites; all RBF = all 4 RBF wells

Overview of titanium concentrations

Outliers are noted in parentheses. Averages are calculated without outliers. There are no water quality standards for Ti.

TITANIUM	n	Low (ppb)	High (ppb)	Average (ppb)
Bore Wells, Town Taps	6	(1)	6	3
Open Wells	8	1	7	3
Kali River	14	<0.08	6	<0.08
Hand Pumps	6	<0.08	7	3
RBF Wellfield	22	<0.08	2	1

Overview of chromium concentrations

Outliers are noted in parentheses. Averages are calculated without outliers. BIS = Bureau of Indian Standards; WHO = World Health Organization

CHROMIUM	n	Low (ppb)	High (ppb)	Average (ppb)	Exceeds BIS and WHO 50 ppb limit
Bore Wells, Town Taps	6	<0.07	2	1	-
Open Wells	8	<0.07	2	<0.07	-
Kali River	8	<0.07	(3)	<0.07	-
Hand Pumps	6	<0.07	(16)	1	-
RBF Wellfield	22	<0.07	(<0.07)	<0.07	-

Average chromium concentrations in each sample category.

Error bars show one standard deviation. Outliers are not shown. BIS = Bureau of Indian Standards; KKR = Kali River at Kariyampalli village; W3 = Well 3; KOW = Open Well at Kariyampalli village; All BWs = Bore Wells in Harnouda, Mainal, and Bada Khanshera villages; BW / TT = Bore Wells and Town Taps; HP = Hand Pumps; OW = Open Wells; all KR = all 8 Kali River sites; all RBF = all 4 RBF wells

Overview of manganese concentrations

Note 100 ppb WHO limit is an aesthetic standard. Outliers are noted in parentheses. Averages are calculated without outliers. BIS = Bureau of Indian Standards; WHO = World Health Organization

MANGANESE	n	Low (ppb)	High (ppb)	Average (ppb)	Exceeds BIS and WHO 100 ppb limit	Exceeds BIS 300 ppb limit	Exceeds WHO 500 ppb limit
Bore Wells, Town Taps	6	<0.5	(820)	110	3 samples	1 sample	1 sample
Open Wells	8	1	1,060	78	2 samples	2 samples	1 sample
Kali River	14	<0.5	340	51	4 samples	1 sample	-
Hand Pumps	6	1	2,400	540	4 samples	3 samples	2 samples
RBF Wellfield	22	<0.5	(950)	120	11 samples	4 samples	2 samples

Average manganese concentrations in each sample category.

Error bars show one standard deviation. Outliers are not shown. BIS = Bureau of Indian Standards (shown with dashed line); KKR = Kali River at Kariyampalli village; W3 = Well 3; KOW = Open Well at Kariyampalli village; All BWs = Bore Wells in Harnouda, Mainal, and Bada Khanshera villages; BW / TT = Bore Wells and Town Taps; HP = Hand Pumps; OW = Open Wells; all KR = all 8 Kali River sites; all RBF = all 4 RBF wells

Overview of iron concentrations

Note 300 ppb WHO limit is an aesthetic standard. Outliers are noted in parentheses. Averages are calculated without outliers. BIS = Bureau of Indian Standards; WHO = World Health Organization

IRON	n	Low (ppb)	High (ppb)	Average (ppb)	Exceeds BIS and WHO 300 ppb limit	Exceeds BIS 1,000 ppb limit
Bore Wells, Town Taps	6	20	270	140	-	-
Open Wells	8	59	(970)	170	3 samples	-
Kali River	14	<3.6	(1,030)	120	4 samples	1 sample
Hand Pumps	6	<3.6	25,000	4,900	6 samples	4 samples
RBF Wellfield	22	49	24,000	5,800	11 samples	11 samples

Average iron concentrations in each sample category.

