Decentralized Water Treatment in Urban India, and the Potential Impacts of Reverse Osmosis Water Purifiers

by

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Submitted to the Faculty in partial fulfillment of the requirements for the degree of

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Abstract

The degrading water quality in India combined with reduced groundwater supplies and insufficient municipal water distribution has led to the adoption of household water purifiers across the country. These water purifiers are used to treat water for potable consumption (drinking and cooking), and include a range of technologies capable of treating contaminants found in municipal water, groundwater, or other supplemental sources. The purifiers vary in cost, and have varying levels of accessibility to different socio-economic groups. As of 2010, market studies estimated that water purifiers, and more specifically reverse osmosis (RO) units, had not yet achieved a high level of diffusion across India, though sales were projected to greatly increase. More recent studies found levels of adoption for RO purifiers in certain urban areas growing above 50%, much higher than the 10% or less of households relying primarily on groundwater. Interviews conducted in January 2016 confirmed that households with a municipal supply were treating their water with RO purifiers, so RO adoption has spread beyond homes with only groundwater as a source.

Though increased RO system diffusion may increase access to improved water quality, the purifiers require a reject line that discards 30 to 80% of the input water. The waste generated can be substantial, and for an average RO recovery of 20% treating 5.0 liters per capita per day drinking water, total up to 100 liters per household per day, 82.2 megaliters per day (MLD) within the city of Delhi, or even 2,340 MLD across all major urban areas of India if complete adoption occurs within the top two socio-economic groups. These volumes can amount to a measurable fraction of the volume of groundwater that a city extracts to supplement its surface water supply, and the volume of wastewater that goes untreated due to insufficient infrastructure. Policy and technology-based alternatives such as a water efficiency ranking program and the replacement of RO with electrodialysis, a more efficient desalination technology, align with government initiatives calling for higher efficiency and public participation, though a combined program is likely needed to make household water treatment sustainable in the long-term.

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This journey began with team ED4India, and I would like to thank my teammates, especially Kishor Nayar, for the enthusiasm and energy put towards this project. In addition, I owe Natasha Wright a huge thank you for introducing us to the challenges of water treatment through desalination in India, and the possibility of change.

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I owe a huge thank you to Sahil Shah for the countless hours preparing for and performing interviews across India so that we could achieve a better understanding of what RO users really need. David Taylor and Dev Ramanujan also played critical roles in improving my understanding of water supply systems in India, as well as how to condense hundreds of interview observations into a succinct list of customer requirements. The team at Tata Projects and Suhail Shaikh from at IIT-Bombay then provided invaluable support through sharing market research data and insights. Aravind Asokan and Gia Medhi were amazing in their introductions to those we later interviewed for RO use or improving our understanding of the cultural factors in our work. For all of the people that welcomed us into their home and even introduced us to friends and family before even meeting us in person, I appreciate every minute you gave us.

To Amos, I cannot thank you enough for giving me the opportunity to work on such a meaningful project, and for supporting me throughout the process. This was an amazing ride, and I could not have done it without the support of my family. To Bernat Olle, Amy, Dan, Fran and Tom O'Connor, I am the luckiest person in the world to have you as my family.

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List of Acronyms

ACA	Adaptive Conjoint Analysis
AMC	Annual Maintenance Contract
ANA	Attribute Non-Attendance
BIS	Bureau of Indian Standards
DCE	Discrete Choice Evaluation
EC	Electrical Conductivity
ED	Electrodialysis
EDR	Electrodialysis Reversal
GPCD	Gallons (United Kingdom) per capita per day
HAM	Hectare Meter
HH	Household
HIG	High Income Group
INR	Indian Rupee
KL	Kiloliter
KW	Kilowatt
LIG	Low Income Group
LPCD	Liters per capita per day
L/HH/D	Liters per household per day
MDGs	Millennium Development Goals
MIG	Medium Income Group
MLD	Megaliter per day
NOC	No-objection Certificate
N-P	Non-Potable
O&M	Operation and Maintenance
P	Potable
RO	Reverse Osmosis
SEC	Socio-economic Classification
SNA	Stated Attribute Non-Attendance
TDS	Total Dissolved Solids
TERI	The Energy and Resources Institute
UFW	Unaccounted for Water
UF	Ultrafiltration
UV	Ultraviolet Lamp
VOC	Voice of the Customer
WoM	Word of Mouth
WSS	Water and Sanitation Services
WTP	Willingness to Pay

Chapter 1. Introduction

According to the United Nation's 2015 report on the Millennium Development Goals (MDGs), 93% of the population in southern Asia has access to improved water sources, compared to 73% in 1990. The MDG target has been reached 5 years ahead of schedule, though as presented later in the same report, a gap in access was identified between the poor and the rich, and between rural and urban households (United Nations, 2015). Aggregating data, therefore, can lead to overly positive assessments of current conditions at the global level. The same can be true for aggregating data at the country level.

In India, annual renewable groundwater and surface water volumes give the appearance of meeting demand through 2030 or even 2050, though unequal distribution of resources both spatially and temporally has caused shortages in arid regions and in urban areas (2030 Water Resources Group, 2009; Government of India: Planning Commission, 2013). In urban areas especially, it is common for inadequate surface water supplies to be supplemented through increased groundwater extraction to meet demand. Continued extraction of groundwater beyond its renewable volume, however, can have long-lasting effects such as a receding groundwater table and increasing salinity levels when the freshwater-saline interface is reached or salt-water intrusion occurs.

In recent years, urban water supply authorities have taken steps towards actively managing groundwater resources and reducing the amount of new development where groundwater has already been stressed by over-extraction. These conservation practices are limited, however, to areas where municipal supply is available and surface water supply is sufficient, so groundwater extraction continues to occur at both the private and public level, including in areas where groundwater has been degraded (Central Ground Water Authority, 2015b).

Urbanization is set to increase substantially within India through the next twenty-five years. As the population of a city grows faster than its water supply, limits in infrastructure will lead to larger gaps between demand and supply, continuing the norm of intermittent water supply, which cities use as a means of controlling distribution and further reducing the amount of freshwater available per capita (Lee & Schwab, 2005). Figure 1-1 presents the status of

Indian cities in terms of water supply and other factors contributing to the quality of life for its citizens as of 2010. Deficiencies are noted for each key indicator when compared to basic service standards. As municipalities take short-term and long-term measures to increase supply and manage demand, individual households are also adapting, together making millions of independent decisions regarding their water supply that end up indirectly impacting the community at large [(Delhi Jal Board, 2015a; Government of India: Planning Commission, 2013; Rosenberg, Tarawneh, Abdel-khaleq, & Lund, 2007; Srinivasan, Seto, Emerson, & Gorelick, 2013)].

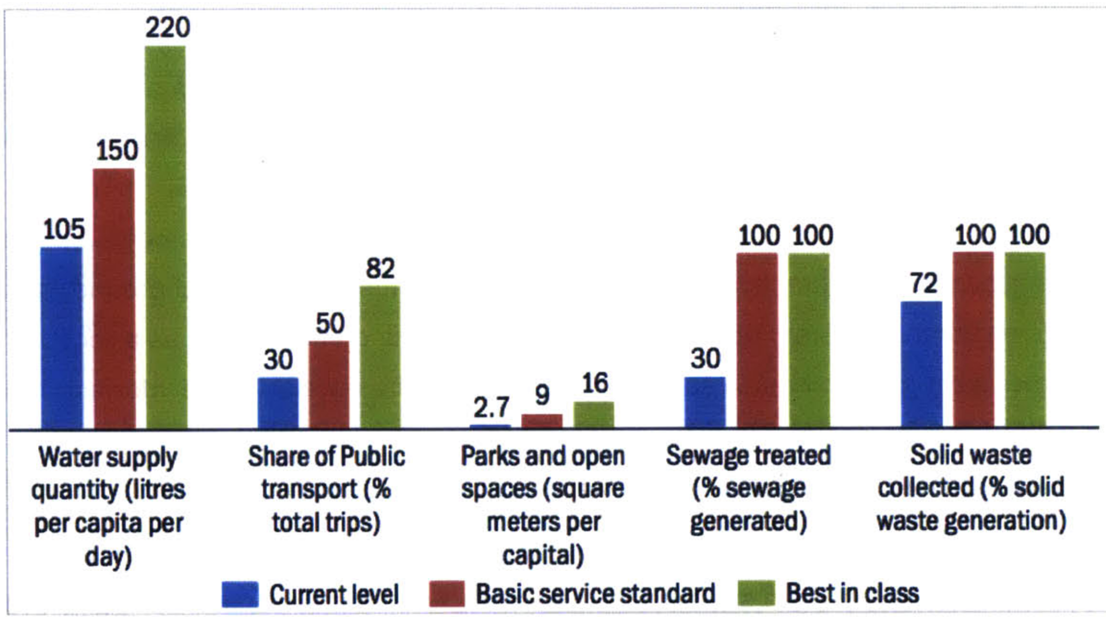

Figure 1-1. Performance of Indian Cities Across Key Indicators of Quality of Life
Source: (The Energy and Resources Institute, 2013))

As households procure supplemental water sources through the installation of private borewells, or the arrangement of private tankers or bottled water deliveries, they are also taking measures to ensure the quality of water consumed within the home is adequate and is protective of their family's health (Rosenberg et al., 2007). Since 1990, decentralized water treatment through the use of household water purifiers has grown substantially, and promises to continue to do so as long as there is risk of contamination to the family's water supply through deteriorating water supplies, inadequate sewerage systems, aging infrastructure, and intermittent operation of municipal water supply distribution networks. The technologies employed in these water purifiers have evolved over time, but the current dominating technology in middle class and upper class households within the urban market is reverse osmosis (RO), a technology that typically produces only 20-40% (with "eco-friendly" systems producing up to 70%) purified water compared to the input volume, and wastes the remainder (Eureka Forbes, n.d.-b; Kent RO Systems Ltd., n.d.-b; Zero B, n.d.). The focus of this evaluation is to look closer at these RO water purifiers, better understand the potential impact of the current level of waste at the household and city level, and explore possible alternatives as the country continues to grow and develop.

1.1 Problem Statement

The intent of this thesis is to better understand the use of these RO-based water purifiers within urban areas of India, and how they may impact residential demand for potable water. The increased demand will be compared to volumes within the overall water balance relating to a city's need for additional water sources and improved coverage of wastewater capture and treatment capabilities.

1.2 Report Organization

This report is organized by first providing an overview of water resources in India in Chapter 2. The different sources are discussed, as well as how cities have managed the supply that is distributed to their constituents. Variation exists in terms of the quantity and quality of water available in different areas of the country. Supplemental sources are then discussed, as there often exists a gap between demand and supply at the homeowner level. Chapter 3 explores domestic water consumption, and compares supply norms with observational data, which are generally much lower than the supply norms. The effects of intermittent supply and customer perception on conservation were found to impact consumption if the supply volume was insufficient, or if households were not directly paying their water bill, as in the case of societies and apartment buildings.

Chapter 4 briefly presents water treatment technologies currently in use at the household level in India. Each of the different technologies has a different set of treatment capabilities, and varying maintenance requirements, though reverse osmosis (RO) is the one technology that requires a reject water line, and wastes anywhere from 30-80% of the input water in the treatment process.

The market for water purifiers is presented in Chapter 5, and a discussion about willingness to pay is included for comparison. Though market reports through 2010 indicate low product diffusion of water purifiers throughout India, significant growth was forecasted, and verified through a summary of studies that looked exclusively at electric water purifiers in urban areas, focusing on Delhi. With recent RO system adoption rates of 45% or higher in medium and high income groups in Delhi, a preference for RO systems was observed beyond the 10% or less of households relying on groundwater as a primary source. A review of willingness to pay (WTP) studies found that households were willing to pay higher tariffs for improved water and sanitation services (WSS), but that significant coping costs were already being spent dealing with insufficient water supply volumes and poor water quality and were considered in total WTP costs. Chapter 6 then presents results from qualitative interviews and a discrete choice evaluation performed in January 2016 on water purifier users in urban areas of India as a means of verifying the market, and further understanding the needs and preferences of the customers with regards to their water treatment equipment. RO users were confirmed to be treating water from municipal sources, as well as from borewells and tankers. Though households were largely unaware of the waste generated by RO systems before purchasing them, there was a significant interest in improving recovery rates within the product price ranges evaluated.

Chapter 7 takes RO use case trends from Chapter 6 and combines them with product information (namely the percent of water recovered from the RO water purifiers currently on the market) and market penetration data to calculate the potential impact from wide-scale adoption of RO systems both at the home level, within a select number of cities (Delhi, Mumbai, Bangalore and Ahmedabad), and then expanded to all of urban India. Volumes were found to be significant, ranging up to 93.2 megaliters per day (MLD) at the city level with full adoption and current RO recovery rates. Compared to the volume of groundwater extracted by municipalities past sustainable levels, and the volume of wastewater that goes untreated due to inadequate infrastructure, these waste volumes could represent a measurable fraction of each.

Chapter 8 uses the results from Chapter 7 to present how a series of policy-based and technology-based alternatives might be structured to reduce the potential impact from RO.

Recent government initiatives were presented that emphasized water conservation through improved efficiencies and public participation. The alternatives presented were each shown to align with the initiatives, though not without certain challenges in implementation. Finally, Chapter 9 provides final conclusions that revisit the impact of RO diffusion, considering it is not limited to households relying on groundwater for their potable water, and encourages the use of a combined policy and technology-based approach to achieve a more sustainable future. Additional work is also recommended in order to verify calculated volumes and better understand the hierarchy of stakeholder requirements, so that future programs can have a higher chance of success.

Throughout the report, data from publicly available government documents and public and private studies are used to support the evaluation. Additional calculations and rationale are then provided in a series of appendices.

Chapter 2. Water Resources in India

The following section first presents an overview of the volume and quality of water resources across India, as well as future projections. The typical urban water supply system is then described, with the different means of distribution. Finally, the water supply systems for four cities visited in January 2016: Delhi, Mumbai, Bangalore and Ahmedabad, are presented for comparison.

2.1 Country Level Water Resources

2.1.1 Sources

India relies on a combination of surface water and groundwater to meet demand from agriculture, industry and domestic uses. In terms of surface water, approximately 4,000 km^3 of precipitation falls in the form of snowfall and rainfall, with approximately 75% of this total from monsoons (Kumar, Singh, & Sharma, 2005). There are over 20 major rivers within India, most of which flow year-round. The total annual utilizable surface water volume, limited by technical, socio-political, and physical restraints, was estimated to be 690 km^3 as of 2005. Groundwater from natural recharge and from recharge augmentation through canal irrigation then provides another 396 km^3 of annual utilizable water. Though annual demand in 2010 was calculated to be approximately 710 km^3, which is less than the theoretical utilizable water supply, certain areas of India have become water stressed, and in some cases the groundwater has been over-exploited (Central Ground Water Board, 2014; Central Water Commission: Water Resources Information System Directorate, 2015; Kumar et al., 2005). Figure 2.1.1-1 and Figure 2.1.1-2 demonstrate the variation in the availability of surface water and renewable groundwater across the country. By reviewing the two maps together, it can be observed that the states located in the western and northwestern regions of the country are low in both surface water and renewable groundwater sources.

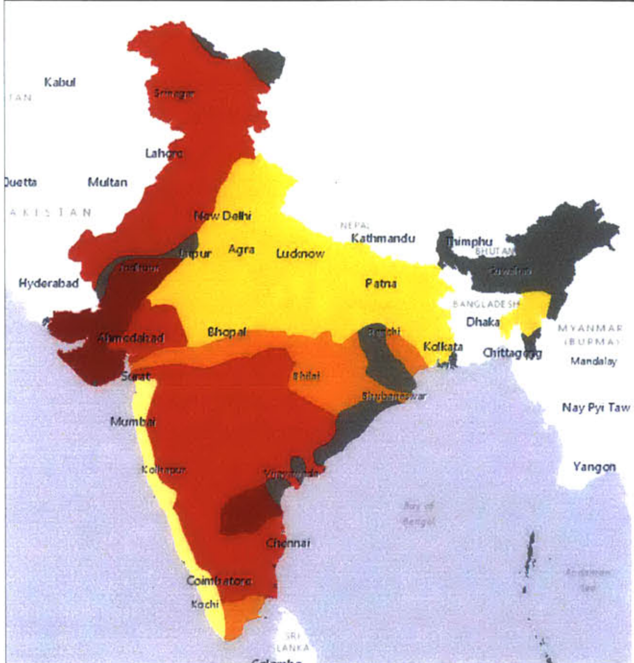

Figure 2.1.1-1. Surface Water Availability

Source: (World Resources Institute, 2016)

Figure 2.1.1-2. Annual Replenishable Groundwater (as of 31-03-2011)

Source: (Central Ground Water Board, 2014)

Surface Water Availability (bin)
Water Availability (m/yr)

- > 1.0 (Very High)
- 0.6 - 1.0 (High)
- 0.4 - 0.6 (Medium)
- 0.1 - 0.4 (Low)
- < 0.1 (Very Low)
- No Data

Annual Replenishable GW (m)

- > 0.5
- 0.25 to 0.5
- 0.15 to 0.25
- 0.1 to 0.15
- 0.025 to 0.1
- <0.025
- Saline
- Not Assessed (Forest/Hilly Area)

2.1.2 Quality

Different types of raw water sources may have pollutants present, as summarized in Table 2.1.2-1. While municipal water suppliers design their water treatment facilities with these parameters and the applicable BIS standards in mind and perform testing to verify compliance, additional contaminants may be introduced during distribution of the treated water (as in the case of direct or indirect exposure to untreated sewage). Contamination may also be present in storage systems at the society or individual home level that have not been fully maintained, and

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this water is not commonly treated prior to arrival at the tap (Kumpel, 2013; Lee & Schwab, 2005; Misra & Goldar, 2008). In addition, families relying on a public or private bore well for water could be susceptible to changes in groundwater quality over time, such as an increase in salinity [measured as total dissolved solids (TDS)] due to over-pumping at depths near the salt-water interface, accumulation from irrigation for agriculture or industrial pollution (California State Water Resources Control Board; Division of Water Quality; GAMA Program, 2010). Figure 2.1.2-1 presents the electrical conductivity concentrations (a surrogate for TDS, with a measurement of 750 μS/cm EC generally equivalent to 480 mg/L TDS) in groundwater across the different regions of India in 2011 (Wright & Winter V., 2014). As shown, a significant area of the country has an EC concentration above 750 μS/cm, which when converted to TDS, is just below the BIS drinking water standard of 500 mg/L, therefore requiring treatment in areas shaded yellow and red on the figure. Additional contaminants in groundwater that often requiring treatment are fluoride, shown in Figure 2.1.2-2, arsenic and nitrate (Central Ground Water Board, 2010; Susheela, 2002).

