Water For All

Sustainable solutions for reducing and utilizing Sarvajal's Reverse Osmosis brine in Northwestern India

Prepared for: Sarvajal (Piramal Water Private Limited)

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Abstract

An interdisciplinary team of six students from the University of Michigan's School of Natural Resources & Environment (SNRE) spent twelve months working with the India based, social enterprise, Sarvajal, to help address a water resource challenge facing their organization. Sarvajal works to provide clean and affordable drinking water to rural communities in India by employing the technology of Reverse Osmosis (RO) on a local scale. This process is considered one of the best water purification technologies currently available; however, as a by-product of this process, brine is produced that contains concentrated dissolved contaminants. Finding affordable methods to treat or use this brine is difficult. The team of students worked with Sarvajal to try and help address the challenges created by this RO brine. The contents of this report outline the work of the students and their recommendations for Sarvajal.

The team conducted extensive research on possible applications for the RO brine, but as the project progressed, the team noticed operational inefficiencies and data gaps that presented barriers to successfully implementing specific applications. As a result, the team developed overarching recommendations, in addition to providing research on specific applications. Applications were researched that had the potential to address environmental, social, and economic impacts of brine management. The team's recommendations were designed to facilitate the eventual implementation of some of the brine applications and to identify promising applications that warrant further consideration from Sarvajal. These recommendations include: expanding data collection and including additional parameters in brine testing, regionalizing efficiency standards for increased production, improving communications about RO brine use amongst Sarvajal and its franchisees, and investing in further research for select promising applications.

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Executive Summary

An interdisciplinary team of six students from the University of Michigan's School of Natural Resources & Environment (SNRE) spent 12 months working with the Indian based, social enterprise, Sarvajal, to help address a water resource challenge facing their organization. Sarvajal works to provide clean and affordable drinking water to rural communities in India by employing the technology of Reverse Osmosis (RO) on a local scale. This process is considered one of the best water purification technologies currently available; however, as a by-product of this process, brine is produced that contains concentrated contaminants. Finding affordable methods to treat or use this brine is difficult. The team of students worked with Sarvajal to try and help address the challenges created by this RO brine. The contents of this report outline the work of the students and their recommendations for Sarvajal.

In working on the project, the team researched the water crisis facing the region of India where Sarvajal operates, the RO process and industry standards for dealing with the challenges of RO brine, and the Sarvajal business model. This work was done primarily from the University of Michigan campus. During the in-country phase of research, the team traveled to India to visit Sarvajal operations and the communities where they are based. The itinerary included: New Delhi; Sarvajal headquarters in Ahmedabad, Gujarat; offices and local franchises in Jaipur, Rajasthan; and franchises in and around the village of Bagar, Rajasthan.

The team conducted extensive research on possible applications for the RO brine, but as the project progressed, the team noticed operational inefficiencies that presented barriers to successfully implementing specific applications. As a result, the team developed overarching recommendations, in addition to providing research on specific applications. The team felt these general recommendations would help facilitate the eventual implementation of some of the brine applications identified in the report that would more successfully address environmental, social and economic impacts of brine management. These recommendations include: expanding data collection and including additional parameters in brine testing, regionalizing efficiency standards for increased production, and improving communications about RO brine use amongst Sarvajal and its franchisees.

Water Crisis in India

India is a water stressed nation that is likely to experience increased water resource challenges as climate change, population growth, and wider industrialization impact water quality and availability in the region.[1,2,3,4] As a result of Climate Change, India is projected to experience higher temperatures, shorter rainy seasons, and more frequent and severe water shortages.[5] The area where Sarvajal operates is one of the most water stressed regions of the country. In the Indian state of Rajasthan, where the majority of Sarvajal franchisees operate, a staggering 80% of groundwater wells are already classified as critically over-drawn.[6]

The Intergovernmental Panel on Climate Change (IPCC) identified three adaptation measures to cope with the effects of climate change on water scarcity: Re-vegetation of barren or agricultural lands, increasing water efficiency, and recycling or reuse of water to reduce new demands on the water supply.[7] Many of these strategies are reflected in the recommendations and applications described in this paper.

Sarvajal Operations

Today, the Sarvajal brand encompasses over 131 franchises, providing clean water to more than 70,000 customers.[8] For a number of maintenance and management reasons, including the desire to prolong machine life and adhere to Indian water discharge regulations, Sarvajal's RO machines currently operate at 40% efficiency, well below the average industry standard of 70-85%.[9] On average, Sarvajal franchises produce between 3,000 – 5,000 liters of potable product water per day during peak summer months, and around 2,000 – 3,000 liters during non-peak months. Sarvajal's RO units are generally designed to process 500 liters per hour. Based on the level of efficiency at which the machines operate (40%), for every 500 liters of raw water that enters the treatment process, 200 liters are available as product water (i.e. purified drinking water), and 300 liters leaves the processing unit as brine. Using such a low efficiency leaves Sarvajal franchisees with up to 4,500-7,500 liters of brine per day to manage.

Recommendations

Based on the team's research and in-country observations, the team generated three overarching recommendations for Sarvajal in addition to an extensive list of possible applications for use of the RO brine.

Recommendation One: Improve Data Monitoring

A more comprehensive data monitoring and sampling program will help develop a stronger baseline of data that is indispensable to addressing Sarvajal's RO brine challenge. Increased data collection will help the company track concentration variations over time, identify regional patterns, and assess the suitability of applications across regions and franchises. For example, it is hard to assess the suitability for brine use in agriculture or domestic uses if the level of Total Dissolved Solids (TDS) and other potentially harmful (in large concentrations) contaminants are unknown. The recommended parameter list for additional brine sampling is included as an appendix to this report. Due to their prevalence in western India, additional analytical parameters should be added to the monitoring program, including metals, minerals, and nutrients. This more rigorous monitoring program will also help to better assess risk associated with increased TDS concentrations in ground water and soil as well as potential human health risks resulting from long-term exposure through dermal contact with brine. It is also recommended that brine data collection should utilize existing infrastructure, such as the Soochak (Sarvajal's data monitoring system), to increase available TDS data at all franchise locations. This may also help to track TDS changes over time, if applicable.

Recommendation Two: Increase Efficiency

All Sarvajal franchises currently operate at 40% efficiency, which is well below the RO industry standard for drinking water supply of around 75%.[10] Increasing RO efficiency could help Sarvajal better manage brine volume, produce more product water for sale, and conserve groundwater resources. Sarvajal already has the capital equipment and management framework in place to increase efficiencies. Beyond creating the potential for additional revenue generation from increased sales, the reduced brine stream could facilitate the implementation of some further treatment and reuse applications. Since higher efficiency would result in more concentrated brine, the implementation of other applications, including some reuse applications, could become more complex and difficult. There is great variation in the TDS levels of raw water inputs; therefore, efficiency levels should correlate with regional concentrations of contaminants. The current efficiency of 40% is the "lowest common denominator" in order to properly address areas with the highest TDS levels and to be consistent across all locations. Managing efficiencies by region can help Sarvajal comply with Indian regulations on TDS discharge rates as well as increase productivity.

Recommendation Three: Improve Communication

There are three general areas where there is a potential for improved communication: between Sarvajal and its franchisees, among franchisees, and in "re-branding RO brine." Initial information from headquarters indicated that a very small minority (less than 10%) of franchisees had considered using their RO brine rather than discharging it to the ground. Site visits in India revealed that 17 out of 22 franchisees visited were either currently using brine, had active plans for brine use, or had at the very least, experimented with brine use at one time.

Increasing the flow of information to Sarvajal headquarters could be accomplished by utilizing existing mechanisms for communication, such as the monthly regional meetings program, or by developing new mechanisms of communication such as initiating a new maintenance questionnaire that maintenance staff could use during routine visits (provided as an appendix to this report). One idea for improving peer-to-peer knowledge sharing is the distribution of case studies that highlight the experiences of franchisees that have experimented with the use of RO brine. Re-branding RO brine means replacing the term "ganda pani" (waste water) that is used by most franchisees and Sarvajal maintenance staff, with the word "khara pani" (brine), as current terminology may be preventing franchisees from looking at the brine as a resource.

Recommendation Four: Brine Applications

The team generated ideas for and researched 20 possible applications for the brine produced by Sarvajal's RO machines. Per the request of Sarvajal, this report contains information not just on promising applications, but also on applications that are unlikely to be applicable to the Sarvajal situation. The information provided on a variety of applications is meant to help Sarvajal identify applications that merit further research and test pilots and to help the company avoid investing time and resources in applications that are unlikely to be feasible. The applications were organized into three categories: Disposal, Further Treatment, and Reuse. These categories are described below and a short list of applications identified as the most promising to Sarvajal follow.

Disposal applications are defined as those that manage brine wastage through either direct disposal (as-is) or minimization of the brine volume. Further treatment applications are those that manage brine wastage through improvement of brine quality. Reuse applications are defined as those that manage brine wastage through beneficial reuse of the brine stream (as-is). The applications evaluated for each category, as well as a summary of key benefits and challenges for each, is included below:

Table Ex1: Application Summary

Type of Application	Applications Evaluated	Benefits	Challenges
Disposal	Evaporation/crystallization, groundwater recharge, solar evaporation, vacuum evaporation	Low operations and maintenance, less dependent on brine chemistry or local industries available	No reuse opportunities, no groundwater preservation, seasonal weather variation, large land-use intensity perceived waste of resources
Further Treatment	Capacitive deionization, coagulation/flocculation, constructed treatment wetlands, soil phytoremediation	Greatest reuse opportunities, groundwater conservation	Technically challenging, high capital costs, need more brine data, waste disposal
Reuse	Agriculture, algae biofuels, aquaponics, construction materials, domestic uses, firefighting, ice making, leather tanning, paper making, public sanitation, wood treatment	Highest entrepreneurship opportunity, lowest cost, groundwater conservation, least technical	Local industry dependent, need more brine data, uncertain long-term effects

A comprehensive set of evaluation criteria was created to address the organizational priorities of Sarvajal and the student project team. These goals were applied to an "Application Utility Matrix" that employed multi-criteria analysis to score the list of applications based on the social, economic and environmental impact as well as practical issues associated with each. Partially based on that analysis and the team's overall assessment of potential applications, the following priorities were identified: Public sanitation, wood treatment, soil phytoremediation, and constructed treatment wetlands are promising opportunities for Sarvajal to address the RO brine problem and may warrant the additional investment of time and resources. Groundwater recharge, vacuum evaporation, evaporation/crystallization, coagulation/flocculation, and capacitive deionization are largely impracticable and likely to be cost-prohibitive. Due to the prevalence of observed franchises already participating in the following activities, Sarvajal should further investigate uncertainties associated with agriculture, construction materials, and domestic uses to ensure human and environmental health are not at risk. The uncertainty associated with other applications is far too vast to determine the feasibility of success or failure at this time.

Conclusion

Unexpectedly, a detailed investigation of applications revealed large data gaps and inefficiencies in Sarvajal's brine management, revealing opportunities for improvement in data collection, communication and RO efficiency that could lead to more sustainable application implementation. These measures not only inform further exploration of potential brine applications, but also, when combined with the applications described above, begin to address one aspect of the water shortage crisis in a creative and cost-effective way that accounts for variability in location-specific challenges and opportunities.

RO technology is used throughout the world to provide clean drinking water to millions but that widespread use comes at a cost.[11] To date, no viable and cost-effective technological solution has been identified to make use of the unavoidable brine that results from the implementation of this technology. While the cultural context and applicability of any one solution described in this report is unique, not only to India but to the circumstances surrounding any given franchise, the system of analysis developed in this research project can be applied to other areas struggling with similar challenges.

As an increasingly complex world struggles with the impacts of global problems that can rarely be solved with blanket solutions, community-based problem solving that capitalizes on the ingenuity, entrepreneurship, local knowledge and determination of people is essential. Using the list of applications as a seed for generating ideas and applying the evaluation criteria and utility matrix as those ideas emerge is only the beginning of an adaptation strategy for addressing one aspect of climate-related water shortages and improving the management of one of the world's most essential resources.

Introduction

In 2010, the founder of Piramal Water Private Limited approached the University of Michigan's School of Natural Resources and Environment (SNRE) with a problem. Piramal Water, the parent company of the brand "Sarvajal", meaning 'Water for All', seeks to provide "Affordable; Accessible; Pure" water to communities in northwestern India.[12] Sarvajal is a model of an entrepreneurial, community-focused social impact company and is taking on a significant resource management challenge in its endeavor to provide clean drinking water to a growing population. However, as a consequence of inefficiencies in the reverse osmosis (RO) technology used to purify the water, Sarvajal's franchises discharge almost one and a half liters of wastewater for every liter of potable water.[13]

Aware of the necessity to manage critical resources, Sarvajal sought means to maximize its corporate water use efficiency and address the challenge of water stewardship in the increasingly arid regions it serves. In January of 2011, Sarvajal welcomed a team of six SNRE master's students to study the company's operations, impact on the environment, and interactions with local communities to inform recommendations for Sarvajal to optimize their water use efficiency. This report describes the team's findings.

Water Availability in India

India has been classified as a water stressed country by the Intergovernmental Panel on Climate Change (IPCC), The United Nation's Children's Fund (Unicef) and other organizations.[14,15,16] In 2003, The United Nations calculated that the per capita water availability in India was just over 5 liters per day.[17] The IPCC has predicted that per capita availability of water in India will dive below 1000 m^3per year (under 3 meters cubed per day) by 2025.[18] This means that there will be less than 3,000 liters of water available per capita per day for all activities in India ranging from agricultural production, industrial processes, and domestic uses. Climate change, population growth, and industrialization are all likely to aggravate the water situation in India.[19]

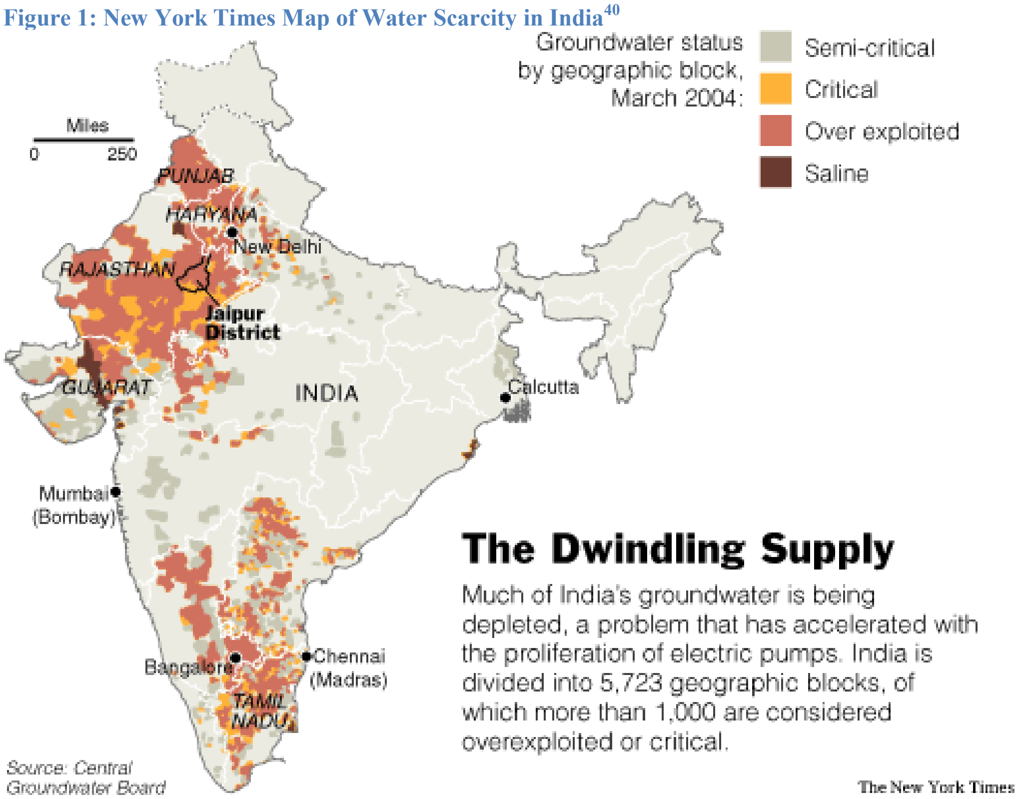
The areas where Sarvajal operates are some of the most water stressed regions of India. The state of Rajasthan, where the majority of Sarvajal franchises are located, is a land locked state in western India that borders Pakistan. Most of the region is arid or semi-arid, receiving all of its 20-23 inches of rain a year in less than 30 days in the form of monsoons.[20,21] Not only is Rajasthan the most arid state in the country, with low amounts of surface water, but the surface water that is available is frequently so polluted that it is unusable for human, agricultural, or industrial use.[22,23] Sewage and industry effluent are the two primary polluters of surface water in the region.[24] Given the low quantity and quality of surface water in Rajasthan, most of the state obtains its water from groundwater sources. Sarvajal recognizes that, beyond basic hydration, access to clean drinking water is vital to the health and wellness of people in India where up to 60% of common alignments are caused by poor water quality.[25]

In Rajasthan Groundwater is the source of 90% of domestic water and 71% of water used for irrigation.[26] The Indian government's ability to provide water to the people of Rajasthan is limited and sporadic in flow and quality.[27,28] As a result, private bore wells have sprung up all over the region and are the only source of water used by industry, as well as the preferred choice for farms and families who can afford it.[29]

With 70% of Rajasthanis making a living through farming, the water needs of the agricultural sector dominates Rajasthan's water politics.[30] In the 40 years between 1961 and 2001, 1.4 million agricultural bore wells were built in the state of Rajasthan and the pace of construction has only increased since then.[31] In that same period of time, total irrigated land has increased 128% with irrigation using 83% of total water resources in the state.[32]

Bore wells increase access to water, attracting businesses, increasing agricultural productivity, and raising the quality of life for Rajasthan's growing population.[33,34,35] While increased access to water has meant good things for Rajasthan's people, it has been damaging for its aquifers. The Groundwater Board of Rajasthan estimates that current withdrawal rates are 25% above recharge rates.[36] The water table has declined in all 28 districts of Rajasthan and has fallen as much as 12.93 meters in some cases.[37] A staggering 80% of groundwater wells in Rajasthan are over-drawn.[38] As water becomes harder to find and harder to extract, farmers, businessmen, and families have been forced to dig more and deeper wells in order to preserve their way of life.[39] Figure 1 depicts a map created by the New York Times, which highlights the water scarcity issues of Rajasthan.

Figure 1: New York Times Map of Water Scarcity in India[40]



Further complicating the water scarcity problem is the relative lack of formal groundwater regulation in Rajasthan and throughout India. As the New York Times wrote in a 2006 story on water scarcity in India, "Indian law has virtually no restrictions on who can pump groundwater, how much and for what purpose. Anyone, it seems, can — and does — extract water as long as it is under his or her patch of land. That could apply to homeowner, farmer or industry."[41] The central Indian government has no authority to regulate water resources in the country, all power to regulate water lies with the states.[42] Only three of India's 28 states have enacted laws regulating use, extraction, or pollution of groundwater, and of those three, none have implemented or enforced these regulations.[43]

Implications of Climate Change

In the IPCC's 2008 Technical Paper VI on the topic of climate change and water, it predicted that India's water resources will be further stressed as a result of climate change. IPCC scientists forecast precipitation events will become shorter and more intense over the next century in India. This change in precipitation patterns will likely lead to increased flooding and could inhibit groundwater recharge necessary to replenish aquifers in many regions in India.[44] Furthermore, increased temperatures and shorter rainy seasons could lead to more frequent and more severe water shortages.[45]

The IPCC, in this same report, suggested a variety of adaptation measures that would help the region cope with climate change. Three suggestions are applicable in the context of this paper. First, re-vegetation of barren or agricultural lands to help keep water where it falls and reduce the amount of water washed away during high storm events. Second, increasing water efficiency will help to reduce initial demands on water. And third, recycling and reuse of water will also reduce new demands on the water supply.[46]

Adaptation to climate change was a key consideration in the approach of this project. Sarvajal, as a company, is both particularly vulnerable to the impact of climate change on India's water resources and particularly well-suited to incorporate adaptation measures into their operations. By incorporating considerations for climate adaptation into their treatment of RO brine, Sarvajal has the potential to create a more robust and climate resilient business. Such measures could give Sarvajal a competitive advantage as the resource availability in India changes over the coming years as a result of climate change.

Client Overview

Piramal Water Private Limited, founded in 2008, is a for-profit social enterprise providing clean water to rural and urban communities in the most arid regions of India, where limited access to clean drinking water is the cause of many health problems. The Sarvajal "water for all" brand encompasses over 131 franchise locations, providing clean water to more than 70,000 customers.[47] More information about Sarvajal can be found in Appendix A.

Figure 2: Sarvajal Franchise Locations in Gujarat, India[48]

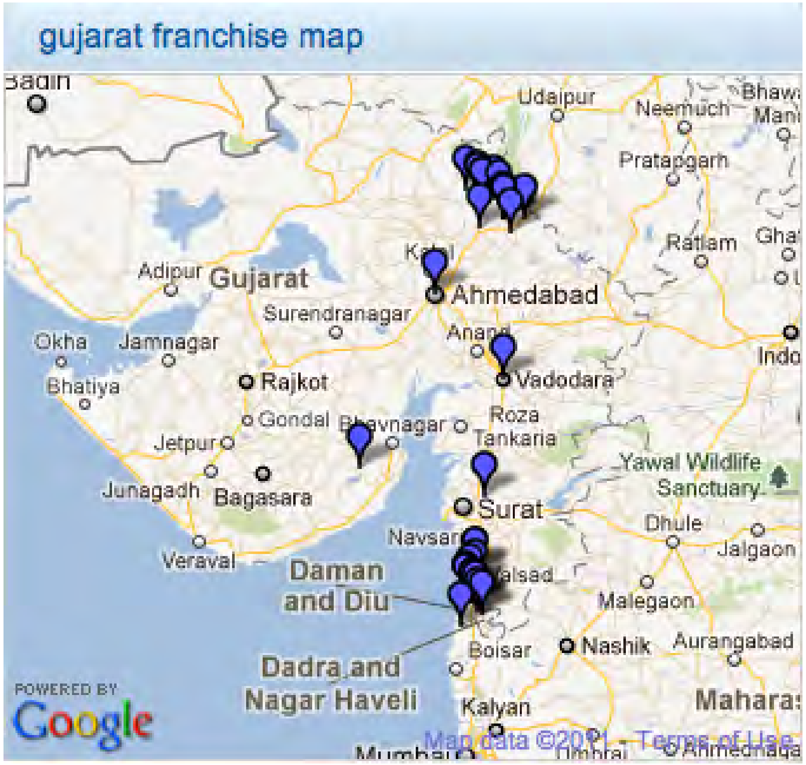
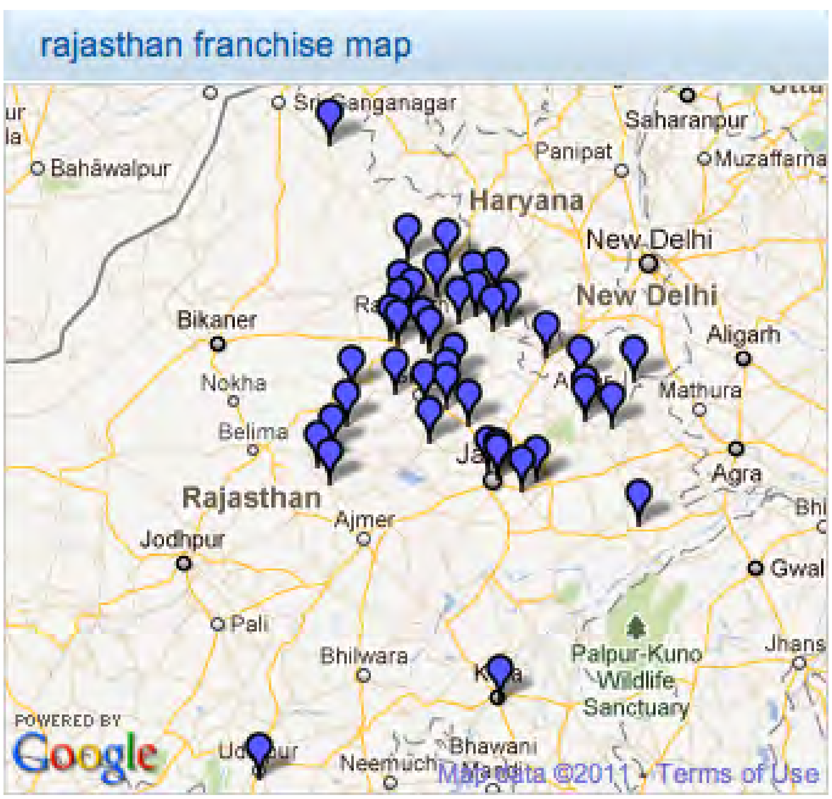


Figure 3: Sarvajal Franchise Locations in Rajasthan, India[49]



The company was established with the aim of finding financially viable, mass-market solutions to India's escalating drinking water crisis. Initial support came from the Piramal Foundation, a charitable trust established by Ajay G. Piramal. The Piramal Foundation supports a number of social venture start-up companies in the region through its Grassroots Development Laboratory located in Bagar, Rajasthan. Sarvajal was initially piloted as the Bagar Drinking Water Initiative under the umbrella of the Grassroots Development Laboratory.[50] The pilot enabled the founders of Sarvajal to identify existing demand, test appropriate pricing indicators, and create a plan to grow the business through franchise agreements throughout the region.

By leasing out RO technical equipment under these franchise agreements, Sarvajal provides safe, affordable drinking water to local communities at a very low price (~$0.01US for 2 liters) and provides income-generation opportunities for entrepreneurs throughout five states; primarily in Rajasthan and Gujarat. Sarvajal implemented a franchise structure for three reasons as described by the company here:[51]

- Franchisees know their communities: Franchisees are responsible for operating the machines and selling water to customers.
- Sarvajal knows the machines: They are responsible for all filtration unit maintenance and repairs.
- They have the same incentives: Both franchise and company earnings depend on how much drinking water is sold to households who need it. Both are incentivized to provide pure water and excellent service in order to strengthen the Sarvajal brand across India.

Profits earned by franchisees are split with Sarvajal, 60% going to the franchisee and 40% to Sarvajal.[52] This business model allows Sarvajal to provide scheduled and emergency maintenance for the RO equipment at all franchises, while franchisees can utilize their ingenuity and social connections within their communities to grow their business. The RO machines are outfitted with Sarvajal's 'Soochak' device, a patent-pending innovation, which is a cloud-connected two-way device that transmits real-time information on water production and an ability to anticipate service issues before they create downtime for franchises.[53]

Like other Piramal endeavors, Sarvajal is a highly visible social enterprise, providing a great community service; however they are not immune to the social and resource management challenges inherent in RO treatment. Industry best-practices for RO efficiency hover around 80%, meaning that in the best case scenario, for every 10 liters processed during treatment operations, 8 liters of product-water are generated as well as 2 liters of highly-concentrated water by-product known as RO brine.[54] For a number of maintenance and management reasons, including a desire to prolong machine life, manage energy costs, and adhere to Indian regulations over concentrated waste discharge, Sarvajal currently operates at 40% efficiency, well below optimal efficiency levels. However, by engaging in this project with SNRE, Sarvajal aims to more fully utilize water inputs.

RO Technology Overview and Sarvajal's Current Operations

The term 'reverse osmosis' is derived from the basic concept of osmosis, which is the diffusion of water from higher to lower concentrations of dissolved solids. Whereas conventional osmosis concerns the movement of water from lower to higher solute concentrations, RO works in the opposite direction by using external pressure to pump water across a selectively-permeable membrane.[55] The membrane acts as a filter, leaving large particles and ions behind and allowing water and smaller ions to pass through. The final product of this process is two-fold: a purified water stream that can be used for drinking water (also called the product water or permeate), and a highly-concentrated waste stream that can be routed for disposal (also called the brine stream).

The brine stream is much more highly concentrated than the source water, and it presents both a challenge for proper disposal and an opportunity for reuse. Source water data and RO brine data provided by Sarvajal are included as Tables 1 and 2, respectively. From the brine data provided by Sarvajal in Table 2, the brine stream has high TDS levels, including sodium, bicarbonate, and chloride ions. This water is not necessarily unsafe for handling, but it is far too concentrated to use in many situations. Finding options for beneficial use thus requires a fair amount of creativity, since without further treatment this water stream has conventionally been thought of as unusable.

Sarvajal's treatment schematic consists of pre-filtration processing followed by RO filtration and disinfection. Groundwater is the predominant source, and is first pumped through a carbon cartridge filter, followed by a microfiltration cartridge. The purpose of these pre-filtration processes is to remove contaminants that may otherwise damage the RO membranes, including large particles, suspended solids, and dissolved organic materials. The water is then pumped using higher pressure through the RO unit filtration, where most dissolved particles and ions are separated from the product water. The brine stream is also removed from this part of the process while the units are in operation. The last part of the treatment schematic is ultraviolet (UV) disinfection, where remaining biological contaminants are treated. See Appendix B for further details on Sarvajal's current treatment schematic, including a process flow diagram and some technical details and best practices for operation.

The average flow rate through Sarvajal water treatment units ranges between 3,000 – 5,000 liters of product per day during peak summer months, and 2,000 – 3,000 liters of product per day during non-peak months. The Sarvajal RO units are generally designed to process 500 liters per hour, and are presently operating at 40% efficiency. This means that from the raw water that enters the treatment process, 40% of it is available as product water (i.e. purified water), and 60% of it leaves the processing unit as brine stream. Using such a low efficiency leaves Sarvajal franchise owners with up to 4,500-7,500 liters a day of brine to manage during peak season.

Sarvajal estimates that the majority of franchise locations employ ground application to discharge the brine water (and remaining contaminants) that flow to the underlying groundwater table. The reason why Sarvajal has kept the operating efficiencies so low is to keep the brine stream relatively dilute for ground application and to keep the efficiencies constant for maintenance simplicity. Sarvajal also believes that by keeping the TDS concentrations relatively low, franchise owners will be able to find more uses for the brine.

Business as Usual: Standard Methods for Brine Disposal

Direct discharge of untreated brine to the ground, sewer, ocean, or other surface body of water is historically the most prevalent practice for managing RO brine.[56] This type of direct discharge is also the predominant business-as-usual practice for Sarvajal franchises, as observed during franchise site visits in India throughout Rajasthan in July and August of 2011.

Although continuing with the business-as-usual scenario assumed to be followed by most franchisees (discharge to the ground or sewer) appears to be the easiest option with no associated short-term economic costs, there are serious environmental resource considerations and potential consequences. Discharging RO brine to the ground may, over time, lead to increased metal and mineral concentrations in the surface soil and underlying groundwater. Long-term increases in TDS concentrations in the surface soil could be detrimental for local ecosystems as well as challenging for successful agricultural production. Increasing TDS concentrations in groundwater is also problematic since higher concentrations in the source water lead to higher future operating costs for the RO unit, reduced volume of recoverable drinking water, and higher brine concentrations in the future, further perpetuating the problem. For franchises in areas of Rajasthan with high TDS concentrations in groundwater already, this problem is further exacerbated.

The social and cultural implications for the business-as-usual scenario may also become problematic over time. As water scarcity in the regions where Sarvajal operates becomes a greater and more tangible problem, the status quo of sending reject water into the ground or down sewer drains may be interpreted by some community members as wasteful and may thus have negative implications for Sarvajal as a brand.

Industry Standards for RO Brine Disposal

Transporting brine for discharge to the ocean is standard practice for industrial operations. This holds true for RO facilities located at great distances from the ocean. For example, the Central Arizona Salinity Study (a project funded by the city of Phoenix, Arizona to address its growing water concerns) found recently that the most cost effective and environmentally friendly option for the city of Phoenix to meet the treatment needs of their increased production of RO brine was to construct a 174 mile pipeline to the ocean.[57] This solution is not unique to this particular project, as ocean discharge is carried out by many municipalities adjacent to coastlines.
The United States Environmental Protection Agency (US-EPA) lists options for brine stream management from small treatment facilities as: Public Owned Treatment Works (POTW) discharge, chemical precipitation, groundwater recharge (i.e. French drain), direct discharge, and evaporation ponds.[58] Conventional disposal options used by RO facilities in the drinking water and desalination industries are listed in Table 3 below.

Table 3: Conventional Brine Disposal Methods (adapted from Metcalf & Eddy[59])

Surface water discharge	The most common method of disposal for concentrated brine streams and the option of choice for locations in coastal regions. Typically transported using a pipeline and deep ocean discharge. For inland locations, truck or rail hauling is not uncommon when pipeline distances are not feasible.
Land (or ground) application	More common method of disposal for inland areas and relatively less concentrated brine streams.
Wastewater collection system discharge	Typically only suitable for low-flow discharges or relatively less concentrated brine streams. Discharge availability for flow rate and brine concentrations depends on ultimate wastewater treatment facility capacity.
Deep-well injection	Typically only used for brackish groundwater areas or other aquifers unsuitable as a drinking water source.
Evaporation ponds	Large surface area is typically required, depending on local weather conditions and evaporation rates.
Thermal evaporation	The most energy-intensive disposal option, however also may be the only option available for many areas.

Direct discharge into the ocean is not very feasible for Sarvajal as most of the franchises are located great distances from the coast and the cost of transporting the reject water to the ocean would be prohibitive. For example, for franchises located around Bagar, India where the student team spent most of their research time, ocean access is approximately 600 miles away. For franchises that are located near the ocean, this might be a workable solution, but still does not address negative perceptions of wasting the water, nor does it address the potential negative impacts of introducing RO brine into a new ecosystem.

Discharge into non-ocean surface water bodies also provides challenges to the Sarvajal situation. First, surface water discharge might attract attention from the public who would not want their water sources to become further concentrated with minerals. Second, the same negative consequences that apply to groundwater discharge apply also to surface water bodies, except water quality degradation becomes more complicated due to potential toxicity to aquatic life, wildlife habitat degradation, and human health concerns. And third, there are also pollution control regulations in the country that forbid any water with a concentration more than 2,200 ppm of dissolved solids from being discharged into the ground.[60] Though this regulation is not currently strictly enforced, environmental regulations in India will likely need to become more stringent in the future. [61]

Project Definition

Sarvajal recognized that its operations were less efficient than industry standards and were faced with the challenge that industry 'best practice' approaches may not be suitable for the company's small-scale franchises. The purpose of this master's project was therefore to generate creative new approaches to improving Sarvajal's water-use efficiency. Sarvajal expressed specific interest in strategies and applications for utilizing RO brine, which not only mitigate negative environmental impacts of their operations, but also provide economically and socially beneficial improvements to their business. See the Letter of Engagement (provided in Appendix C) for more details.

A small group of students began meeting with Sarvajal in the fall of 2010 to define the project and establish an appropriate timeline, budget and project scope. Aware that a 'silver bullet' solution may not exist for this challenge, the project definition focused on creativity and on the intent to thoroughly examine both technical and social approaches to tackling the problem.

Project Approach

Given the scope of the problem and the emphasis on adopting a creative approach, students worked to assemble a small, interdisciplinary team of six students with strengths in engineering, business, behavior and education, sustainable systems, aquatic sciences, and international development (Appendix C). The six students on the team were brought together based on their varied experiences and perspectives and with the hope that they would challenge each other to think critically and consider multiple viewpoints to address the problem.

Initial Research and Project Planning for India

The project consisted of six phases of research prior to the team's visit to India. First, the team endeavored to more fully understand the problem of RO brine facing Sarvajal. Through academic research, the team gained a more complete understanding of water issues in India and the potential impacts of climate change on regions where Sarvajal operates. During this early phase of research, the team quickly realized the magnitude of the RO challenge.

The Saudi Arabian government and the United States Department of Defense have spent billions of research dollars on attempting to determine best practices for RO brine generation and disposal.[62] This project was designed not to emulate or surpass the work of such institutions by attempting to engineer a solution, but instead, it was designed to harness a multidisciplinary approach to develop creative, financially viable approaches to the problem on a local scale. The team planned to define a 'basket of solutions' containing various brine reduction strategies and applications able to address the social, economic, and environmental components of the problem.