Error bars show one standard deviation. Outliers are not shown. BIS = Bureau of Indian Standards (shown with dashed line); KKR = Kali River at Kariyampalli village; W3 = Well 3; KOW = Open Well at Kariyampalli village; All BWs = Bore Wells in Harnouda, Mainal, and Bada Khanshera villages; BW / TT = Bore Wells and Town Taps; HP = Hand Pumps; OW = Open Wells; all KR = all 8 Kali River sites; all RBF = all 4 RBF wells

Appendix 26: Metals ranges by sample type in ppb (ppm conversions for Fe & Zn)

* Stars rt side of value = above BIS limits. ↑ Arrow rt side of value = outlier

# of samples	Sample Type		Chromium	Manganese	Iron
	Distilled	minimum	0.00	0.00	0.00
3	Water	maximum	1.25	1.25	56.41
		average	0.34	0.32	17.77
6	Bore Wells	minimum	0.00	0.19	20.10
	&	maximum	1.77	820.47 *	273.03
	Town Taps	average	0.649	109.15 *	144.30
6	Hand Pumps	minimum	0.00	0.49	0.00
		maximum	15.83 ↑	2431.54 *	25038.49 *
		average	0.80	537.68 *	4880.71 *
8	Open Wells	minimum	0.00	1.02	58.56
		maximum	1.96	1059.27 *↑	974.04 *↑
		average	0.75	78.26	166.26
14	Kali River	minimum	0.00	0.00	0.00
		maximum	3.28 ↑	335.80 *↑	1025.28 *↑
		average	0.40	50.78	122.09
4	RBF W1	minimum		355.50 *	59.03
		maximum	0.35	948.48 *	23749.83 *
		average		671.84 *	10609.32 *
5	RBF W2	minimum	0.00	0.40	70.10
		maximum	0.11	142.01 *	16199.54 *
		average	0.01	72.29	6607.95 *
8	RBF W3	minimum	0.00	0.00	48.94
		maximum	0.08	267.10 *	14375.12 *
		average	0.00	72.83	3522.52 *
5	RBF W4	minimum	0.00	20.49	79.70
		maximum	0.16	276.53 *	12877.44 *
		average	0.02	111.72 *	4946.65 *
59	Overall	minimum	0.00	0.00	0.00
		maximum	15.83	2431.54 *	25038.49 *
		average	0.84	169.15 *	2762.67 *
ppm					
56	No DI or Tap	minimum	0.00	0.00	0.00
		maximum	15.83	2431.54 *	25038.49 25.04 *
		average	0.87	178.20 *	2909.72 *
ppm					
22	Just RBF	minimum	0.00	0.00	48.94 0.05
		maximum	0.35	948.48 *	23749.83 23.75 *
		average	0.13	190.46 *	5835.93 *

Appendix 26: Metals ranges by category in ppb (ppm conversions for Fe & Zn)

* Stars rt side of value = above BIS limits. ↑ Arrow rt side of value = outlier

Copper	Zinc	Cadmium	Lead	Sample Type
0.00	0.00	0.00	0.06	Distilled
0.57	17.73	0.30	2.40	Water
0.14	4.43	0.20	0.757	
0.000	7.12	0.036	0.179	Bore Wells
82.94 *	445.00	0.64	16.76	&
15.258	110.61	0.263	3.960	Town Taps
0.00	5.04	0.07	0.00	Hand Pumps
44.46 ↑	6003.94 *↑	1.37	13.62	
2.17	228.61	0.39	3.58	
0.01	3.05	0.06	0.11	Open Wells
27.50 ↑	416.98 ↑	0.63 ↑	22.20 ↑	
1.58	20.54	0.19	1.11	
0.00	0.00	0.10	0.05	Kali River
5.31	225.66 ↑	0.96 ↑	8.01	
1.43	31.61	0.18	1.37	
0.00	0.00	0.11	0.09	RBF W1
0.00	28.60	0.29	0.64	
0.00	10.06	0.16	0.24	
0.00	4.86	0.02	0.10	RBF W2
2.04	26.16	0.56	1.00	
0.38	15.66	0.18	0.35	
0.00	0.00	0.02	0.06	RBF W3
0.86	29.42	1.42 ↑	0.89	
0.35	12.64	0.13	0.22	
0.00	9.89	0.03	0.13	RBF W4
4.18	40.63 ↑	0.52	0.97	
1.23	17.25	0.21	0.41	
0.00	0.00	0.00	0.00	Overall
82.94 *	6003.94 *	1.42	22.20	
3.35	108.44	0.24	1.75	
ppm				
0.00	0.00	0.02	0.00	No DI
44.46	6003.94 6.00 *	1.42	22.20	or Tap
3.47	112.16	0.24	1.80	
0.00	0.00	0.02	0.06	Just RBF
4.18	40.63 ↑	1.42 ↑	1.00	
0.49	13.75	0.17	0.29	