Table 2.1.2-1. Typical Water Contaminants, by Source

Source Type	Typical Contaminants	Notes
Lakes and Ponds	None if protected and erosion does not take place, otherwise turbidity, carbon dioxide, iron, manganese and on occasions, hydrogen sulfide	Exposure to untreated sewage, short storage periods, and overturning conditions can lead to the presence of additional pollutants
Impounding Reservoirs	Turbidity, carbon dioxide, iron, manganese and on occasions, hydrogen sulfide	Exposure to untreated sewage, short storage periods, and overturning conditions can lead to the presence of additional pollutants
Rivers and Irrigation Canals	Depends on character and area of the watershed; Could include color, turbidity, tastes and odors, hardness, bacterial and other microorganisms	Exposure to untreated sewage can lead to the presence of additional pollutants
Groundwater	Depends on formation; Could include fluorides, salts, carbon dioxide, iron, manganese, hydrogen sulfide, or arsenic	Over-draft from areas adjacent to saline water sources, exposure to untreated sewage, water-logging, and subsurface pollution can lead to the presence of additional pollutants
Collected rainwater	Typically N/A, though collection vessels may be contaminated with microorganisms	

Source: (Central Public Health and Environmental Engineering Organisation, 1999)

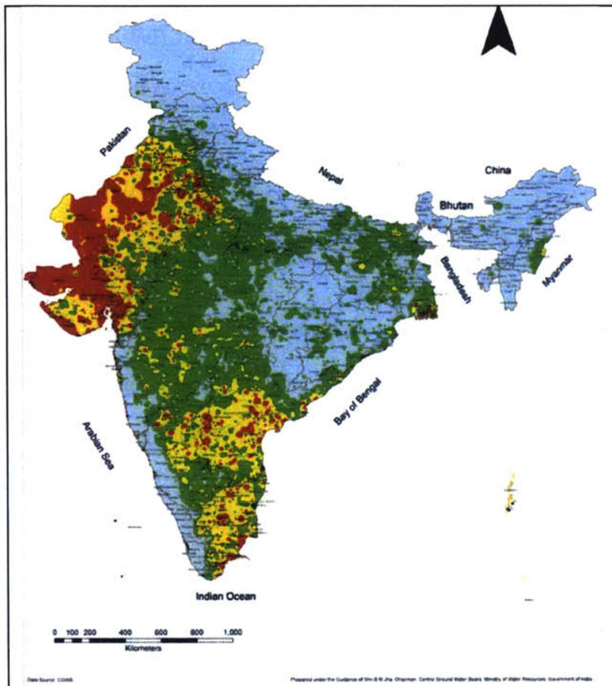

Figure 2.1.2-1. EC Concentrations in Groundwater

Source: (Central Ground Water Board, 2010)

Legend
EC in micro siemens/Cm at 25C
<750
750-1500
1500-3000
>3000
Spot Value >3000
State Boundary
District Boundary
Drainage

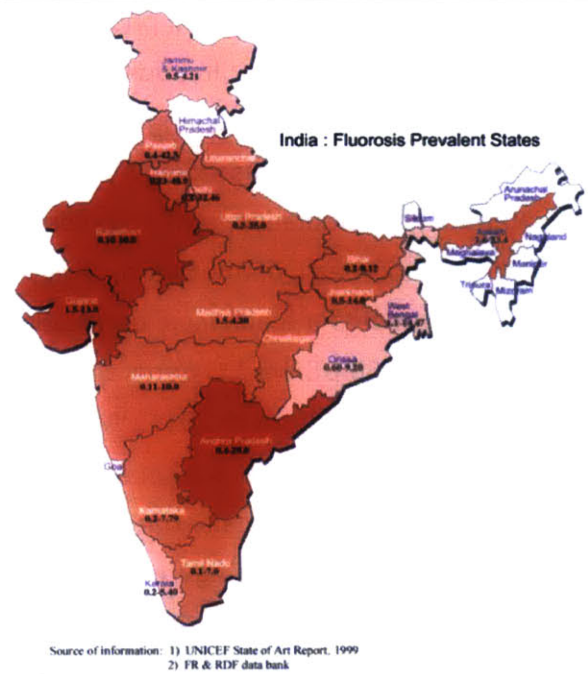

Figure 2.1.2-2. Fluoride Concentrations in Groundwater

Source: (Susheela, 2002)

Legend:
Districts Affected
1 - 40%
40 - 70%
70 - 100%
Not known

2.1.3 Access

According to the 2011 Census of India, approximately 43.5% of households in India (70.6% in urban areas, and 30.8% in rural areas) identified tap water as their main source of water. Data available at the state and union territory level uncovers wide variation in access to tap water, however, with a low of 16.8% urban households and 2.6% rural households (in Lakshadweep and Bihar, respectively). For the remainder of the population that relies on groundwater from private or public borewells, tankers, or other sources of water, availability of water can depend on the condition of the groundwater table and the depth of the well, and the overall demand for water compared to its supply. The per capita volume of water supplied to households throughout India varied significantly in 2001, as summarized in Table 2.1.3-1.

Table 2.1.3-1. Summary of Per Capita water Volume Supplied by State, 2001

State/Union Territory	Water Supply (LPCD)	
	Min.	Max.
Andhra Pradesh	41	131
Assam	77	200
Gujrat	21	157
Karnataka	45	229
Kerala	12	372
Madha Pradesh	28	152
Mizoram	26	280
Maharashtra	32	191
Haryana	30	105
Punjab	42	268
Tamil Nadu	51	106
Uttar Pradesh	63	172
West Bengal	66	237

Source: (Central Pollution Control Board, 2011)

2.1.4 Forecast

Urbanization is set to increase substantially within India through the next twenty-five years (see Figure 2.1.4-1), and the majority of people that migrate to urban areas plan to remain ten years or more (see Figure 2.1.4-2).

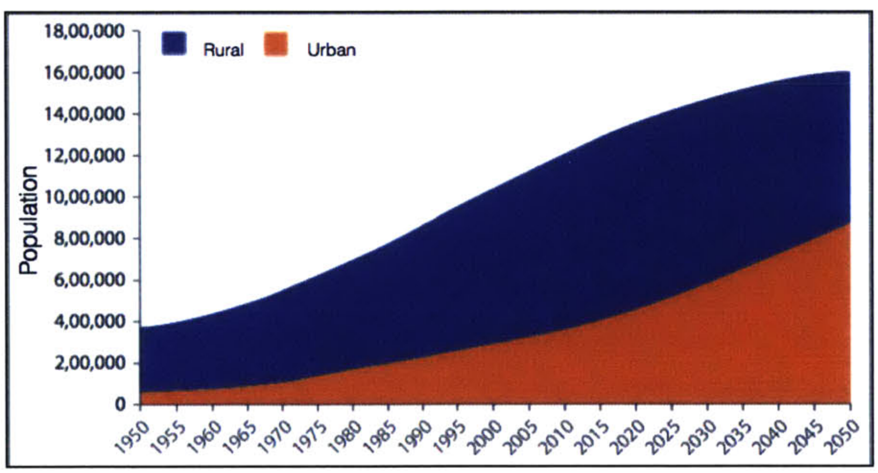

Figure 2.1.4-1. Urban and Rural Population Trends in India, 1950-2050
Source: (World Bank, 2013)

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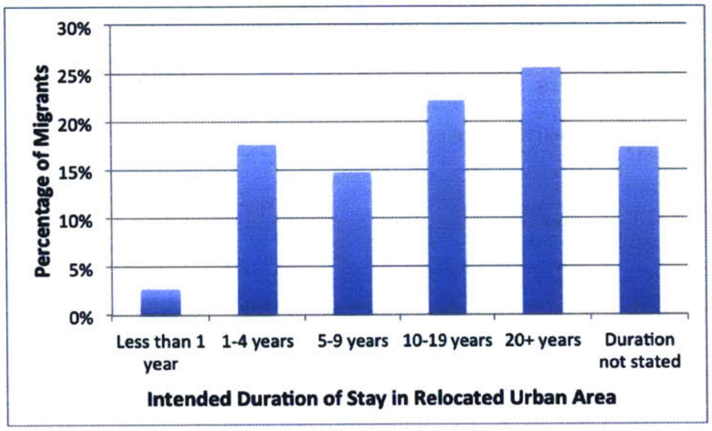


Figure 2.1.4-2. Migrants Classified by Duration of Residence in Places of Enumeration in Urban Areas of India (as per 2001 Census)
Source: (Indiastat, 2001b)

By 2025, India is predicted to be water stressed, with only 1,401 m^3 per capita surface water availability. In addition, the Planning Commission of the Government of India has predicted an increase in annual country-wide demand from 710 km^3 in 2010 to approximately 1180 km^3 in 2050, as domestic and industrial demand are each anticipated to grow as shown in Figure 2.1.4-3 and Figure 2.1.4-4 (Central Pollution Control Board, 2011; Kumar et al., 2005).

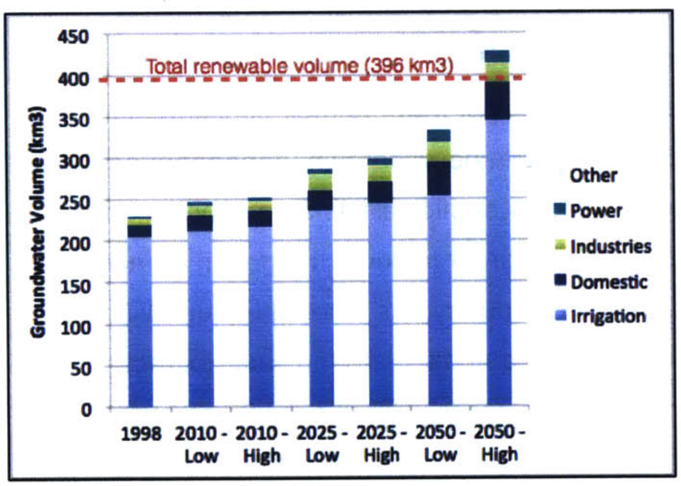


Figure 2.1.4-3. Forecasted Annual Groundwater Consumption, By Use
(Source: (Kumar et al., 2005)**)**

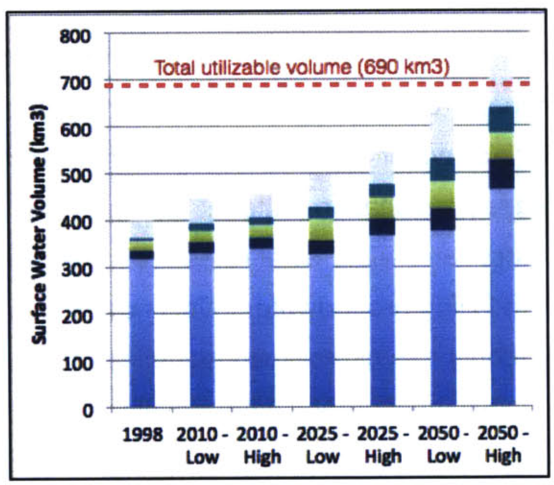


Figure 2.1.4-4. Forecasted Annual Surface Water Consumption, by Use
(Source: (Kumar et al., 2005)**)**

Though the estimated total renewable groundwater volume and total utilizable surface water volumes are in aggregate shown to be sufficient until 2050 (under the high growth scenario), it should be noted that these numbers look at India as a whole. Since distribution of these resources is not equal throughout the country, certain areas are already experiencing shortages.

2.2 Urban Water Supply

2.2.1 Municipal Corporation Water

Supply

Across urban centers of India, water is primarily provided to households by municipal governments through their respective distribution networks. According to the Indian Census of 2011, 70.6% of urban households have access to water at the tap within the premises of their home, 87.8% of which have treated water. The remaining population relies on well water (6.2%), a handpump or tubewell (20.8%), or other sources of water (2.5%) (Census of India, 2011a). The distribution of households with tap water (typically referred to as "corporation water" or "municipal water") varies by state, by city, even by neighborhood within a city, depending on the infrastructure that is in place and the characteristics of the utility's water supply.

A city's location and proximity to water resources will dictate whether they will rely primarily on surface water or groundwater to supply municipal water to their constituents. Surface water sources tend to be limited in volume that can be withdrawn, dependent on the year's precipitation pattern. Groundwater is often used by municipalities as a supplemental source, and withdrawal rates are increased as needed in order to cover the gap in demand. With falling groundwater levels now common across the country, the Central Ground Water Authority has established guidelines for the evaluation of proposed groundwater extraction that prohibits new groundwater development in over-exploited areas without specific permission approval only considered if a no objection certificate (NOC) has been obtained. The NOC approval is based on review, but will only be allowed in areas where municipal supply water is otherwise unavailable, and will be terminated once access to municipal water is provided. Conservation activities such as rainwater harvesting and recycling and reuse for non-domestic purposes are becoming required for new construction, and a condition of obtaining the NOC (Central Ground Water Authority, 2015b).

As cities look towards the future with a limitation on groundwater expansion despite rising urbanization, additional surface water sources – in some cases outside the city limits – are sought out for integration into their network. Table 2.2.1-1 identifies several cities that are evaluating supplemental water sources over 100 km in distance from the end-users. With increased distances comes an increase in cost of transmission, and the need to further raise municipal water tariffs in order to recover the cost of operation.

Table 2.2.1-1. Summary of Surface Water Supply Extension Projects

City	Raw Water Source	Distance (Km)
Ahmedabad	River Sabarmati (Dharoi Dam)	150
Bangalore	River Cauvery (K.R. Sagar)	100
Chennai	River Krishna 9Telugu Ganga)	400
Delhi	River Bhagirathi (Tehri Dam)	250
	Renuka Dam (Planning Stage)	280
	Kishau Dam (Planning Stage)	280
Hyderabad	River Krishna (Nagarjunasagar)	160
Mumbai	Bhasta Dam	54

Source: (Central Pollution Control Board, 2008)

24/7 Water Supply

To make water available at the tap on a continuous (or "24/7") basis, a water storage system is often installed, either informally within the home using buckets or other water storage containers, or at a larger scale incorporating an underground tank and/or overhead tanks, and a booster pump. With the more formal storage system, the underground tank is filled while the municipal supply is "on" (which can be once or twice a day) using a suction pump, then water is pumped to the overhead tank, which is connected to the home's tap. As water is needed throughout the day, it is accessed from the overhead tank. When municipal water is available next, water is again collected to fill the underground tank, and the process repeats. During the January 2016 interviews (discussed in more detail in Chapter 6), several respondents referred to the municipal supply cycle, and for some, the schedule was consistent, but for others the time of day varied to reduce illegal consumption. In all cases, the sump pump was manually turned on/off by either a family member (in the case of stand-alone homes), or maintenance staff (in the case of households living in a flat). For households connected to an intermittent municipal line without the outdoor tank collection system, a family member would manually fill vessels from the tap while the municipal line was open for use throughout the day.

2.2.2 Supplemental Sources

Having continuous access to municipal water may still not ensure a household has sufficient volume to meet its demand (consumption is discussed more in Chapter 3). Depending on the perceived gap in supply and their economic status, households may also seek an additional water source for potable and/or non-potable uses. Bottled jugs, tanker trucks and borewells are some of the options available (Rosenberg et al., 2007; Saleth & Dinar, 2001).

Bottled Water

Bottled water jugs 20L in size are available for on-demand water supply for a fee that ranges from INR 30-80 per jug, including home delivery (WaterBot Online Solutions Pvt Ltd, n.d.). Prices vary by brand and region and some subjects interviewed in January 2016 indicated they had experienced a delay in delivery of one or more days during periods of high demand. Bottled water is typically purchased for potable uses only, and depending on the household's preference and availability of alternatives, it may only be used for drinking, relying on another source of water for the household's cooking needs. With significant sales recorded by the country's number one bottled water brand, Bisleri, has come a surge in unbranded bottled water vendors (Indiastat, n.d.). Uncertainty in the sourcing and treatment operations associated with these vendors has led to a perception that the water quality of bottled water cannot be trusted, in some cases leading to homeowners providing further purification in the home prior to consumption.

Tanker Water

Tanker water is another option homeowners have for on-demand water during periods of insufficient municipal supply. Tanker water can be sourced from surface water bodies, or groundwater, and can be controlled by municipalities or private vendors. The cost per delivery depends on location, the size of the truck, the volume needed (anywhere from 1,000L to

10,000L), and the purpose (regular supply vs. a special event such as a wedding) (Lasania, 2014; Subramanian, 2012). Except for special events, tanker water is generally used for non-potable or combined potable and non-potable use in the home, as temporary storage system is required for its use and not all households have separate tanks for different sources of water. The quality of tanker water is perceived to be low, as indicated by subjects interviewed in January 2016 that identified tanker water as their primary source. Tanker water is typically treated with a household's water purification system prior to its use for potable consumption.