The second phase of research involved brainstorming ideas and researching potential applications for the management of brine. In this phase the team deliberated the merits of a wide range of suggestions. The team also worked to establish a preliminary set of criteria for evaluating potential solutions. Sarvajal requested information on all applications that the team researched, even if the applications appeared unfeasible. This data was provided in order to prevent the company from devoting time and resources to duplicating the student research at a later date. As a result, any application that was substantially researched, even if it was considered to be an unlikely solution for Sarvajal's situation, was documented in this phase of research and included in interim reports to Sarvajal as well as this final report.

The third phase of research revolved around identifying the most promising ideas that merited the development of pilot projects in India and developing an implementation strategy for these pilots. However, despite consultations with the client, as the students tried to define which solutions were most appropriate for the Sarvajal setting and what would be needed to implement selected solutions, they realized their knowledge of local circumstances and understanding of Sarvajal operations was too limited to make pilot planning from their location in Ann Arbor, MI meaningful. This challenge led the team to adopt a new strategy for tackling the problem and organizing their time in India.

In the fourth phase of research the team re-designed their project timeline, scope, and agenda for on-the-ground research in India. Rather than spending the time in India testing pilots, the team planned to use their time in India to gather basic and necessary data about local cultures and economies, general perspectives on water use and scarcity, and to better understand Sarvajal's operations. The original timeline was designed so that the team would spend Spring 2011 researching the problem and generating ideas, the summer testing pilots in India, and the fall making recommendations. The new timeline meant that the summer would be spent understanding the context in which Sarvajal operates and assessing the feasibility of potential applications rather than running in-country experiments. The new plan for fall included assessing the data gathered in India, using this data to further describe the potential of success for various applications, and finally, making recommendations.

The fifth phase of research was a continuous phase that lasted throughout the entire process of research and planning pre-India and involved reaching out to other experts for input. The students solicited feedback from personal and professional contacts across the country including employees at environmental engineering and consulting firms, international development non-profits, and the US-EPA. The team also held two symposiums at SNRE and the School of Engineering. At these symposiums the team presented their ideas and led discussions about the strengths and weaknesses of various ideas and solicited new ideas from the participants.

The sixth phase of the team's preparations for travel to India included the adoption of a framework known as the "Evaluation Criteria." As the team started brainstorming ideas for solution applications, it quickly became clear that a tool was needed to compare solution applications to one another. Some ideas were simply more exciting than others at the on-set and the team felt it was prudent to develop a rubric that would test assumptions for any one solution. It was also intended to test solutions against what Sarvajal was already doing with the brine, using the status quo as a baseline measurement so that any proposed solution would have to be an improvement on the organization's current practices of disposal.

An open meeting was organized at SNRE, including project advisor Ming Xu, to help devise a set of evaluation criteria. From what the team was learning about Sarvajal, they were specifically interested in a sustainable and holistic approach to problem solving. After consulting with the client and project advisors, it was decided that the criteria would be a useful tool in the research process. The intended purpose was to apply this framework to each solution to better understand implications across an array of sustainability issues. The evaluation criteria can be found in Appendix D.

Project Funding

Organizing travel for six students to India presented a financial challenge at the early stages of this project. Funding sources within SNRE and the university at large were researched and considered. The project budget relied upon three funding sources: The International Institute's Experiential Learning Fund (ELF), SNRE's Master's Project Funding, and SNRE's additional climate change adaptation funding opportunity.

The ELF opportunity is intended to support "group travel for undergraduate, graduate or professional school students wishing to incorporate an education abroad experiential component into an ongoing course, group internship, or other academic program during either winter break or spring-summer terms."[63] The Master's Project Funding from SNRE is set aside for any student participating in a qualifying master's project. An additional fund was made available to students that year for projects that specifically sought to address climate change adaptation. The team was eligible for the climate change funding as the master's project focused on how to conserve and reuse water in India, efforts that would help water stressed regions of India adapt to potential water shortages projected as a result of climate change. The team applied for, and received, the maximum available funding through these three sources.

In-country Information Gathering

As an international group of researchers, the team was wary of making assumptions and recommendations without the most complete awareness of local cultural, social, and environmental norms. Therefore the limited time available for in-country research was focused on observing and gathering as much data and locally relevant information as possible. Upon arrival, team members met with the project sponsor and office staff at Sarvajal's headquarters in Ahmedabad, Gujarat. While at Sarvajal headquarters, the team was able to visit a "water ATM" in the nearby slum of Tekra.

In addition to the normal franchise model, Sarvajal also has some franchises managing new solar powered water dispensing ATMs. Sarvajal pilot-tested and launched these innovative ATMs in the Tekra Slum of Ahmedabad. Customers can use these by purchasing a prepaid card, which can be recharged similar to the way mobile phone minutes can be recharged. The machine dispenses water in quantities of 5, 10 or 20 liters. Customers scan the pre-paid card, choose the appropriate quantity, and fill his or her bottle or jerry can. The RO filtration unit is normally housed in a central location and transported to water ATMs nearby and stored in large tanks for dispensing. These are very convenient to provide water in densely populated areas where there is high demand for clean drinking water. After the pilot phase, Sarvajal may be expanding the use of this technology and therefore the student team found it relevant to their research. One particular reason is that concerns had been raised about applications that might confuse Sarvajal's branding efforts. For example, one possible application was to use brine for flushing communal toilets. However, Sarvajal expressed reservations about the association that customers might infer based on the proximity of public restroom facilities to Sarvajal franchises that build their reputation on the principles of cleanliness and purity.

Following the visit to headquarters, the student team then travelled to a Sarvajal office in the city of Jaipur. While there, the group visited two franchises that were accessible by auto rickshaw and got their first taste of franchisee entrepreneurship and ingenuity when they discovered franchisees attempting to use the brine.

Bagar, a small town in Northeastern Rajathstan, was the next destination and this office served as the team's home base for several weeks. Bagar is home to the Piramal Family, the Grassroots Development Lab, Piramal Water Private Limited and the Bagar Drinking Water Initiative. This location was selected as the primary research base for the project due to its proximity to numerous Sarvajal franchises, available access to a Company Owned, Company Operated (COCO) RO machine, and the local culture that was more accepting of "outsiders" and social improvement efforts due to Piramal's reputation in the area.

While in Bagar, the group focused heavily on gathering information at franchises. Sarvajal staff accompanied the team on visits because franchises were frequently located in remote areas, which were difficult to find. Additionally, Sarvajal staff served as translators for the team when necessary. Research records indicate which franchise visits were conducted with the benefit of a translator (Appendix E). Each franchise visit would typically start off with an explanation to the franchisee of what the project team was working on and a brief tour of the RO machine. The team observed machine operations, including drinking water storage, transportation for deliveries, and disposal or use of brine. It was clear that most franchisees were thinking about the brine if not already doing something about it. Most had tried using it for purposes such as agriculture and domestic use. The team encouraged them to consider potential uses of the brine and to communicate ideas and questions to Sarvajal headquarters. Franchise visits are summarized in Table 4 and Appendix E, including a photograph log and journal entries for each visit. A photograph log is also available for other relevant project work in Appendix F.

Non-fieldwork days were dedicated to research, analysis and bench tests conducted in the Bagar office and the COCO. On these days, the team worked with staff, reviewed the intra-office information management system and continued online literature review and colleague outreach. This enabled the team to create an outline of research areas, which required further development throughout the duration of the project. Further research on these topics became top priority upon return to the University of Michigan.

Project Resolution

Upon return to the University in Ann Arbor, the team gathered to devise a plan for completing the project and presenting in December. Final deliverables were to include:

- A final report, including executive summary, background information, overarching recommendations, and an analysis of each solution researched - *Intended for the SNRE community, Sarvajal and publication in Deep Blue.*
- An application utility matrix outlining all possible solutions and quantifying the applicability of each based on the evaluation criteria.
- A supplemental report on the Master's Project experience - *Intended for project advisor, Ming Xu.*
- A brochure with case studies demonstrating creative uses for RO brine – *Intended for distribution to Sarvajal franchisees upon review, revisions and translation by Sarvajal.*
- A maintenance questionnaire template – *Intended for use by Sarvajal staff to collect and track relevant brine use data from franchisees.*
- A final presentation to the SNRE community at the Master's Project Symposium in December, 2011.

Each component of the final project was informed by the team's time spent in India, meetings and conversations with Sarvajal staff and academic research conducted in-country and back at the University.

The team divided individual solutions into three categories: Disposal, Further Treatment, and Reuse Applications. Each member of the team drafted sections for each solution including the research approach used as well as observations and outcomes of the potential for implementation. Informed by the evaluation criteria derived in the pre-India phase of the project, the team evaluated each application using multi-criteria decision analysis (see Appendix G). This analysis lead to the creation of a utility matrix, which provided a more objective platform for comparing the utility of various potential applications and brought attention to solutions that may not seem appropriate on the surface. This analysis helped to frame the conversation about which solutions the team would include in final recommendations to Sarvajal.

In addition to analysis of the individual solutions, further discussions based on the team's observations in India resulted in overarching recommendations for Sarvajal. These recommendations addressed data collection, communication, and efficiency standards for Sarvajal and were meant to facilitate future evaluation and implementation of the researched applications.

Summary of Applications

The following section describes the potential applications for brine use that were researched over the course of the project. To clarify the objective accomplished by each potential application, proposed applications have been grouped into three distinct categories: disposal, further treatment, and reuse. For the purposes of this evaluation, the categories are defined as follows:

- *Disposal applications*: Applications which aim to manage brine wastage through either direct discharge (as-is), and/or minimization of the waste stream quantity. Applications evaluated include Evaporation/Crystallization, Groundwater Recharge, Solar Evaporation and Vacuum Evaporation.
- *Further treatment applications*: Applications which aim to manage brine wastage by improving the quality of the waste stream. Applications evaluated include Capacitive Deionization, Coagulation/Flocculation, Constructed Treatment Wetlands, and Soil Phytoremediation.
- *Reuse applications*: Applications which aim to manage brine wastage through beneficial reuse of the waste stream, as-is. Applications evaluated include Agriculture, Algae Biofuels, Aquaponics, Construction Materials, Domestic Use, Firefighting, Ice Making, Leather Tanning, Paper Making, Public Sanitation and Wood Treatment.

Further details on these categories and project findings for each application evaluated are summarized in the following sections; for a more thorough discussion of these applications see Appendix H.

Disposal Applications

Disposal applications include most industry standard and business-as-usual scenarios. Many of these applications were identified through a survey of available literature on brine management, including the desalination industry in Singapore and conventional drinking water and wastewater treatment practices in the United States. Applications of this type have been used heavily in practice; therefore a large body of literature was available for review in our evaluations. Direct discharge to the ocean was not included in this evaluation due to the perceived unfeasibility resulting from the geographical proximity of the ocean to franchise locations.

Benefits

A brief but important list of benefits for disposal applications was determined from our analysis. Many disposal applications include solutions that are less technology-intensive than further treatment applications, which may help the process of implementation. Also relative to further treatment options, the operation and maintenance requirements may be less rigorous. Another benefit of disposal applications is that they generally may be applied to a wide variety of locations, since they may be less dependent on brine characteristics and/or the local industries at each franchise location (relative to reuse applications).

Challenges

Many challenges exist for disposal applications, some of which present significant barriers to implementation. Most of the disposal applications evaluated present significant logistical challenges, including geographical location, seasonal weather variation, and relatively large land-use intensity. Disposal applications may also present sustainability challenges, including environmental degradation, a perceived waste of resources, and high capital costs.
Some of the evaluated applications may also require significant technical expertise and/or extensive design components, as well as expertise in operation and maintenance. Since most disposal applications lack opportunities for additional entrepreneurship or revenue, many of these challenges may be too significant to overcome.

Summary of Disposal Applications

Below is a summary of specific applications in the Disposal category. For more in depth description and discussion of these methods, see Appendix H.

- **Evaporation/crystallization**: Commercial equipment that could be used to fully evaporate the water off the brine and to crystallize the salts to a form a solid waste.
- **Groundwater recharge**: Recharge to a local aquifer using a deep injection well, recharge pit.
- **Solar evaporation**: Conventional evaporation of brine using the energy of the sun. Would decrease the quantity of brine water for disposal.
- **Vacuum evaporation**: Used to enhance the process of conventional evaporation by using vacuum technology to lower the vapor pressure of the brine, which effectively increases the evaporation rate.

Discussion of Disposal Applications

A common benefit for many of the disposal applications is that their technology requirements are minimal compared to the applications in the "Further Treatment" category. These applications typically require minimal training and less maintenance than other categories. Disposal techniques can generally be implemented on a larger scale because they are independent of brine variations and nearby industries.

This category of applications presents other logistical concerns, however, including accounting for geographical location and seasonal weather variation, and relatively large land-use intensity. Disposal applications, more so than other applications, tend to result in more environmental degradation as brine or solidified brine constituents are discarded into the environment. These applications generally yield minimum to no direct economic benefits, making it impractical to invest in any upfront costs.

The evaporation/crystallization application offers Sarvajal the unique opportunity to dispose of the constituents in the brine without contaminating the ground water. This technique is common in the RO industry, but is used with larger quantities of brine and may not be appropriate for the typical Sarvajal franchise. The cost and logistical issues could be resolved if Sarvajal developed a strategy for grouping franchises close enough together so that that the brine may be easily concentrated in one central location.

Groundwater recharge helps balance the withdrawals made from the raw water source and given the deep injection depth, it helps prevent degradation of surface soils. There are concerns about injection; the cost of digging the pit and the possibility of contamination to drinking water sources due to an incorrectly dug pit. Minimizing these risks would require extensive surveys of the site's hydrogeology and such procedures are likely to be unavailable in this region and/or cost-prohibitive.

Solar evaporation requires simple materials that are available locally and no additional energy cost. However, its slow rate and large space requirement make this application problematic for the quantity of brine produced at any given franchise. These structures would also be rendered useless during monsoon season when precipitation rates will likely exceed the rate of evaporation.

Vacuum evaporation requires low energy inputs, but this benefit is significantly out-weighed by the cost of purchasing, installing and training franchisees and maintenance staff in how to use the necessary equipment. This technology is designed primarily for salt extraction; any other constituents in the brine could alter the effectiveness of this technology.

Further Treatment Applications

Further treatment applications improve the quality of brine, which may allow additional reuse opportunities in some cases. Applications of this type will typically have further disposal requirements for the short and/or long term, but may be determined to be cost-effective due to the increased opportunities for beneficial use of the reclaimed water.

Benefits

Some of the applications included in the further treatment category allow for the widest variety of beneficial reuse options. These opportunities include the applications in the reuse section, but also include additional uses of water for Sarvajal franchisees using the treated effluent as-is, or after additional filtration through the RO unit. Franchise owners may also be able to supplement their available drinking water sales with the treated water, either as-is or through additional RO processing. Operations and maintenance for these applications may also offer additional opportunities for entrepreneurship and revenue.

The use of further treatment applications may also help to conserve virgin groundwater resources, especially if the treated effluent is to be used as an additional drinking water source or for an existing reuse application that requires lower TDS levels of the brine.

Challenges

The further treatment applications evaluated are generally the most technologically challenging group of applications, and may require the most extensive technical expertise for conceptual and detailed design processes, implementation, operations, and maintenance. This may prove to be a significant barrier to implementation, since significant costs will likely be associated with these requirements.

Further treatment does not eliminate the issue of waste disposal, which for some applications may involve disposal of a waste sludge instead of a brine stream. Disposal options may thus be more complicated, since remaining waste may be more complex due to inherent chemical additions.

Summary of Further Treatment Applications

Below is a summary of specific applications in the Further Treatment category. For a more in depth description and discussion of these methods, see Appendix H.

- **Capacitive deionization**: This technology uses the electric field between porous electrodes to remove inorganic ions from the water. Has been used in small pilot-scale testing for the desalination industry in Singapore.
- **Coagulation/flocculation**: Adding chemical coagulants such as alum to the brine to promote coagulation and/or flocculation of the dissolved phase constituents.
- **Constructed treatment wetland:** This application takes advantage of the natural processes that occur in wetland soils, water and biological communities to promote further treatment of RO brine contaminants in a controlled environment.
- **Soil phytoremediation**: This application uses plants to treat contaminated soil. Certain varieties of plants are able to bioaccumulate salt and other dissolved constituents in order to slow or inhibit the accumulation of contaminants in soil.

Discussion of Further Treatment Applications

Further treatment options offer the benefit of further condensing the RO brine stream and thus maximize the amount of useable water. Further treatment options have a fair amount of flexibility in that they could be coupled with many other applications, including most (if not all) reuse options. Coagulation and capacitive deionization were selected for their industry relevance and potential efficacy, whereas soil phytoremediation and constructed treatment wetlands were selected for their ease of operations and maintenance and environmental benefits.

Prior to implementing any of these technologies, Sarvajal should assess the following considerations. Increasing RO unit efficiency may provide the same benefits as further treatment strategies, but with fewer capital, operations and maintenance costs. The initial feasibility of these applications could also be better assessed following a comprehensive look at the baseline brine quality data, including additional data collection.

Further treatment options also have significant barriers to implementation, including the need for a more comprehensive waste management plan. Capital costs as well as operations and maintenance costs for these options may also be high, relative to most reuse options and some disposal options. Additional operations and maintenance capacity would also be required, including technical expertise to run the equipment.

One consideration for implementation of further treatment strategies is to combine RO brine from nearby maintenance clusters. This would allow for further treatment to take place at a single, central facility, which could end up being more cost effective than several smaller units. Additional analysis may thus be warranted to determine a cost-effective brine flow rate to minimized costs.

Capacitive deionization (CDI) technology has been an innovative and promising breakthrough in recent years. As a further treatment technology, the implementation of CDI offers opportunities for additional beneficial reuse of the RO brine stream for franchise owners. Since it is still in a phase of extensive research, CDI technology is not yet commercially available, which is a significant barrier to implementation. Thus if Sarvajal is interested in pursuing this further, they would need to decide how long to wait for commercial-scaled equipment.

Coagulation is a widely used, commercially available further treatment technology that could be used to further treat and condense RO brine. As with CDI technology, coagulation would allow franchise owners opportunities for additional beneficial reuse of the RO brine. Coagulation produces a high volume of waste sludge from the settled-out dissolved constituents and spent coagulant, however. If Sarvajal determines that this is a feasible and implementable option, the next step is to work with a vendor to assess chemical coagulant feasibility and efficacy. If it is determined to be an appropriate process, the chemical coagulant, dosages, and capital equipment can be evaluated and assessed for costs. The demands for sludge disposal could also be assessed at that time, including a volumetric accumulation rate of waste sludge and an assessment of options for responsible disposal.

Constructed treatment wetlands have been an emerging field in wastewater treatment in recent years. As a more natural mechanism for water reclamation than CDI or coagulation technologies, this application offers significantly less operations and maintenance demands, yet it is considered to be just as effective for improving water quality. Consideration and selection of native and locally available plant and animal species when available and appropriate is an important design consideration, which is beyond the scope of this project. The long-term impact of accumulation of RO brine constituents in soil is unknown, including those affecting plant and wildlife health. These impacts would warrant additional investigation should this application be further pursued. The design process would also need to consider water storage aspects for monsoon weather conditions as well as more arid times of the year in order to provide flood control elements. The presence of standing water year-round may also increase vector-borne disease risks (i.e. malaria), which should be further investigated prior to implementation.

Soil phytoremediation is another promising field for water treatment in recent years. Overall, it has been observed that TDS levels can greatly affect plant survival rates. Some promising research from the Gujarat Institute of Desert Ecology regarding appropriate agricultural practices in the region could prove useful in selecting the types of plants to be grown. There are even some species of plant that are edible in addition to bioaccumulating salt. However, as with constructed treatment wetlands, the long-term impacts of dissolved solids accumulation in the soil and plant matter is unknown at this time, and should be further investigated prior to implementation. The selection of locally available and non-invasive plants for use in the application is an important design consideration, as well as planning for brine management during monsoon season.

Reuse Applications

Reuse applications effectively manage the brine stream by using it, as-is, for beneficial reuse projects, which may either be existing or new. Applications of this type do not have further treatment or disposal requirements associated with their direct use, however some may indirectly require disposal. These options seemed to be the most prevalent applications found in our evaluation and in our observations while in India.

Benefits

These options may generally be the most cost effective, since no additional treatment is needed for implementation. Relative to the other types of applications, reuse applications offer the greatest opportunities for entrepreneurship and additional revenue. This is significant since it may offset the initial investment, operation, and maintenance costs. Since many of these applications require the least amount of technology and design for implementation, they may likely have fewer barriers to implementation for rural locations.

These applications also reduce demand on virgin water sources, particularly for reuse applications that are already being pursued and industries that already exist in the franchise location.

Challenges

Due to the specific requirements of these applications on brine characteristics, local industries and resource availability, these options may be better suited to evaluation on a local scale, or a case-by-case basis. They may thus be difficult to implement on a modular scale.

Some applications may require initial significant capital costs, as well as additional resources for operations and maintenance.

Summary of Reuse Applications

Below is a summary of specific applications in the Reuse category. For more in depth description and discussion of these methods, see Appendix H.

- **Agriculture**: Use of brine for irrigation in agriculture, both domestic and commercial.
- **Algae biofuels**: Brine could be used to grow algae for the purpose of biofuel production or used as agricultural fertilizer.
- **Aquaponics**: The use of brine for aquaculture (i.e. fish farming) and/or hydroponic agriculture methods.
- **Construction materials**: The use of brine in construction materials such as bricks and concrete.
- **Domestic uses**: The use of brine for washing laundry, dishes, car washing, or general house-keeping purposes.

- **Fire fighting**: Collection and/or centralization of the brine stream for use in local fire fighting efforts.
- **Ice making**: Brine could be super-cooled in a tank and used to freeze fresh water for ice making.
- **Leather tanning**: Brine could be used in curing and/or transportation process for the manufacture of leather from raw animal hide.
- **Paper Making**: Boiled salt water is commonly used in the paper manufacturing process, particularly for specialty papers. There is the potential to use RO brine for paper production or to supply RO brine to existing specialty paper producers.
- **Public sanitation**: Using brine as flush water for public restroom and sanitation facilities.
- **Wood treatment**: Raw wood could be steamed and/or soaked with brine water for use in wood treatment and/or furniture making.

Discussion of Reuse Applications

Reuse of the brine was by far the most prevalent type of application found to be in practice during the student team's franchise visits in India. Agriculture was found to be the most common application of the brine as well as domestic uses such as laundry, cleaning floors and dishes. The success rates for agriculture applications varied depending on the raw water source, quantity and TDS level of the brine used. In locations with low TDS concentrations, the plants watered with brine did not show any adverse effects; however in areas having high TDS levels, the plants did not appear to thrive and in some cases did not survive. Therefore it appears that agriculture may only be a viable application of brine in locations with relatively low TDS concentrations.

Another potential profit making application of the brine is to use it for aquaponics or growing algae for biofuels. But intensive testing would need to be done at each selected site for brine water composition to ensure survival of the fish/algae. Significant costs are associated with setting up these businesses, and franchisee's willingness to undertake it should be considered. The manufacture of construction materials was also found during franchise visits, and included materials such as concrete septic tank forms and bricks. While the Mukundgarh franchisee had been using the brine to make concrete structures (such as septic tank covers) for about three months at the time of our visit without any noticeable structural weaknesses, the Ramgarh franchisee who used the brine for making concrete structures noticed cracks in the structures after a year, and hence stopped using brine for this application. This still appears to be a workable application, but the right proportions of brine, cement and aggregate in the mixture should be determined for the different TDS levels prevalent at different franchises.

Using the brine for domestic purposes could be a low cost, readily accessible, minimally resource intensive and culturally appropriate application. No negative health effects have so far been reported by the franchisees using brine for domestic uses; however it would be beneficial to further investigate contaminant concentrations and potential effects and risks prior to widespread implementation.

Fire fighting is another possible application of the brine. It can be provided to the local fire brigades for fighting and could generate income for the franchisee if they are able to supply the brine for a small fee. Transportation for this application could be a significant hurdle.

Ice making was an additional business for the franchise in Chirawa. At the time of our visit, the franchisee did not use brine to fill the salt bath. He also reported that the salt bath never needed to be changed. Instead of adding salt to the bath, brine could potentially be used for the ice making process; however more research should to be done to determine if any additional chemicals would need to be added to optimize cooling, as well as the energy requirements to cool the saline water bath made from RO brine.

Given the prevalence of the leather tanning industry in India and the water requirements associated with it, another possible application for the brine is transporting leather to the tanning facilities and processing animal hides with salt water, but more research is needed on any effects other contaminants in the brine might have on the quality of the leather.

Partnering with local paper manufacturers, which is a heavily water intensive industry, could be a profitable operation for Sarvajal franchises. Paper makers, such as Haathi Chaap, a local Indian company that makes paper from collected elephant dung, employs a paper making process whereby salt is added to water and boiled or otherwise applied in different phases of manufacturing. Haathi Chaap and organizations like it, share similar sustainability values to Sarvajal and are already well versed in turning a waste product (such as brine, or in the case of their current operations, animal feces) into a viable and profitable boutique paper business. Given these motivations, it seems likely that the organization would see opportunity in the use of brine as part of their efforts to be sustainable and at the very least, provide insight into marketing brine as a resource instead of a waste product.

The use of brine for public sanitation could work well if Sarvajal partners with a local sanitation non-governmental organization that could provide for set up and operations, leaving Sarvajal to provide only the required flush water. This would free Sarvajal from the burden of having to learn a new industry and would reduce the risk of negative effects to Sarvajal's image as a drinking water provider.

Wood treatment, which the franchise at Sitapura is undertaking, has the potential to create an economic benefit for the brine. The fluorine in brine was found to be beneficial in the wood treatment process, but more research should be done into the long-term effects of the brine on wood. Some franchises could partner with local furniture makers to supply the brine at a low cost, or can alternatively start wood treatment/ furniture making business operations themselves. These reuse applications are site specific. Ground water conditions, local industry prevalence and franchisee willingness to undertake additional brine usage are crucial for the success of these applications.

Over-Arching Recommendations

As described in the discussion of applications above, almost all applications require further research prior to implementation in order to ensure that none of them pose human or environmental health risks, and that they are in fact cost effective and can reasonably be implemented with available knowledge and infrastructure. It became clear to the student team in evaluating possible brine applications that some key data points are missing that would assist in the further assessment of any one application. One such example is the lack of comprehensive data across all franchises. Recommendations for use that include ground application or frequent dermal contact by people require a more complete analysis of brine composition to ensure that there are no harmful effects from extended exposure or direct contact. Additionally, while the one-size-fits-all efficiency standard may simplify maintenance and lengthen the life the machine components, the practice is likely suboptimal and a reassessment of efficiency levels is warranted. Another barrier to implementing the applications described above is the lack of communication mechanisms, both between franchisees and Sarvajal's headquarters as well as peer-to-peer information sharing amongst franchisees themselves. The following recommendations seek to address these issues and lay the groundwork necessary for sustainable brine management.

Recommendations for Implementing a Monitoring Program

One of the primary recommendations to facilitate future application evaluations is the implementation of a comprehensive brine monitoring program. A more rigorous sampling program will help to develop a stronger baseline of data as well as track concentration variations over time. This will help Sarvajal when further evaluating options for brine disposal, treatment, and/or reuse. It will also help Sarvajal to monitor brine stream variability and track potential fluctuations over time, both seasonally and over the long term. Additional analytical testing is useful in the assessment of exposure risks associated with additional handling and reuse of the brine stream.

Existing RO Brine Data

There is a limited set of analytical data available for Sarvajal RO brine streams, both for parameters and number of tests. Presently, Sarvajal has analytical data available for fourteen franchise locations for a relatively limited suite of parameters, including general parameters, metals and minerals, and nutrients. Seven locations in Gujarat and seven locations in Rajasthan were included in this baseline data collection for the following sites: Umergam, Naroli, Chanwai, Kava, Mashal, Manorpur, Samlaji, Vrindavan, Anyol, Gothda, Laxmangarh, Rollsahabsar, Ramgarh, and Choti Pacheri. See data provided in Table 2 for further details on existing brine data.

Sarvajal also has data available for the source water (groundwater) to the RO unit. A total of 124 groundwater samples analyzed for general parameters, metals and minerals, and nutrients were collected between 2008 and 2011; see Table 1 for data provided for existing source water locations. Though this data set is fairly comprehensive, it is difficult to accurately predict contaminant removals for specific parameters due to varying performance of the RO membranes. This means that certain compounds may be rejected from the RO membranes at different removal percentages than others, depending on technical specifications of the RO membranes.[64] Groundwater quality is also subject to significant variability, both over time and location. Therefore collection of additional RO brine analytical data is still warranted.

Regional Groundwater Contaminants

The India Central Groundwater Board lists general groundwater contaminants in Rajasthan and Gujarat as salinity, fluoride, chloride, iron, and nitrate.[65,66] Elevated arsenic concentrations (>0.05 mg/L) have also been detected in the state of Uttar Pradesh, where 10 franchises are currently located.[67] In order to account for possible health risks, Table 5 presents recommendations for additional analytical parameters to be included in regular data collection.

Many of these parameters were added to the proposed monitoring program due to the severe health effects associated with long-term exposure. Other naturally occurring contaminants commonly found in groundwater were added to the recommended parameter list, including metals and minerals such as arsenic, copper and zinc, as well as contaminants introduced from agricultural runoff and industrial pollution, including total kjeldahl nitrogen (TKN). Dissolved solids concentrations in the brine stream are anticipated to be much more concentrated, and therefore more dangerous, than the corresponding groundwater concentrations (i.e. source water). Testing for these additional parameters would help in assessing both the environmental and health risks and the inherent feasibility of brine applications.

Comprehensive Analytical Data Monitoring Program

The implementation of a comprehensive brine-monitoring program will help Sarvajal to better understand how to manage RO brine streams. All further treatment and reuse applications will be highly dependent on site-specific water chemistry and constituents, therefore more data should be collected in order to move forward with future evaluations.

A more comprehensive suite of parameters is recommended to allow for these further evaluations. The additional parameters are both naturally occurring in groundwater as well as introduced from agricultural or industrial pollution. Some of the included parameters present direct contact hazards with high concentrations typically found in RO brine. Some of the additional parameters may also present barriers and limitations for implementation of further treatment options, particularly for coagulation. See Table 5 for the recommended analytical parameters.

There are many options for monitoring frequency recommendations. First and foremost, having a baseline monitoring point for all of Sarvajal's franchise locations is important. Collecting comprehensive analytical samples from most (if not all) franchise locations is recommended in order to develop this baseline.

Because groundwater concentrations can fluctuate significantly over time, it is necessary to have a general understanding of the magnitudes of these fluctuations in order to select appropriate further treatment and reuse applications. Collecting additional analytical samples at periodic intervals to develop this understanding is therefore also recommended. Depending on the resources available to Sarvajal, collection of additional samples over time would be most helpful for capturing these groundwater concentration fluctuations. A simple monitoring program of 2-3 samples collected throughout one year for most (if not all) franchise locations could be a simple way to implement this baseline data collection effort. Collecting samples spread throughout the year will help to capture seasonal variability as well as to identify normal variations in groundwater quality.

TDS Monitoring Program – Additional Soochak Monitoring Point

In addition to the comprehensive analytical data-monitoring program, it is also recommended that Sarvajal add an additional sampling point on to the already-operational Soochak data collection system. This system addition presents a simple way to track brine TDS concentrations over time. Since Sarvajal already has the infrastructure in place for the Soochak monitoring system, adding another sampling point may also be a cost effective means of obtaining this data.

These concentrations could be estimated using a mass-flow balance, which sets the mass of TDS coming into the system equal to the mass of TDS coming out, by multiplying the flow volume by the TDS concentration for each respective flow. Collecting TDS data from monitoring instruments holds key benefits over the use of a mass-flow balance model to determine brine concentrations. Direct measurements are much more accurate than using a mass-flow balance calculation, due to the many assumptions that go into these types of calculations. They are also a much more straightforward method for collecting data and are thus easier to explain. Where possible, adding this measurement collection point is therefore preferable to calculating estimates based on the very broad assumptions made in mass-flow balance calculations. By collecting more quantitative data for their RO brine, Sarvajal will be able to better assess opportunities for increased efficiency and brine management strategies.

Recommendations for Increasing RO Unit Efficiency

Another primary recommendation for Sarvajal is to reconsider the operational efficiency of the RO units at each franchise location or in maintenance clusters. Since RO technology is one of the most effective technologies for removing dissolved constituents from water, it makes sense to re-evaluate the current efficiency prior to the pursuit of other further treatment strategies.[68] All Sarvajal franchises currently operate at 40% efficiency, which means that 40% of the inflows are produced as product (i.e. drinking) water, and 60% of the inflows are produced as brine. Increasing the RO efficiency could also help Sarvajal better manage the volume of the brine stream, as well as to conserve groundwater resources.

Sarvajal already has both the capital equipment and a program in place for training new operators on the equipment and these capabilities could facilitate the transition to operating appropriate RO units at increased efficiency. Should Sarvajal decide to implement an additional further treatment strategy, increasing RO unit recovery would effectively decrease the volume of water in the RO brine stream. This could potentially save in both capital costs and operations and maintenance costs if an additional further treatment application is further pursued.

Industry Standards for Efficiency Rates

Because RO technology is used around the world for drinking water supply, desalination, and wastewater treatment, there is an extensive amount of literature available for comparison. Throughout the different industries, RO recoveries between 50-85% are very common. In the drinking water supply and wastewater treatment industries, percent recoveries around 70-85% are the most common.[69] Only in the desalination industry, where source water TDS concentrations can be up to 35,000 mg/L, are RO recoveries near 50% common.[70]

High Efficiency Reverse Osmosis

In addition to increasing the efficiency of the current configuration, the purchase of additional capital equipment could also help Sarvajal franchises increase percent recovery within the RO configuration. In addition to the two RO unit system currently in place, implementing either a third pass through a supplementary RO unit or the addition of supplemental equipment such as the High Efficiency Reverse Osmosis (HERO™) system, Sarvajal machines could achieve much higher efficiencies. In some cases, up to 93% recovery has been achieved with just three passes through a conventional RO unit.[71]

Summary of Benefits of Higher Efficiency

Increasing the operational efficiency at which RO units are operated offers many benefits to Sarvajal and franchise owners. First and foremost, it would allow greater drinking water production while saving groundwater resources, thereby increasing sales and potable water availability. Though roughly the same mass of dissolved constituents would be present in the brine stream, it would result in a smaller volumetric flow rate of brine.

All alternative further treatment options have further waste management issues associated in either liquid (i.e. brine) or solid (i.e. waste sludge) form. By increasing the percent recovery of the RO units and effectively reducing the volume of brine to be treated, the waste produced from further treatment will also be reduced. Should further treatment options be pursued in the future, it would also mean less capital costs and less waste to manage. Similarly, some re-use options (such as wood treatment or construction materials) would benefit from decreased brine volumes.

Higher Efficiency Implementation Strategies

Due to Sarvajal's interest in operations and maintenance simplicity, changes in RO unit efficiency could be considered for two different schemes: 1) Set constant across all franchise locations; or 2) Set constant within distinct maintenance clusters. These schemes may help preserve consistency and efficiency from a management and maintenance perspective.

Determining RO efficiency by region or maintenance cluster would require a reassessment of the raw water for the clusters in question and additional training for Sarvajal Maintenance staff. However, more specific efficiencies will allow franchisees to extract as much product water as possible from the raw water. This could have a direct result in increased revenue for Sarvajal and preservation of raw water sources.

Other Implications for Increased Efficiencies

Some additional considerations for increasing the efficiency of treatment operations include increased energy demands, increased difficulty finding appropriate reuse applications, and possible environmental implications. Increasing the efficiency of RO operations may increase energy demands; however this may be balanced out by a decrease in required operations time. As seen during site visits in India, locations with higher TDS concentrations generally had more limitations on reuse opportunities as well as lower success rates. Thus increasing the efficiency of operations, which would lead to higher concentrations of TDS in the brine stream, may result in greater challenges for some reuse strategies. In the business-as-usual case, for sites that currently discharge brine to the ground, there may also be increased stresses and negative impacts on surface ecosystems. These potential implications should be thoughtfully considered prior to implementation of an increased efficiency strategy.