Appendix 28: Field Notes from India

Field Notes: Dandeli, Karnataka, India – January, 2008

1/8/08 Tested water at State Lodge Hotel: Dandeli Town Tap

1/9/08 “ Kerwad Town Tap
Kerwad Kali River
Kerwad Open Well
Field diagram of soil pit on road to Kerwad
Kariyampalli Bore Well
Kariyampalli Open Well
Kariyampalli Kali River
Mainal Hand Pump
Mainal Open Well
Mainal Kali River (by the bridge)

1/10/08 “ Bada Khanshera Bore Well
Bada Khanshera Hand Pump
Harnouda Lake Bore Well
Harnouda Hand Pump
Harnouda Kali River
Saksali Open Well
Saksali Kali River
Halmaddi Hand Pump
Halmaddi Kali River

1/11/08 working at Dandeli College chemistry lab

1/12/08 Meeting with Professor S.T. Patil in Dharwad - Dept of Water Management
Throughout the world there has been a problem with regulations. Weak enforcement of groundwater laws. Industrial contamination of surface water is common in Karnataka (i.e. sugar mills). Per capita availability of fresh water is on the decline in Karnataka. Important that this be a demonstration project. Once it's shown that it works, people will accept RBF much more. Private land is easier to use. If it succeeds there, then it will be easier to place a project on public land. People will come to us rather than visa-versa. There are issues elsewhere in Karnataka on drilling

near irrigated fields. Water is very sensitive issue in Karnataka. 2 major water basins in Karnataka: water disputes. Due to this, people are suspicious about water projects. Dharwad University mostly has info on surface water stats, not gw. Patil was on working group and planning committee of 10th plan and working group of 11th plan.

Biocon (pharmaceutical company) – 27 villages around their plant have had problems with gw

Beyond 80 ft depth = mining of water. RBF should be 6-20 meters deep b/c different regulations. Patil will look up exact depth. Deeper water = gov't owned. Shallower water = owned by landowner.

Major worldwide issue: equitable allocation of water. Major issue: fragmented approach to water law/issues. Also: multi-state boundaries.

India doesn't use concept of minimum flows b/c many rivers go dry here perennially (Dec/Jan to May/June). Policy is there, but not practiced.

Rayon factory 150 km from Dharwad has discharged pollutants into Tungabhadra River. Case went to Supreme Court. Negative impact on cattle downstream.

Strength of project is in demonstrating technology. Weakness is in raising hackles about pollution.

State GW Board will have observation bore well info

Govt interactions not helpful to research: they aren't willing to part with data for researchers to use.

Biggest issue: water quality of RBF project's water

Make sure RBF depth and distance of well are not interacting with legal issues therefore use private land.

Pollution Control Board: water quality is not fully mapped. Only extreme point sources. Mostly industrial plants.

<u>1/13/08</u> Tested water at	Kerwad Town Tap
	Halmaddi Kali River, also Halmaddi soil profile
	Halmaddi Hand Pump
	Moulangi Hand Pump
	Moulangi Town Tap
	Moulangi Kali River
	Bommanahelli Kali River

Info from Prof Shanbagh: 8 km underground pipeline from Bommanahelli to Sykes Point:

1 tunnel to 3 tunnels to 6 tunnels. 6 generators for hydroelectric power. Then to Kodasalli Dam. Around Dandeli is where Kali River is a permanent stream. Kali River goes dry after Bommanahelli dam b/c water goes into pipelines.

1/14/08 meeting with D.R. Raikar – Health Inspector, Dandeli General Hospital. He says the hospital does see more cases of water-borne diseases during the monsoon (May- Sept), but they don't keep data.