Private Borewell

In cases where the municipal water supply is unavailable at the time of a home's construction or inadequate to meet a household's anticipated need, installation of a private borewell may be considered. A borewell is a long-term investment that involves significant up-front capital (estimated by Misra and Goldar in Delhi, 2008 as INR 17,000 for the borewell, INR 2,400 for the pump, and INR 1,600 for the overhead tank), but assuming a suitable range in the groundwater depth was incorporated into the design of the well, can provide supply on demand (Misra & Goldar, 2008). It should be noted that depending on the condition of the groundwater in the region, and whether the local governing body has found current groundwater use to be sustainable, a NOC may be required for installation. In addition, the deteriorating quality of groundwater within India's urban areas discussed earlier in Chapter 2 can lead to a household's use of a water purifier for potable uses, or the decision not to install a borewell.

2.3 City Level Data

As mentioned above, evaluating India's water resources in aggregate form present an image of potential future shortages, but no current problems. The following takes a closer look at four cities: Mumbai, Delhi, Bangalore and Ahmedabad, in terms of their demographics, the current water source distribution, capacity and production levels, per capita water supplied as production costs and the average tariff paid. Table 2.3-1 summarizes the conditions of water supply from each city, according to data from a variety of sources, mostly if not entirely based on self-reported values.

Table 2.3-1. Summary of City Level Water Supply Data

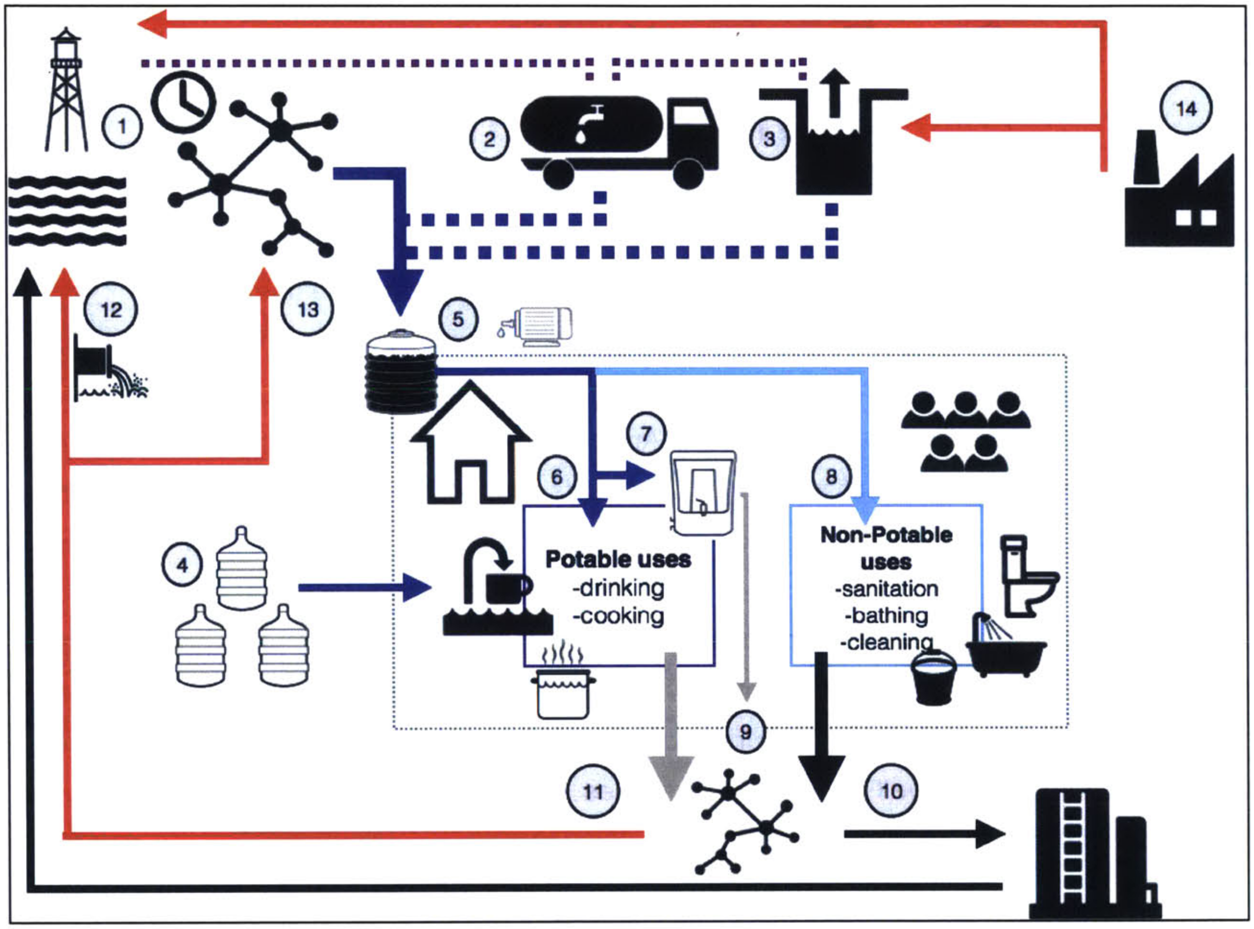
Parameter	Units	Mumbai	Bangalore	Ahmedabad	Delhi	Data Source
Population						
Population (2001)	People	11,914,398	6,523,110	-	13,782,976	(1)
Population (2011)	People	12,442,373	9,621,551	7,214,225	16,368,899	(2)
Avg Production (2005-2006)	MLD	3200	923	624	-	(3)
WTP Installed Capacity						
(2011)	MLD	3128	900	-	2118	(1)
(2015)	MLD	-	-	-	3423	(4)
Service coverage	%	100%	92.9%	74.5%	-	(3)
	%				81.9%	(4)
Water Available (time)	hrs/day	4	4-5	2	-	(3)
	hrs/day	-	-	-	4	(5)
UFW Estimate	%	13.6%	45.1%	-	-	(3)
	%	-	-	-	40.0%	(6)
Surface water %	%	100%	100%	93%	-	(3)
	%	-	-	-	90%	(4)
Groundwater %	%	Nil	Nil	7%	-	(3)
	%	-	-	-	10%	(4)
Per Capita Water Supply						
(Mar 2001)	LPCD	168	80	Not incl.	180	(7)
(Nov 2003)	LPCD	268	141	139	218	(8)
(2005-2006)	LPCD	191	74	171	-	(3)
(2011)	LPCD	263	138	-	154	(1)
Unit Production Cost	Rs/m3	3.67	10.1	1.31	-	(3)
Average Tariff	Rs/m3	4.6	20.6	1.34	-	(3)
	Rs/m3	-	-	-	4.39	(9)

Sources:
(1): (Central Pollution Control Board, 2011)
(2): (Indiastat, 2011a, 2011b, 2011c, 2011d)
(3): (Asian Development Bank, 2007)
(4): (Government of NCT of Delhi, 2015a)
(5): (The World Bank, 2006)
(6): (Government of NCT of Delhi, 2015b)
(7): (Indiastat, 2001a)
(8): (Indiastat, 2003)
(9): (Delhi Jal Board, 2015b)

Chapter 3. Domestic Water Consumption

Domestic water consumption varies based on several factors including but not limited to, household size, convenience, the season, climate, cultural habits and the use of water-consuming appliances (Andey & Kelkar, 2009; Inocencio, Padilla, & Javier, 1999). In addition, the availability of a household's water supply (in terms of volume and timing) and the quality of the water will also impact consumption levels (Andey & Kelkar, 2009; Rosenberg et al., 2007). Figure 3-1 illustrates the domestic water system, and its connections to infrastructure beyond the home (see legend for a description by number of each element, as well as the meaning of the color-coded lines).

The following provides several methods of estimating water consumption per household, splitting the volume between potable and non-potable uses. Theoretical values of minimum demand are presented first, then measured consumption values from studies within India and beyond are presented, as well as a review of studies evaluating the impact of intermittent supply and conservation efforts on consumption.



Legend

- Potable water (primary)
- Potable water (secondary)
- Non-potable water
- Source for tanker water
- Kitchen drain
- Other domestic drain
- Possible contamination

1. Municipal water supply
2. Water tanker supply
3. Borewell supply
4. Bottled water supply
5. Household storage
6. Pot. supply, untreated to tap
7. Pot. supply to water purifier
8. Non-potable supply
9. Domestic wastewater drain
10. Sewage captured and treated
11. Sewage overflow/not captured
12. Untreated discharge of sewage
13. Cross-contamination of pot. supply
14. Potential contamination from industry

Note: Icons sourced from the Noun Project (http://thenounproject.com). See Bibliography for specific references to the creator of each icon.

Figure 3-1. The Domestic Water Supply System, On-Grid Households in Urban India Connected to Municipal Water and Sewer

3.1 Household Water Consumption in India

According to Gleick, the minimum volume of water needed to sustain human life is approximately 50 liters per capita per day (LPCD). Of this total, approximately 5 LPCD is used for drinking and is based on caloric consumption throughout the day, and 10 LPCD for cooking and food preparation. Combined, approximately 15 LPCD (or 30%) of the total consumption is for potable uses, while remaining 35 LPCD is used for non-potable activities including bathing and sanitation (Gleick, 1996).

In urban areas of India, the minimum required daily volume is not representative of the average volume actually consumed. In order to better understand what this volume should be, a review was performed both of water supply norms used in urban areas of India and actual consumption observations from urban households, with volume broken down by activity for each. Table 3.1-1 and Table 3.1-2 provide a summary of the studies reviewed. Since each study referred to the various activities differently, the terminology used in each study was maintained and kept with the corresponding volume. Similar terms were then grouped together when sequencing the data. Drinking and cooking activities were considered to require potable water (and would therefore be treated either with a water purifier or by boiling). The remaining activities were assumed to use non-potable water, with no treatment required for those volumes. When assembling Table 3.1-1 for water supply norms, Gleick's 50 LPCD for meeting basic human needs was included for comparison purposes only, as the CPHEEO and INTACH water supply norms were more than double in volume, and represented households with full flushing sewer systems that were located within a planned colony or an authorized society, and fell within the targeted RO market segment.

As shown in Table 3.1-1, assigning a volume of 5 LPCD for drinking water appears to be standard practice. When accounting for additional water for cooking, or cooking and dishwashing, the volume increases by up to 15 LPCD, though the distinction is not generally made between water used for cooking (which would need to be potable), and water used for washing dishes (which could potentially use non-treated water). The distinction is clear in Table 3.1-2, however, with observations split between cooking and washing dishes or washing utensils. Though drinking and cooking are not always separate, with the exception of the Water

Audit study which measures water running from a tap in the kitchen[1], the volume of water used for drinking only to drinking and cooking ranged only from 3.8 to 7.1 LPCD. Based on this review, an average volume of 5 LPCD produced (treated) water will be assumed for drinking purposes (using Gleick's value as a lower limit), and an average volume of 7 LPCD produced water for combined drinking and cooking purposes. These assumptions are believed to be conservative, given the potential that the volumes observed by Shaban and Ghosh were limited by supply (Andey & Kelkar, 2009). As previously mentioned, water used for washing dishes and utensils, and all other domestic activities are assumed to use untreated, non-potable, water.

Conveyance losses are commonly referred to as unaccounted for water (UFW), and have been a challenge for urban water distribution systems in India, as discussed in Chapter 2. The estimated losses observed and those allocated in the water supply norms presented herein vary in magnitude, though all appear to be low in comparison to the UFW estimated across the country's major cities. As comprehensive metering does not often exist in any of India's urban areas, updates on UFW levels are not commonly available. As a result, for the purposes of the evaluation presented later in Chapter 7, UFW will be excluded from initial calculations, but discussed qualitatively when appropriate.

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[1] According to Shah et al, the measurement of running taps in the kitchen included "water used for rinsing vegetables, dishes, washing hands etc." (p. 2). The value was calculated based on the measured flow rate of the tap (2.83 L/minute), and the average duration the tap was on during the day per person (15 minutes) (Shah, Thakar, & Panda, 2009).

Table 3.1-1. Summary of Water Supply Norms with Breakdown by Activity

Source:	Gleick, Basic Water Requirements for Human Activities: Meeting Basic Needs		CPHEEO Manual on Water Supply & Treatment		INTACH's Holistic Water Policy, Referenced in the Draft Water Policy for Delhi, 2015			
Year:	1996		1999		2013		2013	
Population subgroup:	N/A		Household with full flushing system		Planned Colony in Delhi		Authorized Society in Delhi	
General Activity	**Description**	**LPCD**	**Description**	**LPCD**	**Description**	**LPCD**	**Description**	**LPCD**
Drinking, Cooking & Dish Washing	Drinking	5	Drinking & Cooking	8.1	Drinking	5	Drinking	5
	Cooking & Dish Washing	10	-	-	Cooking & Dish Washing	15	Cooking & Dish Washing	15
Bathing & Sanitation	Bathing & Sanitation	35	Bathing & Flushing	60.8	Bathing	40	Bathing	40
Laundry	-	-	-	-	Laundry	30	Laundry	30
Mopping	-	-	Washing[1]	43.9	Mopping	20	Mopping	20
Garden/Green Space/Public Use	-	-	Garden[1]	22.3	Garden/Green Space/Public	65	Garden/Green Space	40
Conveyance Losses	-	-	-	-	Conveyance Losses, 15%	22.5	Conveyance Losses, 15%	22.5
Other	-	-	-	-	Rounding	2.5	Rounding	2.5
TOTAL		**50**		**135**		**200**		**175**

Notes:

1. Since the CPHEEO breakdown for 135 LPCD was based on percentages and the total slightly exceeded 135 LPCD, 0.5% was deducted from the Washing and Gardening activities.

Sources: (Gleick 1996; Central Public Health and Environmental Engineering Organisation 1999; Delhi Jal Board 2015)

Table 3.1-2. Summary of Water Consumption with Breakdown by Activity

Source:	Water Audit - Need of the Hour; Shah et al, Tata CE		Water Poverty in Urban India: A Study of Major Cities; Shaban, 2008			
Year:	**2009**		**2005**			
Population subgroup:	**Typical Urban Apartment**		**Avg Household (All 7 Cities)**		**Delhi**	**Mumbai**
General Activity	**Description**	**LPCD**	**Description**	**LPCD[2]**	**LPCD[2]**	**LPCD[2]**
Drinking, Cooking & Dish Washing	Running Taps in Kitchen	42.5	Drinking	3.8	3.9	3.8
	-	-	Cooking	2.7	2.9	1.5
	-	-	Washing Utensils	14.9	12.9	15.7
Bathing & Sanitation	Shower & Toilet	107	Bathing & Toilets	44.1	37.6	41.0
Laundry	Laundry	28	Washing Clothes	17.0	11.1	22.0
Mopping	-	-	Cleaning House	6.7	5.5	6.0
Garden/Green Space/Public Use	-	-	-	-	-	-
Conveyance Losses	Leaky Fittings	6.5	-	-	-	-
Other	-	-	Other	2.2	4.4	0.5
TOTAL		**184**		**91.6**	**78**	**90.4**
Standard Deviation		**-**		**51.5**	**49.9**	**32.6**

Source:	Implications of End User Behavior in Response to Deficiencies in water supply for electricity consumption - A Case Study in Delhi; Ghosh, 2016			
Year:	**2014, 2015**			
Population subgroup:	**Organized Housing, HIG**		**MIG**	**LIG**
General Activity	**Description**	**LPCD**	**LPCD**	**LPCD**
Drinking, Cooking & Dish Washing	Drinking & Cooking (Stored)	7.1	6.4	6.1
	Washing dishes	10.1	11.3	11.9
	-	-	-	-
Bathing & Sanitation	Bathing & Toilets	43.7	38.6	38.0
Laundry	Washing Clothes	9.1	10.2	10.8
Mopping	House Cleaning	4.6	4.2	4.1
Garden/Green Space/Public Use	-	-	-	-
Conveyance Losses	-	-	-	-
Other	Other	4.1	4.2	4.2
TOTAL		**78.7**	**74.9**	**75.1**
Standard Deviation		**21.7**	**18.2**	**19.9**

Notes:
* LPCD consumption levels by activity were calculated using the mean total volume consumed, and the average percent of total consumption per day for each activity.

Sources: (Ghosh, Kansal, and Aghi 2016; Shah, Thakar, and Panda 2009; Shaban and Sharma 2007)

3.2 Variation of Household Water Consumption

Water consumption values provided above typically represent the average volume consumed within a subgroup (by city or economic level). As demonstrated by the standard deviation exhibited in Table 3.1-2, variation in this volume exists. In Shaban and Sharma's study alone, of the seven cities surveyed, the average per capita volume ranged from 77 LPCD to over 115 LPCD, with standard deviations that ranged from 32 to 58 LPCD. The impact can also be observed at the household level, with a standard deviation that represented up to 75% of the average household consumption value, suggesting not only a range in consumption, but also in household size. The multi-city study calculates a distribution of households with varying levels of per capita water consumption and as of 2005, a significant amount of households (40%, averaging the cities together) had access to less than 75 LPCD, and 17.5% even had less than 50 LPCD, the assumed minimum standard (Shaban & Sharma, 2007). Since standard consumption and household size values were used to determine the market size in the potential wastage calculations of Chapter 7, it is possible that the number of households was underestimated, and the volume of water consumed was overestimated (though aggregate city supply data would suggest otherwise). To further enforce the range of water consumption, Table 3.2-1 illustrates the range in per capita water supplied by different cities as of 2003.