Recommendations for Increased Communication

Sarvajal, through deliberate and focused communication with franchisees about RO brine, could make significant improvements towards improving brine management and overall best practices. There are three general areas where there is a potential for improved communication: Between Sarvajal and its franchisees, amongst franchisees, and in re-branding RO brine. Improved communication in these areas will enable franchisees to develop sustainable applications for the RO brine independent of a top-down mandate. At the root of this recommendation is the acknowledgement that franchisees have unsurpassed local knowledge that is hard to replicate in either Sarvajal headquarters or in the classrooms of the University of Michigan. This recommendation speaks to a belief that empowering franchisees offers tremendous potential for coming up with applicable and appropriate solutions. Improved communication could provide franchisees with support and technical knowledge that may impact their use of RO brine and could foster an environment where franchisees share ideas, build on their colleague's experiences, and help solve the problem.

Communication Between HQ and Franchisees

Both franchisees and Sarvajal Headquarters staff could benefit from increased and improved communication about RO brine. Initial information from headquarters indicated that a very small minority (less than 10%) of franchises were using the RO brine. Site visits in India revealed that 17 out of 22 franchises visited were either currently using the brine, had active plans for brine use, or had used the brine, but were no longer doing so [See Table 4 and Appendix E]. This information demonstrated two things: franchisees are actively thinking about uses for RO brine and experimenting with applications and Sarvajal may be unaware of the extent of the engagement franchisees already have with RO brine. While it is possible that franchisees over emphasized their involvement with RO brine when they saw that a group of foreigners were interested in brine use, in 10 of the sites the franchisees paired their claims with tangible evidence demonstrating their attempts to use the brine.

It is recommended that Sarvajal gather more data about RO brine use among franchisees. This could be done by utilizing existing mechanisms for communication, such as the monthly regional meeting, or by developing new mechanisms of communication such as initiating a new maintenance questionnaire. Sarvajal already runs a monthly meeting that brings together franchisees by region. At these meetings, Sarvajal staff should encourage a dialogue about what franchisees are doing with their RO brine and what challenges they are facing. This will help Sarvajal gain a better understanding of how their franchisees are approaching the problem, what are the common difficulties, how Sarvajal could help address these problems, and prevent multiple failed experiments as they learn from each other. For example, if Sarvajal learned that many franchisees were attempting to use the brine for agriculture, but with varying success based on TDS levels and plant varieties, they would be in the position to share best practices or conditions necessary for success in the use of brine for agriculture. Furthermore, by making a discussion of RO brine a part of the monthly meeting, maintenance staff can send signals to franchisees that Sarvajal values the reuse of RO brine and may spur further reflection on this issue by franchisees themselves.

Establishing a new set of questions that maintenance employees ask on their routine visits would provide another channel for information sharing about RO brine. Maintenance employees already make routine visits to franchisees and keep records of each visit, thus simply adding a new set of questions to their routine would not create a significant administrative burden on staff. Appendix I illustrates a model questionnaire that could be used by maintenance employees on their visits to franchisees. Creating a comprehensive dataset about brine use that stretches across regions and over time could be immensely helpful to Sarvajal as they continue to address the challenges posed by RO brine. Despite the low administrative burden of a maintenance questionnaire, it is important to acknowledge that it may not be implemented as designed.

However, even if the questions are asked verbally, but never recorded or compiled into a dataset, the process will likely generate results by spurring thought on the issue of RO brine by the franchisees and by creating a repository of knowledge in the maintenance employees.

Communication Between Franchisees

It is also recommended that Sarvajal encourage peer-to-peer knowledge sharing about RO brine, or at least find a way to make franchisees aware of what their peers have tried. Franchisees have the most experience experimenting with various applications and as site visits revealed, many of the franchisees have tried multiple applications and thus would have valuable experiences to share. If Sarvajal facilitates communication between its franchisees on the issue of RO brine, it is possible that this increased knowledge sharing will result in franchisees identifying applications best suited for their particular circumstances.

However, it is important to acknowledge that franchisees who have been frustrated in attempts to find workable applications may discourage others from considering similar applications. This is particularly worrisome in examples where a variable specific to that location or experience created the difficulty in implementation that my not apply elsewhere, but a general conclusion is drawn about the application. For example, a franchisee with very high TDS levels in his brine could discourage other franchisees from using their water for agriculture, even though it might be a viable solution in other circumstances. Thus it should be emphasized to the franchisees that what works for one franchise may not work for another and vice versa. Facilitating the franchisee discussions in a way that asks not just for successes and failures, but contributing factors including TDS levels and franchisee expertise should emphasize this point, and may help prevent franchisees making unilateral statements about what could and could not work for all franchisees.

One possible pathway of franchisee knowledge sharing that could more readily be controlled by Sarvajal is through a simple brochure or series of one page case studies that highlight franchisees who have experimented with RO brine. These handouts would present stories of success (and perhaps sometimes failure) of franchisees and their efforts. Each would contain a brief description of the application attempted, why their specific situation was well suited to the given application, and how they have addressed challenges in implementation. Keeping handouts simple and including pictures, anecdotes and tips in a visually appealing way would be most effective. Maintenance staff could present brochures during maintenance visits and walk through the content with franchisees and operators as a starting point for conversations about brine use.

By producing the brochures at headquarters, Sarvajal could control the information being shared and maintain a positive but realistic tone about brine use. It is well understood that employees are often more influenced by peers than managers and allowing franchisees to see their colleagues addressing the issue might encourage them to come up with more ideas, or tweak a failed idea in a new way that works for them. In addition, franchisees who exemplify outstanding entrepreneurial spirit would be rewarded by receiving recognition for their efforts that may encourage further innovation.

The purpose of such a brochure would not necessarily be to advocate for or recommend specific brine applications, but rather to spur innovation and idea sharing. An example of how such handouts might be designed can be seen in Appendix J.

Reframing Communication about RO Brine

Lastly, it is recommended that Sarvajal work to re-brand RO brine. The brine is currently referred to as “ganda pani” (waste water) by franchisees and Sarvajal maintenance workers. Such terminology may be preventing franchisees from looking at the brine as a resource. Sarvajal could work towards this goal by insuring that all communications coming from Sarvajal headquarters refer to the brine as “khara pani” for example, rather than “waste water”. Even more importantly, Sarvajal should reinforce the use of such terminology in maintenance staff training as these are the individuals interacting with the franchisees on a regular basis.

Communication is an area where Sarvajal could benefit from the changes described above, not only in solving the brine problem, but also perhaps with other issues that may arise. It is recommended that Sarvajal work to increase its top down communication with franchisees about RO brine, facilitate knowledge sharing between franchisees, and shape the dialogue about RO brine as a resource rather than a waste product or “reject water”. While none of the recommendations in this communication section will directly solve the problems associated with RO brine, they are important and practical steps Sarvajal can take to facilitate widespread improvements in the treatment of RO brine and are really a precursor to the successful implementation of whatever brine management strategy they choose to pursue.

Applications

The overarching recommendations delineated above are meant to help Sarvajal address the challenges of RO brine and in many cases to facilitate the implementation of brine applications. This section is meant to recommend to Sarvajal applications that appear promising and thus merit further research and those that appear to be inappropriate for the Sarvajal context and thus do not warrant additional investments from Sarvajal.

Given the variety of applications that were assessed throughout this project, the team of students found it useful to use the tools of multi-criteria analysis to objectively consider applications across the range of decision criteria. Using the methods of multi-criteria analysis (described in depth in Appendix G) the student team evaluated the list of applications based on the social, economic and environmental impact as well as practical issues associated with each. The results of the matrix can be seen in Appendix G.

While the matrix helped spur dialogue about the comparative strengths of each application, it was not designed to identify a “winner” or the one application that was best suited for Sarvajal (the limitations of the matrix are discussed in depth in Appendix G). While the following application recommendations were informed in part by the matrix, they rely much more heavily on observations made in India, discussions with Sarvajal staff, and the research of the student team. The following application priorities were identified for Sarvajal:

- Public sanitation, wood treatment, soil phytoremediation, and constructed treatment wetlands are promising opportunities for Sarvajal to address the RO brine problem and may warrant the additional investment of time and resources.
- Groundwater recharge, vacuum evaporation, evaporation/crystallization, coagulation/flocculation, and capacitive deionization are largely impracticable at this time and likely to be cost-prohibitive.
- Due to the prevalence of observed franchises already participating in the following activities, Sarvajal should further investigate uncertainties associated with agriculture, construction materials, and domestic uses to ensure human and environmental health are not at risk. The uncertainty associated with other applications is far too vast to determine the feasibility of success or failure at this time.

Conclusion

Sarvajal can dramatically increase its water-use efficiency through relatively simple and inexpensive means. First, by measuring brine concentration and composition at each franchise location, Sarvajal can utilize its existing technology and data management systems to significantly increase access to data, which, though currently un-monitored, informs company policy on efficiency standards. For example, monitoring specific Brine TDS levels at franchises currently grouped within regional maintenance clusters may enable Sarvajal to increase standard operating efficiency by maintenance route. Where Brine TDS readings are lowest, this would allow Sarvajal to increase efficiency to produce more product water for every liter of raw water input, while still keeping TDS concentrations below the legally allowable discharge limit. Because efficiency improvements can be made by region, this recommendation would be suitable with Sarvajal's interest in operational consistency between franchises within maintenance clusters.

Monitoring brine concentrations is also a straight forward first step towards further testing brine composition which is a necessary requirement of many application recommendations. Given the number of franchisees currently interested in utilizing their RO brine and Sarvajal's over-arching interest in environmental stewardship, the company would greatly benefit from further brine testing for additional monitoring parameters. Further tests determining mineral composition, potential toxicity and overall brine composition is essential to informing corporate and entrepreneurial decisions regarding the best possible (and perhaps safest) applications for the brine.

This report, along with the application case-study brochure, the Sarvajal maintenance questionnaire, and the application utility matrix, are intended to aid Sarvajal in implementing and promoting environmentally sustainable solutions that are economically viable and socially optimal. Given projections of further water scarcity in Northwestern India, it is in the company's best interest to aggressively pursue efficiency improvements and brine reuse applications, which decrease demand for raw water inputs and extend water resource availability as far as possible.

While research indicates that there are few further-treatment options for RO brine which are technologically and/or more financially feasible than the current RO operations by Sarvajal, increased operating efficiency and reuse applications may hold great promise for Sarvajal. Applications such as wood treatment for furniture-making present the opportunity to significantly increase water-use efficiency while utilizing existing economic infrastructure in regions where Sarvajal franchises currently operate.

Increased communication, corporate intention around brine reduction, and reuse provide the greatest potential for increased water-use efficiency and inspiring entrepreneurial action on a long list of viable applications. Sarvajal's positioning and focus on this issue have potential to make Sarvajal an international model for redefining brine as a valuable substitute for raw water in certain applications and as a key input for collaborative business ventures.

What began as a detailed investigation of applications revealed opportunities for improvement in data collection, communication and RO efficiency that could lead to more sustainable application implementation. These measures not only inform further exploration of potential brine applications, but also, when combined with the applications described in this report, begin to address one aspect of the water shortage crisis in a creative and cost-effective way that accounts for variability in location-specific challenges and opportunities.

RO technology is used throughout the world to provide clean drinking water to millions but that widespread use comes at a cost.[72] To date, no viable and cost-effective technological solution has been identified to make use of the unavoidable brine that results from the implementation of this technology. While the cultural context and applicability of any one solution described in this report is unique, not only to India but to the circumstances surrounding any given franchise, the system of analysis developed in this research project can be applied to other areas struggling with similar challenges.

Using the list of applications as a seed for generating ideas and applying the evaluation criteria and utility matrix to those ideas as they emerge is only the beginning of an adaptation strategy for addressing one aspect of climate-related water shortages and improving the management of one of the world's most essential resources.

As an increasingly complex world struggles with the impacts of global problems that can rarely be solved with blanket solutions, community-based problem solving that capitalizes on the ingenuity, entrepreneurship, local knowledge and determination of people is essential. Globalization presents unique challenges with the diffusion of ideals and aspirations that encourage lifestyles beyond planetary means to support them but also with opportunities in the ability to easily share knowledge and ideas. Understanding that a solution in one context may not be applicable in another, the specific solutions described in this report may not be transferrable. But it is the hope of this research team that the methods and ideas described above serve as a spark for further innovation and foster a renewed commitment to creative problem solving. While no one solution can sufficiently address all aspects of the RO brine conundrum in any given situation and solutions are specific to the unique challenges and opportunities of a place, a broadly applicable framework can serve as a universal theory of action and analytical tool from which new ideas can be thoughtfully and critically considered. This kind of problem-solving may prove to be an effective strategy in sustainably addressing environmental, social and economic challenges.

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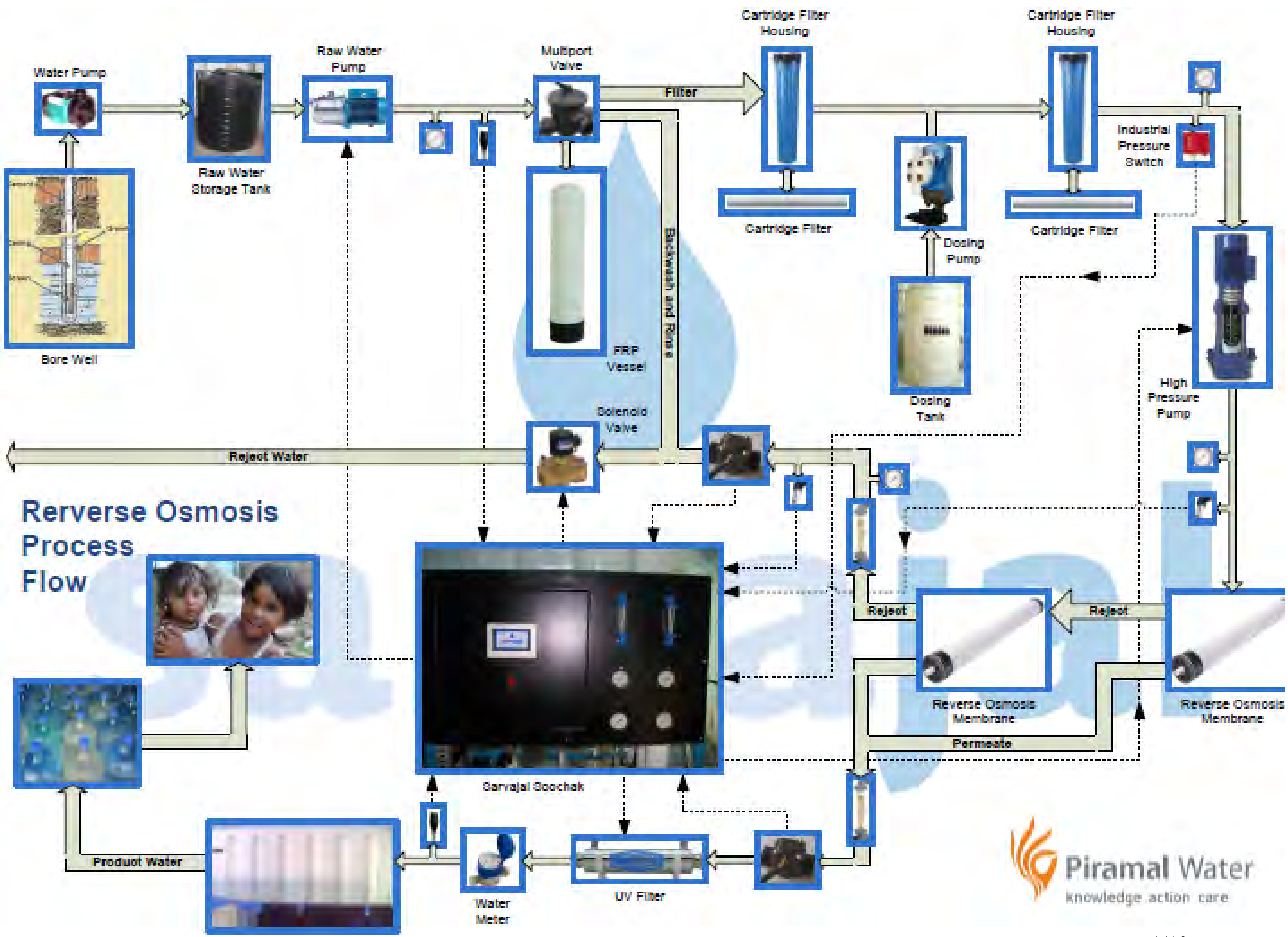
Appendices

Sarvajal

Piramal Water Private Limited is a social enterprise start-up that develops sustainable drinking water solutions for rural and urban populations where the quality of water is often the cause of more than 60% of common health ailments. Their business is designed around scalable innovations, technical/process improvements, ensuring livelihoods for local entrepreneurs, and developing customized community water filtration systems that can produce ultra-affordable drinking water for the masses.

The company was established in 2008 to find financially viable mass-market solutions to India's escalating drinking water crisis, after the Piramal Foundation, a charitable trust established by Ajay G. Piramal, initially piloted the Bagar Drinking Water Initiative as part of its Grassroots Development Laboratory. Through the initial pilot, it became clear that appropriate pricing and access to purified drinking water had both vested demand and enormous promise.

Piramal Water operates under the brand "Sarvajal," with franchises in more than 85 villages in several districts of Gujarat and Rajasthan. The company operates in some of the most arid regions of India, where clean drinking water is a major problem. Often, families spend a large portion of their days to procure water and often, the water is of poor quality. Piramal Water's commitment is to make purified drinking water accessible and affordable to all, and build an enterprise that is vested in people drinking clean water. The Piramal Water franchises have been able to provide this at a very low price ($0.01 for 2 liters) and provide income-generation opportunities for entrepreneurs.


Water Pump
Bore Well
Raw Water
Storage Tank
Raw Water
Pump
Multiport
Valve
Filter
Cartridge Filter
Housing
Cartridge Filter
Cartridge Filter
Housing
Cartridge Filter
Industrial
Pressure
Switch
Dosing
Pump
Dosing
Tank
High
Pressure
Pump
FRP
Vessel
Backwash and Rinse
Solenoid
Valve
Reject Water
Rerverse Osmosis
Process
Flow
Reject
Reject
Reverse Osmosis
Membrane
Reverse Osmosis
Membrane
Permeate
Sarvajal Soochak
Product Water
Water
Meter
UV Filter
Piramal Water
knowledge action care

Reverse Osmosis Overview

Reverse osmosis (RO) is a filtration method for removing large molecules and ions from a solution, through the application of pressure to the solution when it is on one side of a selective membrane. In the case of water treatment, the foreign objects (i.e., anything not H_2O) are retained on the pressurized side of the membrane and the pure solvent (H_2O) passes on to the other side. As a "selective "membrane, any large molecules and ions are trapped, while smaller components of the solution (e.g., solvent) are allowed to pass through the pores (holes) freely[1].

Sarvajal RO Plant

The Sarvajal RO plant system uses a step-by-step process for filtering water:

Intake

Untreated (raw) water is withdrawn from an underground water source (typically from a borewell) and stored in the Raw Water Storage Tank.

Pre-treatment

Pre-treatment of the raw water prevents clogging of the Reverse Osmosis membranes by suspended solids, scale-forming minerals and other impurities. The major components of the pretreatment process are:

Media Filter

Dry media (such as sand, charcoal, and activated carbon) mixed in pre-determined proportions in a pressure vessel are an important line of defence in the filtration process. Sand is used to remove physical impurities such as mud and suspended solids from the raw water. Activated carbon is used for removal of organic contaminants, color and odor.

Cartridge Filters

Cartridge filters are used to remove particles of 1-5 microns in size from the raw water.

Reverse Osmosis Filtration

A High Pressure Pump is used to push the pre-treated water through the membrane housings along the membrane surface. Pure water (permeate) is allowed to pass through the membrane surface while ionic, organic, bacterial, and other contaminants are swept away in a concentrated solution (Reject Water).

Post Treatment

A UV filter is used to neutralize any remaining biological impurities such as bacteria and viruses in the permeate.

Machine Automation

Water treatment must occur in a sequential order and must be carefully monitored. As such, water treatment is often automated using a computational device known as a programmable logical controller (PLC). A PLC assists a human operator in treating the water by providing important information to the operator (e.g., water pressure, TDS levels), and/or stopping treatment if there is an operational risk.

Sarvajal employs a proprietary PLC, called the Sarvajal "Soochak", to automate most of the treatment process. At the same time, the Soochak provides real-time information to Sarvajal's central servers using existing cellular networks, and allows Sarvajal to communicate with the Soochak in the same manner. As a result, filtration operations can be monitored and controlled remotely.

[1] Wikipedia – Reverse Osmosis *en.wikipedia.org/wiki/Reverse_osmosis*

BEST PRACTICES
REVERSE OSMOSIS PLANT OPERATION MANUAL
FOR
PIRAMAL WATER PRIVATE LIMITED

CONTENTS

STARTUP

Startup

Before starting up an RO system, it should be verified that all pretreatment systems are working according to their specifications. It may be necessary to take water samples for analysis. In the case of polyamide (thin film composite) membranes free chlorine must be 0.0 ppm. The Silt Density Index (SDI) should be according to the RO design guidelines (typically < 5.0). If the water analysis (ions, temperature, pH) has changed significantly, it is recommended to run a new scale projection analysis.

On startup, the inlet valve should open prior to the initiation of the high-pressure pump, to completely fill the system with low pressure water (<100 psi [< 7 Bars]). This "soft start" will prevent hydraulic shock at startup. Pre-treatment chemical addition should begin at this time (making sure the chemicals are not over-injected). The high-pressure pump should then be started and the system slowly bought on-line, up to design permeate flow. If starting up after a period of shutdown, flush the permeate to drain for 15-30 minutes to remove residual preservation chemicals. Produced water permeate can be used when it meets the quality requirement of downstream processes.

SHUTDOWN

Permeate Flush

As salts in the feed water have concentrated up and exceeded their solubility during operation, they should be rinsed out prior to any shutdown (for 10-15 minutes). Rinsing of the membranes with permeate water on shut will also aid the flushing of colloids and bacteria from the membrane surface.

Flow rate during flushing should be based on the recommended cleaning instruction flow rates. This is normally **1.4 - 2.3 m^3 /hr** per pressure vessel (for a 4 inch membrane) and 5.5 -9.1 m3/hr (for 8 inch membranes).

Flushing time should be long enough for the **conductivity out to equal the conductivity in**.This is typically 15 - 20 minutes.

If the permeate flush is unavailable, feed water can be used by allowing low-pressure water to replace the water within the system by delaying the inlet valve closing. Scale inhibitor should be turned OFF during the permeate flush.

If the water temperature in the membranes exceeds 48 deg C (115 ^{0}F), flush water should be continuously passed through the system to prevent membrane degradation.

Preservation

For shut downs longer than as 24 hours, biological growth in the RO system should be controlled. This requires the introduction of a chemical to kill bacteria and prevent growth. Any preservation chemical would then have to be rinsed out from the system when it is re-started.

Various membrane preservation procedures are available. Methods and products recommended are given below.

PRESERVATION METHODS FOR RO AND NF MEMBRANES AND SYSTEMS DURING SYSTEM OUTAGES.

It is recommended to preserve membrane systems when the unit is out of production for more than 24 hours. Failure to preserve membranes may result in the development of biofilm on the membrane surface, causing operation problems such as increased pressure drops and lower normalized permeate flow to occur.

Methods of preservation

1. **Preservation with sodium-bisulfite (1%).**
   It is recommended to measure the pH regularly. A fresh solution is needed when the pH < 3.
   A fresh solution is also needed when the liquid becomes turbid or changes colour.
   Regular inspections (weekly) are recommended.
   It has to be verified that the plastic materials (including pressure vessels) used in the membrane plant are resistant to sodium bisulfite . Otherwise cracks might occur in the plastic materials .

2. **Preservation with formaldehyde.**
   0.5% - 3% (w/w) formaldehyde solutions can be applied dependent on the membrane supplier's recommendations. The preservation solution needs to be renewed latest after 12 months.
   Formaldehyde handling requires more precautions due to its suspected carcogenic. Please stick to the relevant safety regulations.

3. **Preservation with gluteraldehyde and other aldehydes.**
   It is strongly recommended not to use gluteraldehyde or other aldehydes as it can reduce the permeate flow of the membranes dramatically.

NOTE: Prior to shutdown, RO membranes need to be cleaned (dependent on the operation parameters). The system then **MUST** be flushed with RO permeate before the preservation solution can be pumped into the RO (at low pressure).

RO DATA COLLECTION AND MONITORING

Data collection is critical for monitoring the performance of the membrane system. Without it, there will be no idea if the system is fouling, suffering from scale formation, or if the membranes are deteriorating.

When operating data is recorded, it should be compared to previously established alert and alarm levels. These levels should be associated with well-defined response procedures corresponding to the potential problem.

The alert and alarm levels are set for a 15% change from normalized start up data.

Silt Density Index (SDI)

The SDI is an on-site measurement of the suspended solids concentration in the feed water. It should be used to monitor the performance of the pre-treatment equipment.

SDI measurements should be made pre and post multimedia filters and post cartridge filters. An SDI < 5.0 for the RO feed water should be maintained at all times. Pre-treatment should be controlled efficiently using the designed flow rates and differential pressure limits for back-washing of the multi-media filters and replacing of the cartridge filters to give an SDI before the membranes of < 3.0.

RO System Pressure Drop

The difference between the inlet to the initial membrane elements and the concentrate stream pressure coming off the tail end elements is what pushes the water across the membrane surface of all the elements. This is called the pressure drop or the hydraulic differential pressure (ΔP).

As long as the flows are constant, the ΔP will not change unless something physically blocks the passage of flow between the membrane envelopes of the elements (fouling). Therefore it is important to monitor the ΔP across each stage of the system. An increase in ΔP can then be isolated as lead end, tail end or both to indicate possible cause.

Salt Rejection

Since the RO systems are used to remove (or concentrate) dissolved salts, measuring salt rejection is a direct way to monitor the performance. Salt rejection is the percentage of the feed water TDS that has been removed in the permeate water. The simple way to monitor the salt rejection is to measure permeate water conductivity.

The permeate water conductivity should be measured for each pressure vessel on a daily basis. This will then help determine if a high salt passage problem is universal (indicating membrane damage), isolated to a certain stage (possible fouling) or isolated to an individual pressure vessel (indicating O-ring problems). Probing of individual pressure vessels can be carried to isolate a salt rejection problem to an individual membrane element.

Normalized Permeate Flow

The permeate (product water) flow of the RO system is related to water temperature and the net driving pressure. Permeate flow should therefore be standardized for the effects of these variables to allow better monitoring of how well water is permeating through the membranes.

The formula used to calculate Normalized Permeate flow is :

$$Q_{norm} = Qi * (NDP_{start} / NDP_{i}) * (TC_{start} / TC_{i})$$

Q_{norm} = Normalized permeate flow

Q_i = Permeate flow at point i

NDP_{start} = Net Driving Pressure at startup or reference condition

NDP_i = Net Driving Pressure at point i.

TC_{start}= Temperature Correction Factor at startup or reference condition

TC_i = Temperature Correction Factor at point i.

The membrane manufacturer provides the temperature correction factors (at a constant net pressure) to allow normalization for temperature effects. An example of temperature correction factors for a TFC membrane is as follows:

Temperature ^{0}C	Temperature ^{0} F	Temperature Correction Factor (TC)
16	60.8	1.312
18	64.4	1.234
20	68.0	1.161
22	71.6	1.093
24	75.2	1.030
25	77.0	1.000
26	78.8	0.971
28	82.4	0.917
30	86.0	0.866
32	89.6	0.819
34	93.2	0.774
36	96.8	0.733

The net driving pressure is the applied pressure minus the permeate back-pressure minus the osmotic pressure. This driving pressure is proportional to the permeate flow rate. We can multiply by a ratio of the startup driving pressure to the current driving pressure to obtain the permeate flow rate if we were at startup pressure conditions.

The calculated permeate flow rate can then be multiplied by the membrane temperature correction factor to give the normalized permeate flow.

A decline indicates that fouling or scale formation is reducing permeate flow through the membranes. An increase indicates that fouling/scaling has been removed or that membrane deterioration is occurring.

<u>It is recommended that normalized permeate flow is monitored for each stage</u>. This will help identify and isolate problems more accurately.

MONITORING LOG

Reference base line data is useful for assessing future performance and trouble shooting performance. Use this form to record and store reference base line data.

REFERENCE BASE LINE DATA

DATE OF COMMISSIONING:	DESIGN	START UP
MEMBRANE MODEL		
CONFIGURATION		
OUTPUT		
% RECOVERY		
FEED CONDUCTIVITY		
REJECT CONDUCTIVITY		
PERMEATE CONDUCTIVITY		
FEED PRESSURE		
STAGE 2 FEED PRESSURE		
REJECT PRESSURE		
FEED TEMPERATURE		

DATE:		

FEED WATER REFERENCE ANALYSIS

As mg/l	As Ca CO_3												
pH	Ca	Mg	Na	K	SiO_2	SO_4	Cl	P Alk	M Alk	Fe	F	Cond	TDS

PERFORMANCE MONITORING LOG

The following **Log Sheet** can used to record system performance parameters. Frequency is site specific and based on the variability of the system and critical value of system performance on the customer's operation. Typical frequency is 1 data set per 8 hours.

TIME				
PRODUCT FLOW STAGE 1				
PRODUCT FLOW STAGE 2				
TOTAL PRODUCT FLOW				
FEED FLOW STAGE 1				
FEED FLOW STAGE 2				
REJECT FLOW				
FEED CONDUCTIVITY				
PRODUCT CONDUCTIVITY				
TOTAL				
PRODUCT CONDUCTIVITY				
STAGE 1				
PRODUCT CONDUCTIVITY				
STAGE 2				
FEED PRESSURE STAGE 1				
FEED PRESSURE STAGE 2				
REJECT PRESSURE				
ΔP STAGE 1				
ΔP STAGE 2				
FEED TEMPERATURE				

CHEMICAL ANALYSIS REPORT

	Time			
FEED WATER	pH			
	Conductivity			
	Chlorine if required			
REJECT	pH			
	Conductivity			
PRODUCT WATER	pH			
	Conductivity			

COMMON SYSTEM FAILURES

FAILURE	EFFECT	RECOMMENDED MONITORING PRACTICE
Antiscalant	Scale formation on membranes, usually in the back-end stages - high salt passage, ΔP in final stage	Check dosing equipment and monitor changes in water quality.
Ineffective sanitization Procedures	Bio-fouled pipe-work, cartridge filters and membranes - high ΔP	Sanitize sand filters and GAC filters. Microbiological analysis, chlorine dosing, contamination in chemical dosing tanks.
High iron content	Iron loading on cartridge filters. Iron fouling of membranes – high ΔP, low permeate flow	Pipe-work corrosion, ferric breakthrough from media beds, failure of media filters.
High organic content	Humic substances and organic fouling on membrane – low permeate flow, high feed P	Feed water composition, review flocculation procedures, feed watercolor, TOC.
Colloidal breakthrough	Colloidal particles foul micron filters and membranes – high ΔP, low permeate flow	Silt Density Index (SDI), condition of cartridge filters, eliminate media fines.
Granular activated carbon filters	Carbon fines foul micro filters and membranes.	Check washing procedure to remove fines from GAC filters.
Overdosing of chlorine	Membrane damage – high salt passage and increased flux	Dosing equipment, Redox meters, bisulfite dosing levels and positioning of dosing point, chlorine test kit.
Permeate tube "O" ring failure	High salt passage	Check individual pressure vessel conductivity, probe suspect PV's to check individual membrane product conductivity.
Ineffective biocide	High bacterial/fungal counts in water samples. Biofouling of membranes – high ΔP	Biocide adsorption on GAC, check contact times and dose rate, select broad-spectrum biocide, Select biocide for organic content.
Sand/Multi-media filter breakthrough	Colloidal and bacterial fouling of micron filters and membranes.	Check wash procedures to remove fines.
Poor performance on start up after shutdown.	Fouling/scaling of membranes.	Check membrane flush procedures on shut down and preservation procedures on extended shutdown.

MEMBRANE CLEANING

Membrane cleaning is an important part of any reverse osmosis maintenance program. Effective cleaning usually requires some knowledge of the type of foulant and the cleaning options available.

Membrane fouling

Foulants on the membrane surface can cause flux loss (permeate flow), an increase in differential pressure (∆P), higher product water conductivity, a need for increased feed pressure to maintain output or a combination of these effects.

Effect of common foulants on system performance

Foulant	Normalized Permeate Flow (NPF)	Salt Passage	Pressure Drop ∆P
Scaling	↓↓	↔	↑
Colloidal Fouling	↓↓	↑	↑↑
Biofouling	↓	↔	↑↑
Organic Fouling	↓↓	↔	↔

When to clean?

It is essential to clean membranes at an early stage of fouling. It is often difficult to clean excessively fouled membranes and irreversible damage may occur during the cleaning process. **Cleaning is recommended when on or more of the following parameters change by 10 - 15% after data normalization**:

- An increase in product water conductivity or salt passage
- An increase in∆P across the plant
- An increase in feed pressure
- A decrease in normalized permeate flow (NPF) output or flux

If any of the above performance parameters deteriorates by more than 30%, it may be impossible to recover plant performance by routine cleaning practices.

RECOMMENDATIONS FOR EFFECTIVE MEMBRANE CLEANING

1. Clean membranes on a regular basis or when differential pressure (DP), normalized permeate flow, salt passage or feed pressure changes by 10 - 15% from the design limits. Regular and careful membrane cleaning is necessary and should not shorten the membrane life.

2. i) **Organic Foulants:** Clean with an alkaline surfactant such as AV CLEAN AL to break down and remove organic matter and biofilms. Acid flushing may follow this program, if necessary .*

   ii) **Scale Deposits:-** Calcium carbonate, iron oxide and iron hydroxide Calcium sulfate, strontium sulfate, barium sulfate, calcium fluoride; clean with a AV CLEAN LO low pH cleaner.

**If there is uncertainty of the type of fouling, always start with an alkaline cleaning product.*

3. Flow rates during cleaning, must be sufficient to remove foulants from the membrane element but not exceed manufacturer's limits. Flow rate should not exceed the feed pressure and pressure drop (ΔP) limitations determined by the membrane element manufacturer. Typical flow rates for membrane cleaning are provided in the table below.

Element diameter (inches)	Feed flow rate per Pressure vessel, m^3/hr	Feed flow rate per pressure vessel, gpm
4	1.8 - 2.3	8-10
8	6.8 - 9.1	30-40
8 (400 and 440 ft^2 membrane surface area)	8.0 - 10.2	35-45

4. The maximum recommended pressure drop during membrane cleaning of 8" membranes should not exceed 1.4 bar [20 psi] per element or 4.1 bar [60 psi] for a multi-element pressure vessel.
5. A cleaning solution is mixed at the rate of 1litre per 40 litre of solution is recommended per 8" x 40" membrane element; this excludes pipe work volumes. A minimum of 12-20 liters (for 4 inch) and 40-75 liters(for 8 inch) of cleaning solution is advised for each membrane element.
6. Where practicable, warm the cleaning solution to the highest temperature allowed by the membrane manufacturer. Typical cleaning solution temperatures should be 25 - 35 ^oC . Increasing the temperature of the alkaline cleaning solution will improve results.
7. Soak the membranes in cleaning solution for a minimum of 15 minutes before recirculation. This procedure should be repeated regularly throughout the cleaning.
8. Flush pipework, membranes and cleaning tank thoroughly with chlorine-free water between each cleaning cycle and when returning the plant to normal operation.
9. When cleaning multi-staged plant, clean each stage individually.
10. Don't panic when the plant returns to service and operating conditions are not improved or are even worse than at the start of the cleaning. Many of the cleaners used *temporarily* affect the membrane or polysulphone support structure, and routine operation for 4-24 hours may be necessary to stabilize operating conditions.

Membrane Manufacturer's recommendations should always be followed with respect to pH, temperature, pressure and flowrate.