Gather data from Panchayat Raj Engineering office – local well logs.

Haliyal Community Health Center – met with G.H. Palek, Health Inspector

Bacterial tests of water samples.

1/16/08 Travel day down to Goa

1/17/08 packing up samples. All samples used for bacteria analysis did not have enough left over to pre-rinse the unacidified 20 mL VOA bottles.

1/18-1/22/08 entering data at TERI office

1/22/08 Tested tap water at Panaji Bore Well (TERI office)

Field Notes: Dandeli, Karnataka, India – January, 2009

1/8/09 testing data loggers, slug tests.

I spoke with Mr. Patil (landowner – not the same Mr. Patil as last year's contact), and he mentioned in passing that the Karnataka Power Corporation, who runs Supa Dam and all the dams on the Kali river (he said 3 dams, not 4...) has complete ownership in perpetuity of all the Kali River's water rights for the entire length of the river. Mr. Patil said the Power Company turns a blind eye to the small farmers who pump river water for irrigation of crops on the riverside villages b/c they don't use much water and it all flows back into the river anyway.

1/9/09 at Dandeli College labs – Chemistry Dept: look at silica equipment
Microbiology Dept: learn how to use incubators

1/10/09 experimental slug tests

1/12/09 iButton testing of incubators

Began sampling at RBF site

Power went out at midday so the incubator was not heating up the whole time we were in the field this afternoon. It was warming up for an hour or two before we put the samples in. It looks like 37.9 °C on the top red readout is actually about 35 °C (according to thermometer inside)

1/13/09 gathered bacteria results

Thermometer read 33.2 °C red display on incubator read 35.2 °C green display in incubator read 11.9 V

1/14/09 Meeting with Dr. Preeti Kudesia from World Bank – New Delhi. She suggests best to ask about acute diarrhea only in past 2 weeks - longer than that is too hard to remember. Also, she suggests we give plotting materials to the primary health center nurse i.e. red dots to put next to a child's name in a graph means they had diarrhea that week, green dot means no diarrhea. That will help us keep more accurate records.

Note: the power company released extra water today so that people can bathe in the Kali River in celebration of Sankranti, so the river is high today.

Collected samples at RBF site

1/15/09 Slug tests

Read bacteria results in lab

Incubator:

red display: 35.8 °C, green display: 12.35 V, thermometer: 34 °C

Note: these sterile sample bottles are hard to judge exactly where the fill line is for 100 mL so our first few bacteria test runs have ended up being a bit short of 100 mL so the Quanti-trays have not been completely full. When reading the bacteria results, therefore, I have noted under each sample location how many of the large Quanti-tray wells ended up being empty. Because of these empty Quanti-tray wells, this has introduced some error into our data, so results are reported as a range of MPN #'s, i.e. at least the # of Quanti-tray wells counted up to at most the added empty wells if they had been positive.

We moved the pump from well #4 to Well #3 this morning. This afternoon we ran the pump for about an hour, then checked water level = 7.135 m. Slight leakage (dripping) out of pipe beyond the meters.

Both meters running together: Right meter: 0.658 m³/10 minutes

Left meter: $0.634 \text{ m}^3/10 \text{ minutes}$
Left meter only running by itself: $1.192 \text{ m}^3/10 \text{ minutes}$

6:07 pm: water level in well #3 after another ~45 minutes of pumping: Depth to water: 7.16 meters. So cone of depression has drawn down ~2 cm in ~1 hr. So probably the cone of depression will not go below 8 m, so we need to suspend the LevelTroll at about 10 meters depth from the top of the well pipe.

1/16/09 data logger testing

LevelTroll in the Kali River was hung from a branch with
3 cm of water above the top of the Troll
Pump started at 11:53 am
Sampled Well #3

1/17/09 Downloaded loggers.

10:22 am start of tracer test in Well #4. Finished adding tracer at 12:57 pm. 5 kg NaCl in 16 L water added to well 1L of solution every 5 minutes.

10:25 am start of tracer test in Well #2. Finished adding tracer at 12:52 pm. 1 kg of KBr in 16 L of water added to well 1L of solution every 5 minutes.