Table 3.2-1. Per Capita Water Supplied by Select Indian Cities in 2003

City	LPCD	City	LPCD	City	LPCD
Greater Mumbai	268	Nagpur	176	Meerut	185
Kolkata	173	Patna	107	Nashik	140
Delhi	218	Indore	149	Jabalpur	95
Chennai	106	Vadodara	169	Jamshedpur	90
Bangalore	141	Bhopal	180	Asansol	120
Hyderabad	164	Coimbatore	108	Dhanbad	70
Ahmadabad	139	Ludhiana	117	Faridabad	120
Pune	283	Kochi	124	Allahabad	111
Surat	139	Visakhapatnam	131	Amritsar	135
Kanpur	124	Agra	134	Vijayawada	137
Jaipur	170	Varanasi	191	Rajkot	88
Lucknow	164	Madurai	88		

Source: (Indiastat, 2003)

3.3 The Impact of Intermittent Supply on Consumption

The water supply norms values presented in Table 3.1-1 do not distinguish between water supplied during intermittent or continuous supply conditions, though all consumption values in Table 3.2-1 represent conditions where water is supplied for only certain hours of the day. The question then exists whether additional water would have been consumed, had there been more water available. During a study of four Indian cities where water supply could be controlled to be either continuous or intermittent, it was determined that household consumption "depends on the adequacy of water supply" and that if water demand is satisfied under intermittent conditions, "consumption does not appreciably change under continuous water supply" conditions (Andey & Kelkar, 2009, 2555). The volume considered adequate appeared to vary between cities, with all consumption values exceeding the observations from Table 3.2-1, as the range was on average, typically 150 to 250 LPCD, indicating lower water availability may have reduced consumption during those studies, or it could mean that some level of water consumption is shifting from the home to the office (Andey & Kelkar, 2009; Ghosh, Kansal, & Aghi, 2016).

Regardless of the volume consumed, intermittent water has been tied to increased levels of contamination, either within the distribution network due to increased stagnation of water and growth within the pipes or negative pressure during the "off" cycle drawing in microorganisms released to soil surrounding water supply pipes through insufficient wastewater collection and management systems, or within water storage systems that have not been properly maintained (Andey & Kelkar, 2009; Kumpel, 2013; Lee & Schwab, 2005; Misra & Goldar, 2008).

3.4 Trends in Water Consumption Observed Outside of India

The influence of cultural norms was referenced as a factor in water consumption for households within India (Andey & Kelkar, 2009), and until this point water consumption studies referenced above have all taken place within India. Though different cultural practices may be present in other countries, the trends in water consumption are considered for potential relevance now or in the future. To begin, public perception of water consumption was evaluated. In a study performed on households in Australia, the level of water conservation practiced by a household was first related to the type of housing. Individual households that dealt directly with their water bill tended to conserve more water than families living in flats. Households living in flats generally paid fixed-price water charges based on apartment size instead of consumption, and therefore had no financial incentive connected to any water savings the household would have made. When respondents were asked if they would accept a rate increase in order to cover general policies aimed at encouraging water conservation, over 52% disagreed. Of the 30% that did agree, the acceptable increase was limited to 10% or less of the bill, indicating a generally low willingness to pay for encouraging public involvement (Randolph & Troy, 2008).

In another study based on households in 16 villages across China, questionnaires, direct measurements and water diaries were used to compare perceived and actual water consumption. The study found that there was a tendency to overestimate certain water use activities, such as those taking place inside the home, with a slight over estimate applied to water consumed for drinking. Underestimates were then more common for outdoor activities and water taken from the kitchen for non-drinking purposes. Groups that were more accurate with their assumptions tended to be female and/or elderly, and practiced more water conservation measures than those that underestimated consumption. Approximately 70% of the respondent group inaccurately estimated their water use, and the subjects within this group tended to be male, young and educated with a higher income (Fan, Wang, Liu, Yang, & Qin, 2014).

In terms of long-term water consumption, studies have explored the potential correlation between per capita consumption and a country's economic growth. In an evaluation based on the United States, Gleick finds that consumption increases with GDP for a period of time, but at some point the association is decoupled, and consumption either stabilizes, or decreases, with time. Whether this point of change occurs is associated with a limitation of supply, or satisfaction of some maximum level of demand is unknown (Gleick, 1996).

Decreases in per capita consumption may be related to the increased efficiency of appliances as demonstrated in a study evaluating the residential end uses of water in 1999 and 2016 with over 23,000 homes in the US, which found an average household's indoor water consumption decrease of 22% over the 7-year period (Water Resources Foundation, 2016). The survey found that the largest changes were observed in water consumption from clothes washers and toilets, and that additional potential remained as efficiency standards for these and other appliances in the home had not been fully met. The study found that water drawn from faucets (kitchen included) did not significantly change over the course of the comparison timeframe, and this was observed regardless of the presence of a dishwasher.

Finally, an evaluation of per capita water consumption in Singapore over time has demonstrated the success of its pricing and non-pricing water conservation initiatives. Able to slow or reduce increases in consumption originally perceived to be a sign of a growing economy and quality of life, this was demonstrated most recently when an increase in consumption in 1994 per capita values were decreased from approximately 175 LPCD to less than 155 LPCD by 2011. Singapore's program combined education strategies, pricing incentives, and repeated campaigns to stress the importance of water consumption, all while developing a partnership with the citizens of the country with the regulating bodies that manage their water source (Tortajada & Joshi, 2013).

Chapter 4. Household Water Treatment

The domestic market is broken down into non-electric products referred to as "off-line" purifiers, and "on-line" purifiers. On-line purifiers consist of products mostly based on ultraviolet (UV) and reverse osmosis (RO) technologies, though manufacturers have created products that have combined treatment elements such that RO and UV are often both included in a system's treatment configuration. The following provides a brief summary about the operation of each type of purifier, the parameters that are targeted, and the regulatory standards that apply.

4.1 Water Quality Standards

As a means of preventing exposure to harmful levels of pollutants in drinking water, the Bureau of Indian Standards (BIS) created India's drinking water quality criteria. There are two sets of limits in these criteria: the Requirement (Acceptable Limit) values, and the Permissible Limit in the Absence of Alternate Source. These criteria apply to "water intended for human consumption for drinking and cooking purposes from any source, [and] includes water (treated or untreated) supplied by any means for human consumption." (Burean of Indian Standards, 2012, 1). BIS standards exist for physical and chemical parameters, as well as bacteria. Table 4.1-1 summarizes a subset of the BIS standards, including those for TDS, hardness, calcium, fluoride, arsenic and nitrate, which were referenced in the January 2016 interviews.

Table 4.1-1. Subset of Relevant BIS Drinking Water Standards (IS 15000: 2012)

Characteristic	Units	Acceptable Limit	Permissible Limit	Remarks
pH	stu	6.5 – 8.5	No relaxation	-
Total dissolved solids	mg/L	500	2000	Maximum
Calcium (as Ca)	mg/L	75	200	Maximum
Fluoride (as F)	mg/L	1.0	1.5	Maximum
Free residual chlorine	mg/L	0.2	1.0	Minimum
Nitrate (as NO3)	mg/L	45	No relaxation	Maximum
Total hardness (CaCO3)	mg/L	200	600	Maximum
Total arsenic (as As)	mg/L	0.01	0.05	Maximum
E. coli or thermotolerant coliform bacteria	Count	Shall not be detectable in any 100 mL sample		Applies to all water intended for drinking, including within distribution system
Total Coliform bacteria				

Source: (Burean of Indian Standards, 2012)

4.2 Off-line Water Purifiers

Off-line purifiers do not require an active water connection or electricity to operate, and rely on passive treatment through a filter. Water is manually poured into the purifier's input tank, and by way of gravity, water drains through the filter at the outlet of the first tank into the treated water, and is then available for consumption. No water is wasted through the process. The filter elements, or bulbs, are rated for a fixed volume of liters treated (1500L or 3000L in the case of the Tata Swach bulb), and require replacement once that limit is met. The filtration technology used within the bulb was designed to remove bacterial contamination from water, and it is not able to reduce the input water's TDS concentration (Hindustan Unilever Limited, n.d.; Tata Chemicals Ltd., n.d.). Table 4.2-1 summarizes treatment capabilities of non-electric gravity filters compared to the other technologies offered.

Table 4.2-1. Treatment Capabilities by Water Purifier Type

Purifier Type/Mthd	Passive/ Active	Targeted Parameters	Strengths	Limitations
Boiling	Active	Microorgnanisms treated through sterilization	No special equipment required	Ineffective at removing inorganics; high energy intensity
Non-Electric Gravity	Passive	Reduces turbidity, and microorganisms (to varying degrees, by product)	Low cost; no energy or continuous water connection required	Does not reduce TDS level
Ultraviolet (UV)	Active	Destroys microorganisms, viruses and cysts through disinfection	Capable of deactivating cysts in low turbidity water; well established treatment technology in household market segment	Requires prefilter to reduce turbidity; no residual disinfectant; Does not reduce TDS level; requires electricity and a continuous water connection
Reverse Osmosis (RO)	Active	Removes many types of large molecules and large ions (over 0.0001 μm); reduces TDS, hardness, fluoride, and arsenic; capable of treating microorganisms	Perception of giving fresh water which is highly pure and hygienic; often combined with several filtration stages and in some cases UV to provide addition levels of treatment	Pretreatment for chlorine required; High percentage reject water with current designs; requires electricity and a continuous water connection

Source: (AnalyZ Research Solutions Pvt Ltd, 2012; Comprehensive Initiative on Technology Evaluation at MIT, 2015; Eureka Forbes, n.d.-a; United States Environmental Protection Agency, 2006; Verma & Saksena, 2013)

4.3 On-line Water Purifiers

On-line water purifiers require electricity for operation, and are connected directly to the kitchen tap for feed water. Ultraviolet (UV) and reverse osmosis (RO) are the two major on-line treatment technologies.

4.3.1 Ultraviolet Treatment Systems

The first on-line purifier developed was based on UV technology. UV treatment is designed for disinfection, the removal of bacteria from water, and involves the use of a lamp 4 to 11 W in size to kill bacteria (Eureka Forbes, n.d.-a, n.d.-b; Kent RO Systems Ltd., 2016b). UV systems typically include one or more filtration steps in advance of the UV lamp, but do not contain a storage tank. The user must therefore manually turn the system on, collect the treated water in a separate vessel placed below the unit as the system operates, then turn the system off. No water is wasted in the UV process, though similar to water treated by non-electric purifiers, the TDS level is not reduced. BIS specification IS-14724:1999 outlines requirements for water purifiers that include UV disinfection capabilities (Bureau of Indian Standards, 2003). Table 4.2-1 summarizes treatment capabilities of UV water purifiers compared to the other technologies offered.

4.3.2 Reverse Osmosis (RO) Treatment Systems

Home-scale reverse osmosis (RO) treatment systems were introduced to the Indian market by Kent in 1999 (Frost & Sullivan, 2012). RO treatment is designed to reduce TDS, as it targets positively and negatively charged ions in water. The technology operates by applying a pressure on one side of the membrane, treating water as it passes through. Openings in the tightly wound membrane are 0.0001 micron in size, smaller than any other filtration method currently available. A certain volume of input water is withheld during the process, and as it gets concentrated with the rejected salts, is wasted from the system through a separate tube into the user's sink. The treated water is then captured in a storage tank, which the user accesses for potable water. A level switch is often installed within the storage tank and used to turn the system on and off to maintain a preset volume of treated water. The recovery rate of the RO system is calculated as the percentage of input water that is fully treated and available as produced water, and varies with the design. Of the top four RO brands in India, percent recovery varies from the typical 20% level to improved recoveries of "eco-friendly" products ranging from 40 to 70%. Due to the taste variation with different levels of salts (or TDS) in the water, certain RO systems now offer a TDS controller that allows the user to manually adjust the amount of salts that are maintained in the product water (Eureka Forbes, n.d.-b; Kent RO Systems Ltd., n.d.-b; Tata Chemicals Ltd., n.d.; Whirlpool of India Limited, n.d.; Zero B, n.d.). According to the draft[2] BIS specification for RO, the minimum recovery requirement for RO systems is 20%. The specification references pre- and post-RO treatment elements, as well as additional standards that should be met in order for certain water treatment claims to be justified (Bureau of Indian Standards, 2011). Table 4.2-1 summarizes treatment capabilities of RO water purifiers compared to the other technologies offered.

4.4 Water Purifier Features

For all on-line water purifiers, products vary in terms of additional features that can include indicator lights warning of upcoming maintenance requirement or filter malfunction, sounds and/or lights during treatment, see-through covers that allow users to view the system components, storage tank level indicators, post-treatment water quality readings, and more. With over 100 products on the market, brands use these features to distinguish their products from one another. One common approach is to offer products with multi-stage treatment (from the top four water purifier brands, options are available up to fourteen treatment stages). A UV lamp is sometimes installed in RO-based systems directly after the RO membrane as an additional treatment stage; otherwise the stages typically consist of sediment and carbon filters, and ultrafiltration or nanofiltration units (Eureka Forbes, n.d.-b; Kent RO Systems Ltd., n.d.-b).

4.5 After-Sales Service

After-sales service related to UV and RO-based systems include the cleaning or replacement of one or more treatment elements per visit, and are charged either per visit or as a

[2] The author did not have access to the final RO specification at the time of this report.

lump sum for the year. Depending on the technology, service visits are recommended monthly, quarterly, or on a semi-annual basis. The first year of visits is generally covered under the product's warranty, but beyond the first year, the cost can range from INR 1000 to INR 5000 (Kent RO Systems Ltd., 2016a; Whirlpool of India Limited, n.d.). Annual maintenance contracts (AMC) are available from manufacturers, and generally cover both the cost of labor during service visits and replacement parts on a predefined frequency. Additional product element repairs and replacements are not always covered, which can lead to additional fees as the product ages.

Chapter 5. The Water Purifier Market

The intent of this section is to provide an overview of the current water purifier market beginning with an overview, followed by estimates of the market value and number of unit sales, and a closer look at the target RO purifier market characteristics. In the final subsection, the bottled water market is briefly presented, as it has become a competitor of water purifiers in the domestic potable water market.

5.1 Overview of the Market

Small-scale water purifiers have been sold in India since at least 1990. The domestic sector, which is the focus of this study, is the primary market, though additional sales are made to commercial entities for use in hotels, schools, and hospitals. Based on a market research report by Frost & Sullivan, the domestic sector was approximately 84.5% of the total market value in 2010, with this percentage expected to remain roughly the same through the end of their forecast in 2015 (Frost & Sullivan, 2012). Another market forecast by IndiaStat and Intecos – CIER estimated the domestic market segment as 70% of the total in 2009 (Indiastat, n.d.; Mohnot, 2004). Though the actual number may change between reports, for the purposes of this evaluation it is important only to demonstrate that of water purifier sales, a majority is attributed to domestic, in-home use.

The domestic market is broken down into non-electric products referred to as "off-line" purifiers, and "on-line" purifiers that consist of products mostly based on ultraviolet (UV) and reverse osmosis (RO) technologies. For each product, there are two costs to the consumer: an initial product purchase price, and reoccurring fees that cover replacement filters and service visits from trained maintenance staff, as needed. The magnitude of these costs varies by technology, as summarized in Table 5.1-1. More information about each technology is provided in Chapter 4.

Table 5.1-1. Water Purifier Product Summary by Type

Water Purifier Type	Price Range (INR)[1]			Products[2]
	Minimum	-	Maximum	
Off-line, Non-electric	1349	-	4200	Tata Swach Smart, Cristella Plus & Silver Boost; Eureka Forbes Aquasure Aayush, Amir with Kitanu Magnet, Xtra Tuff & Shakti; Kent Gold Series; HUL Pureit Classic, Advanced & Intella
On-line, UV-based	6499	-	12999	EF Aquasure Prime, Smart & Aquaflow; Eureka Forbes Aquaguard Reviva, Crystal, Classic & Verve; Eureka Forbes Dr. Aquaguard Magna, Eterniti, Booster, Classic & Compact; Kent Maxx, Ultra, Ultra Storage; ZeroB UV Grande; HUL Pureit Marvella UV ; Tata Swach Viva Silver
On-line, RO-based	9000	-	27990	EF Aquasure Nano Elegant & Xpert; Eureka Forbes Geneus, Pro, Enhance, Reviva, (RO, RO+UV options), and Enhance Green; Kent Grand, Grand+, Pearl, Supreme, Prime, Prime TC, Pristine, Super Star, Wonder, Wonder+, Pride, Ace, Ace+, Superb, Super+; XeroB Wave, Sapphire, Pristine, Emerald, Ultimate & Eco; HUL Pureit Ultima, Marvella & Classic series; Whirlpool Minerala 90 Platinum & Elite

Notes:
1. Prices based on the MRP from the manufacturer's websites, 19-29 April 2016.
2. Summary includes top 6 brands: Eureka Forbes, Kent, HUL Pureit, ZeroB, Tata & Whirlpool.
Sources: (Eureka Forbes, n.d.-b; Hindustan Unilever Limited, n.d.; Kent RO Systems Ltd., n.d.-b, 2016b; Tata Chemicals Ltd., n.d.; Whirlpool of India Limited, n.d.; Zero B, n.d.)

The market for water purifiers in India is dominated by six brands in the organized sector. As shown in Figure 5.1-1, these top brands offer many products across the off-line and on-line water purifier groups. In addition to branded names, there are over 150 manufacturers that offer water purifiers through the unorganized sector of the market. The unbranded purifiers are often designed to look very similar to branded products, but sell at half of the price. Most, if not all, companies in both the organized and unorganized sectors offer after-sales service.