All information contained in this brochure is based on laboratory and field trial data and is considered to be true and accurate. Since the conditions in which these products may be used are outside set guidelines we cannot warrant the results obtained.

Membrane Cleaning Log Sheet

It is recommended to keep good records on the procedure used to clean membranes. This log sheet can be used to monitor and optimize the membrane cleaning process based on results.

CLEANING DATA COLLECTION SHEET

RO System : Stage: **Chemical** **DATE:**

Tank Litres: **Volume litre.** **OPERATOR:**

Minutes	0	15	30	45	1 hour	15	30	45	2 hours	15	30	45
pH												
Flow												
Inlet Pressure												
Temperature												

Comments

Minutes	3 hours	15	30	45	4 hours	15	30	45	5 hours	15	30	45
pH												
Flow												
Inlet Pressure												
Temperature												

Comments

Minutes	6 Hours											
pH												
Flow		15	30	45	7 hours	15	30	45	8 hours	15	30	45
Inlet Pressure												
Temperature												

Comments

CHEMICAL TREATMENT PROGRAM APPLICATION

Coagulant

Coagulant can be used to improve filtration and aid the removal of fine colloids, reducing SDI values of RO feedwater. The coagulant should always be dosed prior to the multi-media/sand filters and as far back in the system as possible for good mixing and coagulation.

Cationic coagulant can foul RO membranes. It is therefore important that the dosage is accurately controlled. Over-dosing, particularly of organic coagulants, can cause the coagulant to break-through the filters and end up in the RO plant. Organic coagulant reaction with anionic polymer antiscalants can also occur, resulting in membrane fouling. It is therefore important to ensure a coagulant compatible antiscalant (e.g. PC-191) is used when using cationic coagulants in the pre-treatment.

Chlorine

Chlorine (Na/Ca hypochlorite, bleach or gas) can be dosed to control biological fouling of the pre-treatment system. If biological contamination is an issue, chlorine can be dosed prior to the pre-treatment system to give a free chlorine residual of 0.2 - 1.00 ppm depending on severity of contamination.

Chlorine will destroy polyamide thin film composite membranes. It is essential that ALL chlorine be removed from the feed water prior to entering the membranes . Even trace amounts of free chlorine can cause oxidation damage, especially in the presence of metals such as iron. Chlorine can be removed by bisulfite/metabisulfite addition or by the use of carbon filters.

The SBS solution should be dosed as close to the RO system as possible (to keep as much of the pre-treatment as possible in contact with chlorine - e.g. cartridge filters). However, if the free chlorine level is high, the SBS should be dosed prior to the antiscalant injection point (or antiscalant dosage adjusted to compensate for chlorine attack). Some antiscalants are attacked by free chlorine. The antiscalant and SBS dosing point should be far enough apart to prevent neat product mixing (SBS and antiscalant can often be mixed when diluted correctly, but pH differences of the neat products can cause problems).

Microbial Biocide

Non-oxidizing, non-ionic biocide can be used either on line or as part of a cleaning program to control biofouling in RO membranes. When used as an on-line treatment(not allowed for drinking water application), the biocide should be dosed prior to the RO system to control bio-growth in the membranes. Application frequency will depend on biological loading and biofilm growth rate. The program should be used to control differential pressures in the RO plant to reduce cleaning frequency.

Dosing biocide further back in the pre-treatment will help control bio-growth but will greatly increase demand and application costs. The main goal of an effective biocide program is to control biofouling in the membranes to an acceptable and cost effective level compared to cleaning program costs (and associated costs).

Scale Inhibitor-AV Guard

Antiscalant dilution and dosing guidelines follow.

The AV Guard can be dosed before the system cartridge filters. If iron is present in the feed water, the AV Guard can be dosed post to prevent "pick-up" of iron. Dose point should be after the sodium bi-sulfite injection to ensure chlorine is removed (especially with high levels of free chlorine). Dose point should be sufficiently down-stream of the SBS injection point to avoid "neat" product mixing.

For Piramal water , RO plant having upto 1000 TDS should be dosed at 10 gms of AV Guard per 1000 litre of feed water and 15 ml per 1000 liter of feed water for 2000 ppm TDS.

It is preferred to dose antiscalants neat. However, in some cases dilution might be necessary due to the capacity of the antiscalant dosage pump.
The below mentioned guidelines should be followed.

1. Use RO permeate for the dilution of the antiscalant.
2. Prepare a fresh antiscalant solution every 3-5 days.
3. Inspect the antiscalant tank before adding the new solution. If needed, the antiscalant tank is cleaned prior to filling.
4. Dilution rate up to a factor 10 are typically applied. Dilution factors higher than 10 will require more attention with respect to the condition of the antiscalant tank (cleaning) and preparation of a new solution (every 1-3 days).

Shimming

It is normal to have some movement of the membrane elements within their pressure vessel housings. This occurs because the pressure drop across the elements can cause them to compress. Fouling or high flow rates can result in significant movement, mostly when the system starts up. When it shuts down, the elements will then relax.

This movement will cause rubbing against the inter-connector O-rings, particularly in the lead end elements. With time, this can cause them to abrade and possibly break. In case of severe pressure drops, O-rings can be completely dislodged and blow out of their slots.

The potential for this movement should be minimized by making certain that the elements fit tightly within their pressure vessel. Any slop should be taken up with shims.

Shims are slices of plastic piping that have an inside diameter that just fits over the outside of an end connector, usually the end connector between the lead end element and the vessel end cap. Enough should be installed so that replacing the end cap in its vessel should be met with some resistance.

Replacing Membrane Elements

Occasionally, it is necessary to replace RO elements. This will be determined if necessary following trouble shooting and other remedial actions.

As with replacing O-rings, the system should be shut down and drained. Prior to installation, the new element serial numbers should be recorded indicating their intended location in the system. This is useful in comparing the membrane manufacturer's test data with the system performance.

It may be necessary to remove both of the vessel end-caps. The elements can then be removed in their normal direction of flow. This will prevent their brine seals from jamming against the pressure vessel. The replacement elements can be inserted in the feed end of the vessel and used to push the other elements through.

The U-cup brine seals and the inter-connector O-rings can be sparingly lubricated with glycerin to aid fitting. Each inter-connector should have O-rings installed. U cup brine seals should be installed only with the open groove of the seal facing the upstream end of each element (note flow arrow on side of element which points toward the downstream end). Never put brine seals on both ends of an element.

After element replacement, any gaps should be limited with shims. The end caps can them be installed and the system started up. It should be filled with low-pressure water prior to starting the high-pressure pump. New elements should be rinsed to drain to remove any residual preservative chemicals. System operating data should be collected after the RO performance stabilizes (within 24 hours).

Not all information provided above has been referenced in this report but is included here in its original format for the sake of completeness.

Piramal Water Private Ltd. Letter of Engagement

February 2, 2011

Mr. Anand Shah
CEO, Piramal Water Private Limited
Ahmadabad, Gujarat, India
+91 98255 99950
anand@sarvajal.com

Dear Mr. Shah,

Thank you for the opportunity to assist Piramal Water Private Ltd. (Piramal) in finding creative solutions for use of excess brine generated through reverse osmosis water filtration (RO brine). We look forward to working closely with you and the Piramal staff and franchisees. This letter is to confirm our mutual understanding of the project objectives, scope, approach, timing, deliverables, and resource requirements.

Project Motivation and Objectives

The primary objective of our Masters Project, for the University of Michigan's School of Natural Resources and Environment, is to generate creative solutions for optimal water use and RO Brine reclamation associated with Piramal's core business. To achieve this, we will research, propose and implement pilot programs which exhibit the greatest potential to optimize the resource-efficiency of Piramal's water processing. Our goals in this project are two-fold. First, to gain experience from of researching and implementing new business solutions Second, to make a meaningful contribution to your business operations.

Project Scope
To accomplish these goals, we will:

- Conduct a baseline analysis of economic, environmental, and social impact of current water use practices at Piramal facilities;
- Identify potential uses and/or reduction of RO Brine. Quantify economic, social, and environmental benefit added to local entrepreneurs and communities by proposed solutions;
- Asses long term pressures on Piramal's core business imposed by climate change and water resource availability in India and evaluate solutions in this light;
- Develop, implement and assess selected pilot solutions on-site at Piramal franchise locations;
- Present a final report on our recommendations including analysis of the viability and scalability of all proposed and tested solutions.

Approach and Timing
Our time and effort will be structured as follows:

Phase 1: Engagement Definition and Preliminary Research (February 1 – February 15)

- Define engagement scope, information needs, timing, resource requirements and constraints;
- Establish approach for communication with key Piramal staff and selected franchise managers. Identify dedicated points of contact.
- Discuss rights to data, findings and corporate confidentiality.

Phase 2: Understanding the Context (February 15 - ongoing)

- Gather information about business operations of Piramal and their franchises. Establish economic restrictions of any solutions.
- Conduct research on industry peers. Develop a firm understanding of RO filtration and how others meet the challenges of RO brine production.
- Develop thorough understanding of regional water-use stressors and cultural framework of the region.
- Solicit input from key Piramal staff, franchise managers and key stakeholders to learn and assess current practices.
- Schedule and conduct interviews with key stakeholders (Piramal staff/ franchises).

Phase 3: Pilot Development (March 6 - August 31)

- Develop multiple potential solutions for waste-water use.
- Solicit input from Piramal and their franchises about various pilot solutions.
- Generate implementation plans for mutually agreed upon pilot water solutions.

Phase 4: Site Visits, Scouting and Pilot Solution Implementation (May 1 - August 31)

- Visit Piramal Water franchisees (Two 3 week phases throughout the summer).
- Facilitate implementation of pilot solutions.
- Conduct solution-specific Impact Assessment and cost benefit analysis.

Phase 5: Project Review, Assessment and Wrap Up (September 1 – November 30)

- Prepare written report and oral presentation.
- Present findings to core Piramal staff.
- Transition projects findings to Piramal Franchise managers for broad scale implementation.

Support Resources Required

- Access to key personnel for interviews during the first three weeks of the project
- Administrative support with the data collection, including access to relevant Piramal plans and documents.
- In-country lodging and transportation as per Piramal policy during summer site visits.
- Translator as needed.
- Funding discretion for pilot solutions will lie solely with Piramal and will depend upon the suitability, efficiency and cost-effectiveness of the solution. In the events that students are able to secure outside funding sources, it will be applied to mutually agreed upon pilot solutions.

Deliverables

We will provide Piramal and the University of Michigan a detailed written report by December 10, 2011 and make a presentation of our findings and recommendations on or before that date. Our final deliverables will provide:

- Results from pilot tests and impact assessment (including economic, environmental, and social analysis), scalability study, and final recommendations
- Evaluation of potential future business implications of climate stressors

We are excited to be working with Piramal. We look forward to delivering meaningful recommendations that will have lasting impact for the organization and the communities that you serve.

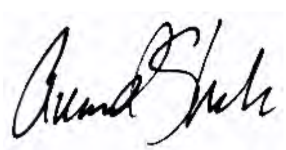
Sincerely,

(Student Signatures)

Lilly Connett   Caitlin Harren   Kate Harris   Lauren Berent

Meredith Neely   Vaishnavi Tripuraneni

This letter accurately describes our expectations of the University of Michigan's School of Natural Resources and Environment Masters project.



(Company Liaison Signature)
Anand Shah

CC: Ming Xu (student team advisor), Ashish Gupta

SNRE Master's Project Team Composition

Lauren Berent is a Master's student in Sustainable Systems and Aquatic Sciences at SNRE. She brought the team expertise on ecological issues and the ability to evaluate potential brine solutions for their impact on terrestrial and aquatic ecosystems.

Lilly Connett is a Master's student in Sustainable Systems and Aquatic Sciences at SNRE. She is interested in water resource management and international development and brought to the team field and research experience approaching environmental issues in developing countries.

Caitlin Harren is a dual degree Master's student in the Ross School of Business and sustainable systems at SNRE. She studies operational efficiency as a mechanism for improving cost structure and brought to the team a familiarity with financial analysis and strategic planning.

Kate Harris is a dual degree Master's student at SNRE in Behavior, Education & Communication and at the School of Education's Center for Higher and Post-Secondary Education in Philanthropy, Advancement & Development. She is interested in international sustainability issues and place-based, experiential learning. She brought knowledge in communication and organizational strategies both within the project team and to interactions with communities in India.

Meredith Neely is a dual degree Master's student in the College of Engineering (Environmental Engineering) and sustainable systems at SNRE. She is interested in using integrated water resource management strategies to close the loop around storm water, wastewater and drinking water systems. She brought to the team extensive field and research experience working with water treatment and other engineered systems.

Vaishnavi Tripuraneni is a Master's Student in Sustainable Systems at SNRE. She has a background in economic analysis and is interested in resource management and community development in developing countries. She is also fluent in Hindi, providing the team's primary avenue for communications while in India. She brought to the team skills of economic analysis and in depth knowledge of local culture and values.

RO Brine Applications Evaluation Criteria

1) Practical Considerations

- Scalability- Taking into account the variability of franchise locations, surroundings and availability of land and local resources, where might this solution be appropriate (urban versus rural) and could it easily be scaled to multiple locations?
- Viability- What is the expected life-span of the solution? Can it be reasonably constructed, implemented and maintained by entrepreneurs? What materials are needed and are they available locally? And what are the long term implications for the triple bottom line.
- Short-term feasibility- Will the Master's Project team be able to implement pilot solutions and collect useful data within the project timeline and budget?
- Suitability- Does it sufficiently address the problem? And how does it compare to "business as usual?"

2) Economic Considerations

- Cost effectiveness- What are the long- and short-term costs associated with this solution (both capital and maintenance costs)? Conduct a cost/benefit analysis.
- Added economic value- Is there potential for an additional business opportunity, either as an extension of the entrepreneurs current work or in partnership with other local entrepreneurs (job creation)?

3) Social Considerations

- Community value- Does the proposed solution build a sense of community or pride for local residents? Does it add value to franchisee locations as a gathering place to strengthen ties and communication within a community?
- Cultural sensitivity- Does the solution account for the local and cultural context? And is it culturally feasible for entrepreneurs and community members to engage with and be accepting of the idea?

4) Environmental considerations

- Does the solution not only prevent environmental degradation but seek to improve the environmental quality of the region and watershed? What are the short- and long-term impacts on water, land and air quality in both local and global contexts? What is materials footprint of supplies needed to implement and maintain this solution?

COCO (Bagar): RO unit and operations building

COCO (Bagar): RO and water treatment unit

COCO (Bagar): Water delivery truck and tank

COCO (Bagar): Locals gathering in front of COCO

COCO (Bagar): Vacant space behind COCO

COCO (Bagar): Team with COCO operator

Pratapnagar: Owners and RO unit


Pratapnagar: Discussing water treatment operations


Pratapnagar: Owner's brine-irrigated vegetable garden


Pratapnagar: Owner's brine-irrigated vegetable garden

Sitapura: RO and water treatment unit


Sitapura: Water cooling system

Sitapura: Discussing wood treatment operations

Sitapura: Wood treatment operations and lumber steamer

Mukundgarh: RO unit and operations building

Mukundgarh: RO and water treatment unit

Mukundgarh: Concrete septic tank forms

Mukundgarh: RO brine storage basin

Nawalgarh: RO unit and operations building

Nawalgarh: RO and water treatment unit

Nawalgarh: Discussing operations

Nawalgarh: Source water borewell

Nawalgarh: Owner's brine-irrigated garden

Nawalgarh: Algae growing in treatment unit

Siriyasar Kalan: RO unit and operations building

Siriyasar Kalan: RO and water treatment unit

Siriyasar Kalan: Standing near ground discharge

Siriyasar Kalan: Standing near borewell

Siriyasar Kalan: Owner's livestock

Siriyasar Kalan: Owner's agriculture fields

Mandawa-2: RO unit and operations building

Mandawa-2: RO and water treatment unit

Mandawa-2: Water delivery truck

Mandawa-2: RO brine ground discharge

Mandawa-2: Developed land behind building

Mandawa-2: Owner filling product water jug

Fatehpur-2: RO and water treatment unit

Fatehpur-2: Discussing operation with owner

Fatehpur-2: RO brine holding tank

Fatehpur-2: Discussing operation with owner

Fatehpur-2: RO brine holding tank area

Fatehpur-2: Source water borewell

Rollsahabsar: Discussing operation with owner

Rollsahabsar: Water delivery truck and jugs

Rollsahabsar: Collecting algae sample from brine discharge gutter

Rollsahabsar: RO brine discharge gutter

Ramgarh-2: Building front - owner not present

Ramgarh-2: Building front - owner not present

Ramgarh-1: RO and water treatment unit (back)

Ramgarh-1: Discussing RO unit operations

Ramgarh-1: RO brine holding basin

Ramgarh-1: Discussing concrete production

Ramgarh-1: Concrete brick operations

Ramgarh-1: Concrete operations

Bissau-2: Front of franchise owner's home and RO operations

Bissau-2: RO and water treatment unit

Bissau-2: Owner's garden (bajra)

Bissau-2: Owner's garden and brine discharge

Bissau-2: Discussing RO unit operations

Bissau-2: Water treatment unit nameplate

Chirawa: RO unit and operations building

Chirawa: Discussing RO unit operations

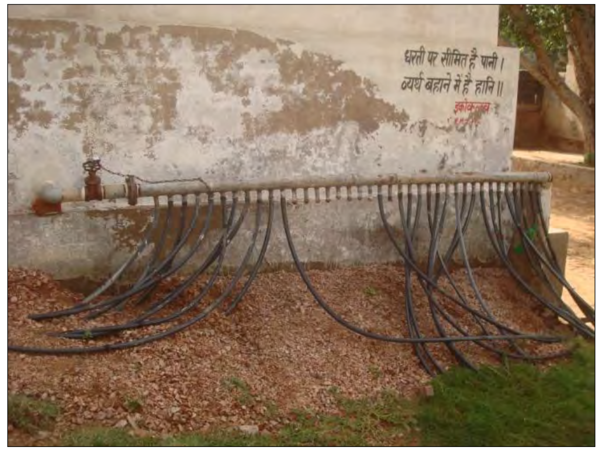
Chirawa: Franchise owner and vegetable garden

Chirawa: Owner's brine-irrigated vegetable garden

Chirawa: Franchise owner and ice-making operations

Chirawa: Ice-making operations building and ice bins

Choti Pancheri: RO unit and operations building



Choti Pancheri: Municipal water hook-up

Choti Pancheri: Discussing operations with owner

Choti Pancheri: Standing in front of recharge pit

Choti Pancheri: Source water borewell

Choti Pancheri: RO product water dispensing line

Singhana-2: RO unit and operations building

Singhana-2: RO unit and operations building

Singhana-2: Discussing RO operations

Singhana-2: Franchise owner and water treatment unit

Singhana-2: RO brine discharge

Singhana-2: Team with Franchise owner

Copper-1: RO unit and operations store front

Copper-1: RO and water treatment unit

Copper-1: RO brine discharge to sewer

Copper-1: RO brine discharge on side of building

Copper-1: Collecting RO brine sample

Copper-1: Discussing operations with owner

Gothara: RO unit and operations building

Gothara: Water delivery truck

Gothara: Owner's livestock and agriculture

Gothara: Discussing operations with owner

Gothara: Using RO brine for domestic purposes

Gothara: RO brine discharge to irrigation ditch

Mandrela: RO unit and operations building

Mandrela: Discussing operations with owner

Mandrela: Discussing RO unit operations

Mandrela: RO brine discharge to sewer

Malsisar: RO unit and operations building

Malsisar: Discussing RO operations


Malsisar: Source water borewell


Malsisar: Water delivery truck


Malsisar: Looking at groundwater recharge pit


Malsisar: Groundwater recharge pit


Sadulpur: RO unit and operations building


Sadulpur: Discussing RO operations

Sadulpur: Groundwater recharge pit

Sadulpur: Source water borewell

Rajgarh: RO unit and operations building

Rajgarh: Discussing operations with owner

Rajgarh: RO brine discharge on side of building

Rajgarh: Vacant land on side of building

Taranagar: RO unit and operations building

Taranagar: RO and water treatment unit

Taranagar: Source water borewell

Taranagar: RO brine ground discharge

Taranagar: Discussing operations with owner

Taranagar: Yard behind operations building

COCO (July and August 2011)

This is a “company owned company operated” (COCO) location that is less than half a mile away from the Bagar headquarters. At this location the operator is paid a decent flat-rate salary, so there is little motivation to find an economic use for the brine. When we arrived at the site, the front of the COCO was used for water sales and the yard at the back of the structure was covered with weeds- but the area closest to the building was cleared. This is where our team conducted some of our tests.

Pratapnagar (07/14/2011)

Franchisee had a vegetable garden and was watering a variety of plants with the brine. A hose ran from the machine to his garden- so whenever his machine ran, his plants received brine water. He claimed to use the water for domestic purposes as well.

Sitapura (07/14/2011)

This franchise was in operation solely to provide the workers of the lumberyard with clean water to drink. A portion of the brine was directly routed to the machine that steam treats the lumber to prevent it from rotting. The unused brine is returned to the collection pit and used again on the next batch of lumber. The leftover brine (not used at all in wood treatment) is piped to a few trees on the property.

Mukundgarh (07/20/2011)

This is the first Sarvajal franchisee established after the COCO. This franchisee uses the brine for a variety of purposes including window and doorframe construction and making concrete septic tank containers. He had been undertaking this activity for about three months at the time of our visit. He also lets the brine run into his fields, the area close to the machine where the hose reaches. He also had insulated the container on the delivery truck to keep the water cold; he claimed that his business had increased since he had started doing this. He has also built a large tank and has been filling it with brine water, which he plans to use for a plant nursery that he is going to start.

Nawalgarh (07/20/2011)

This franchisee currently uses the brine to water a vegetable garden that is just for his family’s consumption. He was growing beans, okra, bajra, bottle gourds, eggplant and some leafy vegetables.

Siriyasar Kalan (07/27/2011)

The franchisee reported that in the past nine years he has been using his borewell for agriculture and more recently for water filtration as a Sarvajal franchisee. He reported to have seen the water level drop from 20 feet below the surface of the ground to more than 200 feet in this timeframe. This franchisee planted several trees and choose to water one with the RO brine. On our visit, the trees were just about 1 year old and all were doing well except the one watered with RO brine. The trees that had been watered with raw water had doubled in size, while the one watered with brine had died. Based on the death of this tree, the franchisee said he would not use the brine for agricultural purposes, however, he did say he would be interested in trying again if we could provide information about specific plants that could survive in the brine. Our team was not convinced that the brine had killed the tree as we also noticed that the dead tree was in a location that was directly in front of the brine discharge spout and given the volume of brine that is discharged daily, it is possible that the death of the tree was caused by overwatering as opposed to the contents of the brine. Also, this was a region with high TDS levels, so the tree would have been receiving extra concentrated brine in excess quantities.

Mandawa-2 (07/27/2011)

The owner said that he had initially tried to use the brine to water plants, but that the plants did not survive. He also tried using the brine to wet a concrete wall during and after construction. He was not happy with the results as a salty residue appeared on the surface of the area of new construction and he attributed this situation to salt in the RO brine. However, our team also speculated that the residue he showed us could be due to a variety of other factors including excessive wetting of the concrete as it dried and/or to debris accumulating on the wetted area (dirt and dust from the bare soil behind the building). It should also be noted that the practice of wetting concrete as it is curing is not standard practice. Despite this franchisee's setback with brine, at the time of our visit he was half way through leveling the field behind his building. His plan is to plant several trees, water them with RO brine, and see which ones will survive.

Fatehpur-2 (07/27/2011)

There was currently no systematic brine use at this location. A majority of the brine was being discharged into a closed sewer. However, the franchisee reported that there was a water shortage in his area and when the municipal water was shut off his neighbors would come to his home to collect brine for domestic purposes (such as car washing and house cleaning).

Rollsahabsar (07/27/2011)

This owner reported only being in operation for 6 months, but he had used the brine to water a few trees at his home. He said the brine completely killed the grown trees he watered with the brine. Our group was a little suspicious of this statement because there was absolutely no evidence that trees ever existed in the location he indicated; no stumps, no holes where roots used to be.

Ramgarh-1 (07/27/2011)

This franchisee had previously been a brick maker and two and a half years ago he also became a Sarvajal franchisee. After a few months of operation, he decided to start making concrete bricks and septic tank covers using RO brine for water in the mixture. He continued to use the brine for this purpose for about a year, until his customers started returning his product complaining that the concrete structures he made were not structurally sound. In response to these complaints, he stopped using brine water and returned to making the structures with raw water. After the switch back, he no longer receives complaints or notices any other problems in his structures. What impressed us about this franchisee was his entrepreneurial spirit. He clearly was motivated to put the brine to good use and so despite his setbacks, he was very interested in the fact that another franchisee was using brine for furniture making. He mentioned that a furniture maker was in the area and that he would contact them to see if they could form some kind of partnership. If he did not find another option, his next plan was to pursue groundwater discharge through the construction of a recharge pit (built using the returned faulty concrete structures).

Ramgarh-2 (07/27/2011)

No one was home at this location, but we noticed that there was a pipe taking the brine to a drain.

Biussau-2 (07/27/2011)

This franchisee was a farmer who had started his franchise approximately a year ago. He had used the brine for four months on his field of bottle gourd, cauliflower, radish, sweet carrots. He said the plants survived, but that they grew at a much slower rate and produced less consumable produce. Two months prior to our visit, he switched back to using raw water for his crops and said they had improved.

Chirawa (08/03/2011, via translator)

The owner has been using brine to water his organized garden with a watering system since the franchise opened in August of 2008. He uses product water for ice. The structure cost 8 lakhs (800,000 rupees) to build and uses 15,000 L of brine water to freeze the clean water; however that salt water hardly ever needs to be changed.

Choti Pancheri (08/03/2011, via translator)

This location is a unique case because it is set up as a municipal service by the town. Taxes are collected from residents to pay for the operation of the RO machine and residents help themselves to the water. There is an “honor system” in place stipulating that no person use more than an hour of water per day. The operator is not making a profit. The brine is dumped into a well dedicated purely to the collection of RO brine. The level in the discharge well has increased over the time of operation, but it is unclear if it is recharging into the ground or just collecting in the well.

Singhana-2 (08/03/2011, via translator)

Owner initially said that he was not using the brine, however as the conversation continued he said he uses brine for agriculture. There was a hose that appeared to pump brine out to the yard, but there did not seem to be any sort of organized crop planting or watering system. Our group observed that the owner may simply have been trying to give us the answer he thought we wanted to hear.

Copper-1 (08/03/2011, via translator)

The owner/operator claimed to have never done anything with the brine other than dump it down the drain for the copper mine to “recycle” (he has been told that the water that goes into the drain ends up at the copper mine and is used for some purpose there). As the franchisee said (via translator) there isn't any agriculture in the area and "the copper mine is recycling it, so he doesn't need to know anymore about it".

Gothara (08/03/2011, via translator)

This franchisee uses brine for watering one part of his field. The language barrier made it difficult to know for sure, but it seemed as if there was a heated discussion between this franchisee and the Sarvajal staff about the 3-phase electricity used to operate the RO unit. Three-phase electricity hookup in India is much more expensive than the conventional single-phase electricity hookup. Apparently he needs this sort of electricity to run the RO filter at a pressure that can deal with his high TDS levels, but he does not think the expense is worth it.

Mandrela (08/03/2011, via translator)

He currently dumps the brine into the sewer. He claimed to have plans to use it to water plants in a field nearby in the future (as described via the translator).

Malsisar (08/03/2011, via translator)

This franchisee owns two other machines at other locations. He has built a concrete recharge pit (concrete well walls, open bottom to allow the water to soak into the ground) for each of his locations. He has a good deal of contact with other franchisees because he designs chiller plants for franchisees to cool water.

Sadulpur (08/03/2011, via translator)

This franchisee had only been in operation for less than a month. He had not yet established a firm business (he was not yet making a profit). He also seemed a little discouraged about any possible solution being applicable to his operation because there was “no space” to do anything with it on his property, but said he would be interested in hearing form Sarvajal about what other franchises are doing with the brine.

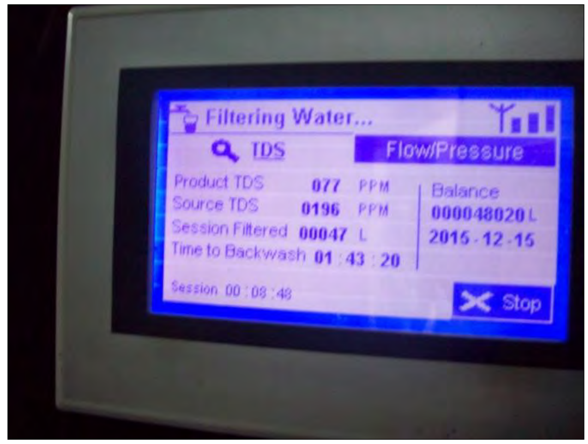
Rajgarh (08/03/2011, via translator)

The owner/operator stated that he never considered using the brine for anything because "there isn't enough space” on his property to do anything with it. When asked about the industry in the area, he mentioned that there was a dhobi in the town, which was located far away. Perhaps if the franchisee were to get into contact with this dhobi, a partnership could be developed between the two.

Taranagar (08/03/2011, via translator)

This site was fairly remote and was not attached to the owner’s home. The brine was being released into the side yard. The plants in this yard were just growing there naturally; they were not specifically planted by the owner or operator.

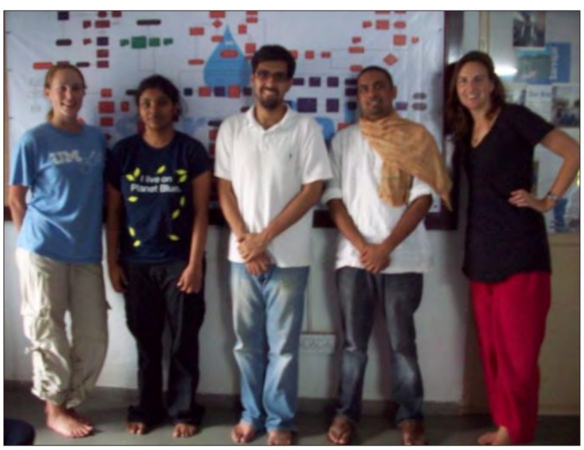
Headquarters: RO and water treatment unit in Ahmedabad (07/12/11)



Headquarters: RO and water treatment unit monitoring system in Ahmedabad (07/12/11)

Tekra Slum: Water ATM pilot installation in Tekra, a slum in Ahmedabad (07/12/11)

Tekra Slum: Water ATM demonstration in Tekra (07/12/11)



Headquarters: Team with Sarvajal headquarters staff in Ahmedabad (07/13/11)

Headquarters: Team at Piramal Headquarters in Ahmedabad (07/13/11)

COCO (Bagar): Looking at algae from COCO (07/17/11)

COCO (Bagar): Yard behind COCO to be cleared for bench tests (07/17/11)

COCO (Bagar): Clearing yard for bench tests (07/17/11)

COCO (Bagar): Clearing yard for evaporation pit bench tests (07/17/11)

COCO (Bagar): Forming evaporation pit for bench test (07/17/11)

COCO (Bagar): Evaporation pit lined with black plastic (07/17/11)

COCO (Bagar): Filling lined evaporation basin in concrete structure (07/19/11)

COCO (Bagar): Lined evaporation basin and catchment hood for evaporation tests (07/19/11)

COCO (Bagar): Lined evaporation basin and catchment hood for evaporation tests (07/19/11)

COCO (Bagar): Lined evaporation basin and catchment hood for evaporation tests (07/19/11)

COCO (Bagar): Evaporation basin after vandalism (07/20/11)

COCO (Bagar): Agriculture bench test in COCO yard (07/18/11)

Ice Factory (Mukundgarh): Cooling pipes (07/20/11)

Ice Factory (Mukundgarh): Liquid nitrogen pump (07/20/11)

Ice Factory (Mukundgarh): Ice factory equipment (07/20/11)

Ice Factory (Mukundgarh): Cooling tank (07/20/11)

Ice Factory (Mukundgarh): Explanation of the freezing process (07/20/11)

Ice Factory (Mukundgarh): The team observing ice factory operations (07/20/11)

Nursery Visit: Discussing plant species with nursery owner (07/25/11)

Nursery Visit: Ficus religiosa plants, apparently salt-tolerant (07/25/11)

Nursery Visit: Continuing nursery tour with owner (07/25/11)

Nursery Visit: More plant seedlings (07/25/11)

Nursery Visit: Ficus religiosa plants to take back to Bagar (07/25/11)

Nursery Visit: Team with nursery owner, Padam Chand Saini (07/25/11)

Algae Bench Test: Placing algae in RO brine and source water bottles (08/05/11)

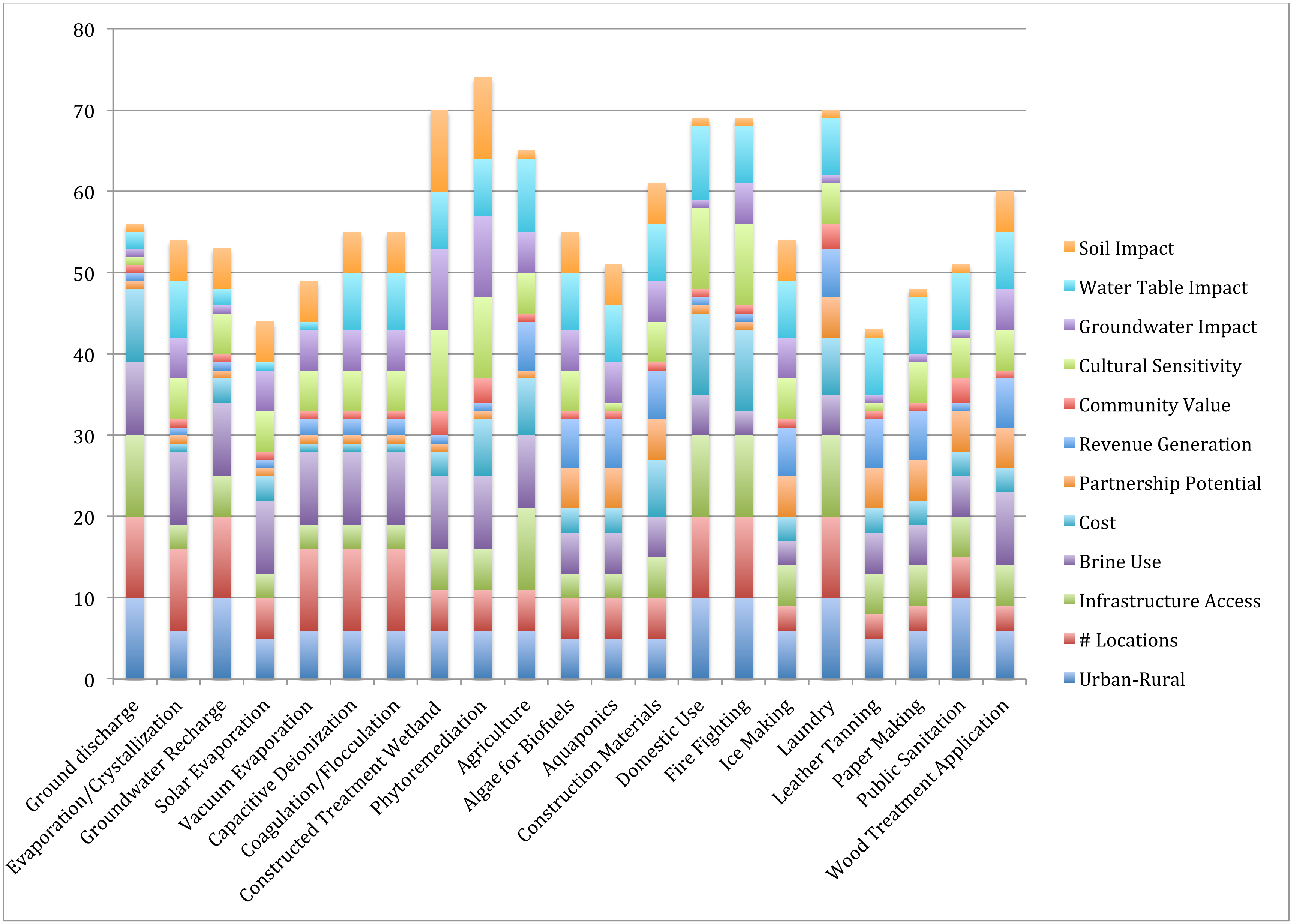
Algae Bench Test: Algae in product (right) and source water (left) bottles (08/05/11)