Collected samples at RBF site

Plan to switch pump from well #3 to Well #4 2nd week of March

1/18/09 Mr. Patil says he turned on pump today at 5 am (so it was not pumping for about 15.5 hrs before that). But water meter is not spinning. I turned the red ball valve off and on again the meter started spinning. Reddy says it looks like the electricity is not at full power b/c he thinks the meter is not spinning as fast as a few days ago.

Collected samples at RBF site

pH/Temp/EC meter wouldn't settle on a reading so we took it apart and drained water from inside it. It worked again after letting it dry out.

3:15 pm: we switched to the other water meter which reads 0002.708 m^3 .
Final reading on old meter: 0098.312 m^3

1/19/09 power was out when we arrived, but only for a short amount of time.

Collected samples at RBF site

Incubator in microbiology lab

thermometer: $33.5 \text{ }^\circ\text{C}$; red display: $35.6 \text{ }^\circ\text{C}$ Green display: 012.35 V

Did another iButton check of incubator temps. Rollover had occurred. It looks like the iButton settled down at about 34.9 °C.

Expiration dates: Colilert-18 packs: Oct 18, 2009
Comparator: June 18, 2009 (brought by Tom in January)
Comparator: April 16, 2009
(this one got hot in the taxi in Hubli)
Comparator: March 13, 2009
(This one sat in a cardboard box in Dandeli for 3 months without refrigeration, though it is pretty cool inside the classroom where the box was stored)

Set up schedule for future sampling after I am gone

1/20/09 Collected samples at RBF site

LevelTroll in the Kali River is out of the water
(water level has gone down since it was hung out there)

3:30 pm: Levellogger LTC: I switched the conductivity measurement from 80.00 mS/cm to 30.000 mS/cm for more accuracy

Kali River data logger: 2.4 meters from tip of branch down to the mud. We lengthened the rope holding the data logger so it is in the water now. 4:45 pm I started a new program with the 1st log set for 21 cm water gauge reading. I think this may be the first time this meter was correctly set for Kali River actual conditions. I think the others have all been programmed wrong for various reasons.

Mr. Patil said 2001 no rain, Kali was very low. 2002 pipeline to Kariyampalli installed. Worked on and off until 2008 when it broke completely. It served Kariyampalli, Mainal, Kerwad, Harnouda, Saksali, and Halmaddi. 6 Lakh from West Coast Paper Mill (10 % of cost) other 90% from World Bank. 2001: drought: >100 cattle owned by Mr. Patil died b/c no clean water. "Kali River was just black." Lots of other people lost cattle then also.

April + May = summer

Jun – September = rainy season

October – February = dry

West Coast Paper Mill paid 10% to supply water via pipelines to villages and World Bank supplied the other 90%, but work was not done properly so pipeline was constantly breaking down and getting repaired until 2008 when it broke down a year ago and still hasn't been fixed so people in Kariyampalli and Mainal must use the Open Well.

1/21/09 Collected samples at RBF site

Mainal Bore Well: this is one of 3 tanks from one bore ~200 m away from this one. This one is the one they drink from. Mr. Patil says it is >160 ft deep. Mainal

villagers say they used to have cattle that all died from bad water just like Mr. Patil's herd.

Mainal Open well: water table is really low here. They only drink from this well if the bore well is dry and Kali River is low. I don't think that happens very often, but it's a bit hard to tell from the communication.

Gave lab demonstration to Microbiology students about IDEXX system

1/22/09 Collected samples at RBF site

Read bacteria results in lab.

Incubator red display: 36.0 °C, green: 12.3 V, thermometer: 33.5 °C

All but controls were overfilled (= >100 mL, so media % was low)

4:15 pm: LevelTroll is out of the water again at the

Kali River (i.e. water level has dropped again)

1/23/09 Collected samples at RBF site

11:45 am: We hung Kali River LevelTroll from end of long bamboo branch and measured how long the rope it hung from was wet after lowering down the Troll as low as we could. Wet string = 2.3 m from bottom of Troll to end of wet line. Length of Troll = 20 cm from tip to where cap affixes. Kali River depth on bamboo branch programmed to take linear readings 1x /10 minutes until 90 days from now. Set for surface water gauge height / stage of 230 cm. But I don't actually know if the Troll was on the river bottom when I measure the wet string, so this is what we'll work with and we'll be able to get relative change from this data. On graph, I'm pretty sure where temp skyrockets = Troll was above water, in air.