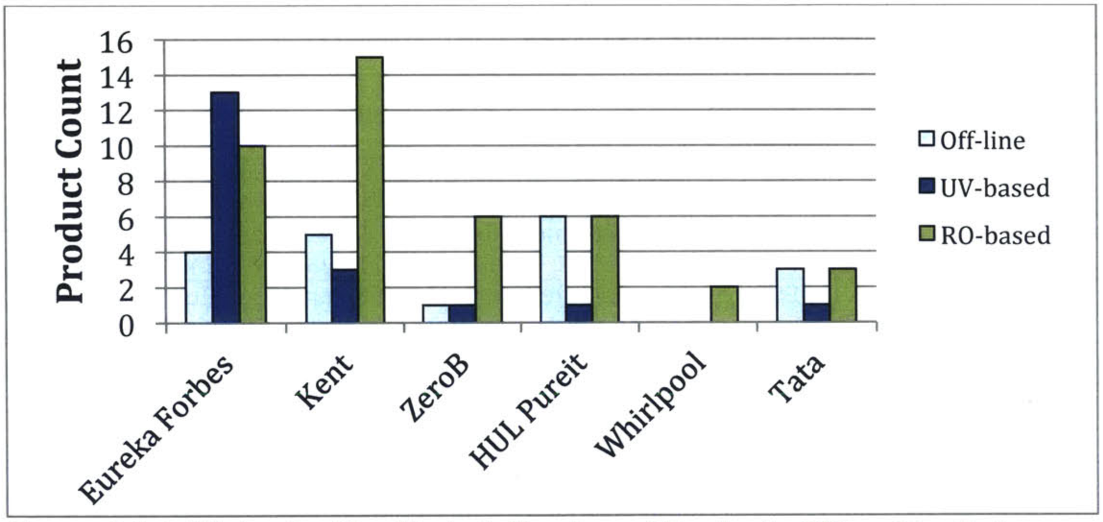

Figure 5.1-1. Water Purifier Market: Number of Products Offered by Category, Top Brands
Source: (Eureka Forbes, n.d.-b; Hindustan Unilever Limited, n.d.; Kent RO Systems Ltd., n.d.-b, 2016b; Tata Chemicals Ltd., n.d.; Whirlpool of India Limited, n.d.; Zero B, n.d.)

5.2 Market Report Data

Several market analysis reports have been generated for the domestic water purifier market in India over the past decade. These reports typically present total value in terms of the financial value of the entire market, combining all water purifier types, or the number of units sold. The following summarizes data and trends obtained from a series of market reports focused on point of use (POU) water purifiers in India.

5.2.1 Market Size

Actual and predicted water purifier sales are shown in Figure 5.2.1-1. As shown, IndiaStat and Intecos - CIER provide sales data beginning in 1990, and demonstrate significant growth in the water purifier market over time, with a projected value of INR 84.4B in the total market by 2020, and nearly INR 149B by 2025 (Indiastat, n.d.; Mohnot, 2004). According to Frost & Sullivan, the total domestic market value in 2010 was estimated at INR 20.8B, with 61% of the value in new product sales, and 39% of the value in after-sales services (Frost & Sullivan, 2012).

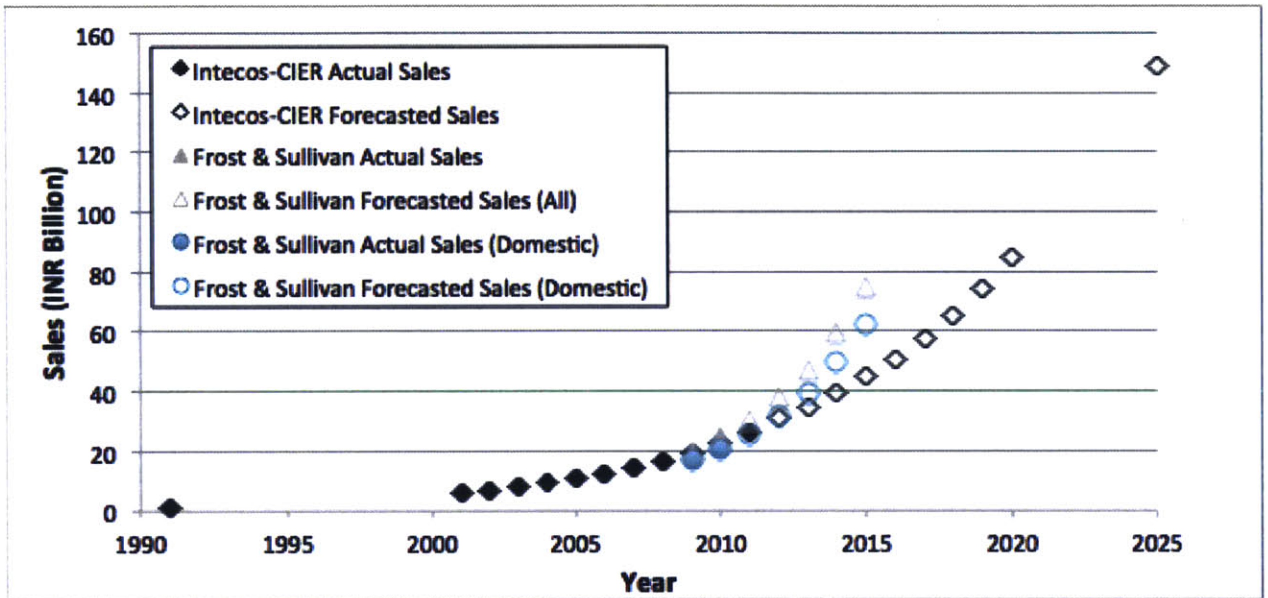

Figure 5.2.1-1. Actual and Forecasted Market Value of Water Purifiers in India
Source: (Frost & Sullivan, 2012; Mohnot, 2004)

The next set of forecasts focus on the number of units sold. The estimate from ADI Media estimates the market from 2010-2011 (with a total of INR 11.42B[3]) represented a total of over 3.6M units sold (approximately 2.7M off-line filters, 0.52M UV purifiers, and 0.39M RO purifiers) (ADI Media, 2012). Later estimates quoted by IndiaStat and the Economic Times from the Market Pulse report "Opportunities in the Water Purifier Market in India" refer to approximately 0.79M RO purifiers sold in 2013-2014, with a projection of over 3.0M RO units to be sold in 2017 (Indiastat, n.d.; Singh, 2014). Gfk Global then compares the number of units sold in the first five months of 2014 with 2013, when the volume increased by 15%, and sales increased by 30% in value (GfK Global, 2014). Approximately 31% of purifiers sold were online systems, with 72% of that fraction consisting of RO units, indicating an increase of the proportion of RO units over UV units in the online water purifier category. The studies with specific unit sales numbers or predictions are summarized in Table 5.2.1-1.

[3] It is assumed that the value presented by AnalyZ Research Solutions represents product sales for the domestic water purifier market. In this case, a total value of INR 11.4B is lower than INR 12.7B presented by Frost & Sullivan.

Table 5.2.1-1. Actual and Forecasted Unit Sales of Water Purifiers in India

Reference	Year	Non-Electric Units	UV-based Units	RO-based Units	Total Units Sold
Whirlpool	2008-2009*	-	-	-	2,300,000
ADI Media	2010-2011	2,713,000	520,500	394,259	3,627,759
Market Pulse	2011-2012	3,010,000	-	-	4,300,000
Market Pulse	2013-2014	-	-	786,000	-
	2016-2017*	-	-	3,000,000	-

* Indicates forecasted values.
Sources: (ADI Media, 2012; Market Pulse, 2013; People in Business India Pvt Ltd, 2009; Singh, 2014)

As understanding the growth of a market involves not just the total value and number units sold, but also the extent of market penetration, several reports report on this metric as well. During 2010, Frost & Sullivan estimated the market penetration of water purifiers had reached only 10% in urban areas, and less than 5% for rural. This is consistent with an estimate by AnalyZ Research Solutions that calculates an overall market penetration in India of 6%, with levels that vary by city and state, and reach approximately 15% in Greater Mumbai and 25% in Delhi (AnalyZ Research Solutions Pvt Ltd, 2012; Frost & Sullivan, 2012).

Overall, though the precise market value estimates, number of units sold or market penetration achieved by certain years vary between firms, all projections point towards a significant amount of RO unit sales in the next few years[4]. The product lifetime of these water purifiers is anticipated to be 5-10 years or more (based on Frost & Sullivan's report, as well as in-person interviews discussed more in Chapter 6), so it is unlikely that these sales will be replacement purchases (Frost & Sullivan, 2012). The projected growth therefore appears to be heavily reliant on increased adoption for households not currently using RO water purifiers.

5.2.2 Target Market Characteristics

The market for each water purifier type varies, but as the intent is to better understand the RO market, that will be our focus. Common characteristics across customers of all products will be included as they are relevant to the discussion. Characteristics first addressed are

[4] It is noted that market reports also predict significant growth in the area of non-electric purifiers. As there is no waste from these systems, the focus of this thesis will be placed instead on the growth of the RO water purifier market.

related to water quality and general location, then utility access (water and electricity) and socio-economic status and education level, and finally willingness to pay.

Water Quality and Awareness of Impacts on Health

The initial driver for household water purifier use is poor water quality and an awareness of the potential effects of water pollutants on a family's health. Though more significant health impacts of poor water quality are associated with the presence of bacteria (Kumpel, 2013), elevated salinity concentrations can impact the taste, and prevent a family from wanting to use that source for direct consumption (Wright & Winter V., 2014). As discussed previously, RO systems remove salts through treatment, so the targeted population for RO water purifiers lives in an area with drinking water TDS levels above the BIS standard of 500 ppm, or lower, depending on the household's taste preference. Groundwater in many areas across India has been found to be brackish, so households with access to private or public borewells, or relying on the municipal water system that includes groundwater as a source to fill its supply needs may be exposed to water that could be improved through desalination (currently provided through RO treatment).

Location

According to IndiaStat and Intecos – CIER, water purifier sales are not equally distributed across India; the west consists of 40% of the sales, the north and east each contribute 25% to total sales, and the south only consists of 10% of sales (Indiastat, n.d.; Mohnot, 2004). Though it is unknown how sales vary by purifier type in each region, a confidential RO manufacturer had the lowest amount of service partners in the south compared to any other region (Tata Projects, n.d.). This distribution generally matches the water quality (specifically TDS) trends discussed previously in Chapter 2.

It is noted that the RO service providers are typically located within urban areas, as after-sales service makes up nearly 15-30% of the value of the market (Frost & Sullivan, 2012), and each brand typically requires that servicemen authorized through the company perform maintenance, or else the warranty becomes invalid. Locating providers within urban areas allows for a higher density of service visits. In addition, the Indian Census of 2011 indicated a higher percentage of households have access to water within the home in urban areas (71.2%)

compared to rural areas (35.0%) (Census of India, 2011a). Access to water within the home fulfills one requirement for online RO units in that a direct connection to a water line must be provided. Water could be sourced from municipal corporation supplies, borewells, or tanker trucks, but since the household RO systems pull and treat water when needed to fill their storage tank, a piped source is required in order to operate the system continuously. Urban homes are also more likely to have access to electricity[5], another requirement for on-line systems.

Household Finances and Education Level

Due to the high to premium price of RO units sold throughout India, households must have sufficient financial means to be able to purchase and maintain the RO purifier as required. They must also have an interest in purchasing a treatment system, which can be tied to the education level of members of the house, as well as the family's willingness to pay for improved water services, which was discussed in Chapter 5.5.

One approach that has been used by marketing companies to estimate the purchasing power of a household within India is the SEC (socio-economic classification) system. Revised in 2011, the new SEC system uses a combination of consumer durables owned or accessible by the family and the education level achieved by the head of the household to determine the household's classification. See Appendix A for the standard list of eleven consumer durables, and the matrix used to identify the household's SEC group. Group SECA (which is comprised of subgroups A1, A2, and A3) is anticipated to have the highest consumption value of goods, followed by SECB, then SECC, SECD and SECE. Groups SECA and SECB are the primary target market for water purifiers, as higher education is often linked to awareness of environmental conditions, such as deteriorating water quality, and the connection between poor water quality and health impacts (Jalan, Somanathan, & Chaudhuri, 2003). Households from additional SEC groups may also purchase RO systems, but for purposes of initially estimating the market size, SECA and SECB will be the focus. Table 5.2.2-1 provides the estimated number of households (as of 2011) by SEC group for a select number of cities and major

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[5] Based on the Indian Census of 2011 reporting 92.7% households in urban areas use electricity for lighting, compared to 55.3% in rural areas of India (Census of India, 2011b).

districts in India[6]. The cities and districts were first sorted based on groundwater TDS levels (high and medium, with no low TDS cities included in this shortened version), then the approximate number of households calculated assuming a standard household of five people. The individual list of top cities and targeted districts for RO sales across India is provided in Appendix A. Together, the SECA and SECB groups for these high and medium TDS cities and districts demonstrate the potential market size for RO water purifiers relying on treatment of TDS (likely in addition to other pollutants) of over 5 million households in the top 20 cities with evaluated, or over 8 million households in the major districts evaluated.

Table 5.2.2-1. Approximate Total Number of Households by SEC Category, Cities & Major Districts

CITIES	SECA	SECB	SECC	SECD	SECE
High TDS	869,641	1,101,073	1,324,242	1,061,387	987,261
Medium TDS	1,366,345	1,732,926	2,083,404	1,692,642	1,601,111
Subtotal (High + Medium)	2,235,986	2,833,999	3,407,646	2,754,029	2,588,372
Group Totals (SECA+)	-	5,069,985	8,477,631	11,231,660	13,820,032
MAJOR DISTRICTS	**SECA**	**SECB**	**SECC**	**SECD**	**SECE**
High TDS	1,531,364	3,662,390	4,875,152	5,757,089	8,679,153
Medium TDS	899,667	2,151,632	2,864,122	3,382,255	5,098,950
Subtotal (High + Medium)	2,431,031	5,814,022	7,739,274	9,139,344	13,778,103
Group Totals (SECA+)	-	8,245,053	15,984,328	25,123,672	38,901,774

*See Appendix A for the complete list of cities and districts included in this analysis.
Source: (Tata Projects, n.d.)

Though SEC groups were not determined for households interviewed in January 2016 (results from interviews are discussed in more detail in Chapter 6), it is anticipated that the subjects all fell within the SECA and/or SECB groups based on the inferred education level (some college, at a minimum), and observing at least five of the consumer durables from the standard list present during home visits. These households were also assumed to fall within the middle-upper and upper class segments.

Growth is likely to continue within the middle and upper class segments of India, as shown in Frost & Sullivan, which forecasted the rise in the number of households in both

[6] It should be noted that there is some overlap between major districts and cities summarized herein. As a result, the total number of households from cities and major districts were kept separate (and not added together) when evaluating potential total market size.

categories between 2010 and 2015 as approximately 15% per year (Frost & Sullivan, 2012). In addition, the report estimated that the top 20% urban households would earn an additional INR 75,000 throughout the same timeframe, further supporting the claim that increasing purchasing power would be one of the water purifier market's main drivers. Data provided by the Government of India's Ministry of Statistics and Programme Implementation National Survey Office then demonstrates an actual increase in household consumer expenditure in durable goods, growing from a share of 3.3% the total consumer expenditure in 1993-1994 to 4.1% in 2004-2005, and 6.7% in 2009-2010 (Ministry of Statistics and Programme Implementation: National Sample Survey Office, 2011).

5.2.3 Market Drivers and Constraints

Besides the degradation of groundwater, and increase in purchasing power, factors that market experts expected to grow the market include the increased mix of products available and the availability of multiple channels for sales and distribution. Since the growth is not without potential constraints, a brief discussion presents these as well.

Product Mix

In terms of the product mix, manufacturers often offer multiple products within each category: non-electric purifiers, on-line UV-based systems, and on-line RO-based systems (refer back to Figure 5.1-1 for the number of different products available from each of the top six brands). Within each category, products may include a range in the total number of treatment stages, creating further options for the customer, and increasing the chance of something satisfying a customer's particular preference. Upon reviewing RO water purifier sales data over a period of two years for a confidential RO manufacturer, it was observed that purifiers with more treatment stages priced in the premium end of the range had greater unit sales. Figure 5.2.3-1 presents these sales data for three products across multiple cities. The trend is observed in all but one city, Jaipur. The preference for the premium, seemingly more complex model also matched comments from several interviewed subjects (discussed further in Chapter 6), as it was commonly believed that a purifier with a high level of treatment stages would perform better than a model with fewer stages.

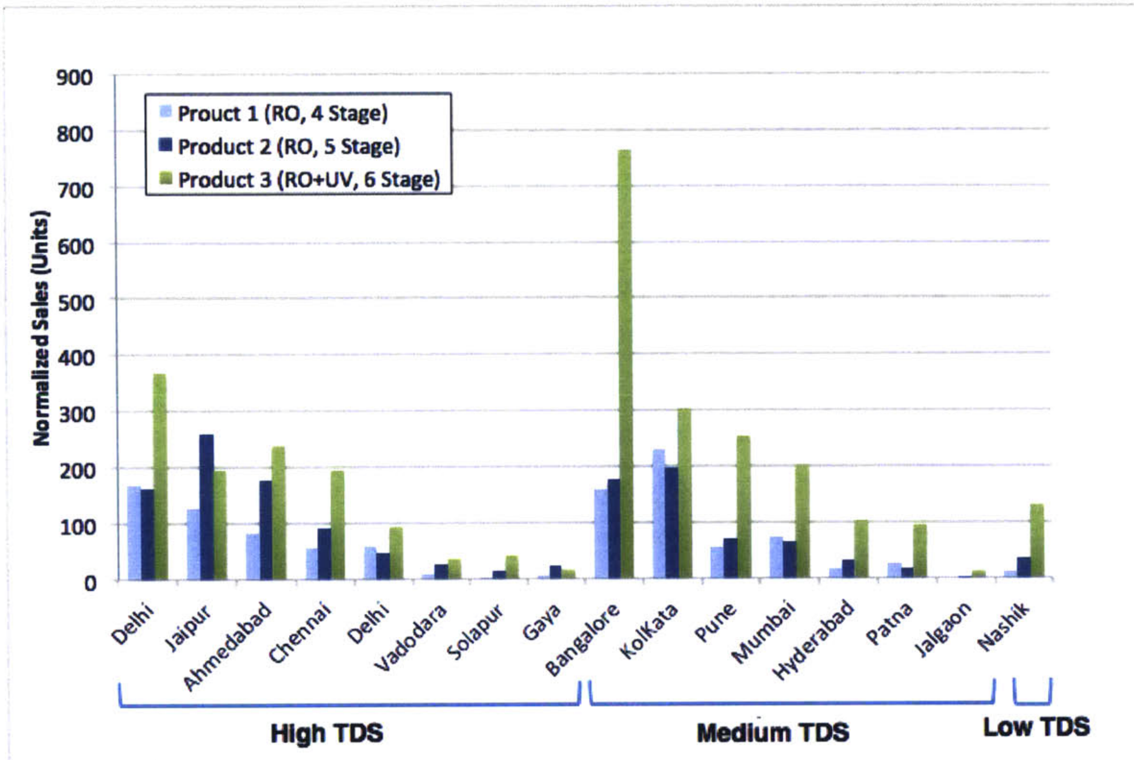

Figure 5.2.3-1. RO Unit Sales by Product
Source: (Tata Projects, n.d.)