Evaporation Bench Test: Acrylic basin for evaporation test in office courtyard (08/05/11)

Evaporation Bench Test: Filling up containers with RO brine for evaporation test (08/05/11)

Evaporation Bench Test: Acrylic basin filled with RO brine (08/05/11)

Evaporation Bench Test: Measuring depth of RO brine in basin (08/05/11)


80
70
60
50
40
30
20
10
0
Soil Impact
Water Table Impact
Groundwater Impact
Cultural Sensitivity
Community Value
Revenue Generation
Partnership Potential
Cost
Brine Use
Infrastructure Access
Locations
Urban-Rural
Ground discharge
Evaporation/Crystallization
Groundwater Recharge
Solar Evaporation
Vacuum Evaporation
Capacitive Deionization
Coagulation/Flocculation
Constructed Treatment Wetland
Phytoremediation
Agriculture
Algae for Biofuels
Aquaponics
Construction Materials
Domestic Use
Fire Fighting
Ice Making
Laundry
Leather Tanning
Paper Making
Public Sanitation
Wood Treatment Application

Practical Considerations

	Objective	Scalability							Necessary Infrastructure				Brine needs		
	Sub-Objective	Urban-Rural				Works at how many locations?			Access to Necessary Infrastructure				Percentage Brine Use		
	Assesment Criteria	Urban only	Rural only	Rural and Periurban	All sites	0-10 site	Up to 50	50+	Not possible to meet need	Need to introduce new institutions	Can Use Available but unfamiliar/ uncommon institution	Needs only currently available institutions	Only uses little brine	Uses some (1/2) of brine produced	Could make use of most or all of brine
	Utility Scores	***2***	***5***	***6***	***10***	***3***	***5***	***10***	***1***	***3***	***5***	***10***	***3***	***5***	***9***
Business as usual	Ground discharge				10			10				10			9
Disposal Applications	Evaporation/Crystallization			6				10		3					9
	Groundwater Recharge				10			10			5				9
	Solar Evaporation		5				5			3					9
	Vacuum Evaporation			6				10		3					9
Further Treatment Applications	Capacitive Deionization			6				10		3					9
	Coagulation/Flocculation			6				10		3					9
	Constructed Treatment Wetland			6			5				5				9
	Phytoremediation			6			5				5				9
Reuse Applications	Agriculture			6			5					10			9
	Algae for Biofuels		5				5			3				5	
	Aquaponics		5				5			3				5	
	Construction Materials		5				5				5			5	
	Domestic Use				10			10				10		5	
	Fire Fighting				10			10				10	3		
	Ice Making			6		3					5		3		
	Laundry				10			10				10		5	
	Leather Tanning		5			3					5			5	
	Paper Making			6		3					5			5	
	Public Sanitation				10		5				5			5	
	Wood Treatment Application			6		3					5				9

Economic Considerations

	Objective	**Cost**				**Partnership Potential**		**Revenue Generation**		
	Sub-Objective	**Prive to Establish and Operate**				**Partnership Potential**		**Generate Revenue through**		
	Assesment Criteria	**Very expensive**	**Expensive**	**Affordable**	**Very affordable**	**No potential for partership**	**Partnership potential exists**	**No additional economic gains**	**Water profits**	**New income generation potential**
	Utility Scores	***1***	***3***	***7***	***10***	***1***	***5***	***1***	***2***	***6***
Business as usual	Ground discharge				9	1		1		
Disposal Applications	Evaporation/Crystallization	1				1			2	
	Groundwater Recharge		3			1		1		
	Solar Evaporation		3			1		1		
	Vacuum Evaporation	1				1			2	
Further Treatment Applications	Capacitive Deionization	1				1			2	
	Coagulation/Flocculation	1				1			2	
	Constructed Treatment Wetland		3			1		1		
	Phytoremediation			7		1		1		
Reuse Applications	Agriculture			7		1				6
	Algae for Biofuels		3				5			6
	Aquaponics		3				5			6
	Construction Materials			7			5			6
	Domestic Use				10	1		1		
	Fire Fighting				10	1		1		
	Ice Making		3				5			6
	Laundry			7			5			6
	Leather Tanning		3				5			6
	Paper Making		3				5			6
	Public Sanitation		3				5	1		
	Wood Treatment Application		3				5			6

Social Considerations

	Objective	Community value		Cultural sensitivity		
	Sub-Objective	Potential to Add Value to Local Community		Application Fit With Local Culture		
	Assesment Criteria	No Potential	Potential to Add Value	Not culturally appropriate for India	Culturally appropriate	Culturally appropriate and improves brand image
	Utility Scores	*1*	*3*	*1*	*5*	*10*
Business as usual	Ground discharge	1		1		
Disposal Applications	Evaporation/Crystallization	1			5	
	Groundwater Recharge	1			5	
	Solar Evaporation	1			5	
	Vacuum Evaporation	1			5	
Further Treatment Applications	Capacitive Deionization	1			5	
	Coagulation/Flocculation	1			5	
	Constructed Treatment Wetland		3			10
	Phytoremediation		3			10
Reuse Applications	Agriculture	1			5	
	Algae for Biofuels	1			5	
	Aquaponics	1		1		
	Construction Materials	1			5	
	Domestic Use	1				10
	Fire Fighting	1				10
	Ice Making	1			5	
	Laundry		3		5	
	Leather Tanning	1		1		
	Paper Making	1			5	
	Public Sanitation		3		5	
	Wood Treatment Application	1			5	

Environmental Considerations

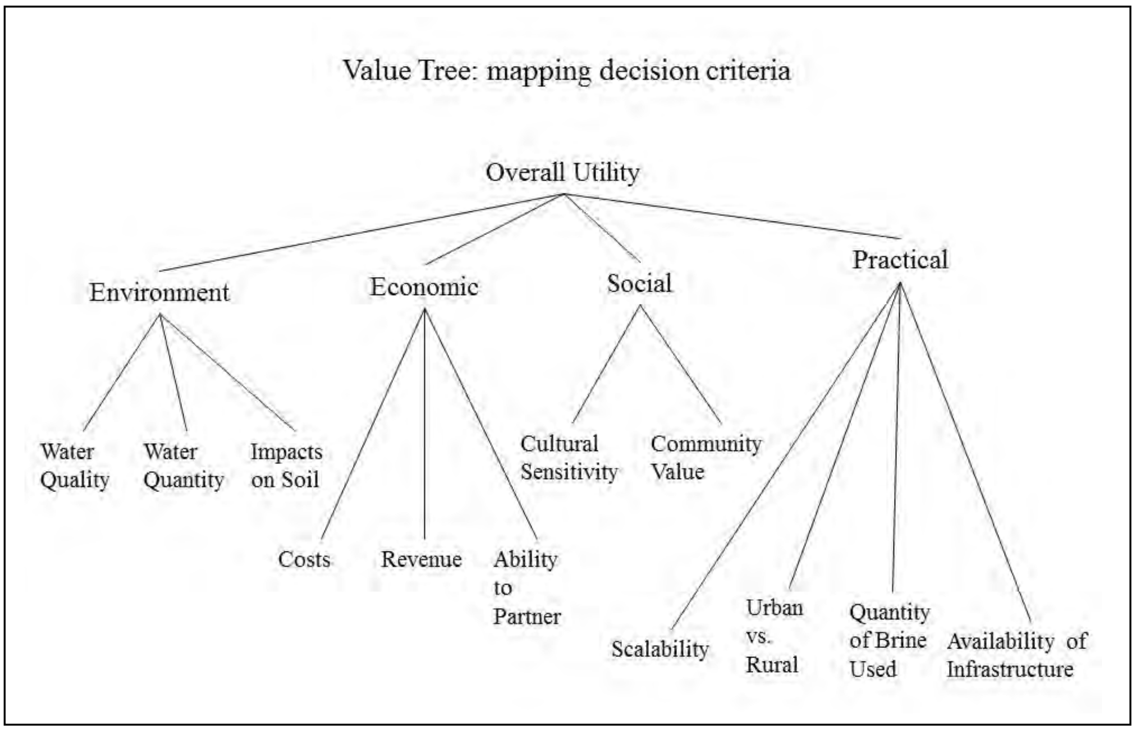
	Objective	Groundwater								Soil		
	Sub-Objective	**Impact on Groundwater Quality**			**Impact on Water Table**					**Soil Quality**		
	Assesment Criteria	**Diminishes Quality**	**No impact on quality**	**Improved quality**	**Does not replenish groundwater**	**Replenishes with low quality water**	**replenishes with high quality water**	**decreases demand on raw water**	**Replenishes and decreased demand**	**Diminishes soil quality**	**no impact on soil quality**	**improves soil quality**
	Utility Scores	***1***	***5***	***10***	***1***	***2***	***7***	***7***	***9***	***1***	***5***	***10***
Business as usual	Ground discharge	1				2				1		
Disposal Applications	Evaporation/Crystallization		5					7			5	
	Groundwater Recharge	1				2					5	
	Solar Evaporation		5		1						5	
	Vacuum Evaporation		5		1						5	
Further Treatment Applications	Capacitive Deionization		5					7			5	
	Coagulation/Flocculation		5					7			5	
	Constructed Treatment Wetland			10			7					10
	Phytoremediation			10			7					10
Reuse Applications	Agriculture		5						9	1		
	Algae for Biofuels		5					7			5	
	Aquaponics		5					7			5	
	Construction Materials		5					7			5	
	Domestic Use	1							9	1		
	Fire Fighting		5					7		1		
	Ice Making		5					7			5	
	Laundry	1						7		1		
	Leather Tanning	1						7		1		
	Paper Making	1						7		1		
	Public Sanitation	1						7		1		
	Wood Treatment Application		5					7			5	

Methods: Application Utility Matrix

The student team used multi-criteria analysis to incorporate a variety of economic, environmental, social, and practical considerations into the analysis of appropriate brine applications for Sarvajal. Multi-criteria analysis (MCA) provides a systematic way of evaluating multiple criteria in a decision-making context.[i] The team employed methods taught in the University of Michigan School of Natural Resources and Environment Fall 2010 course, Systems Analysis, taught by Professor Shelie Miller. The methods used are consistent with multi-criteria analysis literature and are based on multi-attribute utility theory.[ii] The Reference text used to guide the multi-criteria analysis in this paper was "Multi Criteria Analysis: a Manual" written and published by the government of England in 2009.[iii]

The objective of this analysis was to provide an analytical and normative tool for comparing applications for RO brine for use by the company Sarvajal. The first step of the MCA was to create a performance matrix which conveyed information about the performance of each application option against a given criteria. The criteria used in this matrix were refined from the list of evaluation criteria generated by the team of students in their pre-India phase of research [See Appendix D]. A common way to organize objectives and group criteria for MCA is through the creation of a value tree.[iv] The students created a value tree that groups decision criteria in categories of economic costs and benefits, environmental considerations, social concerns, and practical implementation considerations. Each of these categories was made up of a collection of sub-objectives, which informed an overarching objective.

Value Tree



Organizing the criteria this way facilitated evaluation of specific criteria (For example what is the application's impact on water quality, impact on the quantity of water in the water table, or impact on soil quality) while providing a mechanism for judging applications on overall results of a given objective (What is the overall environmental impact of the application). As is required in MCA, the criteria were evaluated by the team of students to assure completeness (have all categories been included that are necessary to evaluate the performance of the applications) and independence of preferences (can the performance of an application in a given criterion be determined without the knowledge of the applications performance in any other criteria).[v] Once the criteria for evaluation were established, application options were assessed based on these criteria and the results of these assessments were displaced in a performance matrix. The performance matrix was constructed with application options listed in rows and evaluation criteria listed in columns. The performance matrix conveyed information in a mixture of qualitative descriptions (For example, the application is expensive, moderately expensive, or cheap) and binary terms (For example, the application does or does not work in a rural setting).

The second step involved converting these qualitative and binary terms into consistent numerical values. This process is referred to as scoring.[vi] The students scored each criterion on a scale of 1 to 10 with 1 reflecting the lowest preference and 10 reflecting the highest preference. The students assigned the value of 1 rather than 0 for the lowest preference so that all judgment criteria would be present in graphical representation of the utility calculation. For each criterion, an interval scale was defined which assigned a given number of points (between 1 and 10) for each choice within any given criteria. For example, for the criteria of location scalability there are three choices: application could be used at 0-10 franchisees, 11-50 franchisees, or more than 50 franchisees. These three choices were assigned the values of 3, 5 and 10 respectively indicating an increased preference for scalability to more franchisees. No application option could receive a value different than those assigned in the interval scale for the given criteria (in the case of the scalability example: 3, 5 and 10). Subjectivity is inherent in this system of scoring, but bias and inconsistency is minimized when a group of well-informed individuals score the criteria and when the same people or group assigns the values for all criteria.[vii] The students attempted to minimize the introduction of bias in their scoring by being well informed about all aspects (from social to economic) and by having the same group of students score all criteria.

Once the criteria were scored, the students converted the qualitative and binary answers in the performance matrix to their associated numerical values [As seen in the charts above in Application Utility Matrix]. Numerical values for each criterion were summed for a given option to give that option's overall utility score. These aggregated scores are visually represented in the graph above.

It is important to acknowledge the limitation of this matrix as a decision tool. Some important limitations of this method are listed below:

- Uncertainty associated with converting qualitative statements into quantitative values
- Possibility of misinterpretation of the results. For example, the risk that the matrix will be misinterpreted and that the application with the highest overall score is the ideal solution for any context when there are other nuances, intricacies and opportunities that can't be captured in the matrix.
- Inability to account for entrepreneurial passion or local opportunities already in operation
- Bias towards practical considerations because the number of factors within that category weigh the practical considerations more heavily than other categories.

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[i] Department for Communities and Local Government, *Multi-Criteria Analysis: A Manual* (London: The Crown of England, 2009), 1-168.
[ii] Department for Communities and Local Government, *Multi-Criteria Analysis: A Manual*, 24-26.
[iii] Department for Communities and Local Government, *Multi-Criteria Analysis: A Manual*, *24-26*.
[iv] Department for Communities and Local Government, *Multi-Criteria Analysis: A Manual*, 58.
[v] Department for Communities and Local Government, *Multi-Criteria Analysis: A Manual*, 35-37.
[vi] Department for Communities and Local Government, *Multi-Criteria Analysis: A Manual*, 41.
[vii] Department for Communities and Local Government, *Multi-Criteria Analysis: A Manual*, 44.

Provided below are detailed descriptions and findings of the evaluated applications for RO brine.

Disposal Applications

- Evaporation and Crystallization
- Groundwater Recharge
- Solar Evaporation
- Vacuum Evaporation

Evaporation and Crystallization

Evaporation and crystallization technology are used by many industrial wastewater treatment processes as a means of disposal for brine streams. Both processes rely heavily on thermal energy to effectively concentrate and solidify RO brine. Evaporation equipment condenses the brine into a smaller volume while the crystallization equipment eliminates any remaining water, effectively turning the salts into crystal form.[1] Once the dissolved constituents in the brine are solidified and crystallized, they can be shipped offsite for disposal or used onsite for additional reuse opportunities.

Methodology and Results

This application was researched mainly through a review of applicable literature for insight into industry practices and applicability of technology. Previous engineering consulting and design experience were also relied heavily upon for this analysis.

During franchise visits, sites were observed for available space. Due to the commercial and industrial nature of this equipment, it is not likely that locations outside of the rural areas would have the required space for this application.

Analysis of Benefits

Evaporation and crystallization technology as a means of disposal could offer some benefits to Sarvajal and franchise owners. Benefits include a source of disposal without contamination of the underlying groundwater or surficial agricultural soils. Crystallized salts may also be available for additional reuse applications. An application of this nature also offers disposal of the brine without contamination of the aquifer or agriculture areas, since there is no disposal necessary for the water.

This technology is also a proven and reliable method of disposal, since it is widely used in the industrial wastewater treatment sector for RO brine management.

Analysis of Barriers

Particularly on such a small scale, evaporation and crystallization technologies are most likely extremely cost prohibitive. Since they are conventionally applied on a large commercial or industrial scale, options for smaller-scale equipment are likely to be unavailable. Disposal of the crystallized solids could also prove to be problematic and cost-prohibitive if reuse options are not available.

Discussion

This application may become a more viable solution if franchise clusters (or portions thereof) were to combine brine volumes at a central facility. In this scenario, additional analysis to determine a minimum cost-effective brine flow rate may be warranted. Reuse or disposal of crystallized solids would still be problematic, however.

Groundwater Recharge

Groundwater recharge applications include deep well injection and recharge pits. These techniques are used in practice throughout the world and across many different industries, including disposal of municipal wastewater treatment effluent. The US-EPA defines an injection well as a device that places fluid deep underground into porous rock formations and is deeper than it is wide.[ii] Deep injection wells are ideally installed below the portion of the aquifer used for potable water; however, depending on geologic and hydrogeological characteristics, they may be installed in a large variety of ways in practice.

Alternatively, a groundwater recharge pit discharges water to a higher portion of the aquifer, using a large, relatively shallow pit. The India Central Groundwater Board recommends that the top 3 meters of the unsaturated zone above the aquifer not be used for groundwater recharge, since many adverse environmental impacts may be encountered including water-logging and increased soil salinity.[iii] Site-specific conditions such as geology, hydrology, and space-availability can help determine which groundwater recharge technique is most appropriate.

Methodology and Results

This application was researched mainly through relevant literature review. Previous environmental consulting and academic experience were also relied heavily upon for this evaluation.

This application was included due to its widespread use around the world and its particular relevance to Sarvajal franchisees. During site visits, several franchise owners mentioned that they were interested in using groundwater recharge (i.e. recharge pits), including the Ramgarh site, which planned to use it in the future as a means for RO brine disposal. Some sites were also currently using groundwater recharge for the brine, including Choti Pacheri and Malsisar, which were using an injection well and recharge pit, respectively. See the Site Visit Summary and Photograph Log (Appendix E) for more details.

Analysis of Benefits

According to the India Central Groundwater Board, the benefits associated with groundwater recharge include enhancing the sustainable yield in areas of groundwater that has been depleted due to excessive development, and conservation and storage of excess water for future requirements.[iv]

Using groundwater recharge as a means of RO brine management is also a less-technical application with fewer operations and maintenance considerations, relative to further treatment applications. It potentially offers management and disposal of RO brine without degradation of surface soils.

Analysis of Barriers

Groundwater recharge applications present several hydrogeological concerns, including potential water chemistry and quality concerns. There are also numerous environmental concerns, including potential uptake into nearby production wells (including Franchise owner‟s source water bore well). Though it allows for water storage within the aquifer, this application also does not allow for direct beneficial reuse of the brine.

According to the US-EPA, to evaluate the risk associated with groundwater recharge applications, it is critical to understand the regional and local variations in geology and hydrogeology that underpin the subsurface fate and transport of injected water.[v] Several factors must be taken into account for both local and regional subsurface conditions, including groundwater flow direction (both inflows and outflows), hydraulic conductivity, storage capacity, transmissivity, and local and regional geologic formations. This evaluation is likely to be time intensive and cost-prohibitive.

Discussion

Environmental considerations for implementation of this application are beyond the scope of this project, and would warrant additional investigation should this application be further pursued. It is also unknown if a groundwater discharge permit would be required for this application.

Solar Evaporation

Taking advantage of the prevailing hot and dry conditions in regions where Sarvajal operates, solar evaporation could present a low-cost, easily scalable option for further treatment and water reclamation. Under this application, the brine would be released into modular black basins (either plastic lined or painted) in full sun. Each basin would be capped with an up-ended pyramidal, clear plastic catchment hood.

Evaporative basins allow brine to concentrate as water evaporates and is trapped by a clear plastic cover. Condensation run-off (with a lower TDS level) would collect along slanted gutters at the base of the hood where it would drain to a fresh-water cistern and collected, combined with newly produced raw brine and re-run through the RO system. The use of evaporation ponds is an industry standard treatment of RO brine. For example, the city of Phoenix, Arizona which produces more than 4 million gallons per day of concentrated RO brine (4.15 mgd as of 2010) utilizes evaporation ponds as their second most common method of RO brine disposal, despite the extremely large space requirements of this process (1 square mile per 3 mgd of brine for effective evaporation in Phoenix).[vi]

Methodology and Results

Daily evaporation rates in Rajasthan were estimated to be at a minimum in January (2-8 mm/day) and maximum in May (4-20 mm/day).[vii] In order to confirm research on the effectiveness of solar evaporation, a small scale experiment was conducted outside the company owned, company operated (COCO) in Bagar. The initial test confirmed that solar evaporation is a successful procedure for decreasing TDS concentrations in evaporated water. An 8 liter test sample of brine containing 986 mg/L of TDS was poured into a black plastic basin with dimensions of 33 in by 33 in. At the end of the 6 hour test 3-4 mL of condensation was collected with a TDS concentration of 106 mg/L.

To further determine the feasibility of solar evaporation, tests were conducted tests to localize researched figures on solar evaporation rates in Rajasthan. The 1x1 m acrylic box was filled with brine to a depth of 15 cm deep. The box was placed over a black plastic sheet to aid in evaporation. An average evaporation rate of 4.2 mm/day was observed, with a range of 1.9 – 5.9 mm/day. Total material requirements for these tests were limited to: black sheet plastic (1.5x1.5 m), clear plastic (2x2 m), a basin (a trough behind the COCO for test-1 and the acrylic box for test-2), water and air temperature thermometers, and measuring tape. See table below for evaporation bench test measurements.

Table H-1: Evaporation Bench Test Measurements

Date and Time	Depth of Water (cm)	Air/Water Temperatures (^{0}C/^{0}C)	Evaporation Rate (mm/day)	Weather Notes
7/30/2011 19:00	15.1*	32.5/32.0	NA	Sunny
7/31/2011 11:00	15.4	29.8/34.0	NA	Post-rainfall measurement; 0.3 cm measured in rain gauge.
8/1/2011 9:45	15.4	30.0/31.0	NA	Post-rainfall measurement; 0.2 cm measured in rain gauge.
8/1/2011 18:35	15.1	33.0/32.0	NA	Sunny
8/2/2011 10:30	15.0	32.0/33.0	3.9	Sunny
8/2/2011 18:25	14.6	35.0/36.0	NA	Sunny
8/3/2011 17:08	14.0	37.0/40.0	5.6	Sunny
8/4/2011 13:40	14.6	37.0/33.0	NA	Post-rainfall measurement; 0.9 cm measured in rain gauge.
8/4/2011 19:15	14.6	38.0/35.0	NA	Sunny
8/5/2011 12:10	14.4	38.0/35.0	1.9	Sunny
8/5/2011 17:30	14.0	36.0/35.0	5.5	Sunny
8/6/2011 10:30	17.3	35.0/30.0	NA	Post-rainfall measurement; 3.1 cm measured in rain gauge.

*Start of experiment; initial measurement
NA - Not applicable

(shaded box) indicates post-rainfall

Analysis of Benefits

The material and technical requirements of this solution may be relatively low cost and easy to meet. As observed through the pilot tests, evaporation-catchment mechanisms can be constructed with common materials at minimal cost and technical effort. Furthermore the application runs entirely on solar power and thus its operation is not labor intensive, nor would it incur the high electrical costs associated with other further-treatment solutions.

Using a modular approach with a series of relatively small basins would allow franchises to scale this application appropriately according to their own volume of brine production and the amount of available space. In rural locations, where space is abundant, this application could be an affordable and viable way to reclaim some reject water for alternate use.

Finally, to increase the efficiency of this application, it may be combined with other reuse applications such as aquaponics or agriculture. By placing a clear plastic catchment hood over a tank of brine, as in the aquaponics application, from which condensate can be collected, conservation and reuse potential could be maximized.

Analysis of Barriers

Solar evaporation is slow and rates vary considerably throughout the year. As observed in the bench tests, heavy rains during the summer monsoons may slow evaporation rates below those that are typical, as well as compromise the effectiveness of rudimentary evaporation mechanisms. Therefore seasonal variability poses a barrier to this application‟s success.

The greatest barrier to success of this application is that the space required for evaporation at the observed rates of 4.2 mm/day is much greater than that which is available at most franchise locations (given the current daily rate of brine production). For example, for a brine flow rate of 3,000 liters per day and an evaporation rate of 5 mm/day, a minimum area of 25m by 25m would be required for evaporation. This number would likely be much higher depending on the time of year and actual brine production, and would not be feasible at all during monsoon season where precipitation rates may exceed the rate of evaporation. This makes a small-scale approach of evaporation and catchment unfeasible at Sarvajal‟s current standard operating rate of 40% RO efficiency. The current rate of brine production is too great to allow any number of small-scale solutions, as many franchise locations do not have adequate space or capacity to address their own brine production.

The accumulation of dissolved solids and metals in the bottom of the evaporation basin could also create some problems over the long term. These accumulated solids may need to be periodically removed for proper maintenance, which could be an environmental concern if not disposed of properly, as well as costly.

Discussion

While this application may seem attractive on a very small scale in terms of cost effectiveness and the little to no energy costs, after comparing the evaporation rates to the daily brine production rates, it may not actually be feasible. A lot of space would be required for sufficient evaporation of brine volume, which the majority of the franchises do not have. Solar evaporation would also not be feasible during the monsoon season, as the precipitation rates will likely exceed rates of evaporation. This application could become more feasible when combined with other applications such as aquaponics or agriculture, especially with franchises in rural and remote locations that have large space available to set up an evaporation basin.

Vacuum Evaporation

Pressure causes liquids to evaporate at lower temperatures. Internal pressures in a large vacuum can be adjusted to the point at which water will boil at room temperature. Brine is often pumped through a series of cylinders whereby boiling it produces steam which then passes to subsequent cylinders. The condensation of the steam causes the pressure to drop which affects the boiling point. Salt obtained in this way is known as vacuum pan salt. Vacuum evaporation is less energy intensive than conventional thermal evaporation methods since it requires less heat than if it were boiled at atmospheric pressure.[viii] The technology is most often applied to the dehydration of food products.

Methodology and Results

Research for this application consisted of mainly internet and academic research. We did not find any such applications in use in the region, however our research, did identify manufacturers and suppliers of vacuum evaporation equipment in the country.[ix]

Attempts to obtain a quote regarding the average cost of this technology were unsuccessful.

Analysis of Benefits

As a low-energy technology solution, vacuum evaporation is a promising technology for extraction of salts and other dissolved solids. Further research is needed to understand the effects of other dissolved solids found in Sarvajal"s RO brine.

Analysis of Barriers

Capital and operations and maintenance costs for investing in the installation would likely be the largest barriers to implementation of this technology. Training and operation of an additional technology to the RO process would also require significant time and financial resources. This application also does not allow for reuse of the water portion of the brine stream.

Discussion

While the technology is effective and well-known, it may not be the appropriate application for Sarvajal franchises. Cost is likely the most prohibitive aspect of this application, for both capital and operations and maintenance. Also the requirement of additional infrastructure and training beyond what is currently available to most franchisees and maintenance staff limits the applicability of this solution. More research is needed to explore whether this is a viable solution or one in which the cost of implementation outweighs any benefit gained.

Further Treatment Applications

- Capacitive Deionization
- Coagulation/Flocculation
- Constructed Treatment Wetland
- Soil Phytoremediation

Capacitive Deionization

Capacitive Deionization technology (CDI) was developed by researchers in the Singapore desalination industry for further treatment of RO brine from treated ocean water. CDI technology uses the electric field between porous electrodes to remove inorganic ions from the water, thereby further condensing the brine stream.[x] Inorganic ions in the water are attracted to oppositely charged electrodes (effectively concentrating them inside the unit), while the product water is pumped through the electrode assembly unit.[xi] Spent electrodes are then regenerated or replaced when they are saturated with ions.[xii]

This further treatment strategy is a relatively new technology, and as such has been mostly employed at the bench and pilot scales. The NEWater Factories in Singapore, arguably some of the most well-known plants in the desalination industry, are currently incorporating CDI technology into their treatment trains to increase their product water recovery to 95%.[xiii] If this promising technology continues to be developed for commercial use, it could be a viable option for further treatment of franchisee RO brine.

Methodology and Results

This application was researched mainly through a review of applicable literature for insight into industry practices and applicability of technology. During franchise visits, sites were observed for available space as well as constraints that may limit implementation.

It is not expected that CDI technology would require more space than the existing RO unit at franchise locations, however there are many unknowns at this time.

Analysis of Benefits

CDI technology has been highly effective in initial research stages for advanced RO brine treatment in the desalination industry, and has been increasingly explored in the pilot-scale in Singapore. CDI technology also offers relatively low operations costs (compared to reverse osmosis), due to a lower required operating pressure.[xiv]

Analysis of Barriers

Since CDI technology is still actively undergoing bench and pilot-scale testing, not a lot of information is available (relative to more developed treatment technologies). Thus many uncertainties remain for this technology, including treatment efficiency, capital costs, and operations and maintenance costs (particularly related to scaling technology up to commercial scale). These aspects may prove to be significant barriers to implementation.

There will also be additional expertise and capacity required for operations and maintenance of this application.

Disposal of the further-concentrated brine could also prove to be problematic if reuse options are not available, and would warrant additional investigation prior to implementation.

Discussion

Since CDI technology is currently in the stages of research and small-scale pilot studies, Sarvajal would need to decide how long it would be willing to wait for commercial availability.

Waste stream management for condensed brine stream will continue to be a critical aspect of application for this technology. Increasing RO unit efficiency may provide the same benefits, but without the additional capital costs and uncertainties.

Like other disposal and further treatment options, this application may become a more viable solution if franchise clusters combined brine volumes at a central facility. Additional analysis may thus be warranted to determine a minimum cost-effective brine flow rate.

Coagulation/Flocculation

The application of coagulation and/or flocculation could be used to remove additional dissolved solids from the RO brine. Coagulation and flocculation refer to the addition of chemicals such as aluminum sulfate to promote the aggregation and precipitation of dissolved-phase constituents.[xv] The term coagulation is used specifically for the addition of a chemical coagulant to destabilize the suspended, colloidal, and dissolved constituents.[xvi] In contrast, the term flocculation refers to the aggregation of destabilized particles and subsequent precipitation of these particles. For the sake of simplicity, the term coagulation will be used to refer to both processes for the remainder of this analysis.

Aluminum sulfate, also known as alum, is the most common coagulant used in water treatment in the United States. Ferric chloride is also used quite commonly, and both are typically readily available in most locations. With the addition of an appropriate coagulant, dissolved constituents in the brine may be settled out of solution. The treated water is then available for use after further filtration or settling using gravity clarification, and may be suitable for additional drinking water supply or another reuse application.

This process takes place in a settling basin, and would require adequate mixing of the brine with the coagulant, as well as adequate contact time to allow coagulation to occur.[xvii] Franchisees may need a fairly large holding basin, as well as an additional holding tank for brine water accumulated during the coagulation cycle, depending on the flow rate of the brine and the required contact time for coagulation and/or settling to occur.

Methodology and Results

This application was researched using a variety of resources including a review of relevant literature for insight into industry practices and applicability of technology. Water treatment vendors were also consulted, as well as environmental engineering faculty member at the University of Michigan. Previous coursework and textbooks in drinking water and wastewater treatment and engineering consulting experience were also relied on heavily for this analysis.

During franchise visits, more urbanized locations were observed to have space limitations that may hinder the implementation of this technology. In general, locations in more rural areas will likely have sufficient space.

Analysis of Benefits

The use of coagulation as a further treatment strategy may be beneficial to both Sarvajal and franchise owners. Coagulation is less technology intensive than treatment strategies such as capacitive deionization, and thus may require less expertise for proper operation and maintenance.

Coagulation may also be less energy intensive than other further treatment strategies, including further reverse osmosis treatment.

Analysis of Barriers

The use of chemical coagulation for further treatment presents several barriers. First and foremost, the technical feasibility needs to be assessed through bench-scale and pilot tests with a chemical coagulant vendor. This is necessary since predicting optimal coagulant compatibility and efficacy using water quality data (i.e. brine analytical data) alone is not possible.[xviii] The vendor will perform jar tests in order to determine an appropriate coagulant and dosage for the desired TDS removal. This process can be expensive, depending on the vendor selected and the arrangements made for implementation. Dosages for each franchise location will likely vary due to the heterogeneity of the brine, so samples from several locations may need to be tested.

After working with a vendor, capital costs for equipment and operations and maintenance can be determined. Up-front capital costs may be substantial, depending on mixing and settling requirements. Chemical costs for conventional coagulants such as alum are typically inexpensive, however depending on the dosage required for desired TDS removal, it will add up over the operational lifetime of the system.

Options for reuse of treated brine may also have limitations. Depending on the coagulant used for removal, re-filtering the effluent through the RO unit may be problematic since some coagulants (such as alum) may create soluble chemical complexes that can foul the RO membranes.[xix] Some reuse applications may also be inhibited by these complexes, including agriculture.

Sludge disposal issues associated with the settled-out coagulants will be an important consideration. Coagulation produces a lot of solid and liquid waste, and proper handling and disposal of this sludge could turn out to be complicated and expensive. Options for disposal are typically limited to trucking waste to a landfill, and it is not likely that ground application would be advisable or permitted by the regulating authority. Sludge volumes can be estimated after the initial design process and feasibility analysis with the vendor.

Other barriers include space limitations for locations with little room for expansion. Additional site requirements for extra tanks, equipment, and chemical storage will compete with existing uses of land, including options for reuse like agriculture. Space limitations will be most important if gravity clarification is used for settling, since the size of the basin would be determined by the settling velocity of the coagulant.

Discussion

Additional analytical data would help to assess the applicability and effectiveness of using coagulation as a further treatment strategy. If Sarvajal is interested in pursuing this application, the next step is to work with a vendor to determine an appropriate chemical coagulant and dosages, capital costs for equipment, and regional equipment and coagulant availability. This process will require collection of brine samples from a selection of franchise locations, as well as extensive coordination with the vendor for gathering information.

Constructed Treatment Wetland

The use of constructed treatment wetlands as a natural mechanism for wastewater treatment has been an emerging field in recent years. Natural wetland ecosystems act as buffer communities between land and water systems, and are capable of treating a variety of contaminants, including both urban stormwater and agriculture runoff.[xx] Constructed wetland treatment systems include any engineered natural systems that are designed to replicate the processes that occur in natural wetland soils, vegetation, and their associated microbial communities, but are constructed to do so within a controlled and monitored environment.[xxi]

Constructed treatment wetlands differ from other phytoremediation strategies in that they are designed to retain water throughout the year, in addition to having flood control and stormwater storage properties. Treatment wetlands are also be implemented as a strategy to promote wildlife habitat, since they are some of the most productive and diverse ecosystems. In recent years, they have been established as cost-effective and technically feasible options for wastewater treatment applications.[xxii]

Methodology and Results

This application was researched mainly through relevant literature review. Previous environmental consulting and academic experience were also relied heavily upon for this evaluation.

During franchise visits, it was observed that more urbanized locations had space limitations that could hinder the implementation of this application. In general, locations in more rural areas will likely have sufficient space.

Analysis of Benefits

This application offers many of the same benefits as groundwater recharge, including enhancement of groundwater recharge in areas that may be become depleted due to excessive development in the future. As an improvement to groundwater recharge and the business as usual scenario, however, it also offers the added benefit of further treatment before water is ultimately discharged to a deeper aquifer. This may result in higher surface soil and groundwater quality, which could also help the long-term viability of using local groundwater as source water for existing Sarvajal operations.

Constructed wetlands also offer an opportunity to rebuild wildlife habitat in overly developed or impaired areas, which can also have positive community and social perception implications. Increasing area for wildlife habitat can also have many other benefits, including flood control during monsoon season and erosion prevention during dry weather.

Relative to other further treatment options, the use of constructed treatment wetlands as a brine management strategy also offers relatively low operations and maintenance costs.