Well #2: height from ground to top of well pipe = 50 cm

Well #4: = 42 cm

Well #1: = 23 cm

Well #3: = 7 cm

(no cement box around it = more prone to mud getting down well)

Kariyampalli Open well height from paved area around well to seat: 53 cm. Height from ground to paved area ~10 cm

1:20 pm had to pull up data logger for a minute to untangle it from bailer

Bacteria samples: incubator was off. Turned on at 3:54 pm. Samples put in incubator at 4:03 pm. Red display: 32.6 °C, green display: 12.3, thermometer: 30 °C iButton in incubator: high temp alarm: 36 °C. low temp alarm 34 °C. No violation of high temp alarms Low temp alarm went off at 60, 240, 1860 (probably when I removed it from incubator). Sample rate every 30 minutes. # of mission samples: 208.

1/24/09 Read bacteria results.

Red display: 35.7 °C, green display: 12.3 Thermometer: 33 °C

Collected samples at RBF site

Pump not running – electricity out

Appendix 29: Tom Boving Field Log, May 2009

05/11/2009 Meeting at TERI, Goa

- Discussed field visit and defined goals to be achieved during visit

05/12/2009 Meeting at TERI, Goa

- Prep field visit, check instrumentation, program loggers
- Discussed and refined outreach/education strategy

05/13/2009 Preparation for salt tracer test

Note: Well #4 had been pumping for previous 5 wks (compare Mr. Reddy's field log)

- Well #3 water level at 15:00 (#4 had been shut down for 1 hr prior to measurement): 5.603 m (top of casing)
- Moved pump from well #4 to #3; installed at approx. 18 m below top of casing
- Started well #3 at 17:47 Flow meter reading: 1993.295 m³

05/14/2009 Salt tracer test I

- Flow meter reading at 9:23: 2128.230 m³ (→ Δ 134.935 m³ / 15:36 hrs = 8.7 m³/hr) → pump constantly running overnight!
- Water level readings:
  - W#1: 5.535 m
  - W#2: 5.556 m
  - W#3: 8.93 m → Δ Top of well to ground surface: 0.795 m
  - W#4: 5.556 m
- Electricity down between 9:40 and 11:20
- Preparation of salt tracer solution: dissolved 3 kg salt (NaCl) in 20 l well #3 water. After electricity returned at 11:20, pump was running for 25 min before pouring salt tracer solution down well #2 over following 15 min (11:45-12:00)
- Flow meter reading at 11:53: 2141.001 m³
- Flow meter reading at 16:34: 2183.503 m³
- Amanda and Kavita presented to Kariyampali town nurse and teach (incl. some villagers) what RBF project is about. Discussed best outreach strategy for town meeting on 05/17/09.

05/15/2009 Salt tracer test II

- Flow meter reading at 9:11: 2336.416 m³ (→ Δ 152.913 m³ / 16:37 hrs = 9.2 m³/hr) → pump constantly running overnight!
- Electric conductivity W#2: 307 uS/cm → back to “background” level, i.e. salt tracer has completely infiltrated into aquifer.

- Pulled data logger from W#3 → **not submersed in water!** Decided to repeat salt tracer test because unsure if 1st tracer slug had already broken through.
- 10:38 AM: Logger re-installed at 16 m below top of casing, i.e. about 7 m below water level during pumping (approx. 8.96 m)
- Flow meter reading at 15:46: 2397.754 m³
- Preparation of salt tracer solution: dissolved 3 kg salt (NaCl) in 20 l well #3 water. Poured down well #2 between 16:05 and 16:15
- Flow meter reading at 16:16: 2402.309 m³
- Water level W#2: 5.665 m
- Flow interrupted at between 16:29 and 16:44 to connect Well #3 to pipeline. Pumped till 16:59 to test water distribution system. Approx. yield at Kariyampali water tanks: 6.5 m³/hr (Δ meter: 2404.414 to 2406.077 m³ = 1.663 m³ / 15 min)
- Restarted tracer test at 17:10