<u>Distribution Channels</u>

The presence of multiple sales channels is also anticipated to promote an increase of water purifier sales. According to Frost & Sullivan, and consistent with the interviews conducted under this study, a high percentage of water purifiers (45.4%) in 2010 were sold through direct sales. In addition, dealers and distributors were responsible for approximately 46.8% of sales (Frost & Sullivan, 2012). Together, the high percentage of use of these distribution channels demonstrates the potential role of the salesman in helping a consumer select the appropriate water treatment system. Sales from retail stores in 2010, on the other hand, were measured at less than 10%, though several visits to retail stores during January 2016 suggested that this may have increased. Each of the chain appliance stores visited in Bangalore and Mumbai (Reliance Digital, Chroma and Vijay Sales) were observed to showcase a variety of treatment systems that represented each of the three main types described above. In each store, twenty or more water purifiers from Eureka-Forbes, Kent, HUL and additional brands such as LG, AO Smith, and Whirlpool, were on display. Salespeople were available to answer questions regarding the benefits of each system, and the applicability to the type of water available in the home. The marketing material for each brand likely informed this knowledge, as the sales section was full of posters and pamphlets presenting the benefits of certain systems.

Market Constraints

Finally, though significant growth is anticipated in the water purifier market, constraints also exist. Restraints identified in the market reports include a lack of understanding of water treatment technology(s), low market penetration, and two factors that are not likely present in the targeted RO market: poor hygiene practices and price-sensitivity (within reason) (Frost & Sullivan, 2012). Given the strength of the drivers mentioned above, these factors may slow adoption, but are unlikely to prevent it from growing further. The negative impact of increased adoption, at various levels, will therefore be the focus of the rest of this study.

5.3 The Role of Media

As discussed above, education level likely drives adoption of water purification systems, though there appears to be a lack of complete understanding about the different treatment technologies. During January 2016, it was observed that water purifier advertisements are ubiquitous in urban areas. Advertisements were present in the newspaper, on television, and even in less conventional marketing locations such as an airport shuttle and as a sponsor of the Republic Day celebrations in Delhi. Most, if not all material involved an endorsement from a celebrity[7], with Bollywood actress Hema Malini endorsing Kent's RO purifiers since 2005, and emphasized the importance of treating water to improve a family's health (Singh, 2015). The distinction was not obvious which technology would be most relevant, and under what circumstances in these commercials, but premium RO systems were typically the models displayed, suggesting to the audience that the more expensive the unit, the better the performance in treating (any) water source.

Besides advertisements, print and online media also provide a means of informing the public through coverage of waterborne diseases, industrial pollution events, and water shortages.

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[7] A Euromonitor International Passport report titled "Power and its Influence on Global Consumer Behavior" found that the celebrity endorsements are relatively new in India, but "the phenomenon...has gained momentum in a relatively short space of time" (Euromonitor International, 2014, p. 1).

Potential consumers can even be alerted to negative water purifier traits, such as high wastage from RO treatment systems or reliability problems with a company's after-sales service. The extent to which negative product or company information influences new purchases is unknown, but a study by Jalan et al. demonstrated that demand for environmental quality, such as for drinking water, was increased when a female in the household either reads a newspaper or listens to the radio at least once per week. Another study performed by AnalyZ Research Solutions found that the media influenced a majority of subjects when purchasing their water purifiers, as 53% were influenced by television advertisements and 20% by newspaper advertisements. In addition, the 2015 Environmental Survey performed by The Energy and Resources Institute (TERI) in India found that television and local/regional newspapers were the most important sources of environmental information, as referenced by 90% and 32% of respondents, respectively (AnalyZ Research Solutions Pvt Ltd, 2012; Jalan et al., 2003; The Energy and Resources Institute, 2015).

5.4 City-Level Product Adoption Rates from Additional Sources

The market data summarized above uses actual and predicted market values to demonstrate predicted growth in the water purifier market. The latest report providing product diffusion data, however, relied on sales data from 2010. Because considerable growth had been predicted through 2010 to 2015, and this report looks at potential impacts from the collective use of water purifiers (specifically those with RO technology) at the city level, updated and specific product adoption data was needed. Table 5.4-1 summarizes a series of government-led surveys, and private research studies that have provided estimates on water purifier adoption in certain cities. Consistent with the market studies' projected increased adoption, water filter adoption rates have increased over time according to these studies. The level of adoption of filters (specifically RO, if the data was available) varies by income group, which was expected due to the average cost of each type of water treatment product. The more specific purifier breakdown in Ghosh's 2014 and 2015 surveys indicates that not only are RO purifiers (with and without UV treatment capabilities) used more in the middle and high income groups, but they are also in use at the low income group and even within slums, indicating the market extends beyond the SECA and SECB groups presented earlier (Ghosh et al., 2016).

This level of product diffusion in Delhi is later used in Chapter 7 as the potential impacts of RO treatment system use are evaluated.

Table 5.4-1. Summary of Water Purifier Adoption Rates

Study Name, Reference	Year: Location, Representation	Adoption Rates
(Dutta & Tiwari, 2005), Cost of Services and WTP for Reliable Urban Water Supply: A Study from Delhi, India	2004: Delhi, A survey of 1100 households within unplanned settlements	Overall, within the unplanned settlements • 16.99% Ceramic Filter use • 12.25% UV Filter use • 0.32% RO Filter use • 12.74% Boiled water use
2006 National Family Health Survey referenced by (Poulos et al., 2012), Consumer Preferences for Household Water Treatment Products in Andhra Pradesh, India	2006: Nationwide	Overall, urban adoption levels were • 3.4% Electric • 13.4% Ceramic, Sand or Other Filters Rural levels were reported to be much lower at • 0.1% Electric • 3.3% Ceramic, Sand or Other Filters
(Misra & Goldar, 2008), Likely Impact of Reforming Water Supply & Sewerage Services in Delhi	2005: Delhi, A survey of 8000 households	<u>High-income group (HIG) Flats</u> • ~79% Invested in a Water filter <u>Middle-income group (MIG) Flats</u> • ~59% Invested in a Water filter <u>Low-income group (LIG)</u> • ~48% Invested in a Water filter <u>Flats (<100 sq m)</u> • ~40% Invested in a Water filter <u>Flats (100-150 sq m)</u> • ~47% Invested in a Water filter <u>Flats (150-300 sq m)</u> • ~58% Invested in a Water filter <u>Flats (>300 sq m)</u> • ~88% Invested in a Water filter
(The Energy and Resources Institute, 2014), 2014 Environmental Survey	2014: Delhi, Mumbai, Coimbatore, Guwahati, Indore, Jamshedpur, Kanpur, Pune; Total sample size 11,214 households	**Overall**, 50% treated their drinking water • 68% from high-income localities • 46% from middle-income localities • 40% from low-income localities **Coimbatore** survey (1,200 households) – 59% of respondents performed some sort of treatment (though this varied by income level) • 38.3% Boiled water • 19.1% Water Filter/RO use • 1.7% Other method of treatment

(Ghosh et al., 2016), Implications of end-use behavior in response to deficiencies in water supply for electricity consumption – A case study of Delhi	2014 & 2015: Delhi, A survey of 496 households	High-income group (HIG) • 4% Filtration only • 3% Filtration + UV • 14% Filtration + RO • 63% Filtration + RO + UV Middle-income Group (MIG) • 3% Filtration only • 34% Filtration + UV • 21% Filtration + RO • 23% Filtration + RO + UV Low-income Group (LIG) • 12% Filtration only • 38% Filtration + UV • 11% Filtration + RO • 16% Filtration + RO + UV Slum Dwellers • Nil Filtration only • 9% Filtration + UV • 16% Filtration + RO • 1% Filtration + RO + UV

5.5 Willingness to Pay Studies

Critical to the adoption of household water purifiers is the family's willingness to pay for improved water quality conditions at the level that would be needed to cover the cost of a treatment unit. To date, a series of studies have been performed within and outside India that look at the price subjects are willing to pay for improved water and sanitation services (WSS). These studies often look at quantity and quality together, with an intermittent supply of water the norm to be improved upon. Often households are already making decisions to improve their own access to and quality of water used in the home, with each action typically involving some fee referred to as a coping cost. The following summary in Table 5.5-1 provides an overview of the WTP studies performed to date that are considered relevant to this work. Though the individual studies may focus on a different type of treatment system, or a population group other than the SECA and SECB households of urban India, the findings are considered relevant, presenting factors that are relevant for increasing or decreasing WTP for a particular household, and identifying the baseline WSS conditions that customers are already coping with, as well as the future conditions that would be worth paying increased tariff rates or other water charges for.

Table 5.5-1. Summary of Select Customer Preference and Willingness to Pay Studies for Improved Water and Sanitation Services

Study Year, Description and Reference	Relevant WTP Factors and Resulting Level(s)
1996: Chennai, India. Choice modeling through a survey of 148 respondents (Anand, 2001), Consumer Preferences for Water Supply? An Application of Choice Models to Urban India	Selected Chennai based on the occurrences of water supply shortages, the lack of a major river basin, and the late monsoon season beginning at the end of September or beginning of October. Results found a negative correlation between what respondents were currently spending on their water supply with the estimated willingness to pay for an improvement potentially related to the following: • "lack of trust in the water utility • public water supply is excessively expensive • urban consumers claiming their entitlement to subsidy • preference reversal, or • accounting for capital and sunk costs and side payments" (pgs 24-25)
2002: Delhi, India. Contingent valuation method applied, with 564 respondents. (Dasgupta & Dasgupta, 2004), Economic Value of Safe Water for the Infrastructurally Disadvantaged Urban Household: A Case Study in Delhi, India	Targeted respondents either (1) had a household municipal water connection, but was not satisfied with the level of service, or (2) did not have their own household municipal water connection. Higher income levels lead to higher WTP. For households that have an individual connection, the WTP is higher, and to go a step further, the higher the maintenance cost, the higher the WTP for an alternative that would not require the same maintenance requirements. For both types of households, the presence of a working mother leads to a higher WTP. Though the adjusted R^2 was low (0.30), for households with an individual water connection, the WTP was calculated to be: • Mean 54.52 INR/month • Median 54.94 INR/month 53% of water samples contained coliform above the 1993 WHO drinking water standards.
2004: Delhi, India. A survey of 1100 households within unplanned settlements; the contingent valuation method applied. (Dutta & Tiwari, 2005), Cost of Services and WTP for Reliable Urban	The evaluation looked at WTP for water that meets WHO standards. Marginal opportunity costs made up of marginal production costs, marginal user costs and marginal environmental costs were calculated. Supplemental supply projects (several dams) were estimated to take 15 years to implement. Households relying on a single water supply are willing to pay more per month (INR 295.05) compared to households with dual supply (INR

Water Supply: A Study from Delhi, India	189.32)
2005: Delhi, India. A survey of 8000 households (Misra & Goldar, 2008), Likely Impact of Reforming Water Supply & Sewerage Services in Delhi	Coping costs, average utility bills, and WTP were calculated for various subjects, grouped by housing type. 3.3% of a household's income was determined to be the norm for affordability criteria of water-related costs. Coping costs were broken down by interest and depreciation on coping investments for equipment such as water filters, booster pumps, borewells, and overhead reservoirs, booster pump energy charges, and other recurring costs. Per month coping costs for a subset of housing groups ranged from: <u>Janta flats</u> • 83 INR/month Coping cost • 190 INR/month WTP • 317 INR/month affordable water bill <u>MIG housing</u> • 188 INR/month Coping cost • 180 INR/month WTP • 634 INR/month affordable water bill <u>HIG housing</u> • 234 INR/month Coping cost • 291 INR/month WTP • 803 INR/month affordable water bill <u>Residential plots (150-300 square meters)</u> • 258 INR/month Coping cost • 224 INR/month WTP • 684 INR/month affordable water bill <u>All Households*</u> • 187 INR/month Coping cost • 170 INR/month WTP • 394 INR/month affordable water bill *Additional housing categories not presented above were included
2008: Andhra Pradesh, India. A survey with 506 respondents using conjoint analysis (Poulos et al., 2012), Consumer Preferences for Household Water Treatment Products in Andhra Pradesh, India	Existing electric water purifier users were removed from the analysis due to anticipated bias associated with having more information about the treatment products. In terms of product costs, only capital costs are statistically significant; monthly reoccurring fees were not. Attribute non-attendance was observed in a segment of the respondents. The most important attributes were found to be the type of product (filters preferred), the extent to which the system removes pathogens, the retail outlet type (department stores and weekly markets preferred), and the time to treat 10L of water.

2004-2005: Rethymno, Greece. A contingent evaluation study with 306 respondents (Genius et al., 2008) Evaluating Consumers' Willingness to Pay for Improved Potable Water Quality and Quantity	Water was generally continuous throughout the year, except for periods of high tourism, at which time it becomes intermittent Additional water sources had a high cost of transportation; expansion of the existing system was being proposed. Higher WTP was associated with: • Female respondents • Households with high income • Households with children • Households which do not currently use tap water for drinking Lower WTP was associated with: • People that had experienced water cuts Other findings • Water quality and quantity interrelated • WTP was calculated as a percentage of the average water bill (17.67%, equivalent to approximately 10.64 €)
2013 Evaluation of WTP full price of water in select cities (The Energy and Resources Institute, 2013) TERI Environmental Survey, 2013	Survey was performed in Hyderabad, Kolkata, Chennai, Bangalore, Mumbai and Delhi. Among the water-related questions, respondents were asked what the major causes of wastage of water were, and if they should pay the actual cost of water. A summary is provided below. Major causes of wastage of water (% of each cause selected) • Leakages from taps/faucets in your home: Cities varied in terms of magnitude (<15% in Kolkata to >35% in Bangalore) • Leakages during distribution (from municipalities, tankers, etc.): Ranged from ~30 to 40% between cities • Too much water used where less is required by us as customers: Ranged from 15% in Bangalore to nearly 50% in Kolkata • I don't know: Generally < 10%, but nearly 15% in Kolkata • Water is not being wasted: Chennai and Bangalore were the only cities that selected this (at 10% and ~12%, respectively) Willingness to pay actual cost of water (ranged considerably by city): • Hyderabad and Mumbai had slight majorities that were willing to pay • Kolkata had > 55% unwilling to pay • Chennai was mixed, in that 40% were unwilling, and 35% were undecided • Delhi and Bangalore had significant majorities that were unwilling to pay
2014 Evaluation of WTP full price of water in select cities (The Energy and Resources Institute, 2014)	Survey was performed in Mumbai, Delhi, Pune, Coimbatore, Guwahati, Kanpur, Jamshedpur and Indore. Responses indicated inconsistencies regarding willingness to pay the actual cost of water even though the majority was aware that water is currently being subsidized. Awareness of water subsidy: • All cities (except Coimbatore) had an awareness level of

TERI Environmental Survey, 2014	approximately 60% or greater • The remainder of subjects interviewed generally didn't know about the subsidy (this went up to 90% in Coimbatore) • A small fraction (<15%) in Jamshedpur and Indore were not aware of the subsidy Willingness to pay actual cost of water that reflects scarcity value and discourage wastage: (Cities were mixed) • Mumbai, Pune, Guwahati, Kanpur and Indore had a majority that were willing to pay • Delhi, Coimbatore and Jamshedpur had a majority that were not willing to pay • Mumbai had nearly 35% of its population that was unsure The best/ideal billing mechanism: (Cities were mixed) • Mumbai, Coimbatore, and Indore had a majority that preferred fixed charges • Delhi, Pune, Guwahati, and Jamshedpur preferred a metered/ consumption structure (with ~20-30% of each city preferring fixed charges) • Kanpur was 60% undecided, and otherwise split between fixed charges and a metered/consumption structure

In addition to the studies included in Table 5.5-1, the World Bank published a report that challenged the use of WTP studies without an "explicit linkage to future policy development or investment decisions" (UNDP - World Bank: Water and Sanitation Program - South Asia, 1996, 3). The report argues that the level of coping costs residents in Delhi, for example, are found to be paying for improved services is evidence enough that subjects would be willing to pay higher tariffs for an increase in service level. Combined with the lack of Indian cities currently providing continuous water service, the uncertainty that additional water sources are available to allow a city's water utility to operate on a continuous basis, the connection between intermittent water supply and contamination from an unpressurized distribution system, and the potential for homes to be using more than one source (and therefore a water purifier that is used for all different water sources in the home), it is possible that costs households are currently paying now cannot be divided easily between those associated with higher volumes of water, and improved quality.