Analysis of Barriers

There are a few potential barriers that may prevent implementation of constructed treatment wetlands for RO brine management. The selection and availability of plant species that are native, locally-available and effective for brine treatment may be problematic and unfeasible. Local climates, geological characteristics, and surface terrain may also limit the franchise locations at which this application could be viable. Many uncertainties also exist such as long-term accumulation and sequestration of metals and dissolved solids. Treatment wetlands also do not allow for direct beneficial reuse of the brine stream, since recharge to the underlying aquifer would be considered an indirect reuse.

Constructed treatment wetlands also offer fewer opportunities for entrepreneurship and additional revenue compared to most reuse opportunities. This application may also require a relatively significant allocation of land compared to other further treatment options, depending on design-specific parameters such as hydraulic retention time.

Discussion

Consideration and selection of native and locally-available plant and animal species when available and appropriate will also be an important design consideration, which is beyond the scope of this project. The long-term impact of accumulation of RO brine constituents in soil is also unknown, including those affecting plant and wildlife health. These impacts would warrant additional investigation should this application be further pursued.

The design process would also need to consider water storage aspects for monsoon weather conditions as well as dry weather. This presence of year-round standing water may also increase vector-borne disease risks (i.e. malaria), which should be investigated prior to implementation.

Soil Phytoremediation

Phytoremediation is the use of plants to treat contaminated soil.[xxiii] Long term exposure to excess salt, heavy metals and other undesirable elements may negatively impact soil quality, particularly in brine applied to agricultural land. Some plants, known as halophytes, are tolerant to salt. A subcategory of halophytes has properties that allow them to bioaccumulate, or uptake, salt into their leaves or vascular tissue. A carefully-planned field or crop rotation that incorporates these types of plants may delay or inhibit the salt contamination of soils.

Methodology and Results

In country observations combined with site visits, field research as well as internet and academic research form the basis for this solution. Field research included observations and semi-structured interviews with operators and owners. While the data was not conclusive, we heard mixed opinions about the effect of brine on plants.

The discrepancy in outcomes could likely be derived from differing TDS levels. For example, at site three, the TDS level was almost twice what was reported at site two.

While in India, interviews were conducted with knowledgeable horticulturists in the region, including a large vendor in Delhi. Two nurseries were visited: one in Jaipur and another in Delhi (the Joginder nursery). The first nursery did not appear to yield any useful information, as the owner did not know of any plants that would grow in water with high TDS concentrations or uptake dissolved salts. At the second nursery, the owner specifically showed plants that would tolerate saline or poor water quality conditions. Several species were shown, including *Ficus religiosa* (pipal tree), which the owner emphasized for soil remediation. He also referred to the recent extensive use of this species in the coastal areas in Gujarat, which tend to have more saline soils.

As part of a small experiment while in India, a small-scale garden was planted behind the COCO (see Agriculture Application section). Five pepper seedlings, four eggplant seedlings, and an aloe vera plant were placed in a row, and watered with RO brine from the COCO during our time in Bagar. Due to monsoon season, there was also a significant amount of rain that may have affected results. In the three weeks we were on site, plant health appeared to deteriorate over time. A number of factors likely contributed to this result, however, including overwatering due to monsoon conditions, poor soil quality, and a lack of farming knowledge. See Agriculture Application sections for further details.

Analysis of Benefits

Phytoremediation is advantageous because it is often cost effective, applicable as a long term solution and provides some aesthetic benefits as well.[xxiv] Without a better understanding of the absorption of fluoride in plants, it is difficult to conclusively recommend edible varieties. However, the use of edible halophytes that can survive in saline soil and provide nutritional benefit to consumers or livestock and/or a combination of traditional plants with a rotating crop of plants well suited for phytoremediation is a worthwhile investment in the long term soil health of this arid region.

In cases where plants are intended for consumption, careful planning and education about what parts of the plant are safe to eat is important from a human health perspective. One study cited that fluoride absorption is concentrated in plant roots, possibly making leaves or other edible portions of the plant besides roots less susceptible to dangerous fluoride concentrations.[xxv]

Analysis of Barriers

Extensive research is needed to verify both the specific species of plants that are appropriate for the region and the absorptive capacities of each species. This investment of resources on the part of Sarvajal may be cost prohibitive. Phytoremediation is a long-term adaptation that may not produce immediate results, but may be sustainable in the long term.

Discussion

Overall, it appears that TDS concentrations greatly affect plant survival rates. Additionally, some promising research from the Gujarat Institute of Desert Ecology regarding appropriate agricultural practices in the region could prove useful in selecting the types of plants to be grown.

Reuse Applications

- Agriculture
- Algae Biofuels
- Aquaponics
- Construction Materials
- Domestic Use
- Fire Fighting
- Ice Making
- Leather Tanning
- Paper Making
- Public Sanitation
- Wood Treatment

Agriculture

At present, agricultural irrigation in Rajasthan makes up 83% of the state"s total available water resources.[xxvi] This number is expected to increase in future years in conjunction with increasing nutritional requirements of India"s growing population, as well as potential and expected threats to farming and agriculture by shifting climate and weather patterns that further compound the issue. A vital strategy to increase food security in an uncertain future requires increasing available water resources by decreasing demand for raw/virgin water. Sarvajal franchises in regions with relatively-low groundwater TDS levels may do this by using RO brine for irrigation. Under this application, brine would be used to water vegetable and fruit crops, either for personal or commercial use.

Methodology and Results

This application was researched using a combination of literature review and observations from several franchises that were trying (both successfully and unsuccessfully) to grow plants using brine and those who had tried and given up. While in India, our group planted five pepper seedlings, four eggplant seedlings, and an aloe vera plant behind the COCO and watered them with brine for the duration of our stay in Bagar. In our short time in Bagar, however, plant health appeared to deteriorate over the course of time. This may be due to a variety of factors, including over-watering, poor soil quality, vandalism and a lack of knowledge on how to farm in this region. In lieu of these considerations, agriculture using these plant varieties is therefore not ruled-out.

A spectrum of results at franchise visits was also observed, ranging from great successes to failures. Of the franchisees visited, Pratapnagar, Nawalgarh, Chirawa, Singhana-2 and Gothara were actively using the brine for agriculture. Franchises that were no longer using the brine for agriculture (but had previously used it) include Siriyasar Kalan, Mandawa-2, Rollsahabsar, and Bissau-2. Successful crops observed in franchisee gardens included bajra (millet), okra, peppers, and bottle gourds.

A wide range of results was observed from brine application in agriculture. Some franchisees reported no negative effects of using brine for irrigation and stated further that the supplemental income from farming operations added to their monthly profits. However, the operator at the Rollsahabsar franchise said that brine discharged near mature trees had killed them over the course of a short amount of time. It should be noted that most franchises had only been in operation for a few months to a year. On the other hand, one franchisee reported using brine in bajra fields for over three years with no problems. Half his field was irrigated with brine and the other with rain and well water according to its proximity to the RO machine with no observable difference between the two areas. This same franchise had constructed a large water storage tank for brine that would eventually be used to water a planned nursery.

Analysis of Benefits

Use of brine for agriculture is, in many ways, an ideal application of RO reject water. With no further technical treatment, this application would allow complete utilization of withdrawn water while meeting irrigation demand with water which would otherwise go to waste. Furthermore, this application may provide some economic savings, either through a reduced personal food budget or by adding a supplementary business.

Analysis of Barriers

Utilizing RO brine for irrigation purposes does not automatically translate to agricultural success. The success of this application also depends primarily on TDS levels of the brine (lower levels seem to be preferable) as well as available space, soil suitability and a working knowledge of farming techniques.

Long-term effects are still unknown. Salts and dissolved metals may accumulate near the ground surface, leading to soil degradation and decline in plant health. It is also unknown if dissolved minerals and metals may further accumulate in irrigated plants, and how accumulation would impact the humans and/or animals consuming the produce.

The literature suggests that long term application of water with high TDS levels may lead to saline soils in agricultural land. For many plants, chronic exposure to salt at increasing levels of concentration may decrease yield over time. The possibility of absorption of other contaminants from brine such as fluoride requires further study. Additionally, concerns with recharging saline water into increasingly brackish groundwater requires further research, investigation, and considerations.

Discussion

Further research on long-term soil and plant impacts is warranted prior to large-scale implementation of RO brine for agriculture.

There could be a relationship between TDS levels and successful irrigation with brine. In general, franchisees with lower raw water TDS levels experienced greater success in growing plants than did franchisee with higher TDS levels. Prior to large-scale implementation, it would also be advisable to conduct more research on correlations between brine TDS concentrations and agriculture success.

Algae for Biofuels

Using RO brine to grow algae for biofuels is a variation on other aquiculture applications in that the focus is on generating fast-growing biomass with high embodied energy as a potential alternative to conventional and fossil fuels. Algal biofuels are seen in some ways to be preferable even to other biofuels given algae"s rapid growth and relatively low land-use requirements.

This application has the potential to be combined with simple solar-evaporation catchment hoods for maximum water reclamation. There is also a potential for profit generation depending on the development of localized markets for small-scale biofuel production. Finally, in addition to the general benefits of reuse solutions, this application presents the possibility of lower local greenhouse gas balances and may offset demand for conventional fuels thereby decreasing dependency on external or foreign fuel sources.

Methodology and Results

Research on this topic builds from an existing report on the feasibility of producing biofuels from farmed algae. Further development for the implications of the 2010 initial report from IIT to Piramal Water, Private Ltd. on the "proposed waste water utilization for algae production also helped guide research for this application.[xxvii] Leading U.S. scientists and biofuels researchers including Shelie Miller and Jia Yang were also consulted.

An extensive literature review was conducted to identify global best practices and lessons learned from comparable algae production endeavors. All research findings were contextualized by observed knowledge of the average brine production of Sarvajal franchises. This knowledge was gleaned from Sarvajal reports, 22 franchisee site visits, and observed dynamics of the local economies.

Bench tests were planned for algae samples growing in reject water hoses at franchise locations, with the intention of comparing the biological properties of the algae present to algal varieties known to have high embodied energy profiles such as C*hlorella* sp., and *Scenedesmus* sp.[xxviii] The decision to focus on the algae currently growing in and around Sarvajal franchisee reject water sites was due to the fact that it was a variety already observed to grow well in environments with high TDS concentrations. Unfortunately, U.S. customs restrictions and ecological concerns over inter-continental species and microbial invasion prevented transport of algae samples back to the University of Michigan Labs for detailed testing and classification.

A review of the research indicates that the energy content of algae may be as high as approximately 22.6 MJ/kg of dry biomass.[xxix] An estimate for the total embodied energy of the algae can then be estimated by multiplying this value with the biomass that has been farmed. Further tests may be conducted in-country to determine the estimated mass-energy balance of local algal varieties.

Analysis of Benefits

This application offers the potential coupled benefits of an additional source of revenue for franchisee owners through the sale of processed biofuels while increasing local energy security through decreased demand for conventional fossil fuels. If a market existed for biofuel production, this application could add to an existing biofuel (i.e. biodiesel) supply. This application could also create benefits for energy security on a local scale, since farmed algae could be harvested, dried and potentially used as a alternative fuel for cooking stoves.

Analysis of Barriers

Logistical barriers to this application relate to the difficulties of farming algae at an appropriate scale. Required equipment may take considerable physical space and initial capital investment. All typical farming challenges (including yield variability and basic knowledge requirements) also apply.

Technical barriers to algal biofuel production are greater for biodiesel production, which requires extraction and refining of plant oils, than for producing cellulosic bio-briquettes, made of dried and compressed algae biomass.[xxx]

Discussion

The economic viability of either form of bio-fuel production depends on the existence, or creation, of a market for the fuel. Several local Rajasthani residents were observed cooking with compressed natural gas cook-stoves. Similar small-scale domestic stoves are powered by incinerating compressed bio-briquettes in New England and in some locations in East Africa. However, there was no indication of an existing market for biofuels in Rajasthan or Gujarat.

Aquaponics

Brine could be used for three very similar purposes: aquaculture, hydroponics and hybrid aquaponics. Fish, plants or both could be cultivated in large tanks filled with brine water and has no soil. Fish and plants would eventually be sold to either domestic or international merchants for consumption, medicinal purposes or the fish could be sold to aquariums. Fish and plants would be cultivated in the same tank with brine water. The plants provide habitat for the fish and in turn, the fish provide fertilizer for the plants. Given the varying TDS concentrations of the brine water between franchises, a range of fish species that can survive in brackish water are presented as options.

Methodology and Results

Research was conducted on appropriate species for the brine. The group also consulted with aquatics faculty member David Allen and students within the University of Michigan; as well as Rex Lowe of Bowling Green University.

Analysis of Benefits

Once the fish grew to the desired size, they could be sold to various merchants, creating an economic benefit. This would be especially true for ornamental fish typically sold for private aquariums.

An attribute of these applications that involve fish, is that many of the suggested fish also consume mosquito larvae. The relatively small numbers of fish would not have a drastic effect on reducing the mosquito population, but the fishes‟ diet should keep the tank from becoming a breeding ground for mosquitoes.

Analysis of Barriers

The initial set-up would be cost-prohibitive due to the purchase of a tank, aerator, food, and fish and/or plants. The brine would need to be assessed at each franchise location for its suitability of any of these applications. Water could also need to be altered to make it habitable (pH, hardness, dissolved oxygen, etc). If a problem arises with the tank equipment, the maintenance staff would need to attend to it right away or the initial investment of the fish would be lost. If just hydroponics was being utilized, maintenance would be less urgent because plants can survive if they stay moist.

Sarvajal operates in a primarily vegetarian region, where there is not a demand for fish for consumption or fish products; pursing hydroponics might be a more socially acceptable endeavor. Exportation presents a significant cost, both monetarily and environmentally (emissions). Even if shipping costs are overlooked, ornamental fish are a luxury industry and as such it is not very stable.

Only a portion of the brine would be utilized. The water in the tank would need to be changed fairly often to maintain a healthy environment for the fish, but there would likely to be left-over brine and the initial water in the tank would also need to be released at some point.

Another concern is that there is a potential to introduce new species into the country, because some of the suggested fish species are not native to India.

Discussion

Sarvajal would need to test each site where an aquaponic solution would be implemented for other water quality characteristics such as pH, hardness, dissolved oxygen, etc. Before moving forward with this application, Sarvajal would need to research the social implications of this application. The region in which Sarvajal operates is primarily vegetarian. There may not be any market demand for fish for. The nearby communities might actually response negatively to an operation that grows animals for consumptive purposes. The large upfront cost, both monetary and man-power, and the unknown social response make this application unfeasible at this time.

Construction Materials

Another possible application of the brine is producing construction materials, specifically mixed concrete and bricks. India‟s largest cement company, Ambuja Cement, already uses RO brine for dust suppression.[xxxi] However, possibly the greatest opportunity for water conservation in concrete production comes when the dry cement mix is combined with water before use. In many cases in India, this step in the construction process is done on a small scale by local users of cement. Typically, the water weight to concrete weight ratio is around 0.2 (meaning to produce 10 pounds of concrete mix typically requires 2 pounds of water).[xxxii] The water intensity and local nature of this process makes it an attractive fit for reuse of Sarvajal‟s RO brine.

Methodology and Results

In researching this application structural engineers from the University of Michigan and engineering text-books were consulted. Additionally internet research on the construction industry in India was conducted to compliment gathered data from two site visits completed in India.

The basic components of concrete are water, cement, and aggregate. However, additional chemical and mineral materials are frequently added to the mixture in order to achieve specific characteristics (such as quick drying or high heat resistance) in the concrete composition.[xxxiii] One aspect of concrete production that makes it adaptable to use with RO brine is the fact that cement mixtures can be optimized to work with varying water qualities including saline water.[xxxiv] It is necessary, however, to differentiate between types of salts rather than simply looking at overall TDS levels, as different dissolved particles have varied effects on the construction process.[xxxv] A high presence of sulfates, for instance, can lead to cracking in the concrete.[xxxvi] The table below shows the maximum standards for dissolved solids in water to be used for construction purposes as set forth by the Indian government code IS 456: 2000.[xxxvii]

Table H-2: Bureau of Indian Standards Code of Practice for Plain and Reinforced Concrete: Permissible Limit for Solids[xxxviii]

Type of dissolved solid	Maximum allowed level
Sulfates	400 mg/l
Chlorides	2,000 mg/l for concrete structures without steal 500 mg/l for reinforced concrete
Organic Compounds	200 mg/l
Inorganic Compounds	3,000 mg/l

Experiences and success rates of two franchise owners who had tried using RO brine for construction materials varied. The Mukundgarh franchisee located outside of Jaipur had been making concrete structures with the brine for 3 months at the time of our July visit and stated that he had been very happy with the results to-date. The Ramgarh franchisee used the RO brine to make concrete structures for one year. By the end of that year he began to notice cracks in his concrete structures and concluded that the brine diminished the integrity of the concrete. He has subsequently continued to make concrete structures, but now uses raw ground water instead of RO brine.

Analysis of Benefits

Construction is one of the largest employers in India and the Indian Government‟s most recent 5 year plan estimates that employment in the construction industry in India will grow at an annual rate of 8-9%.[xxxix] The use RO brine for construction materials provides a potentially profitable second business for the franchisee in a growing industry in India. Furthermore, by sequestering the contaminants within the construction materials, this solution not only makes use of the reject water, but would not require further treatment or waste disposal.

Analysis of Barriers

Before this solution can be implemented more data would need to be gathered about the RO brine composition and TDS levels at specific franchisee locations. According the regional data (from Brine Analytical Data) the level of sulfates or chloride in the RO brine are higher than the permissible levels put forth by the Indian government in all regions in Rajasthan. However as sulfate and chloride concentrations can vary significantly within a region, it would be necessary to test these levels at each franchisee location where concrete production is an option.

Other factors that could provide barriers to the success of this solution are the level of additional training or expertise that would be necessary to produce cement and the challenge of breaking into a new market (construction).

Discussion

Concrete production could be a viable use of RO brine that would minimize the environmental impacts of the brine while generating additional income. However, more detailed information should be gathered about the composition of RO brine at different franchisee locations before such a solution is implemented. This information would help determine if concrete production was feasible in a given location and what adjustments might be necessary in the concrete production process to address higher TDS and particle concentrations. Gathering this type of information for just the two franchisees that are currently producing concrete could help explain the varying results and determine if possibilities existed for the Ramgarh franchisee to alter is concrete production practices so that he could continue to use RO brine in concrete production without compromising the structural integrity of his product.

Domestic Use

Domestic use of the brine includes laundry, dishwashing and general house cleaning. Often women in households are responsible for these tasks and many franchisees live in close proximity to the RO machines they operate. Variability in the volume of brine produced, TDS levels and the proximity of brine reject hoses to franchisee residences are factors that should be considered for handling brine in this way. This solution provides a secondary use for brine, however proper disposal of brine mixed with cleaning solutions (many of which contain phosphates and other contaminants) is often unregulated and/or not enforced.

Methodology and Results

A three-pronged approach to researching this solution included field observations and conversations with franchisees using the brine for domestic purposes, empirical research through small experiments in Bagar (mostly with laundry), and a brief review of literature on the subject.

Of the franchises visited, three out of 22 were using brine for domestic use that ranged from occasional floor cleaning to daily dishwashing, laundry and general household use except for consumption. One franchisee mentioned use for personal washing with no adverse effects. In conversations with franchisees and their families, no undesirable effects from use of the brine had been observed. One professional launderer, or dhobi, in Jhunjhunu, reported that clothes felt cleaner and less soap was needed when washing with brine. In small laundry experiments in Bagar with a variety of fabrics, hand washing with brine appeared to be just as effective if not more so than with raw water. Without proper drainage and wastewater treatment infrastructure, used laundry and dishwater are most often directly discharged onto surrounding land after use.

Analysis of Benefits

Reuse of water already pumped from wells reduces pressure on ground water resources to provide raw water for all water needs. While domestic use of the brine is not an income generating solution for Sarvajal, it is an added benefit to franchisees, which may affect employee retention and franchisee satisfaction. Implementation presents no ongoing cost to Sarvajal aside from franchisee education. Given the quantity of brine being produced, providing it to houses located in close proximity to the franchise, for their domestic use, could improve the goodwill of the franchisee in the local community. This is being done by the franchisees in Pratap Nagar, and Jaipur.

Analysis of Barriers

The effect of frequent, long-term exposure of RO brine to skin is not well understood. There were no observable or obvious effects on skin during small experiments. Salt not being the only contaminant, the presence of fluoride or heavy metals could have adverse effects, however, there is no empirical evidence to support or negate this claim.

Long term, improper disposal of brine can lead to soil damage and further concentration of contaminants in ground water. These negative cumulative effects are described above. It was observed that raw water used for domestic purposes is disposed of via direct discharge onto surrounding land or sewers. It is likely that brine water used for the same purpose would be disposed of similarly resulting in the same soil and ground water damage in a more concentrated form.

Cultural barriers include stigma that may propagate within communities where brine is referred to as "waste water." As discussed in the overall analysis, overcoming this cultural hurdle is a matter of education and organizational practices to disassociate the word "waste" with brine.

Discussion

Given what was observed, it is reasonable to assume that brine for domestic use is an appropriate application that is low cost, readily accessible, minimally resource intensive and culturally appropriate.

A possible income generating operation would be to supply the brine to the local „dhobi" for a small fee (less than what the dhobi pays for his current water supply, which is Rs26 per month and Rs150 for a water tanker he has to get when the municipal water is not sufficient). This is a pretty minimal amount, and more than the monetary benefit, the franchisee would get the goodwill of the community for reusing the brine.

However, not fully understanding the effects of brine on skin and the addition (instead of removal) of contaminants to brine prior to improper disposal presents a human health and environmental concern that should be taken into account. Based on limited observations, it can be inferred that saline water may have a drying effect on skin. However, salt water is often used for medicinal purposes to relieve muscle tension. Exposure to some salts, particularly magnesium chloride, has been shown to have positive effects on skin and inflammatory diseases.[xl] On the other hand, salt is not the only contaminant and contaminants vary by franchise location, some more concentrated and harmful than others.

Further research is needed to determine whether brine can be handled safely. Education about proper disposal and perhaps searching out suppliers of more environmentally friendly soaps, detergents and other cleaning products is worthwhile.

Firefighting

In India, fire brigades are located in most major towns, cities and district headquarters. Water is the predominant resource used for firefighting, and the large volumes of reject brine water generated by the Sarvajal franchises could potentially be used for local firefighting efforts.

Methodology and Results

This is a solution that we came up with based on observations in Rajasthan. This was followed up with internet research for fire brigade locations.

Fire brigades in Rajasthan are located in Udaipur, Kota, Jodhpur, Jaipur, Alwar, Sikar, Dungarpur, Bikaner, Bundi, Jhalawar, Barmer, Bharatpur, Bhilwara, Sirohi and Bhiwadi[xli]. In Gujarat they are located in the districts of Ahmedabad, Vadodara, Godhra, Surat, Valsad, Rajkot, Jamnagar, Junagadh and Kutchh.[xlii]

Analysis of Benefits

The primary benefit for using reject brine water in firefighting is reusing an available water source instead of further depleting ground water. Monetary benefits could accrue to the franchise and Sarvajal if this reject brine was provided to the fire brigade at some low cost.

Analysis of Barriers

The barriers to this solution, is that most of the fire brigades in Rajasthan and Gujarat are not located near current Sarvajal franchise locations. So there would be an additional cost of transporting the brine.

Discussion

Charging fire brigades for reject water is viable depending on the price they currently pay for water. If fire brigades are obtaining water for free, they have no incentive to buy reject water from Sarvajal. This solution is limited in scope but could be applicable in certain instances. Further research on possible reactions between brine and fire is recommended before actual implementation of this solution.

Ice Making

Ice is made in rural India by chilling water in metal forms in a bath of refrigerated salt water. Salt is added to well water to make the necessary salt water bath for the process. The purpose of the salt is to lower the freezing point of the bath water thus enabling it to remain in its liquid state and efficiently chill the metal forms for ice production. Block ice is commonly used for refrigeration of food during special events, such as weddings.

Methodology and Results
Two sites producing ice were visited during our field observations. The first ice making facility was a relatively large ice factory next to the Mukhundgarh franchise. In addition to salt water and refrigeration for cooling the ice, this facility used ammonia gas in the cooling process. The second ice making facility was run by the Chirawa franchisee in a small out building. He did not use brine for the salt bath, however he used filtered water for the ice. The operator at the large ice factory reused the salt water in the holding tank and rarely replaced it. He explained that he has occasional need for more salt water because of evaporation or spillage; however his need for additional salt water is limited.

Analysis of Benefits
Franchisees could use their RO brine for the salt baths necessary in ice production. They could use this for their own facilities or provide it to nearby ice factories. This could potentially reduce the cost of ice production and reduce the amount of groundwater needed, while providing a reuse for a portion of RO brine.

Analysis of Barriers
The need for brine is sporadic and minimal compared with the consistent high volume of availability of brine. The risk of cross contamination from brine to water in the ice molds, particularly in cases where ice is to be used on food, is also cause for concern. In the case that RO brine would need to be transported to another facility, this would produce additional costs. Furthermore, ice making could be a risky business as sufficient electricity for refrigeration is not always readily available, particularly in rural areas.

Discussion
It is unfortunate that ice factories pump raw well water and then purposefully add salt to it when there is an abundant supply of super saline brine from the RO machines. While it is likely that RO brine could be used for the necessary water bath in ice production, the limited quantity needed for this process means that this application cannot provide a meaningful use for the majority of the large quantities of RO brine produced daily by franchisees. The occasional application of brine for this purpose could be viable; however it is a rare and limited solution.

Leather Tanning
Tanning is the chemical treatment of animal hides to resist decay so they can be used to make leather products. Given the cultural norms in India, the leather talked about in this section refers almost exclusively to goat hide.

India produces a number of leather products, both for local consumption and international markets. Leather tanning factories exist throughout India and it serves as an important export. In 1990, exports of leather footwear amounted to Rs. 8,552,000,000.[xliii] That same year, India also exported over 180,000 leather traveling bags.[xliv]

Water is an important component to the leather tanning process. Bacteria can begin breaking down the proteins in the skin as soon as the animal dies. If left untreated, this can cause the skin to decompose and putrefy in transit to the tanning factory.

There are various methods for curing rawhide, but the crucial process is to remove excess water from the skin. The most applicable curing method for the purposes of this study is the brine-curing method. Hides are placed into a constantly agitated brine bath for 16 hours. This method is preferred in the industry because it is considered faster and easier than other methods. Despite the fact that this is the simplest curing method, it can also be one of the most expensive.[xlv] Regardless of curing method used for the hides, brine is typically used to transport hides from the farm and/or butcher‟s shop to the factory. The current use of brine in the leather tanning industry presents an opportunity for the use of RO brine.

Methodology and Results

A review of the literature on leather tanning was the primary source of data collected for this solution.

Analysis of Benefits

One of the benefits to this application is the presence of existing leather tanneries in India. A current franchise would not have to develop a completely new industry or help create a new market. Instead, seeking out partnerships and locating future franchises in proximity to leather tanning factories could make this an effective solution.

Given the cost of brine-curing, there could be a demand for this material that could result in additional income for the franchisees willing to transport brine to tanneries or start their own tanning business.

Analysis of Barriers

Brine is often recycled at the leather tanning facility, so it is quite likely that this application would not use all of the brine produced at any one franchise. A solution would still need to be found for the excess brine.

Discussion

Given that the brine can be used without further treatment, but only in limited quantities, this application would only be suitable for very few franchises. Those who operate within a short distance of a leather tanning company could pursue a partnership, but increasing transportation distance rapidly makes this application cost-prohibitive.

Further research is necessary to determine if the other minerals/contaminates in the brine would have any adverse effects on the quality or safety of the leather.

Paper Making

Boiled salt water is commonly used in the paper manufacturing process, particularly for specialty papers. There is the potential to use RO brine for paper production or to supply RO brine to existing specialty paper producers.

Methodology and Results

This application was developed through communications with existing specialty paper making facilities operating in India as well as with internet research on the paper making process.

Haathi Chaap, also known as the elephant poo paper company, which operates in Rajasthan uses a lot of water in the preparation of paper fibers and pulp. Readily available elephant dung is collected and washed in large tanks of water. The fibers are then cooked in salt brine. Fiber is then dried, sorted and beaten into a fine pulp. After which, pulp is mixed with water and a sieve-like instrument is used to extract pulp to form paper.

Analysis of Benefits

Paper manufacturers are adding salt to well water for paper making. This addition of salt to raw well water when there is available brine in the region is counter to the need for controlling the amount of dissolved solids in water. The application of brine for a non-consumable use is promising.

Analysis of Barriers

Transportation of brine to paper-making facilities is inefficient. At the end of its usefulness in the paper making industry, the brine will still face disposal issues, and possibly with the addition of other chemicals.

Discussion

Further conversation with elephant poo paper and other paper manufacturers seems to be a worthwhile investment, particularly for franchise locations that might be located nearby existing paper manufacturing facilities. More research is needed to determine exactly which salts are needed in the paper making process and if that is compatible with the salt available in the RO brine. Eventual disposal of the brine should also be addressed.

Public Sanitation

A possible application of the RO brine is using it as flush water in public restrooms. In 2010, the World Health Organization found that approximately 30% of the Indian population had access to "improved sanitation facilities".[xlvi] In rural areas in particular the situation is even worse; 74% of the population still practices open defecation.[xlvii] Sarvajal‟s primarily rural locations and excess brine water could mean that they are uniquely situated to address this problem.

Methodology and Results

A literature review of small-scale sanitation systems identified a pour flush system as a possible sanitation system appropriate for Sarvajal‟s situation. RO Brine could be used in a pour flush system, in which the waste would be collected in a basin in the ground below the toilet structure. The basin would contain RO brine, to help eliminate unpleasant odors and unwanted pests. These two toilet structures (one for each gender) could be operated on a pay per use basis.

Investigation of NGOs already operating public sanitation facilities in India highlighted the opportunity for Sarvajal to partner with an organization for this application. Sarvajal could partner with NGOs already in the business of operating public toilets by providing them brine at a low cost for flushing. For example, the NGO Sulabh International has set up pay per use toilet facilities in urban in India and has already established its brand as a public sanitation provider.[xlviii]

Analysis of Benefits

Apart from reuse of the brine and thus less usage of virgin water, a number of other benefits can be associated with this application. Socially, public sanitation being provided in rural India would make Sarvajal stand out as a leading social entrepreneur. Partnering with an NGO such as Sulabh in implementing pay-per-use toilets, would also be an additional revenue generating possibility and any maintenance costs would be borne by Sulabh. This partnership would shield Sarvajal"s clean water brand from association with sanitation facilities.

Analysis of Barriers

Those who reside in rural locations are not out-right opposed to latrines or public sanitation projects, but many are ill-informed or have pre-conceived notions about such facilities; they are unpleasant to use because of the odors, they are unsafe- especially for children, they attract pests and that they are too expensive to construct.[xlix] Efforts to educate potential users would be needed to overcome these stigmas.

The barriers to this application would be the additional cost of constructing a public restroom and labor costs to clean and maintain it. The franchisees would not be willing to take up this additional cost unless some monetary benefit would accrue from it. Charging people to use the restroom might also discourage them from using it- especially in poor rural villages.

The barrier to partnering with an NGO is that the possibility of such partnerships would only exist for a few franchisees. The barriers of working with Sulabh International specifically are that they have so far been unresponsive and unwilling to venture in to rural areas.

From franchise visits, it was found that locating the public restroom in view of the drinking water supply would not be socially acceptable. People would be worried about the possibility of clean water getting mixed with dirty water. So for this application to work the restroom has to be located away from the place people come to collect water, but not so far away that transportation costs become prohibitive.

A serious potential health risk with this solution could be the excessive production of hydrogen sulfide which can be produced when organic material is broken down in the absence of oxygen. Another barrier is that there can only really be two types of holding tanks: a sealed tank and one that releases the broken down waste into the soil. Both have the potential to contaminate the ground water, and the sealed tank will at some point fill and no longer be available for use.

Discussion

If Sarvajal can find an NGO willing to partner with them to provide the capital for public restroom facilities, then this could be a good income generating opportunity for Sarvajal and the franchisees, and would also enhance Sarvajal"s image among the local communities. But care should be taken to locate the restrooms not in view of the point of sale for the drinking water to ensure acceptability by the locals.

Wood Treatment Application

The woodworking industry involves chemically treating raw wood to resist decay. It is an intermediary step between the production of lumber and conversion of lumber into a finished building material or product. In light of India"s growing population there may be increased demand on the lumber treatment industry, as more lumber is needed to build structures and household furniture.

Methodology and Results

The Sitapura franchise is already employing this application of RO brine. The franchisee originally leased the RO machine from Sarvajal to provide clean water to his factory workers at his lumberyard. The wood treatment process essentially involves "steaming" the lumber to prevent decomposition and repel insects. The factory had previously been using ground water for this process, but once the RO machine was installed, they tried using the RO brine for this treatment process instead. Information from the workers in the lumberyard revealed that half of their daily reject of 7000 L is used to treat wood and the remainder is used to water trees in their compound and dumped into the ground. For every 5 L used, 3 L is taken up by the wood.

One of the operators at the plant said that treating the wood with brine actually made it stronger than the previous chemical they had been using. The franchisee speculated that this improvement in quality was due to the higher concentrations of dissolved minerals, such as fluoride, in the brine as compared to the ground water (which he had used previously).

Analysis of Benefits

A major benefit to this application is the abundance of lumber treatment facilities in the region. A current or future franchisee would not have to learn a new trade, but instead could simply seek out partnerships with nearby lumber businesses.

This application is also one of the few where dissolved constituents in the brine are absorbed in the wood material for the lifespan of the lumber or wood product thereby delaying leaching back into the water supply.

Analysis of Barriers

One prominent barrier is the cost and risk of starting a lumber business for franchisees willing to enter a new trade. Additionally, finding potential partners or locating future Sarvajal franchises in close proximity to existing lumber treatment facilities requires an investment in researching and negotiating partnerships. Transporting brine long distances is inefficient and cost prohibitive. In some cases, ambivalence among franchisees for engaging in additional work could limit the applicability of this solution.

An environmental drawback of this solution is that the use of RO brine in the treatment process, while sequestering pollutants from community water sources, also prevents recharge of the water meaning that groundwater wells are not being replenished.

Discussion

While many other applications are best suited for locations with low TDS levels, this application is one of the few that could be geared specifically towards franchises with higher TDS levels. Given that this application uses the brine in its present form for a wide-spread and growing industry and that this application keeps potentially harmful dissolved solids in the brine from leaching back into the water supply, this application could provide a promising use of the RO brine for some franchises. Given the intrinsic differences among franchise locations, however, implementation of this strategy at every location is limited.

More research is needed on the long-term effects of this treatment on wood; specifically its effects on quality and durability. Also, additional research is needed on the potential health risks of prolonged exposure to wood treated in this manner, as well as what the health risks could result from the burning of this material, i.e. in either a house fire or if it was purposely burned for heat and/or energy.

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Date: _________

Franchise: _______________

Maintenance Questionnaire for Sarvajal Franchises

Do you make use of the brine? ☐ Yes ☐ No

If yes,

1. What are you using the brine for

   ____

   ____

2. When did you begin using the brine for this purpose?

   ____

3. Since you began using the brine for this purpose, have you noticed any potential problems? ☐ Yes ☐ No

   If yes, what change have you seen?

   ____

   ____

4. Have you used raw water for this same application? ☐ Yes ☐ No

   If yes, have you noticed any significant differences in using raw water for this purpose as opposed to brine water?

   ____

   ____

5. Is the use of the brine personal or commercial?

   ☐ Personal ☐ Commercial

6. Do your customers and neighbors know you use the brine? ☐ Yes ☐ No

   If yes, have they expressed any concerns about its use? ________________________

   ____

7. Are the locals concerned about dropping well water levels or about water shortages affecting business? ☐ Yes ☐ No

   If yes, what are their concerns? ____

   ____

If no,

1. Why don't you use the brine?

   ____

   ____

2. Are you willing to use the brine

   ☐ Yes ☐ No

   If yes, for what purpose?