05/16/2009   Continue salt tracer test

- Flow meter at 9:38: 2451.396 m³ (Δ 45.319 m³ = 2.75 m³/h → electricity must have been off for about 11 hrs overnight!)
- Flow meter at 12:36: 2478.251 m³ (Δ 26.855 m³ ; Q = 9.0 m³/hr)
- Electric conductivity W#2 at 12:43: 310 uS/cm → back to “background” level, i.e. salt tracer has completely infiltrated into aquifer. Temp: 27.3 °C, TDS: 162 ppm, pH: 6.52
- Water levels at 12:15 (W#3 is pumping):
  - W#1: 5.45 m
  - W#2: 5.65 m
  - W#4: 5.64 m
  - Open Well: 3.67 m
- Electricity off at 14:15
- Electricity back on at 17:35
- Flow meter at 17:39 2492.868 m³
- Recorded interviews for project video
- Site visit by Dr. Shanbar and Dr. Sabhahit (liaison with papermill)

05/17/2009   Outreach/Education in Kariyampali incl. visit of field site

- Amanda and Kavita presented RBF project to assembled villagers
- Walked from village to RBF site – explained purpose of RBF
- Return to Goa

05/18/2009 through 05/20/2009   Post-field visit session

- Recorded additional video interviews
- Field data transfer and organization
- Brainstormed RFB implementation strategy at other Indian sites

Appendix 30: Monsoon hydrograph from Dandeli (1990 – 2007)

Appendix 31: Slug, Pump, and Recovery Test Data for Aqtesolv

Pump Test Type	Slug
Pump Test Date	1/15/2009
Datapoints used	1102-1282
Saturated Thickness (cm)	820
Initial Displacement (cm)	70
Casing radius (cm)	9.5
Well Radius (cm)	7.6
Well Skin Radius (cm)	9.5
Screen Length (cm)	610
Solution Type	Bouwer-Rice
Match Type	Visual
Hydraulic Conductivity (m/day)	13.5

Subset of Slug Test data from 1/15/09
from data points 1102-1282 (9:33 - 9:36 am):

Elapsed Time (min)	Change in Level (cm)
0.12	60.47
0.23	53.81
0.35	57.67
0.47	42.12
0.58	26.24
0.70	17.11
0.82	12.37
0.93	8.87
1.05	6.5
1.17	4.88
1.28	3.66
1.40	2.73
1.52	1.92
1.63	1.23
1.75	0.8
1.87	0.34
1.98	0.09

Pump Test Type	Pump
Pump Test Date	May, 2009
Datapoints used	2925-3731
Saturated Thickness (cm)	730
Casing radius (cm)	9.5
Well Radius (cm)	7.6
Pump Rate (L/min)	116.67

Fully Penetrating Well
Cooper-Jacob Solution
Visual Matching

Hydraulic Conductivity (m/day)	10.94
Elapsed Time (min):	744
Max Displacement (cm):	133.5
Min Displacement (cm):	76.3
Overall Change in Displacement (cm):	57.2

count for	Elapsed Time	Displacement			
Aqtesolv	Time (min)	(min)	(cm)	Level	period #
1	4244	0	0	921.1	2928
2	4275	31	76.3	844.8	2959
3	4306	62	87.5	833.6	2990
4	4337	93	96.4	824.7	3021
5	4368	124	101.0	820.0	3052
6	4399	155	110.1	810.9	3083
7	4430	186	115.8	805.2	3114
8	4461	217	118.6	802.5	3145
9	4492	248	121.5	799.5	3176
10	4523	279	125.4	795.6	3207
11	4554	310	125.7	795.3	3238
12	4585	341	128.6	792.4	3269
13	4616	372	128.4	792.7	3300
14	4647	403	133.5	787.6	3331
15	4678	434	130.6	790.5	3362
16	4709	465	126.9	794.2	3393
17	4740	496	127.7	793.4	3424
18	4771	527	128.8	792.3	3455
19	4802	558	129.2	791.8	3486
20	4833	589	128.8	792.3	3517
21	4864	620	124.7	796.4	3548
22	4895	651	127.9	793.2	3579
23	4926	682	127.1	793.9	3610
24	4957	713	119.1	801.9	3641
25	4988	744	121.8	799.3	3672