5.6 The Bottled Water Market

A major competitor to domestic water purifiers in India is the bottled water market. Available in sizes that range from 500mL bottles up to 20L jugs, and with home delivery only a small increase in price, the convenience of bottled water is intended to be the primary appeal. Bisleri, the market leader and brand synonymous with bottled water in India, had introduced the 20L jug, which achieved a 40% market share by 2006-2007. Households began to adopt these jugs as their potable water source, avoiding the need for maintenance associated with water purifiers and acting as a potentially more reliable source of water during municipal supply shortages. It was estimated in 2006-2007 that the per capita consumption of bottled water was 0.5 L per year, though a more recent estimate in 2015 has placed the average at approximately 4.5L per year[8], which is still below the global average of 29L (Indiastat, n.d.; Mintel Market Sizes, 2015). It is important to note, however, that due to India's population, it was recorded as one of the top five countries in terms of overall bottled water consumption in 2013 (BCC Research, 2014).

The market for bottled water in India has grown exponentially over time, and the number of vendors has also increased. Sales were valued at INR 60 Bn in 2013, with bottled water (also referred to as mineral water) available from over 1,800 vendors. With expected growth at a CAGR of 22%, the market is anticipated to reach INR 160 Bn in 2018 (Indiastat, n.d.; Mohnot, 2004). The potential impact of the individual costs of bottled water, when used continuously in place of a water purifier, will be presented in Chapter 7, where household decisions are evaluated in more detail.

[8] Assumed varying levels of consumption between socio-economic groups, and India's large population are likely the reason why the per capita bottled water consumption in India is so low.

Chapter 6. Verifying the Market

Before evaluating the potential impact of RO adoption, it was important to understand the use cases of the RO systems currently available today, the requirements that households have developed for these systems, and the level of importance that households assign to certain changes in attributes as it relates to their willingness to pay. To do this, a program that combined qualitative interviews with a discrete choice evaluation was performed with urban households in India in January 2016. The following sections outline the methodology used for each element of the program, as well as a summary of results, and a discussion of study limitations.

6.1 COUHES Review and Approval

The interviews conducted for this thesis was considered human subject testing, and as a result MIT's Committee on the Use of Humans as Experimental Subjects (COUHES) training and approval of interview methods and materials was required. Approval was obtained for a joint submittal with graduate student Sahil Shah, and consent forms were combined to cover both of our research projects. All respondents were provided a consent form in accordance with COUHES, and asked for permission to include results from the interview in the Master's thesis for both Sahil and myself. See Appendix B for a copy of the COUHES consent form.

6.2 Qualitative Interviews

The intent of performing interviews with urban households in India that were using RO units was twofold: first, to determine the conditions under which the systems were being used (mainly relating to water source and any other factor that contributed to the purchase) so that a comparison could be made against the assumed target market characteristics presented in Chapter 5. The second purpose was to better understand the needs of the RO users that either were or were not being addressed by water purifiers currently available on the market.

6.2.1 Methodology

Data Collection

During January 2016, forty-one interviews were performed with families living in urban areas of India. The families were located within, or in close proximity of, the following cities: Bangalore, Mumbai, Ahmedabad, Durgapur, Jaipur and Delhi. Each interview was approximately thirty minutes to one hour in duration, and included a set of approximately thirty-five qualitative questions as well as a discrete choice evaluation question set described below in Chapter 6.3. Myself and another graduate student conducted the in-person interviews, with one person leading the questions and discussion, and the other taking notes by hand. A majority of these interviews were performed within the respondents' homes. Twelve interviews were administered over the phone, including three performed as a group, with the balance conducted on my own.

The sampling method was classified as non-probability sampling, since the intent was to speak with as many household RO users as possible, and RO customer data was not available by neighborhood (Doherty, 1994). Originally, we planned to randomly select houses in affluent areas of the cities mentioned above, but availability of household representatives that were involved in the water purifier purchasing decision and spoke English was limited. As a result, potential respondents were instead identified through convenience by way of personal contacts of the researchers, and references from interviewees through snowball sampling. With the exception of five interviews in Ahmedabad performed in a combination of English-Gujarati with an interpreter, all interviews were performed in English.

Interview questions covered household demographics, water source details, the family's water purification system type, brand, and thoughts on the purifier's performance and maintenance program. A selection of questions also targeted the water wasted by the purifier (if the purifier included RO technology), its approximate percentage of the total inflow to the system, and whether it was typically captured and reused or allowed to drain into the sink. Respondents were asked to elaborate on their answers, and encouraged to provide any additional thoughts that came to mind throughout the interview. During the visit, interviewees were also asked to show the researchers their water purifier and demonstrate how it was used within the home. Photographs were taken of each system, and used to determine common or unique installation and use conditions. Appendix C includes the list of interview questions.

Following each interview, notes from the questionnaire were transcribed into an Excel spreadsheet for analysis. Characteristics that could possibly be used to describe the household or the water purifier use conditions were also entered into the Subject file used for the Discrete Choice Evaluation described in Chapter 6.3.

Results Evaluation

After a general review of interview observations was complete, a Voice of the Customer (VOC) review was performed to evaluate the overall needs of the RO customers, in their own voice. The results would be used to determine if there were unmet needs that could be addressed in a future replacement product. Throughout the evaluation, it was important to focus on the customer's words and phrases, and not match the perceived need with a solution, as entries could be misinterpreted. The following outlines the methodology used, accounting for any deviations due to availability of subjects.

The standard VOC approach as outlined by Griffin and Hauser was followed to the extent possible, and began with reviewing the full set of interview notes for direct quotes from subjects related to their water purifier needs. Needs were not repeated, and statements were tracked to the subject reference number(s) in case later review of the statement was needed. Due to an interest in better understanding the use context of the RO systems, statements from all sections of the interview were considered, and an initial (raw) list from the forty-five interviews was generated that included 538 items. The raw list was trimmed to 165 items based on common themes, then printed on a set of cards (one statement per card) for use in creating an affinity chart through group consensus. As the first step in assembling the affinity chart, a team of three researchers, myself and two others, sorted the 165 cards into piles, each pile unique in meaning from the other piles. During the sorting process (considered to be an affinity analysis), each statement was read aloud, additional context provided if needed, and the team discussed which pile, or piles, could be appropriate. Cards were shuffled around between piles as needed, and certain piles were flagged for potential combination or overlap later on. During two additional meetings, the same team reviewed each pile of cards, confirmed the location of each statement, and created a hierarchical structure that split up statements into primary (strategic) needs and secondary (tactical) needs. As discussed below, a customer sort could not be performed, and information on the relative importance or priority of each primary need was flagged as future work (Griffin & Hauser, 1993).

6.2.2 Results

General demographics

As stated above, forty-one subjects were interviewed either in-person or over the phone. Table 6.2.2-1 provides a summary of these subjects, broken down by location, RO use (or not), household size, residence type, and whether the subject interviewed was a male or female. Due to the sample size of one in Durgapur, results will not be separated out in future tables that indicate respondent preferences. Data were not collected on income or education level, though as respondents were introduced through our personal networks at MIT, it was conservatively estimated that all respondents were middle-upper class to upper class, and the head of the household was well educated.

Table 6.2.2-1. Summary of Interview Respondents by Sex, Housing Type, and Household Size

	Location									
	Ahmedabad		Bangalore		Delhi		Durgapur	Jaipur	Mumbai	
	RO?		RO?		RO?		RO?	RO?	RO?	
M/F	**No**	**Yes**	**No**	**Yes**	**No**	**Yes**	**Yes**	**Yes**	**No**	**Yes**
F	1	2	3	2	0	5	1	3	0	0
M	0	4	1	5	1	10	0	2	1	2
Res_Type										
Flat	0	0	2	6	1	14	0	4	1	1
Flat_PT	1	1	0	0	0	0	0	0	0	0
House	0	5	1	0	0	0	0	1	0	0
Unk.	0	0	0	0	0	1	1	0	0	0
Household size										
2	0	0	2	0	0	1	0	0	0	0
3	0	0	1	3	0	4	0	3	0	0
4	1	3	1	4	1	5	1	0	0	1
5	0	2	0	0	0	0	0	0	0	0
6	0	0	0	0	0	1	0	1	1	0
7	0	0	0	0	0	0	0	0	0	1
8	0	0	0	0	0	1	0	1	0	0
9	0	1	0	0	0	0	0	0	0	0
Unk.	0	0	0	0	0	3	0	0	0	0

Unk. = unknown; Flat_PT = Flat receiving pretreated water

It is noted that although the target respondent was an RO user, introductions made through acquaintances and subjects included households using a range of water purification technologies beyond just RO. During analysis, information gathered from the non-RO user group was kept separate, and used to consider potential differences between households that had direct experience with the technology vs. those without. Figure 6.2.2-1 summarizes the product distribution, grouped into products that include an RO membrane, and those that do not.

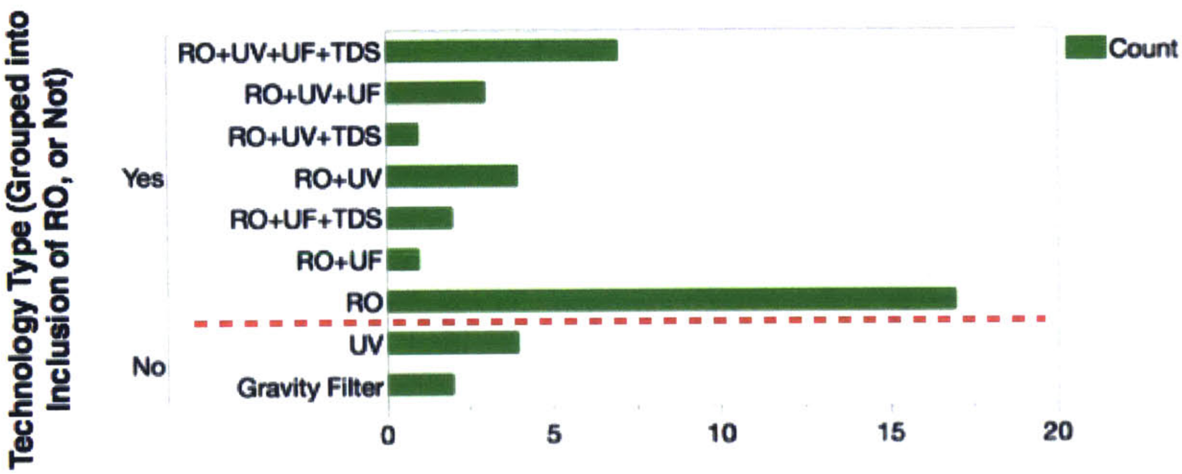

Figure 6.2.2-1. Distribution of Water Purifiers, January 2016 Interviews

RO = Reverse Osmosis, UV = Ultraviolet lamp, UF = Ultrafiltration, TDS = Total Dissolved Solids control

Use Cases

Based on water quality data presented in Chapter 2, it was anticipated that the primary user group for RO systems would rely on groundwater with an average TDS concentration above 500 ppm as the primary source of drinking water. By targeting actual RO users in areas where groundwater was anticipated to be one of several sources available, we were able to challenge this hypothesis and better understand the consumer groups that are currently using the technology. Table 6.2.2-2 summarizes the main use cases of RO that were observed during the interviews, grouped by location, home type, and the household's primary and secondary water sources.

Table 6.2.2-2. Summary of RO Use by Housing Type and Primary and Secondary Water Sources

	Location													
	Ahmedabad			Bangalore			Delhi			Durgapur	Jaipur		Mumbai	
	Housing_Type			Housing_Type			Housing_Type			Housing_Type	Housing_Type		Housing_Type	
	Flat_PT		Plot	Flat		Plot	Flat		Unk.	Plot	Flat	Plot	Flat	
	RO		RO	RO		RO	RO		RO	RO	RO	RO	RO	
Water Source 1	No	Yes	Yes	No	Yes	No	No	Yes	Yes	Yes	Yes	Yes	No	Yes
Borewell	1	1	2	0	0	0	0	2	1	0	4	0	0	0
Bottled	0	0	0	1	0	0	0	0	0	0	0	0	0	0
Municipal	0	0	3	1	4	1	1	10	0	1	0	1	1	1
Tanker	0	0	0	0	2	0	0	2	0	0	0	0	0	0
Water Source 2														
Borewell	0	0	1	0	6	0	0	1	0	0	0	0	0	1
Bottled	1	0	0	0	0	0	0	0	0	1	0	0	1	0
Municipal	0	0	1	0	0	0	0	1	0	0	0	0	0	0
Tanker	0	0	0	2	0	1	0	0	0	0	0	1	0	0

Flat_PT = Flat receiving pretreated water.

As shown above, households with borewell water as their primary water supply were not the only users of RO water purification systems. In fact, 83% of households surveyed that relied primarily on municipal water were also using water purifiers that included the RO technology (it should be noted, however, that RO users were targeted for the study, so this percentage should be used as an indicator or trend, instead of the actual percentage applied to all municipal consumers). This may have been a result of households having multiple sources of water, the second of which having a lower water quality than that of their municipal water[9]. The trend could also be related to the RO technology itself, potentially providing better treatment performance or reliability (perceived or actual) over other water treatment technologies such as UV and standard filtration.

It should be noted that there was some uncertainty in terms of what the actual water source was for some households. In one community, several homes were connected to the same water supply, but the answers that were given in terms of the primary water supply varied between the homes. Due to this observed inconsistency and the study's lack of verification associated with the answers provided by each household, all results should be considered estimates that can be used only in determining general trends in perceived conditions, such as the water source, from the perspective of the household.

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[9] The secondary water source may, in some cases, have been a source only used for emergency backup.

Additional observations related to the RO-based water purifier use conditions of the households visited are summarized in Table 6.2.2-3.

Table 6.2.2-3. Summary of RO-based Water Purifier Use Conditions, January 2016

Category	Observations
Location/Position	• All water purifiers were installed within the kitchen near the sink • Only one water purifier was installed under the sink; the remainder were mounted on the wall or on top of the counter • Three of the systems were mounted inside a kitchen cabinet • A majority of the systems were connected to a second tap within the kitchen (in some cases there was only one water supply to the kitchen, but a second tap existed in preparation for access to municipal water)
Integration with other treatment equipment	• Most systems had at least one separate sediment pre-filter installed upstream of the system's intake line • Traditional clay water storage jars were often present
Operation	• Subjects reported manually turning their system on and off, even though the unit was configured to draw water as needed to maintain a full treated water tank
System Wastage	• Three of the system waste lines were installed such that they drained into a container (the remainder drained into the sink) • One system's waste line had been rerouted back into the system to avoid complete mineral loss
Reference	• Water purifiers were typically referred to by brand, with Aguaguard and Kent the most-represented brands

Product Lifetime and Timing of Purchase Events

During each interview, a subset of questions targeted the age of the household's current water purification system, the expected lifetime of the purifier, and the factors that led to the decision to purchase a purifier with RO technology, and the specific model selected. Figure 6.2.2-2 summarizes the range of current age and expected lifetime of the household treatment systems in use. As shown, the bulk of the products in use are less than five years old, and the anticipated lifetime is ten years or less. For RO-based water purifiers, the age of the current system ranged from less than one year to eleven years old. Non-RO units were up to twelve years old. When asked about the expected lifetime of the product, respondents gave an estimate that ranged from three years to fifteen years. To justify the anticipated lifetime of the product, respondents frequently referred to previous water treatment systems (not always RO-based) that either they or a family member had owned. In the few cases when a short (less than five years) product lifetime had been given, respondents had also expressed dissatisfaction in the durability of their current product during the interview.

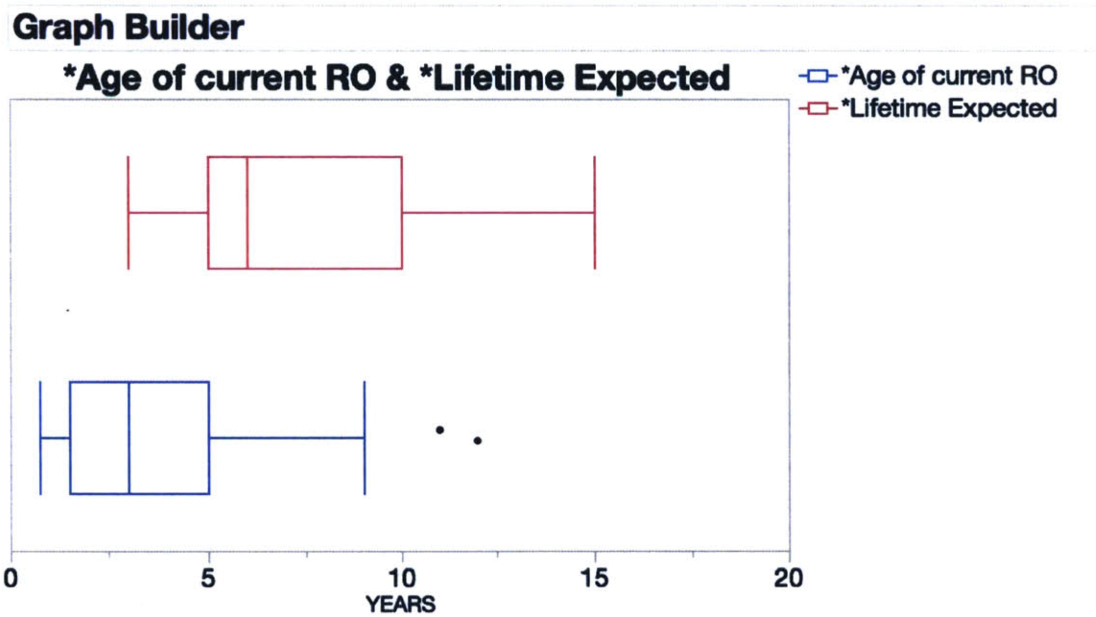

Figure 6.2.2-2. Age of Current Water Treatment Systems, and Expected Lifetime

Regarding the factors that impacted the decision to purchase an RO unit, subjects referred to the following as key drivers:

- A move to a new home,
- The birth of a child,
- The occurrence of a health issue within the family,
- The recommendation of a friend or family member based on experience,
- A change in water quality observed when using a different water purifier, or
- A change in the household's water source and/or the quality of an existing source.