   ____

   ____

3. Can you think of any other potential uses for the brine? Are there any opportunities for partnering with local businesses in the area to make use of the brine?

   ____

   ____

4. Do you think using the brine affects how customers and neighbors feel about your business?

   ____

   ____

A Sarvajal Case Study:

Don't waste a drop! Saving water, for all.

sarvajal
affordable • accessible • pure

Sarvajal is proud of the high quality drinking water we provide to our customers but the salt brine that your reverse osmosis machine produces has many benefits as well. Sarvajal franchisees like you are the key to helping us save this precious resource. The following case study is part of a series on creative reuse of RO brine.

Ram Swaroop is the very essence of an entrepreneur. Before he became a Sarvajal franchisee, he was a brick maker. Shortly after opening his Sarvajal franchise in Ramgarh in 2009, he decided to start making cement bricks and septic tank covers using the brine. He continued to use the brine for cement for about a year, until his customers began noticing cracks in the cement. In response to these complaints, Ram stopped using brine. After changing back to using raw water, he no longer noticed any structural problems in his cement.

But Ram didn't stop there. He knows that water is a precious resource and has since been trying to find new ways of using the brine, or even reworking his cement mixture to use a combination of brine and raw water. He is motivated to put the brine to good use and so despite his setbacks, he is very interested in trying new ideas and learning about what other franchisees might be doing with their excess brine.

If you have an idea, share it with your local maintenance supervisor.

<u>Do you have an idea?</u> *With any new ideas, test them out on a small scale first just in case it does not work with your type of brine. If you do find something that works well, share your idea with Sarvajal and other franchisees. Together we can help save water.*

Sarvajal Private Water Limited | Ahmedabad, India

Single sheet case studies provide tips and anecdotes of franchisee efforts to use RO brine.

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For a number of years, when his laundry business was located next door to a Sarvajal franchise, Abdul Sattar used the RO brine from his neighbors RO machine to wash clothes. Abdul said that using the brine was helpful to him because he did not have to pay for municipal water or wait for his turn to get raw water from the pump, he could simply use what his neighbor had left over. He also found that with the brine did not require as much soap. This helped him save money. He even said that he felt the clothes came out cleaner as a result of using the brine instead of raw water. Clothes washed in brine can save water and money. It is possible to partner with a local dhobi in your neighborhood or use brine for laundry at home.

In Pratap Nagar, Suresh Saini's wife collects brine from the reject pipe and uses it for laundry, to clean floors and other uses around the home. Her efforts have helped her family save money and time they used to spend collecting well water or having it delivered by truck. Saving water is important and it shows Suresh's customers and his community that his family cares about protecting the environment and providing water for all.

If you have an idea, share it with your local maintenance supervisor.

What is brine? *Brine is the water that comes out of your "reject" pipe. It is not meant to be tossed aside or wasted. The concentration of dissolved solids in the brine make it unsuitable for drinking, but in certain cases, this brine provides added benefits to a number of uses.*

Sarvajal Private Water Limited | Ahmedabad, India

Single sheet case studies provide tips and anecdotes of franchisee efforts to use RO brine.

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Sanvarmal Jhangid began operation of his Sarvajal RO machine in Sitapura in 2011. He runs a furniture-making business and wanted to provide clean drinking water for his employees in the lumberyard and furniture factory. The first step in making furniture is treating wood to protect it. This step requires a lot of water. Sanvarmal saw an opportunity in the brine that flowed from his reject pipe, so he tried using it in his wood treatment process. He fills a tank with brine and wood treatment chemicals he uses and steam treats the wood in that tank. The lumber is then left to dry and the water evaporates out of the wood leaving the chemicals behind to protect the wood.

Since starting to use brine, Sanvarmal doesn't have to pump additional water for his wood treatment business - he simply uses what's leftover from his RO machine. In fact, the salt and fluoride found naturally in brine is useful in the wood treatment process, making the product better, saving money and saving water – all at the same time.

Transporting water: *Trucking water or piping it long distances is expensive and does not make economic sense. Partnering with other local businesses in your neighborhood is a great idea, but consider the distance the water has to travel from your reject pipe.*

If you have an idea, share it with your local maintenance supervisor.

Sarvajal Private Water Limited | Ahmedabad, India

Single sheet case studies provide tips and anecdotes of franchisee efforts to use RO brine.

Tips

- **What is brine?** Brine is the water that comes out of your "reject" pipe. The concentration of dissolved solids in the brine make it unsuitable for drinking, but in certain cases, this brine provides added benefits to a number of uses.
- **Transporting water:** Trucking or piping water long distances does not make economic sense. Partnering with businesses in your neighborhood is a great idea, but consider the distance the water has to travel from your reject pipe.
- **Do you have an idea?** With any new ideas, test them out on a small scale first just in case it does not work with your type of brine because all brine is different. If you find something that works well, share your idea with Sarvajal. Together we can help save water.

Other creative uses for RO Brine:

- Watering plants
- Brick making
- Washing cars
- Paper making
- Concrete making
- Laundry
- Cleaning
- Wood treatment
- Fire fighting
- And your next great idea!

Piramal Private Water Limited

Prepared for Sarvajal by the University of Michigan School of Natural Resources & Environment Master's Project Team, 2011

Creative Uses for RO Brine

Sarvajal

Private Water Limited
Ahmedabad, India

A summary version of three case studies that could be translated and distributed to franchisees.

Brine-Use Case Studies

Sarvajal is proud of the high quality drinking water we provide to our customers but the salt brine that your reverse osmosis machine produces has many benefits as well. Sarvajal franchisees like you are the key to helping us save this precious resource. The following examples are from a series of case studies on creative reuse of RO brine. If you have an idea, share it with your local maintenance supervisor.

"Water for all – don't waste a drop"

Case 1: After opening his Sarvajal franchise in Ramgarh in 2009, Ram Swaroop decided to start making cement bricks and septic tank covers using brine. After a year, his customers began noticing cracks in the cement. In response to these complaints, Ram switched back to using raw water.

But Ram didn't give up. He knows that water is a precious resource and has since been trying to find new ways of using the brine, or even reworking his cement mixture to use a combination of brine and raw water. He is motivated to put the brine to good use and so despite his setbacks, he is very interested in trying new ideas and learning about what other franchisees might be doing with their excess brine.

Case 2: Sanvarmal Jhangid began operation of his Sarvajal RO machine in Sitapura to provide drinking water to employees in his furniture business. The first step in making furniture is treating wood, which requires a lot of water. Sanvarmal saw an opportunity in the RO brine, so he tried using it in his wood treatment process. He fills a tank with brine and wood treatment chemicals then steam treats the wood. Water evaporates as the lumber dries leaving the chemicals behind. Since starting to use brine, Sanvarmal doesn't have to pump additional water for wood treatment - he simply uses what's leftover from his RO machine. In fact, the salt and fluoride found naturally in brine is useful in the wood treatment process, making the product better, saving money and saving water – all at the same time.

Case 3: When his laundry business was located next door to a Sarvajal franchise, Abdul Sattar used the RO brine from his neighbor to wash clothes. Abdul said that he did not have to pay for municipal water or wait for his turn to get raw water from the pump. He also found that with the brine did not require as much soap and the clothes were cleaner.

In Pratap Nagar, Suresh Saini's wife collects brine from the reject pipe for laundry and cleaning. Her efforts help her family save money and time they used to spend collecting well water or having it delivered by truck. Saving water is important and it shows Suresh's customers and his community that his family cares about protecting the environment and providing water for all.

A summary version of three case studies that could be translated and distributed to franchisees.

List of Tables

Table 1
Source Water Data
(provided by Sarvajal)

location name	territory name	state	report type	lab name	report upload date	Electrical Conductivity	pH	Total Dissolved Solids (mg/L)	Colour	Odour
Ajeetgarh	Shekhawati	Rajasthan	Source Water	Vishal Analytical Laboratory	1/31/2010					
Alwar	Jaipur	Rajasthan	Source Water	Vishal Analytical Laboratory	4/10/2010					
Anyol	Mathura	Uttar Pradesh	Source Water	Vishal Analytical Laboratory	9/30/2010	3760	7.56	2490	CLEAR	ODOUR FREE
Anyol	Mathura	Uttar Pradesh	Source Water	Vishal Analytical Laboratory	9/29/2010					
Balajipuram	Mathura	Uttar Pradesh	Source Water	Vishal Analytical Laboratory	10/12/2010					
Balajipuram	Mathura	Uttar Pradesh	Source Water	Vishal Analytical Laboratory	9/29/2010					
Balajipuram	Mathura	Uttar Pradesh	Source Water	Vishal Analytical Laboratory	9/30/2010	3060	7.43	2080	CLEAR	ODOUR FREE
Balda	South Gujarat	Gujarat	Source Water	Vishal Analytical Laboratory	11/3/2009	2600	7.73	1890	CLEAR	ODOUR FREE
Balitha	South Gujarat	Gujarat	Source Water	Vishal Analytical Laboratory	7/12/2010	1500	7.84	1010	CLEAR	ODOUR FREE
Balitha	South Gujarat	Gujarat	Source Water	Vishal Analytical Laboratory	1/2/2010	1500	7.64	970	CLEAR	ODOUR FREE
Bangohtri	Shekhawati	Rajasthan	Source Water	Vishal Analytical Laboratory	5/10/2010	1540	8.96	1090	CLEAR	ODOUR FREE
Barvav	North Gujarat	Gujarat	Source Water	Vishal Analytical Laboratory	5/8/2010	2540	7.46	1610	CLEAR	ODOUR FREE
Bassi	Jaipur	Rajasthan	Source Water	Vishal Analytical Laboratory	4/29/2010	1050	8.42	770	CLEAR	ODOUR FREE
Bhensrol	South Gujarat	Gujarat	Source Water	Vishal Analytical Laboratory	4/22/2010					
Bhuma bada	Shekhawati	Rajasthan	Source Water	Vishal Analytical Laboratory	4/29/2010	3300	8.57	2500	CLEAR	ODOUR FREE
Billimora	South Gujarat	Gujarat	Source Water	Vishal Analytical Laboratory	7/2/2010	2380	7.93	1560	CLEAR	ODOUR FREE
Bissau-2	Shekhawati	Rajasthan	Source Water	Vishal Analytical Laboratory	8/3/2010	1800	8.27	1140	CLEAR	ODOUR FREE
Chanwai	South Gujarat	Gujarat	Source Water	Vishal Analytical Laboratory	4/22/2010					
Churi miyan	Shekhawati	Rajasthan	Source Water	Vishal Analytical Laboratory	7/12/2010	1490	7.95	1070	CLEAR	ODOUR FREE
Churu 1	Shekhawati	Rajasthan	Source Water	Vishal Analytical Laboratory	8/30/2009	2840	8.27	1930	CLEAR	ODOUR FREE
Churu 2	Shekhawati	Rajasthan	Source Water	Vishal Analytical Laboratory	8/30/2009	4860	8.33	3270	CLEAR	ODOUR FREE
Churu 3	Shekhawati	Rajasthan	Source Water	Vishal Analytical Laboratory	5/10/2010	4590	8.57	2760	CLEAR	ODOUR FREE
Copper-2	Shekhawati	Rajasthan	Source Water	Vishal Analytical Laboratory	6/3/2010					
Dabhela	South Gujarat	Gujarat	Source Water	Vishal Analytical Laboratory	9/30/2009	1000	7.24	690	CLEAR	ODOUR FREE
Dadra	South Gujarat	Gujarat	Source Water	Vishal Analytical Laboratory	3/20/2010	670	7.37	460	CLEAR	ODOUR FREE
Deeg	Jaipur	Rajasthan	Source Water	Vishal Analytical Laboratory	6/18/2010					
Dewas	Indore	Madhya Pradesh	Source Water	Vishal Analytical Laboratory	11/19/2010	2750	7.58	1700	CLEAR	ODOUR FREE
Fatehpur 2	Shekhawati	Rajasthan	Source Water	Vishal Analytical Laboratory	8/1/2009	2130	7.43	1700	CLEAR	ODOUR FREE
Finchod	North Gujarat	Gujarat	Source Water	Vishal Analytical Laboratory	2/1/2009	830	8.14	600	CLEAR(1)	ODOUR FREE
Gadhsisa	Central Gujarat	Gujarat	Source Water	Vishal Analytical Laboratory	5/5/2010	2330	7.46	1510	CLEAR	ODOUR FREE
Goliyawas	Jaipur	Rajasthan	Source Water	Vishal Analytical Laboratory	10/11/2010	1130	7.57	760	CLEAR	ODOUR FREE
Gothara	Shekhawati	Rajasthan	Source Water	Vishal Analytical Laboratory	2/12/2011					
Govindgarh	Jaipur	Rajasthan	Source Water	Vishal Analytical Laboratory	7/12/2010	3250	7.64	2290	1	ODOUR FREE
Hanumangarh	Jaipur	Rajasthan	Source Water	Vishal Analytical Laboratory	9/9/2010	4440	7.93	2930	CLEAR	ODOUR FREE
Hanumangarh	Jaipur	Rajasthan	Source Water	Vishal Analytical Laboratory	9/29/2010					
Hathras	Mathura	Uttar Pradesh	Source Water	Vishal Analytical Laboratory	12/5/2010	1960	7.75	1400	CLEAR	ODOUR FREE
Indore	Indore	Madhya Pradesh	Source Water	Vishal Analytical Laboratory	5/8/2010	1850	7.37	1280	CLEAR	ODOUR FREE
Jaisalya	Jaipur	Rajasthan	Source Water	Vishal Analytical Laboratory	3/10/2010					
Jajod	Shekhawati	Rajasthan	Source Water	Vishal Analytical Laboratory	9/14/2009	3300	8.24	2360	CLEAR	ODOUR FREE
Jhunjhunu Zone 3	Shekhawati	Rajasthan	Source Water	Vishal Analytical Laboratory	8/24/2009	2080	8.36	1620	CLEAR	ODOUR FREE
Kacchi	South Gujarat	Gujarat	Source Water	Vishal Analytical Laboratory	4/22/2010					
Kakad Faliya	South Gujarat	Gujarat	Source Water	Vishal Analytical Laboratory	4/22/2010	1750	7.91	1060	CLEAR	ODOUR FREE
Kama	Jaipur	Rajasthan	Source Water	Vishal Analytical Laboratory	2/7/2011	2210	7.34	1390	CLEAR	ODOUR FREE

Table 1
Source Water Data
(provided by Sarvajal)

location name	territory name	state	report type	lab name	report upload date	Electrical Conductivity	pH	Total Dissolved Solids (mg/L)	Colour	Odour
Kava	North Gujarat	Gujarat	Source Water	Vishal Analytical Laboratory	3/7/2009	980	8.22	670	CLEAR(1)	ODOUR FREE
khachrod	Indore	Madhya Pradesh	Source Water	Vishal Analytical Laboratory	7/26/2010	1130	7.43	770	CLEAR	ODOUR FREE
Khandela	Shekhawati	Rajasthan	Source Water	Vishal Analytical Laboratory	8/30/2009	2110	8.36	1420	CLEAR	ODOUR FREE
khargone	Indore	Madhya Pradesh	Source Water	Vishal Analytical Laboratory	7/26/2010	1210	7.64	800	CLEAR	ODOUR FREE
Khatu 2	Shekhawati	Rajasthan	Source Water	Vishal Analytical Laboratory	12/21/2009	1960	8.06	1320	CLEAR	ODOUR FREE
Khed	North Gujarat	Gujarat	Product Water	Vishal Analytical Laboratory	11/30/2009	210	7.05	155	CLEAR	ODOUR FREE
Kheradi	North Gujarat	Gujarat	Source Water	Vishal Analytical Laboratory	3/31/2010	2880	7.75	1980	CLEAR	ODOUR FREE
Kolak	South Gujarat	Gujarat	Source Water	Vishal Analytical Laboratory	7/3/2009	2400	7.82	1640	CLEAR	ODOUR FREE
Kosamba Road	South Gujarat	Gujarat	Source Water	Vishal Analytical Laboratory	6/5/2010	1140	7.93	850	CLEAR	ODOUR FREE
Kotkasim	Jaipur	Rajasthan	Source Water	Vishal Analytical Laboratory	5/10/2010	2860	7.55	1890	CLEAR	ODOUR FREE
Krishnanagar	Mathura	Uttar Pradesh	Source Water	Vishal Analytical Laboratory	12/5/2010	3050	7.91	1990	CLEAR	ODOUR FREE
Krishnanagar	Mathura	Uttar Pradesh	Source Water	Vishal Analytical Laboratory	1/31/2011					
Ladnu	Jaipur	Rajasthan	Source Water	Vishal Analytical Laboratory	7/12/2010	1860	7.52	1330	CLEAR	ODOUR FREE
Lai	North Gujarat	Gujarat	Source Water	Vishal Analytical Laboratory	3/27/2009	1140	8	790	CLEAR	ODOUR FREE
Laxmangarh 2	Shekhawati	Rajasthan	Source Water	Vishal Analytical Laboratory	7/15/2010	1280	8.02	970	CLEAR	ODOUR FREE
Laxmangarh2	Jaipur	Rajasthan	Source Water	Vishal Analytical Laboratory	4/29/2010	1300	7.52	860	CLEAR	ODOUR FREE
Loharu	Shekhawati	Rajasthan	Source Water	Vishal Analytical Laboratory	8/3/2010	1590	7.7	1170	1	ODOUR FREE
Mahensar2	Shekhawati	Rajasthan	Source Water	Vishal Analytical Laboratory	3/20/2010					
Mandawa-2	Shekhawati	Rajasthan	Source Water	Vishal Analytical Laboratory	7/6/2010					
Mandora	Mathura	Uttar Pradesh	Source Water	Vishal Analytical Laboratory	11/11/2010	4200	7.64	2640	CLEAR	ODOUR FREE
Mandrela	Shekhawati	Rajasthan	Source Water	Vishal Analytical Laboratory	8/1/2009	4000	7.82	2460	CLEAR	ODOUR FREE
Mangroda	North Gujarat	Gujarat	Source Water	Vishal Analytical Laboratory	1/5/2010	1880	7.73	1300	CLEAR	ODOUR FREE
Manorpura	North Gujarat	Gujarat	Source Water	Vishal Analytical Laboratory	2/4/2009	680	7.56	530	CLEAR(1)	ODOUR FREE
Masar	Central Gujarat	Gujarat	Source Water	Vishal Analytical Laboratory	1/13/2010	3190	7.52	2160	CLEAR	ODOUR FREE
Mashal	North Gujarat	Gujarat	Source Water	Vishal Analytical Laboratory	12/22/2008	1990	7.66	1340	CLEAR(2)	ODOUR FREE
Mathura	Shekhawati	Rajasthan	Source Water	Vishal Analytical Laboratory	6/17/2010					
Moti Daman	South Gujarat	Gujarat	Source Water	Vishal Analytical Laboratory	2/26/2010	1360	7.55	970	CLEAR	ODOUR FREE
Mukundgarh	Shekhawati	Rajasthan	Source Water	Vishal Analytical Laboratory	8/1/2009	1550	8.65	1130	CLEAR	ODOUR FREE
Murlipura	Jaipur	Rajasthan	Source Water	Vishal Analytical Laboratory	11/9/2009	660	8.2	475	CLEAR	ODOUR FREE
Muval	Central Gujarat	Gujarat	Source Water	Vishal Analytical Laboratory	7/29/2010	1650	8.09	1240	CLEAR	ODOUR FREE
Nadbai	Jaipur	Rajasthan	Source Water	Vishal Analytical Laboratory	7/14/2010					
Naliya	Central Gujarat	Gujarat	Source Water	Vishal Analytical Laboratory	5/5/2010	3540	7.37	2340	CLEAR	ODOUR FREE
Naroli	South Gujarat	Gujarat	Source Water	Vishal Analytical Laboratory	4/22/2010	1750	7.91	1060	CLEAR	ODOUR FREE
Naujheel	Mathura	Uttar Pradesh	Source Water	Vishal Analytical Laboratory	9/24/2010					
Naujheel	Mathura	Uttar Pradesh	Source Water	Vishal Analytical Laboratory	9/30/2010	4340	7.64	2820	CLEAR	ODOUR FREE
Nawalgarh2	Shekhawati	Rajasthan	Source Water	Vishal Analytical Laboratory	7/12/2010	1270	8.02	860	CLEAR	ODOUR FREE
Palitana	Central Gujarat	Gujarat	Source Water	Vishal Analytical Laboratory	9/18/2010	1970	7.47	1430	CLEAR	ODOUR FREE
Panol	North Gujarat	Gujarat	Source Water	Vishal Analytical Laboratory	1/2/2010	670	7.48	480	CLEAR	ODOUR FREE
Pithisar	Shekhawati	Rajasthan	Source Water	Vishal Analytical Laboratory	4/20/2010					
pofaran	Thane	Maharashtra	Source Water	Vishal Analytical Laboratory	8/23/2010	550	7.73	390	CLEAR	ODOUR FREE
Pratapnagar	Jaipur	Rajasthan	Source Water	Vishal Analytical Laboratory	1/31/2011					
Pratappura	North Gujarat	Gujarat	Source Water	Vishal Analytical Laboratory	11/25/2008	1090	7.57	720	CLEAR(2)	ODOUR FREE
Rajgarh	Shekhawati	Rajasthan	Source Water	Vishal Analytical Laboratory	11/23/2009	4780	8.27	3330	CLEAR	ODOUR FREE

location name	territory name	state	report type	lab name	report upload date	Electrical Conductivity	pH	Total Dissolved Solids (mg/L)	Colour	Odour
Ramgarh	Shekhawati	Rajasthan	Product Water	Vishal Analytical Laboratory	11/27/2010	4450	7.48	2760	2	tipical
Ramgarh	Shekhawati	Rajasthan	Product Water	Vishal Analytical Laboratory	11/27/2010	4450	7.48	2760	2	tipical
Ramgarh	Jaipur	Rajasthan	Source Water	Vishal Analytical Laboratory	10/31/2010					
Ramgarh	Shekhawati	Rajasthan	Product Water	Vishal Analytical Laboratory	11/27/2010	4450	7.48	2760	2	tipical
Ramgarh	Jaipur	Rajasthan	Source Water	Vishal Analytical Laboratory	10/25/2010	4000	7.84	2440	CLEAR	ODOUR FREE
Ranjhi	Jabalpur	Madhya Pradesh	Source Water	Vishal Analytical Laboratory	5/20/2010	630	7.31	470	CLEAR	ODOUR FREE
ringus2	Shekhawati	Rajasthan	Product Water	Vishal Analytical Laboratory	11/19/2010	2350	8.46	1450	CLEAR	ODOUR FREE
ringus2	Shekhawati	Rajasthan	Source Water	Vishal Analytical Laboratory	11/19/2010	2350	8.46	1450	CLEAR	ODOUR FREE
Rollsahabsar	Shekhawati	Rajasthan	Source Water	Vishal Analytical Laboratory	9/14/2009	3600	8.33	2530	CLEAR	ODOUR FREE
sachodar	North Gujarat	Gujarat	Source Water	Vishal Analytical Laboratory	1/22/2010					
sanjan	South Gujarat	Gujarat	Source Water	Vishal Analytical Laboratory	5/10/2010	2200	8.06	1400	CLEAR	ODOUR FREE
Sardarshar	Shekhawati	Rajasthan	Source Water	Vishal Analytical Laboratory	3/20/2010					
Shahjhapur	Jaipur	Rajasthan	Source Water	Vishal Analytical Laboratory	2/19/2011					
Shamlaji	North Gujarat	Gujarat	Product Water	Vishal Analytical Laboratory	11/30/2009	140	7.03	103	CLEAR	ODOUR FREE
Shri madhopur 1	Shekhawati	Rajasthan	Source Water	Vishal Analytical Laboratory	12/21/2009	950	7.95	700	CLEAR	ODOUR FREE
Sikar 2	Shekhawati	Rajasthan	Source Water	Vishal Analytical Laboratory	8/14/2009	820	8.27	600	CLEAR	ODOUR FREE
Singhana2	Shekhawati	Rajasthan	Source Water	Vishal Analytical Laboratory	8/3/2010	2500	7.46	1590	CLEAR	ODOUR FREE
Siriyasar Kalan	Shekhawati	Rajasthan	Product Water	Vishal Analytical Laboratory	5/10/2010	2840	8.1	2030	CLEAR	ODOUR FREE
Siriyasar Kalan	Shekhawati	Rajasthan	Source Water	Vishal Analytical Laboratory	5/10/2010	2840	8.1	2030	CLEAR	ODOUR FREE
Sitapura	Jaipur	Rajasthan	Source Water	Vishal Analytical Laboratory	3/24/2010					
Sujangarh	Shekhawati	Rajasthan	Source Water	Vishal Analytical Laboratory	7/15/2010	2860	7.64	1780	CLEAR	ODOUR FREE
Sultana	Shekhawati	Rajasthan	Source Water	Vishal Analytical Laboratory	8/24/2009	1050	8.22	700	CLEAR	ODOUR FREE
Sundhiya	North Gujarat	Gujarat	Source Water	Vishal Analytical Laboratory	4/16/2010	680	8.24	680	CLEAR	ODOUR FREE
Surajgarh	Shekhawati	Rajasthan	Source Water	Vishal Analytical Laboratory	6/12/2010					
Surir	Mathura	Uttar Pradesh	Source Water	Vishal Analytical Laboratory	1/21/2011	5490	7.66	3410	CLEAR	ODOUR FREE
Tajpur	North Gujarat	Gujarat	Source Water	Vishal Analytical Laboratory	6/23/2010	1820	7.49	1190	CLEAR	ODOUR FREE
Tamkore	Shekhawati	Rajasthan	Source Water	Vishal Analytical Laboratory	8/3/2010	12280	7.93	7170	CLEAR	ODOUR FREE
Taranagar	Shekhawati	Rajasthan	Source Water	Vishal Analytical Laboratory	11/23/2009	890	7.37	700	CLEAR	ODOUR FREE
Thanagazi	Jaipur	Rajasthan	Source Water	Vishal Analytical Laboratory	2/3/2010					
Torada	North Gujarat	Gujarat	Source Water	Vishal Analytical Laboratory	6/23/2010	3120	7.52	1840	CLEAR	ODOUR FREE
Umedpura	North Gujarat	Gujarat	Source Water	Vishal Analytical Laboratory	7/6/2010	600	7.34	446	CLEAR	ODOUR FREE
Umergam	South Gujarat	Gujarat	Product Water	Vishal Analytical Laboratory	2/15/2010	220	7.04	135	CLEAR	ODOUR FREE
Vapi	South Gujarat	Gujarat	Source Water	Vishal Analytical Laboratory	9/15/2009	950	7.75	670	CLEAR	ODOUR FREE
Vapi	South Gujarat	Gujarat	Source Water	Vishal Analytical Laboratory	7/3/2009	520	7.55	380	CLEAR	ODOUR FREE
Vasai	North Gujarat	Gujarat	Product Water	Vishal Analytical Laboratory	8/16/2009	190	7.37	130	CLEAR	ODOUR FREE
Vasai	North Gujarat	Gujarat	Product Water	Vishal Analytical Laboratory	8/16/2009	190	7.37	130	CLEAR	ODOUR FREE
Vasai	North Gujarat	Gujarat	Source Water	Vishal Analytical Laboratory	1/17/2009	1670	7.84	1090	CLEAR(2)	ODOUR FREE
Vrindavan	Mathura	Uttar Pradesh	Source Water	Vishal Analytical Laboratory	1/21/2011	910	7.3	600	CLEAR	ODOUR FREE

Table 1
Source Water Data
(provided by Sarvajal)

location name	Turbidity (NTU)	Calcium (mg/L)	Magnesium (mg/L)	Sodium (mg/L)	Potassium (mg/L)	Carbonate (mg/L)	Bi-Carbonate (mg/L)	Sulphate (mg/L)	Chloride (mg/L)	Fluoride (mg/L)	Nitrate (mg/L)
Ajeetgarh											
Alwar											
Anyol	NIL	165	81	514	10.4	NIL	830	199	584	2.1	105
Anyol											
Balajipuram											
Balajipuram											
Balajipuram	NIL	50	45	561	8.8	NIL	732	141	400	1.9	136
Balda	NIL	60	51	430	2.7	NIL	976	48	320	0.62	2.6
Balitha	NIL	115	81	55	3.9	NIL	500	47	200	1.7	6.2
Balitha	NIL	130	81	39	2	NIL	403	25	280	1.31	3.2
Bangohtri	3	30	15	289	301	24	464	44	216	0.9	5.25
Barvav	NIL	305	75	87	5.2	NIL	500	110	480	1.65	44.2
Bassi	NIL	15	33	160	2.2	12	439	10	96	0.86	3.2
Bhensrol											
Bhuma bada	NIL	30	21	680	6.8	12	1342	55	336	1.7	4.6
Billimora	NIL	115	72	275	4.4	NIL	537	71	480	0.95	3.5
Bissau-2	NIL	10	27	349	3.6	12	549	13	168	1.9	112
Chanwai											
Churi miyan	NIL	35	15	272	2.4	NIL	476	50	208	1.45	6.1
Churu 1	NIL	30	51	518	4.7	12	671	145	496	0.72	7.1
Churu 2	NIL	40	99	878	6.9	12	1074	225	920	1.22	10.2
Churu 3	NIL	50	114	775	8.9	24	415	247	1120	1.7	49.6
Copper-2											
Dabhela	NIL	35	69	57	1.3	NIL	378	53	96	0.35	2.5
Dadra	2	10	3	133	6.2	NIL	24	228	48	1.25	6.2
Deeg											
Dewas	NIL	170	111	221	6.4	NIL	464	118	520	1.4	87
Fatehpur 2	NIL	20	21	425	2.6	NIL	1086	49	88	0.46	3.9
Finchod	2	60	36	52	1.6	NIL	354	12	80	1.55	8.9
Gadhsisa	NIL	100	51	320	4.6	NIL	329	256	432	1.75	12.4
Goliyawas	NIL	45	36	137	3.9	NIL	342	8	104	2.25	81
Gothara											
Govindgarh	2	35	48	612	5.4	NIL	842	304	432	1.6	6.2
Hanumangarh	NIL	45	78	726	14.8	NIL	573	558	592	2.15	93
Hanumangarh											
Hathras	NIL	55	60	269	5.3	NIL	634	208	144	1.8	25
Indore	NIL	85	75	182	3.4	NIL	610	51	264	1.2	4.6
Jaisalya											
Jajod	NIL	20	45	648	3.6	12	1086	61	480	0.66	6.6
Jhunjhunu Zone 3	NIL	35	15	408	3.2	12	964	70	112	0.53	4.2
Kacchi											
Kakad Faliya	NIL	120	57	154	2.6	NIL	281	46	424	1.2	2.3
Kama	NIL	140	51	248	3.2	NIL	342	86	504	1.7	15.4

Table 1
Source Water Data
(provided by Sarvajal)

location name	Turbidity (NTU)	Calcium (mg/L)	Magnesium (mg/L)	Sodium (mg/L)	Potassium (mg/L)	Carbonate (mg/L)	Bi-Carbonate (mg/L)	Sulphate (mg/L)	Chloride (mg/L)	Fluoride (mg/L)	Nitrate (mg/L)
Kava	2	95	27	64	1.1	12	293	23	136	1.15	18.6
khachrod	NIL	105	15	109	2	NIL	305	28	192	1.05	9.3
Khandela	NIL	130	60	219	3.5	12	488	210	296	0.53	5.27
khargone	NIL	145	48	18	2.2	NIL	366	44	152	1.25	28
Khatu 2	NIL	55	90	213	2.7	NIL	561	96	256	1.45	37
Khed	NIL	10	6	25	NIL	NIL	98	NIL	16	NIL	NIL
Kheradi	NIL	245	108	166	3.4	NIL	854	105	448	1.35	4.6
Kolak	NIL	150	54	275	2.2	NIL	708	33	416	0.32	4.13
Kosamba Road	NIL	30	18	192	2.1	NIL	476	12	112	0.73	6.2
Kotkasim	1	100	102	344	5.7	NIL	622	229	448	1.15	31.1
Krishnanagar	NIL	235	84	263	12.5	NIL	464	321	576	1.95	31
Krishnanagar											
Ladnu	NIL	65	30	294	3.1	NIL	622	48	256	1.55	6.2
Lai	NIL	85	9	146	1.4	NIL	305	48	168	1.27	21.2
Laxmangarh 2	NIL	15	15	247	2.2	NIL	561	NIL	128	1.25	4.6
Laxmangarh2	NIL	65	36	154	2.8	NIL	329	43	224	1.16	3.25
Loharu	1	20	24	295	2.8	NIL	598	39	184	1.8	3.2
Mahensar2											
Mandawa-2											
Mandora	NIL	105	84	677	12.7	NIL	500	244	984	1.8	31.4
Mandrela	NIL	115	126	542	6.9	NIL	476	139	1040	0.62	12.8
Mangroda	NIL	80	39	264	2.4	NIL	573	45	272	1.95	25.1
Manorpura	2	65	9	63	1.7	NIL	293	NIL	40	1.25	54.1
Masar	NIL	35	63	570	3.8	NIL	781	73	624	1.4	8.2
Mashal	2	55	18	359	2.1	NIL	415	56	424	0.91	12.5
Mathura											
Moti Daman	NIL	65	6	224	3.8	NIL	390	21	240	1.3	15.2
Mukundgarh	NIL	20	12	309	2.6	12	537	32	200	0.35	3.2
Murlipura	NIL	35	30	53	1	12	293	NIL	48	0.41	2.9
Muval	NIL	30	30	286	2.5	NIL	720	9	160	0.8	2.3
Nadbai											
Naliya	NIL	60	57	632	6.3	NIL	671	168	728	1.9	12.4
Naroli	NIL	120	57	154	2.6	NIL	281	46	424	1.2	2.3
Naujheel											
Naujheel	NIL	150	117	593	14.6	NIL	659	505	720	1.85	56
Nawalgarh2	NIL	35	18	216	2.2	NIL	317	31	208	1.4	31
Palitana	NIL	40	33	342	3.2	NIL	695	74	240	0.73	2.3
Panol	NIL	80	21	21	1.4	NIL	268	2	80	1.05	3.2
Pithisar											
pofaran	NIL	55	21	22	17	NIL	207	10	64	0.55	3.2
Pratapnagar											
Pratappura	1	110	33	60	1.4	NIL	305	25	120	2.1	62
Rajgarh	NIL	20	36	1004	6.4	12	1183	262	800	1.15	4.85

Table 1
Source Water Data
(provided by Sarvajal)

location name	Turbidity (NTU)	Calcium (mg/L)	Magnesium (mg/L)	Sodium (mg/L)	Potassium (mg/L)	Carbonate (mg/L)	Bi-Carbonate (mg/L)	Sulphate (mg/L)	Chloride (mg/L)	Fluoride (mg/L)	Nitrate (mg/L)
Ramgarh	1	150	198	464	12.8	nil	586	427	856	2.8	59
Ramgarh	1	150	198	464	12.8	NIL	586	427	856	2.8	59
Ramgarh											
Ramgarh	1	150	198	464	12.8	NIL	586	427	856	2.8	59
Ramgarh	1	125	180	427	7.1	NIL	549	275	720	3.26	155
Ranjhi	NIL	85	15	18	1	NIL	305	NIL	48	1.35	6.2
ringus2	NIL	50	90	309	3.6	12	342	131	496	1.9	24.8
ringus2	NIL	50	90	309	3.6	12	342	131	496	1.9	24.8
Rollsahabsar	NIL	30	84	630	5	12	988	336	440	0.72	7.2
sachodar											
sanjan	NIL	185	81	136	3.9	NIL	464	64	464	1.35	4.6
Sardarshar											
Shahjhapur											
Shamlaji	NIL	5	3	15	NIL	NIL	61	NIL	16	NIL	NIL
Shri madhopur 1	NIL	25	30	131	1.4	NIL	403	32	72	1.15	4.1
Sikar 2	NIL	20	9	148	1.3	12	305	5	96	0.44	1.35
Singhana2	NIL	265	126	28	1.3	NIL	354	511	272	1.7	28.4
Siriyasar Kalan	NIL	50	45	507	4.9	12	939	77	376	1.7	12.4
Siriyasar Kalan	NIL	50	45	507	4.9	12	939	77	376	1.7	12.4
Sitapura											
Sujangarh	NIL	70	75	430	5.6	NIL	378	101	664	1.7	49.6
Sultana	NIL	45	51	91	1.7	12	317	19	160	0.55	2.1
Sundhiya	2	25	27	137	1.8	12	354	7	112	1.15	2.3
Surajgarh											
Surir	NIL	145	171	759	16.3	NIL	439	739	1040	1.8	93
Tajpur	1	115	51	187	3.5	NIL	415	52	352	1.82	12.4
Tamkore	NIL	215	342	1910	20.8	NIL	415	588	3640	2.6	37.4
Taranagar	NIL	20	15	152	1.2	NIL	464	8	40	0.46	1.8
Thanagazi											
Torada	2	225	60	315	6.1	NIL	329	100	792	2.15	9.3
Umedpura	NIL	65	9	45	1	NIL	256	4	64	0.75	1.5
Umergam	NIL	15	12	11	NIL	NIL	49	NIL	48	NIL	NIL
Vapi	NIL	80	45	39	1.4	NIL	366	60	80	0.42	1.9
Vapi	NIL	55	18	21	1	NIL	232	NIL	48	0.11	1.15
Vasai	NIL	10	6	21	NIL	NIL	61	N			
Vasai	NIL	10	6	21	NIL	NIL	61	NIL	32	NIL	NIL
Vasai	2	165	30	133	6.4	NIL	390	51	168	1.86	140
Vrindavan	NIL	50	48	59	2.3	NIL	232	61	136	0.3	6.4