Pump Test Type	Recovery
Pump Test Date	May, 2009
Datapoints used	4158-4995
Saturated Thickness (cm)	730
Casing radius (cm)	9.5
Well Radius (cm)	7.6
Pump Rate (L/min)	116.67
Fully Penetrating Well	
Cooper-Jacob Solution	
Visual Matching	
Hydraulic Conductivity (m/day)	13.47
Elapsed Time (min):	780
Max Displacement (cm):	102.3
Min Displacement (cm):	-237.2
Overall Change in Displacement (cm):	-134.9

count for	Time (min)	Elapsed Time (min)	Displacement (cm)	Level
1	5525	0.1	0.1	102.3
2	5526	1	140.0	-37.7
3	5542	17	264.5	-162.2
4	5558	33	280.5	-178.2
5	5574	49	291.9	-189.6
6	5590	65	295.7	-193.4
7	5621	96	299.1	-196.7
8	5637	112	301.7	-199.4
9	5653	128	304.9	-202.6
10	5669	144	312.0	-209.7
11	5685	160	311.3	-209.0
12	5701	176	312.8	-210.4
13	5717	192	314.9	-212.6
14	5733	208	315.9	-213.5
15	5749	224	316.9	-214.5
16	5765	240	319.7	-217.4
17	5781	256	323.0	-220.7
18	5797	272	325.5	-223.2
19	5813	288	323.1	-220.8
20	5829	304	321.4	-219.1
21	5845	320	326.1	-223.7
22	5861	336	324.5	-222.2
23	5877	352	321.7	-219.3
24	5893	368	323.1	-220.8

25	5909	384	324.1	-221.8
26	5925	400	321.2	-218.8
27	5941	416	324.0	-221.7
28	5957	432	327.0	-224.7
29	5973	448	326.3	-224.0
30	5989	464	329.7	-227.4
31	6005	480	330.2	-227.9
32	6021	496	339.5	-237.2
33	6033	508	157.1	-54.7
34	6049	524	63.7	38.6
35	6065	540	45.5	56.9
36	6081	556	35.3	67.0
37	6097	572	29.0	73.3
38	6113	588	24.2	78.1
39	6129	604	21.8	80.6
40	6145	620	17.3	85.0
41	6161	636	14.5	87.9
42	6177	652	12.9	89.4
43	6193	668	10.3	92.0
44	6209	684	8.8	93.5
45	6225	700	5.9	96.5
46	6241	716	6.3	96.0
47	6257	732	5.8	96.6
48	6273	748	3.0	99.3
49	6289	764	2.5	99.8
50	6305	780	1.7	100.6

Pump Test Type		Pump
Pump Test Date		May, 2009
Datapoints used		5042-5891
Saturated Thickness (cm)		730
Casing radius (cm)		9.5
Well Radius (cm)		7.6
Pump Rate (L/min)		116.67
Fully Penetrating Well		
Cooper-Jacob Solution		
Visual Matching		
Hydraulic Conductivity (m/day)		13.56
Elapsed Time (min):		792
Max Displacement (cm):		214.4
Min Displacement (cm):		153.3
Overall Change in Displacement (cm):		61.1
count for Time	Elapsed Time	Displacement
Aqtesolv (min)	(min)	(cm)
1	6361	0
2	6394	33
3	6427	66
4	6460	99
5	6493	132
6	6526	165
7	6559	198
8	6592	231
9	6625	264
10	6658	297
11	6691	330
12	6724	363
13	6757	396
14	6790	429
15	6823	462
16	6856	495
17	6889	528
18	6922	561
19	6955	594
20	6988	627
21	7021	660
22	7054	693
23	7087	726
24	7120	759
25	7153	792
		206.0

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