Table 1
Source Water Data
(provided by Sarvajal)

location name	Total Hardness (mg/L as $CaCO_3$)	Total Alkalinity (mg/L)	Total Coliforms
Ajeetgarh			
Alwar			
Anyol	750	665	NIL
Anyol			
Balajipuram			
Balajipuram			
Balajipuram	300	585	NIL
Balda	360	750	NIL
Balitha	625	400	NIL
Balitha	660	310	NIL
Bangohtri	135	385	NIL
Barvav	1075	375	NIL
Bassi	175	350	NIL
Bhensrol			
Bhuma bada	160	1025	NIL
Billimora	585	430	NIL
Bissau-2	135	460	NIL
Chanwai			
Churi miyan	150	380	NIL
Churu 1	285	535	NIL
Churu 2	510	845	NIL
Churu 3	600	350	NIL
Copper-2			
Dabhela	375	290	NIL
Dadra	37	20	NIL
Deeg			
Dewas	885	375	NIL
Fatehpur 2	135	835	NIL
Finchod	300	275	NIL
Gadhsisa	460	250	NIL
Goliyawas	260	275	NIL
Gothara			
Govindgarh	285	375	NIL
Hanumangarh	435	460	NIL
Hanumangarh			
Hathras	385	510	NIL
Indore	525	460	NIL
Jaisalya			
Jajod	235	855	NIL
Jhunjhunu Zone 3	150	760	NIL
Kacchi			
Kakad Faliya	535	225	NIL
Kama	560	275	NIL

Table 1
Source Water Data
(provided by Sarvajal)

location name	Total Hardness (mg/L as $CaCO_3$)	Total Alkalinity (mg/L)	Total Coliforms
Kava	350	235	NIL
khachrod	325	240	NIL
Khandela	570	395	NIL
khargone	560	255	NIL
Khatu 2	510	435	NIL
Khed	25	75	NIL
Kheradi	1070	640	NIL
Kolak	600	550	NIL
Kosamba Road	150	180	NIL
Kotkasim	675	470	NIL
Krishnanagar	935	375	NIL
Krishnanagar			
Ladnu	285	500	NIL
Lai	200	235	NIL
Laxmangarh 2	100	450	NIL
Laxmangarh2	310	250	NIL
Loharu	150	480	NIL
Mahensar2			
Mandawa-2			
Mandora	610	400	NIL
Mandrela	650	370	NIL
Mangroda	360	445	NIL
Manorpura	200	225	NIL
Masar	350	610	NIL
Mashal	215	320	NIL
Mathura			
Moti Daman	185	275	NIL
Mukundgarh	100	425	NIL
Murlipura	210	245	NIL
Muval	200	580	NIL
Nadbai			
Naliya	385	505	NIL
Naroli	535	225	NIL
Naujheel			
Naujheel	860	530	NIL
Nawalgarh2	160	255	NIL
Palitana	235	560	NIL
Panol	285	210	NIL
Pithisar			
pofaran	225	165	NIL
Pratapnagar			
Pratappura	330	235	NIL
Rajgarh	200	930	NIL

location name	Total Hardness (mg/L as $CaCO_3$)	Total Alkalinity (mg/L)	Total Coliforms
Ramgarh	1200	470	12
Ramgarh	1200	470	12
Ramgarh			
Ramgarh	1200	470	12
Ramgarh	1060	440	NIL
Ranjhi	245	100	NIL
ringus2	500	295	NIL
ringus2	500	295	NIL
Rollsahabsar	425	780	NIL
sachodar			
sanjan	800	350	NIL
Sardarshar			
Shahjhapur			
Shamlaji	37	47	NIL
Shri madhopur 1	185	340	NIL
Sikar 2	70	255	NIL
Singhana2	1180	250	NIL
Siriyasar Kalan	310	725	NIL
Siriyasar Kalan	310	725	NIL
Sitapura			
Sujangarh	485	305	NIL
Sultana	325	265	NIL
Sundhiya	175	305	NIL
Surajgarh			
Surir	1075	350	NIL
Tajpur	500	335	NIL
Tamkore	1960	330	NIL
Taranagar	110	360	NIL
Thanagazi			
Torada	810	265	NIL
Umedpura	200	180	NIL
Umergam	87	64	NIL
Vapi	385	280	NIL
Vapi	130	180	NIL
Vasai			
Vasai	40	50	NIL
Vasai	430	300	NIL
Vrindavan	325	185	NIL

Table 2
RO Brine Data
(provided by Sarvajal)

South Gujarat - Umergam

	Source Water	Between Media and Carbon Filters	Before RO	After RO	Reject
Water properties (at inlet)					
* pH	7.49	7.45	7.46	7.03	7.51
* Temperature					
* TDS (ppm)	1260	1250	1250	157	1310
* TSS (ppm)					
* Hardness (ppm)	375	375	360	50	400
* Turbidity (NTU)	Nil	NIL	Nil	Nil	Nil
* Color (Hazen units)	Clear	Clear	Clear	Clear	Clear
* BOD (ppm)					
* COD (ppm)					
Minerals / metals					
* Fluoride (ppm)	0.7	0.7	0.7	Nil	0.8
* Arsenic (ppm)					
* Iron (ppm)					
* Calcium (ppm)	70	70	70	15	80
* Magnesium (ppm)	48	48	45	3	48
* Copper (ppm)					
* Mercury (ppm)					
and others					
Electrical Conductivity	1870	1860	1840	230	1930
Turbudity	Nil	Nil	Nil	Nil	Nil
Sodium	256	253	254	30	258
Potassium	3.4	3.4	3.4	Nil	3.5
Carbonate	Nil	Nil	Nil	Nil	Nil
Bi-Carbonate	464	464	464	61	488
Sulphate	84	80	81	Nil	94
Chloride	328	328	320	48	328
Fluoride	0.7	0.7	0.7	Nil	0.8
Nitrate	2.8	2.8	2.8	Nil	3.5
Alkalinity	370	370	370	49	390

Table 2
RO Brine Data
(provided by Sarvajal)

South Gujarat - Naroli

	Source Water	Between Media and Carbon Filters	Before RO	After RO	Reject
Water properties (at inlet)					
* pH	7.37	7.37	7.36	7.02	7.43
* Temperature					
* TDS (ppm)	1090	1070	1070	141	1600
* TSS (ppm)					
* Hardness (ppm)	525	510	535	37	760
* Turbidity (NTU)	Nil	Nil	Nil	Nil	Nil
* Color (Hazen units)	Clear	Clear	Clear	Clear	Clear
* BOD (ppm)					
* COD (ppm)					
Minerals / metals					
* Fluoride (ppm)	1.15	1.15	1.15	Nil	1.25
* Arsenic (ppm)					
* Iron (ppm)					
* Calcium (ppm)	130	120	130	10	190
* Magnesium (ppm)	48	51	51	3	69
* Copper (ppm)					
* Mercury (ppm)					
and others					
Electrical Conductivity	1770	1750	1750	210	2620
Turbudity	Nil	Nil	Nil	Nil	Nil
Sodium	164	165	153	31	249
Potassium	3.1	3.1	3.1	Nil	4.4
Carbonate	Nil	Nil	Nil	Nil	Nil
Bi-Carbonate	232	220	220	49	317
Sulphate	68	68	68	Nil	106
Chloride	440	440	440	48	664
Fluoride	1.15	1.15	1.15	Nil	1.25
Nitrate	2.3	2.3	2.3	Nil	3.5
Alkalinity	185	180	180	39	255

Table 2
RO Brine Data
(provided by Sarvajal)

South Gujarat - Chanwai

	Source Water	Between Media and Carbon Filters	Before RO	After RO	Reject
Water properties (at inlet)					
* pH	7.35	7.35	7.34	7.12	7.46
* Temperature					
* TDS (ppm)	620	605	605	485	980
* TSS (ppm)					
* Hardness (ppm)	285	285	300	260	460
* Turbidity (NTU)	Nil	Nil	Nil	Nil	Nil
* Color (Hazen units)	Clear	Clear	Clear	Clear	Clear
* BOD (ppm)					
* COD (ppm)					
Minerals / metals					
* Fluoride (ppm)	0.9	0.9	0.9	Nil	Nil
* Arsenic (ppm)					
* Iron (ppm)					
* Calcium (ppm)	65	65	70	55	95
* Magnesium (ppm)	30	30	30	30	54
* Copper (ppm)					
* Mercury (ppm)					
and others					
Electrical Conductivity	880	860	860	690	1380
Turbudity	Nil	Nil	Nil	Nil	Nil
Sodium	69	65	59	37	103
Potassium	1.4	1.4	1.4	1.2	2.2
Carbonate	Nil	Nil	Nil	Nil	Nil
Bi-Carbonate	305	293	305	256	512
Sulphate	59	59	49	33	71
Chloride	88	88	88	72	136
Fluoride	0.9	0.9	0.9	Nil	1.1
Nitrate	2.3	2.3	2.3	Nil	3.2
Alkalinity	245	235	245	205	410

Table 2
RO Brine Data
(provided by Sarvajal)

North Gujarat - Kava

	Source Water	Between Media and Carbon Filters	Before RO	After RO	Reject
Water properties (at inlet)					
* pH	7.39	7.41	7.4	7.03	7.48
* Temperature	-	-	-	-	
* TDS (ppm)	725	725	740	110	990
* TSS (ppm)	-	-	-	-	
* Hardness (ppm)	410	425	410	62	575
* Turbidity (NTU)	Nil	Nil	Nil	NIl	NIL
* Color (Hazen units)	clear	Clear	Clear	Clear	Clear
* BOD (ppm)	-	-	-	-	
* COD (ppm)	-	-	-	-	
Minerals / metals					
* Fluoride (ppm)	1.05	1.05	1.05	Nil	1.25
* Arsenic (ppm)	-	-	-	-	
* Iron (ppm)	-	-	-	-	
* Calcium (ppm)	95	100	105	20	130
* Magnesium (ppm)	42	42	36	3	60
* Copper (ppm)	-	-	-	-	
* Mercury (ppm)	-	-	-	-	
and others					
Electrical Conductivity	1110	1110	1130	170	1490
Turbudity	Nil	Nil	Nil	Nil	
Sodium	63	58	68	3	82
Potassium	3.7	3.7	3.7	Nil	4.8
Carbonate	Nil	Nil	Nil	Nil	NIL
Bi-Carbonate	281	281	281	37	390
Sulphate	39	39	38	Nil	48
Chloride	184	184	192	40	256
Fluoride					
Nitrate	15.5	15.2	15.5	Nil	18.9
Alkalinity	225	225	225	30	315
Odour	NONE	NONE	NONE	NONE	NONE
Colifoms	NIL	NIL	NIL	NIL	NIL

Table 2
RO Brine Data
(provided by Sarvajal)

North Gujarat - Mashal

	Source Water	Between Media and Carbon Filters	Before RO	After RO	Reject
Water properties (at inlet)					
* pH	7.46	7.43	7.44	7.07	7.52
* Temperature	-	-	-	-	
* TDS (ppm)	1015	1030	1020	161	1440
* TSS (ppm)	-	-	-	-	
* Hardness (ppm)	450	460	460	50	675
* Turbidity (NTU)	Nil	Nil	Nil	Nil	NIL
* Color (Hazen units)	clear	Clear	Clear	Clear	Clear
* BOD (ppm)	-	-	-	-	
* COD (ppm)	-	-	-	-	
Minerals / metals					
* Fluoride (ppm)	1.3	1.3	1.3	Nil	1.5
* Arsenic (ppm)	-	-	-	-	
* Iron (ppm)	-	-	-	-	
* Calcium (ppm)	110	105	105	15	140
* Magnesium (ppm)	42	48	48	3	78
* Copper (ppm)	-	-	-	-	
* Mercury (ppm)	-	-	-	-	
and others					
Electrical Conductivity	1480	1520	1500	230	2130
Turbudity	Nil	Nil	Nil	Nil	
Sodium	132	136	131	30	177
Potassium	2.5	2.5	2.5	Nil	3.5
Carbonate	Nil	Nil	Nil	Nil	NIL
Bi-Carbonate	451	451	451	73	622
Sulphate	48	45	40	Nil	97
Chloride	224	240	240	40	312
Nitrate	3.1	3.2	3.2	Nil	9.2
Alkalinity	360	360	360	55	500
Odour	NONE	NONE	NONE	NONE	NONE
Coliforms	NIL	NIL	NIL	NIL	NIL

Table 2
RO Brine Data
(provided by Sarvajal)

North Gujarat - Manorpur

	Source Water	Between Media and Carbon Filters	Before RO	After RO	Reject
Water properties (at inlet)					
* pH	7.52	7.57	7.55	7.07	7.57
* Temperature	-	-	-	-	
* TDS (ppm)	370	350	370	108	540
* TSS (ppm)	-	-	-	-	
* Hardness (ppm)	185	185	185	62	285
* Turbidity (NTU)	Nil	Nil	Nil	Nil	
* Color (Hazen units)	Clear	Clear	Clear	Clear	Clear
* BOD (ppm)	-	-	-	-	
* COD (ppm)	-	-	-	-	
Minerals / metals					
* Fluoride (ppm)	1.1	1.1	1.1	Nil	1.3
* Arsenic (ppm)	-	-	-	-	
* Iron (ppm)	-	-	-	-	
* Calcium (ppm)	70	60	70	20	95
* Magnesium (ppm)	3	9	3	3	12
* Copper (ppm)	-	-	-	-	
* Mercury (ppm)	-	-	-	-	
and others					
Electrical Conductivity	480	460	480	140	700
Turbudity	Nil	Nil	Nil	Nil	NIL
Sodium	23	19	23	4	28
Potassium	1	1	1	Nil	1.4
Carbonate	Nil	Nil	Nil	Nil	NIL
Bi-Carbonate	244	232	244	73	366
Sulphate	NIL	NIL	NIL	NIL	NIL
Chloride	24	24	24	8	32
Nitrate	2.3	2.3	2.3	Nil	3.2
Alkalinity	195	185	195	58	295
Odour	NONE	NONE	NONE	NONE	NONE
Coliforms	NIL	NIL	NIL	NIL	NIL

Table 2
RO Brine Data
(provided by Sarvajal)

North Gujarat - Samlaji

	Source Water	Between Media and Carbon Filters	Before RO	After RO	Reject
Water properties (at inlet)					
* pH	7.34	7.39	7.37	7.03	7.47
* Temperature	-	-	-	-	
* TDS (ppm)	515	515	530	101	850
* TSS (ppm)	-	-	-	-	
* Hardness (ppm)	250	235	250	75	425
* Turbidity (NTU)	Nil	Nil	Nil	NIl	
* Color (Hazen units)	clear	Clear	Clear	Clear	CLEAR
* BOD (ppm)	-	-	-	-	
* COD (ppm)	-	-	-	-	
Minerals / metals					
* Fluoride (ppm)	1.1	1.1	1.1	Nil	1.3
* Arsenic (ppm)	-	-	-	-	
* Iron (ppm)	-	-	-	-	
* Calcium (ppm)	70	65	70	15	115
* Magnesium (ppm)	18	18	18	9	33
* Copper (ppm)	-	-	-	-	
* Mercury (ppm)	-	-	-	-	
and others					
Electrical Conductivity	720	720	730	150	1190
Turbudity	Nil	Nil	Nil	Nil	NIL
Sodium	52	55	52	NIL	76
Potassium	2.2	2.2	2.2	Nil	3.4
Carbonate	Nil	Nil	Nil	Nil	NIL
Bi-Carbonate	268	268	281	61	439
Sulphate	22	22	21.6	Nil	48
Chloride	80	80	80	16	128
Nitrate	2.6	2.8	2.8	Nil	3.9
Alkalinity	215	215	225	49	350
Odour	NONE	NONE	NONE	NONE	NONE
Coliforms	NIL	NIL	NIL	NIL	NIL

Table 2
RO Brine Data
(provided by Sarvajal)

Rajasthan - Vrindavan

	Source Water	Between Media and Carbon Filters	Before RO	After RO	Reject
Water properties (at inlet)					
* pH	7.45	8.12	7.43	7.1	7.73
* Temperature					
* TDS (ppm)	600	590	590	162	1010
* TSS (ppm)					
* Hardness (ppm)	310	310	310	112	525
* Turbidity (NTU)	NIL	NIL	NIL	NIL	NIL
* Color (Hazen units)	CLEAR	CLEAR	CLEAR	CLEAR	CLEAR
* BOD (ppm)					
* COD (ppm)					
Minerals / metals					
* Fluoride (ppm)	1.2	1.2	1.2	NIL	1.45
* Arsenic (ppm)					
* Iron (ppm)					
* Calcium (ppm)	50	50	50	20	75
* Magnesium (ppm)	45	45	45	15	81
* Copper (ppm)					
* Mercury (ppm)					
and others					
Electrical Conductivity	900	890	890	250	1520
Turbudity	NILL	NIL	NIL	NIL	NIL
Sodium	62	59	59	6	107
Potassium	2.8	2.8	2.8	NIL	2.6
Carbonate	NILL	NIL	NIL	NIL	NIL
Bi-Carbonate	256	256	256	73	427
Sulphate	48	43	43	NIL	98
Chloride	128	128	128	48	208
Fluoride	1.2	1.2	1.2	NIL	1.45
Nitrate	5.9	6.2	6.2	NIL	9.5
Alkalinity	205	205	205	58	340

Table 2
RO Brine Data
(provided by Sarvajal)

Rajasthan - Anyol

	Source Water	Between Media and Carbon Filters	Before RO	After RO	Reject
Water properties (at inlet)					
* pH	7.64	7.65	7.65	7.09	7.82
* Temperature					
* TDS (ppm)	2520	2540	2460	136	4090
* TSS (ppm)					
* Hardness (ppm)	935	935	910	88	1500
* Turbidity (NTU)	NIL	NIL	NIL	NIL	NIL
* Color (Hazen units)	CLEAR	CLEAR	CLEAR	CLEAR	CLEAR
* BOD (ppm)					
* COD (ppm)					
Minerals / metals					
* Fluoride (ppm)	1.7	1.7	1.7	NIL	2.4
* Arsenic (ppm)					
* Iron (ppm)					
* Calcium (ppm)	200	210	200	30	365
* Magnesium (ppm)	105	99	99	3	141
* Copper (ppm)					
* Mercury (ppm)					
and others					
Electrical Conductivity	3850	3840	3740	220	6170
Turbudity	NIL	NIL	NIL	NIL	NIL
Sodium	451	449	437	10	724
Potassium	5.5	5.5	5.3	NIL	9.1
Carbonate	NIL	NIL	NIL	NIL	NIL
Bi-Carbonate	842	903	842	37	1403
Sulphate	146	147	147	NIL	247
Chloride	744	704	704	56	1152
Fluoride	1.7	1.7	1.7	NIL	2.4
Nitrate	22	22	22	NIL	43
Alkalinity	675	725	675	30	1125

Table 2
RO Brine Data
(provided by Sarvajal)

Rajasthan - Gothda

	Source Water	Between Media and Carbon Filters	Before RO	After RO	Reject
Water properties (at inlet)					
* pH	7.73	7.55	7.64	7.03	7.82
* Temperature					
* TDS (ppm)	3350	2900	3090	132	3970
* TSS (ppm)					
* Hardness (ppm)	2575	2200	2425	38	3000
* Turbidity (NTU)	NIL	NIL	NIL	NIL	NIL
* Color (Hazen units)	CLEAR	CLEAR	CLEAR	CLEAR	CLEAR
* BOD (ppm)					
* COD (ppm)					
Minerals / metals					
* Fluoride (ppm)	1.4	1.25	1.4	NIL	1.55
* Arsenic (ppm)					
* Iron (ppm)					
* Calcium (ppm)	720	625	660	10	840
* Magnesium (ppm)	186	153	186	3	216
* Copper (ppm)					
* Mercury (ppm)					
and others					
Electrical Conductivity	5470	4730	5150	190	6490
Turbudity	NIL	NIL	NIL	NIL	NIL
Sodium	70	71	66	26	109
Potassium	5.5	4.8	5.2	NIL	6.5
Carbonate	NIL	NIL	NIL	NIL	NIL
Bi-Carbonate	366	305	183	61	512
Sulphate	1052	936	147	NIL	1092
Chloride	880	744	880	56	1120
Fluoride	1.4	1.25	1.4	NIL	1.55
Nitrate	64.2	54.1	59.2	NIL	68.2
Alkalinity	295	245	150	49	410

Table 2
RO Brine Data
(provided by Sarvajal)

Rajasthan - Laxmangarh

	Source Water	Between Media and Carbon Filters	Before RO	After RO	Reject
Water properties (at inlet)					
* pH	7.64	8.3	7.58	7.01	7.66
* Temperature					
* TDS (ppm)	3290	3220	3230	103	5150
* TSS (ppm)					
* Hardness (ppm)	860	875	860	38	1500
* Turbidity (NTU)	NIL	NIL	NIL	NIL	NIL
* Color (Hazen units)	CLEAR	CLEAR	CLEAR	CLEAR	CLEAR
* BOD (ppm)					
* COD (ppm)					
Minerals / metals					
* Fluoride (ppm)	1.55	1.55	1.55	NIL	1.75
* Arsenic (ppm)					
* Iron (ppm)					
* Calcium (ppm)	125	130	135	10	210
* Magnesium (ppm)	132	132	126	3	234
* Copper (ppm)					
* Mercury (ppm)					
and others					
Electrical Conductivity	5050	4970	4960	150	7960
Turbudity	NIL	NIL	NIL	NIL	NIL
Sodium	761	736	740	17	1134
Potassium	7.1	7	7	NIL	11.3
Carbonate	NIL	12	NIL	NIL	NIL
Bi-Carbonate	769	756	756	49	1318
Sulphate	609	561	576	NIL	729
Chloride	824	824	824	24	1424
Fluoride	1.55	1.55	1.55	NIL	1.75
Nitrate	61.5	61.5	61.4	NIL	83.6
Alkalinity	615	625	605	39	1055

Table 2
RO Brine Data
(provided by Sarvajal)

Rajasthan - Rollsahabsar

	Source Water	Between Media and Carbon Filters	Before RO	After RO	Reject
Water properties (at inlet)					
* pH	7.41	8.11	7.37	7.01	7.55
* Temperature					
* TDS (ppm)	3160	3170	3150	120	4880
* TSS (ppm)					
* Hardness (ppm)	460	460	510	25	640
* Turbidity (NTU)	NIL	NIL	NIL	NIL	NIL
* Color (Hazen units)	CLEAR	CLEAR	CLEAR	CLEAR	CLEAR
* BOD (ppm)					
* COD (ppm)					
Minerals / metals					
* Fluoride (ppm)	1.35	1.35	1.4	NIL	1.55
* Arsenic (ppm)					
* Iron (ppm)					
* Calcium (ppm)	35	30	40	5	40
* Magnesium (ppm)	90	93	99	3	129
* Copper (ppm)					
* Mercury (ppm)					
and others					
Electrical Conductivity	4620	4630	4610	170	7100
Turbudity	NIL	NIL	NIL	NIL	NIL
Sodium	845	848	820	28	1333
Potassium	7.5	7.5	7.5	NIL	11.5
Carbonate	NIL	NIL	NIL	NIL	NIL
Bi-Carbonate	915	915	915	61	1525
Sulphate	638	643	634	NIL	803
Chloride	600	600	600	24	1000
Fluoride	1.35	1.35	1.4	NIL	1.55
Nitrate	29.1	28.9	28.9	NIL	33.2
Alkalinity	735	735	735	49	1220

Table 2
RO Brine Data
(provided by Sarvajal)

Rajasthan - Ramgarh (Alwar)

	Source Water	Between Media and Carbon Filters	Before RO	After RO	Reject
Water properties (at inlet)					
* pH	7.48	8.06	7.46	7.02	7.84
* Temperature					
* TDS (ppm)	3410	3440	3490	170	4740
* TSS (ppm)					
* Hardness (ppm)	1425	1475	1410	25	2125
* Turbidity (NTU)	NIL	NIL	NIL	NIL	NIL
* Color (Hazen units)	CLEAR	CLEAR	CLEAR	CLEAR	CLEAR
* BOD (ppm)					
* COD (ppm)					
Minerals / metals					
* Fluoride (ppm)	1.7	1.75	1.75	NIL	1.9
* Arsenic (ppm)					
* Iron (ppm)					
* Calcium (ppm)	175	180	185	5	240
* Magnesium (ppm)	237	246	228	3	366
* Copper (ppm)					
* Mercury (ppm)					
and others					
Electrical Conductivity	5620	5660	5690	210	7930
Turbudity	NIL	NIL	NIL	NIL	NIL
Sodium	632	618	654	59	839
Potassium	8.8	8.8	8.9	NIL	12.5
Carbonate	NIL	NIL	NIL	NIL	NIL
Bi-Carbonate	549	549	549	61	671
Sulphate	559	633	618	NIL	767
Chloride	1120	1080	1120	40	1680
Fluoride	1.7	1.75	1.75	NIL	1.9
Nitrate	124	124	124	NIL	155
Alkalinity	440	440	440	49	540

Table 2
RO Brine Data
(provided by Sarvajal)

Rajasthan - Choti Pacheri

	Source Water	Between Media and Carbon Filters	Before RO	After RO	Reject
Water properties (at inlet)					
* pH	7.54	8.1	7.52	7.05	7.83
* Temperature					
* TDS (ppm)	3350	3340	3340	280	5320
* TSS (ppm)					
* Hardness (ppm)	535	535	550	38	925
* Turbidity (NTU)	NIL	NIL	NIL	NIL	NIL
* Color (Hazen units)	CLEAR	CLEAR	CLEAR	CLEAR	CLEAR
* BOD (ppm)					
* COD (ppm)					
Minerals / metals					
* Fluoride (ppm)	1.2	1.2	1.22	NIL	1.55
* Arsenic (ppm)					
* Iron (ppm)					
* Calcium (ppm)	140	140	140	10	235
* Magnesium (ppm)	45	45	984	3	81
* Copper (ppm)					
* Mercury (ppm)					
and others					
Electrical Conductivity	5470	5460	5400	440	8750
Turbudity	NIL	NIL	NIL	NIL	NIL
Sodium	1006	1004	984	84	1579
Potassium	8.7	8.7	8.7	NIL	14
Carbonate	NIL	NIL	NIL	NIL	NIL
Bi-Carbonate	366	366	427	61	610
Sulphate	205	200	231	NIL	276
Chloride	1560	1560	1480	120	2520
Fluoride	1.2	1.2	1.22	NIL	1.55
Nitrate	15.7	15.6	15.5	NIL	24.8
Alkalinity	295	295	345	49	488

Table 3
Conventional Brine Disposal Methods

Surface water discharge	The most common method of disposal for concentrated brine streams and the option of choice for locations in coastal regions. Typically transported using a pipeline and deep ocean discharge. For inland locations, truck or rail hauling is not uncommon when pipeline distances are not feasible.
Land (or ground) application	More common method of disposal for inland areas and relatively less concentrated brine streams.
Wastewater collection system discharge	Typically only suitable for low-flow discharges or relatively less concentrated brine streams. Discharge availability for flow rate and brine concentrations depends on ultimate wastewater treatment facility capacity.
Deep-well injection	Typically only used for brackish groundwater areas or other aquifers unsuitable as a drinking water source.
Evaporation ponds	Large surface area is typically required, depending on local weather conditions and evaporation rates.
Thermal evaporation	The most energy-intensive disposal option, however also may be the only option available for many areas.

(also included in report body)

Adapted from: Metcalf and Eddy. Wastewater Engineering: Treatment and Reuse. New York: McGraw Hill, 2002.

Table 4
Franchise Visit Summary

	COCO	Pratapnagar	Sitapura	Mukundgarh	Nawalgarh	Siriyasar Kalan	Mandawa - 2
Date of Visit	NA	7/14/2011	7/14/2011	7/20/2011	7/20/2011	7/27/2011	7/27/2011
Contact during Visit	operator	owner	operator	owner	owner	operator	owner
Location	Bagar	Jaipur	Sitapura	Mukundgarh	Nawalgarh	Siriyasar Kalan	Mandawa
Date of Installation*	NC	2/12/2011	4/27/2011	9/13/2008	7/7/2010	5/25/2010	7/9/2010
No. of Customers	NC	200	NA	200	300	350	240
Customer Frequency	NC	not daily	NA	NC	daily	not daily	most are daily
Delivery or Pickup?	both	delivery	NA	delivery	delivery	delivery	both
Daily Hours of Operation	NC	5	6	8	7-Jun	6-May	6
Involvement at Meetings	NC	NC	NC	sometimes	attended one meeting	yes	sometimes
Product Water (L/day)	NC	NC	NC	NC	NC	NC	NC
Profitability	NC	NC	NC	NC	NC	NC	NC
Largest Expense	NC	NC	NC	NC	NC	NC	NC
Urban, rural, very rural	rural	urban	urban	rural	rural	very rural	rural
Water Source	municipal	borewell	NC	borewell	borewell	borewell	borewell
Average Raw TDS (mg/L)*	NC	550	NC	NC	600	1400	1750
Average Brine TDS (mg/L)#	NC	1100	NC	NC	NC	NC	4500
Past use for Brine	agriculture, algae	agriculture, laundry, mop water, bathing, dish water	wood treatment	window/door frame construction, concrete for septic containers	agriculture	agriculture	agriculture
Current use for Brine	none	agriculture, laundry, mop water, bathing, dish water	wood treatment	window/door frame construction, concrete for septic containers	agriculture	agriculture	agriculture
Future use for Brine	none	same	same	same	same	none	planting trees

*From data provided by Sarvajal.

#Fron data collected during site visits.

NA - not applicable

NC - data not collected

Table 4
Franchise Visit Summary

	Fatehpur - 2	Rollsahabsar	Ramgarh - 1	Ramgarh - 2	Bissau - 2	Chirawa	Choti Pancheri	Singhana-2
Date of Visit	7/27/2011	7/27/2011	7/27/2011	7/27/2011	7/27/2011	8/3/2011	8/3/2011	8/3/2011
Contact during Visit	owner	owner	owner	not present	owner	owner	operator	owner
Location	Fatehpur	Rollsahabsar	Ramgarh	Ramgarh	Bissau	Chirawa	Choti Pancheri	Singhana
Date of Installation*	11/18/2009	4/1/2009	1/28/2009	11/3/2010	6/4/2010	8/21/2008	2/25/2010	7/27/2010
No. of Customers	225	450	230	--	250	500	200	200
Customer Frequency	NC	NC	NC	--	NC	NC	daily	unknown
Delivery or Pickup?	delivery	delivery	delivery	--	delivery	deliver	self serve	delivery
Daily Hours of Operation	NC	7-Jun	NC	--	7-Jun	12	NC	NC
Involvement at Meetings	NC	no	rarely	--	yes	yes	NC	yes
Product Water (L/day)	NC	NC	NC	NC	NC	5000	3000	2000
Profitability	NC	NC	NC	NC	NC	yes	NA	no
Largest Expense	NC	NC	NC	NC	NC	electricity (6rps/unit)	electricity (2rps/unit)	delivery expenses and electricity
Urban, rural, very rural	urban	rural	rural	urban	rural	rural	rural	very rural
Water Source	borewell	borewell	borewell	--	borewell	borewell	borewell	borewell
Average Raw TDS (mg/L)*	1300	2000	1600	--	1900	700	2500	1300
Average Brine TDS (mg/L)#	NC	NC	NC	NC	NC	1500	unknown	3000
Past use for Brine	wash cars and floors, discharge to sewer	agriculture	concrete brick making	--	agriculture	agriculture, ice making	recharge well	agriculture
Current use for Brine	wash cars and floors, discharge to sewer	none	none	none	none	agriculture, ice making	recharge well	agriculture
Future use for Brine	trucking to city	none	none	--	none	same	same	same

*From data provided by Sarvaja

#Fron data collected during site

NA - not applicable

NC - data not collected

Table 4
Franchise Visit Summary

	Copper-1	Gothara	Mandrela	Malsisar	Sadulpur	Rajgarh	Taranagar
Date of Visit	8/3/2011	8/3/2011	8/3/2011	8/3/2011	8/3/2011	8/3/2011	8/3/2011
Contact during Visit	operator	owner	operator	owner	owner	owner	owner
Location	Copper	Gothara	Mandrela	Malsisar	Sadulpur	Rajgarh	Taranagar
Date of Installation*	11/27/2009	2/27/2011	2/21/2009	12/28/2011	unknown	1/18/2010	10/15/2009
No. of Customers	600	150	200+	150	unknown	150	400
Customer Frequency	unknown	daily	daily	daily	unknown	daily	daily
Delivery or Pickup?	both	both	mostly pickup	delivery	NC	all delivery	both
Daily Hours of Operation	NC	NC	NC	NC	NC	NC	NC
Involvement at Meetings	NC	no	yes	NC	no	NC	no
Product Water (L/day)	8,000-10,000	3,000	1,000	2,000	1,000	1,500	4,000
Profitability	no	no	yes	yes	NC	yes	yes
Largest Expense	labor and staff	electricity (5rps/unit)	electricity (5rps/unit)	electricity (5rps/unit)	electricity	electricity	delivery expenses and electricity
Urban, rural, very rural	rural	rural	rural	rural	rural	rural	rural
Water Source	municipal	borewell	borewell	borewell	borewell	borewell	borewell
Average Raw TDS (mg/L)*	1,100 -1,800	2,500	1,500	2,200	1,400	750	500
Average Brine TDS (mg/L)#	unknown	5,000	unknown	2,700	unknown	unknown	1,100
Past use for Brine	sewer discharge	agriculture, toilet	sewer discharge	recharge pit	recharge pit	ground application	ground application
Current use for Brine	sewer discharge	agriculture, toilet	sewer discharge	recharge pit	recharge pit	none	none
Future use for Brine	same	same	agriculture	same	agriculture	same	same

*From data provided by Sarvaja
#Fron data collected during site
NA - not applicable
NC - data not collected

Table 5
Recommended Analytical Parameters

General Parameters
pH
Temperature
Electrical Conductivity
Total Dissolved Solids
Total Suspended Solids
Colour
Odour
Turbidity
Total Coliforms
Metals and Minerals
Total Alkalinity
Total Hardness
Arsenic
Barium
Bicarbonate
Cadmium
Calcium
Carbonate
Chloride
Copper
Fluoride
Iron
Lead
Magnesium
Mercury
Potassium
Silica
Sodium
Zinc
Nutrients
Total Kjeldahl Nitrogen
Nitrate
Sulfate
Total Coliforms
Biological Oxygen Demand
Chemical Oxygen Demand