Homeowners were not likely to move with their unit, and in some cases the purifier came with the residence (in each of these cases, the residence was a flat). Reported RO replacement purchases were the result of faulty equipment or a move to a new home.

Voice of the Customer Evaluation

For purposes of this evaluation, it was assumed that all subjects using RO-based treatment systems could be represented together by one market segment. During the VOC sorting process, several statements were found to conflict, but as the intent of the exercise was to understand the range of use cases for these RO systems, all statements were retained in the analysis, and variations were simply noted for future consideration.

The results from the VOC group sort analysis were originally broken down into a series of categories, represented each by one term, considered to be the primary need, with a series of more detailed secondary needs associated with each. According to Griffin and Hauser, primary needs are used to differentiate a product, so these can also be seen as "strategic needs". After additional review and consideration of the potential strategies associated with each of the categories the team identified, a subset were determined to be related to a higher level of user interaction with the system – and not necessarily its direct use. These categories were kept separate, and considered to be informative of use context, not necessarily a direct customer need. Though these use context categories could be used to draw customers toward a particular company or market segment (such as RO-based water purifiers), the attraction would unlikely be toward a specific product, as the information conveyed would not be unique (Griffin & Hauser, 1993).[10] See Table 6.2.2-4 for a summary of the final list of primary needs and the list of categories used to better understand context.

[10] Respondents identified lack of information as an issue (related to water purifier selection and evaluation) during the January 2016 interviews. Because of this, it is possible that a manufacturer could differentiate itself by appearing to provide more information about raw water quality and treatment capabilities. Since customer requirements are assumed to extend beyond these marketing schemes, they are not included in the list of primary customer needs.

Table 6.2.2-4. Summary of Interpreted Primary Customer Needs and Use Context Categories

Interpreted Primary Customer Needs	Use Context Categories
- After-sales service – Availability - After-sales service – Contract Clarity - After-sales service – Coverage - Quality - Cost – capital - Cost – O&M - Design aesthetics - Design features (storage and other) - Assurance of system performance - System can treat all drinking water, and at least some water used for cooking - Wastage – Convenience - Wastage - Quality	- Information Source (Corporate, Social) - Information – Lack of - Marketing (Brand Position, Demos, Features, Financial incentives) - Adoption (Shops, Social, TV Ads) - Perception – Health - Perception – System - Perception – Treated Water Quality - Water Availability - Water Quality (raw feed water) - Water Quality Effects

Within the list of interpreted primary customer needs from the VOC analysis, up to three secondary needs were identified, as summarized in Table 6.2.2-5. Secondary needs are thought to be tactical in nature, and can be used by the manufacturer in determining how customers judge satisfaction associated with a met (or unmet) primary need (Griffin & Hauser, 1993). Table 6.2.2-5 summarizes the secondary needs drawn from the customer statement cards by the review team. Though the procedure is intended to use direct quotes and terms used by the customer, it was challenging to summarize several statements into one phrase, and as a result, the wording for most, if not all, needs were adjusted to be more general and comprehensive in nature.

Table 6.2.2-5. Interpreted Primary and Secondary Customer Needs, VOC Group Sort Process

Adaptability
1. System can be used on all different water sources

After-Sales Service - Availability

2. Local Representation by manufacturer
3. Convenient Schedule

After-Sales Service – Contract Information

4. Contract terms are clear
5. Cost of Annual Maintenance Contract (AMC) is commensurate with coverage
6. Coverage includes housing elements that frequently need replacement

After-Sales Service - Quality

7. Quality of design, service and materials is high, and comparable to other manufacturers

Capital Cost

8. Price is consistent with quality, as compared to other manufacturers
9. Comparable to other major appliances in the kitchen
10. A range of products and price ranges are offered

Total Cost of Operation and Maintenance

11. Minimizes resource consumption

Aesthetics

12. Allows user to see the process
13. Complex but not overwhelming

Features – Storage tank

14. Storage tank reduces wait time for treated water
15. Storage tank facilitates cleanliness

Features – Other

16. Protects system from voltage spikes
17. Physical attributes (size and weight) fit within lifestyle

Assurance of System Performance

18. Feedback communicates performance to user
19. Feedback protects user from inadequate water quality

Usage

20. Covers drinking water requirement and some cooking needs, depending on volume
21. Operation timeframe and duration can be controlled

Wastage Quantity and Quality

22. Minimizes manual nature of wastewater reuse
23. Eases burden of collection with buckets (convenience)
24. User is informed on quality of wastewater and appropriate uses

In terms of tertiary, or operational, needs, the sorting team found a few examples, but overall the reduction of cards to a manageable number, and the inclusion of cards later defined as more informative of use context than customer needs, may have led to this limitation. According to Griffin and Hauser's VOC protocol, a full hierarchical sort should have been performed within the list of secondary needs, also establishing an order of importance for the primary needs/categories. Since the original VOC sort was performed by a group of researchers, customers were not available to perform a comparable sort and ranking, and using statement frequency is not considered an accurate representation of importance (Griffin & Hauser, 1993), the hierarchical structure of needs has not yet been established, and is recommended for future work, as discussed in Section 9.2.

In a related study, the use context list from Table 6.2.2-4 was explored in more detail, and is summarized in Appendix D. This list provides more insight into consumers' understanding of water supply conditions, types of systems on the market, and how they make purchasing decisions. This information can be aggregated to understand tertiary needs that in turn inform primary needs such adaptability and assurance of system performance. The developed tertiary needs can be potentially useful for generating operational product requirements and to support product development programs.

6.3 Quantitative Discrete Choice Evaluation

As part of the January 2016 interviews, a discrete choice experiment (DCE) was performed to evaluate the subject group's product preferences and attribute trade-offs associated with RO water purifiers. The DCE results, providing level of importance and potentially financial values (or willingness to pay, WTP) for certain attribute levels, could then be coupled with that of the VOC analysis described above to better understand potential area(s) for product improvement, though the eyes of the customer and their association of attribute utility, in a future replacement water purifier system.

6.3.1 Methodology

The DCE questionnaire was designed through JMP Software's Consumer Choice Discrete Choice module (JMP, 2015a, 2015b). Four (4) attributes were used to define each hypothetical product: purchase price, annual maintenance fee, percent water recovered, and power rating. Each attribute then had three (3) levels based on the range of RO water purifier products offered in the market, and was treated as a categorical variable. Levels were ranked in order of the assumed preference (low cost, low maintenance fee, high recovery, and low power rating assumed to be the most preferred). Table 6.3.1-1 provides a summary of the attributes and levels included in the DCE study. A full factorial study would have involved asked subjects to evaluate 4^3 profiles, which would be a significant burden, so instead, JMP was used to create a partial factorial study based on more practical constraints. A choice set of nine, with each set consisting of two profiles representing hypothetical products, was considered to be more reasonable. Because the number of choice sets was limited to avoid subject fatigue, it was important to create multiple questionnaires so that performance could be improved. Three questionnaires were then created in JMP, and during administration of the DCE (in person and in links sent over email to phone subjects), the different tests were assigned in an ordered A-B-C sequence.

Table 6.3.1-1. Attribute and Level Summary used in the Discrete Choice Experiment

Attribute	Level 1	Level 2	Level 3
Cost	INR 8000 - 10000	INR 13000-15000	INR 18000-20000
Annual Maintenance	INR 3500	INR 4500	INR 5500
Percent Recovery	75%	50%	25%
Power Rating	30W	45W	60W

Note: All attribute levels are presented in order of most preferred (L1) to least preferred (L3)

To reduce potential bias related to the order of attributes on the page, the sequence of attributes was varied between the three questionnaires. In addition, due to the possibility of respondents misunderstanding the difference in attribute levels, a combination of terms and images were used to represent each attribute level (Kanetkar, n.d.). For all in-person interviews[11], the DCE was performed following the qualitative questions using a series of cards with the choice sets printed one per card. All phone interview subjects were provided a link to the discrete choice survey as a Google Form in a follow up email sent no more than one day following the call, with a reminder to complete the survey sent one to two weeks following the interview, if needed. See Appendix C for an example choice set card used in the DCE.

Respondent selections from the DCE were entered in the Responses table generated by JMP in the Discrete Choice Study platform. The Profile table generated during construction of the questionnaire was left as is, and used later on in the JMP data evaluation. As mentioned previously, characteristics of the household that may have contributed to the selections made were recorded in the Subjects table generated by JMP for potential inclusion in the results analysis.

[11] In certain cases where in-person interview time was limited, the conjoint analysis questionnaire was not reviewed with the respondent.

6.3.2 Results

In total, thirty-seven (37) respondents completed one of the discrete choice questionnaires (12 set A, 12 set B, and 13 set C). The results were analyzed using conditional logistic regression by JMP's Consumer Research Choice model. Initially, the program was run without consideration of any of the respondent's characteristics. Table 6.3.2-1 provides the part-worth (or main effect utility) estimate and standard error associated with each attribute level. Table 6.3.2-2 presents the effect likelihood ratio test results, which confirm that each of the four attributes are statistically significant. For the parameter estimates, the attribute levels not shown (Cost of 19000 INR, annual maintenance of 5500 INR, recovery of 75%, and power rating of 60W) are considered baseline conditions. Firth bias-adjusted estimates are used to deal with potential bias of the small sample set, and the chance of separated variables.

Table 6.3.2-1. Parameter Estimates from the DCE Evaluation, January 2016

Parameter Estimates

Term	Estimate	Std Error
Cost[9000]	0.50649909	0.1479701878
Cost[14000]	0.22337716	0.1278940236
Annual Maintenance[3500]	0.56596281	0.1461582473
Annual Maintenance[4500]	0.04611358	0.1361885915
Recovery[25%]	-1.65624702	0.1732983296
Recovery[50%]	0.18599924	0.1242514056
Power[30 W]	0.60134758	0.1534250217
Power[45 W]	0.10173271	0.1272219265

Table 6.3.2-2. Effect Likelihood Ratio Test Summary

Effect Likelihood Ratio Tests

Source	L-R ChiSquare	DF	Prob>ChiSq
Cost	22.153	2	<.0001*
Annual Maintenance	21.993	2	<.0001*
Recovery	194.186	2	<.0001*
Power	22.362	2	<.0001*

In order to calculate the utility of a hypothetical product, the utility value for the relevant attribute levels are summed together. The total can be compared against the total utility value for other hypothetical systems, with the higher of the two preferred more by our subject group. As shown in Table 6.3.2-3, which presents the results as marginal probability ("the probability of an individual selecting attribute factor A over factor B with all other attributes at their mean or default levels")(JMP, 2015a, p. 99) and marginal utility values (the utility, or value derived from, selecting a product with a certain attribute factor) and Table 6.3.2-4, which summarizes variable importance (the level at which the variable contributes statistically to the utility of a product). The larger range of utility values for the recovery attribute indicates that its level of importance (67.8%) exceeds that of all other attributes, including cost (11.9%). Since this is the case, the willingness-to-pay (WTP) was estimated according to the procedure outlined in Appendix E. The procedure produced values that extend above and below of the cost range used in this test for certain water purifiers, as summarized in Table E-1 (JMP, 2015a).

Table 6.3.2-3. Marginal Probabilities and Utility Values for DCE Attributes, by Level

Marginal Probability	Marginal Utility	Marginal Utility (-1.6 … 0 … +1.6)	Cost
0.4893	0.50650		9000
0.3686	0.22338		14000
0.1421	-0.72988		19000
Marginal Probability	**Marginal Utility**		**Annual Maintenance**
0.5256	0.56596		3500
0.3125	0.04611		4500
0.1618	-0.61208		5500
Marginal Probability	**Marginal Utility**		**Recovery**
0.0332	-1.6562		25%
0.2096	0.1860		50%
0.7572	1.4702		75%
Marginal Probability	**Marginal Utility**		**Power**
0.5325	0.60135		30 W
0.3231	0.10173		45 W
0.1445	-0.70308		60 W

Table 6.3.2-4. Variable Importance Summary

Variable Importance: Independent Uniform Inputs

Summary Report

Column	Main Effect	Total Effect	.2 .4 .6 .8
Recovery	0.658	0.678	
Cost	0.099	0.119	
Power	0.093	0.113	
Annual Maintenance	0.079	0.099	

The WTP trends shown in Table E-1 were generally expected, but not at the magnitude that they were observed. In comparison, the predicted acceptable cost for the highest recovery purifier would be nearly double the cost of the most expensive system in department stores, and place it approximately 50% more than the cost of a refrigerator, which arguably provides more value to the consumer (Site visits to Croma, Reliance Electronics 2016). To expect to successfully capture a large share of the market with this pricing scheme is unlikely, so it was decided that the calculated WTP values would not be used in further evaluations, but the importance of recovery to respondents as a priority would be retained. In addition, it is noted the the cost range used in the discrete choice study was not likely high enough to prompt a trade-off in all cases, and should be reconsidered in future studies.

A closer review of the individual discrete choice data was performed in an attempt to better understand why this trend was so exaggerated. A simple comparison was made in Excel between each pair of selected and rejected attribute levels, to determine whenever the "best" level was selected for a given choice set. By looking at the full set of attributes, and the indicator for whether the best level was selected for one or more attributes, it could be determined which attribute levels were found acceptable in at least one hypothetical product. Trends were then sought out to identify choice respondents that appeared to ignore one or more attributes in making their decision, a condition known as attribute non-attendance (ANA) (Poulos et al., 2012). Since identifying an ANA condition with one or two or three (of the four) attributes could not be done using a simple visual comparison, the focus was spent on looking for an extreme condition, when a respondent appeared to use only one attribute to make his or her decisions, a condition referred to as lexicographic reasoning (Lancsar & Louviere, 2006).

A review of the results found that fourteen respondents appeared to base their product choice selections only on recovery throughout the DCE and two respondents appeared to base their decision only on the power level throughout the DCE. In these cases, no trade-offs appeared to be made with other attributes, regardless of level; all selections within the choice set involved the best condition for the chosen attribute (recovery or power, in this case), according to the original level sequencing. As shown in Table 6.3.2-5, in addition to the apparent instances of lexicographic reasoning, there were three subjects that avoided the highest product price point, and three that did not accept the highest annual maintenance fee, confirming that for a subset of respondents, a trade-off was made to avoid unacceptable costs (Alemu, Morkbak, Olsen, & Jensen, 2011).

Table 6.3.2-5. Summary of DCE Attribute Non-Attendance Instances, January 2016

Description	Primary Water Source			
	Borewell	Municipal	Tanker	TOTAL
Apparent Attribute Non-Attendance Occurrences				
Maximum Recovery				
0	7	11	5	23
1	4	9	1	14
Minimum Power				
0	11	19	5	35
1	0	1	1	2
Examples of Instances Where Trade-offs Were Made				
Price < Rs. 18,000 to 20,000				
0	11	18	5	34
1	0	2	1	3
Maintenance Fee < Rs. 5,500/year				
0	10	19	5	34
1	1	1	1	3

When deciding if changes should be made to the DCE data evaluation, specifically the removal of all attribute non-attendance instances from the dataset, it was decided that to do so would cause the results to no longer be representative of the subject set. In a choice experiment performed by Alemu et al to evaluate German preferences on fishing site characteristics in Denmark, approximately 65% of respondents self-identified as having ignored one or more attributes. The stated attribute non-attendance (SNA) instances were identified when respondents were asked follow-up questions regarding the potential for having ignoring certain attributes, and the reason(s) for doing so. The study found the main SNA rationale to be that the attribute(s) did not impact utility, that to do so simplified the choices, or for protest-like reasons such as when there is a minimum (or maximum) acceptable level or the levels provided were not believable (Alemu et al., 2011).

In terms of the protocol for potentially adjusting results based on confirmed ANA conditions, Lacsar and Louviere argue that these data should not be removed from the evaluation, as in some cases the design of the DCE itself may be causing the response. Though the other researchers have deleted certain DCE responses due to having been assumed "irrational", the author identifies the following four issues associated with DCE evaluation that can potentially lead to ANA instances:

- Subjects consider additional attributes that are not included in the choice set,
- Labels are interpreted differently among subjects,
- A subject is unwilling to trade given the options presented, but given different levels may have reacted differently, and
- One or more attributes are not important to all subjects.

Given the commentary observed during the DCE process, there were subjects that felt the price range included in the study did not extend high enough, that energy was not important as the price was so low, and the consideration of additional product characteristics, such as the brand of each product in the choice set, would cause them to make a different choice. As presented above in the ANA summary table however, these statements conflict with the DCE results of other subjects. Because of this, and because the attribute utility values were calculated in the aggregate and were thus intended to represent the group as a whole, DCE responses were not omitted from the evaluation, but instead used to further understand the preferences of the subject group, and how they may vary.

6.4 Summary of Interview and DCE Findings

Combining findings from the qualitative interviews, VOC and the DCE, several observations can be made. First, households using RO water purifiers are not limited to those that rely on groundwater as their primary drinking water source. For many of the respondents, municipal water was available for at least a few hours each day, and was treated by the RO prior to its use for drinking, and in some cases, cooking. From the VOC review, customers are generally satisfied with their RO systems, but the amount of water wasted through the process was not expected, and represented a characteristic of the system that many respondents were unhappy with and would like to change. These water purifiers require scheduled maintenance, and are expected to have a lifetime of ten years or more. When considering a range of hypothetical products, respondents again verified their interest in improved recovery. For a significant amount (14 of the 37) of respondents that completed the DCE, no trade-off was found acceptable for recovery, suggesting that overall, there may be willingness to pay for an improvement beyond the cost range considered in the evaluation (up to INR 18,000 – 20,000).

6.5 Study Limitations

6.5.1 Qualitative Interview Results Evaluation

It should be noted that several limitations were present that may have impacted the qualitative evaluation of interview observations. To begin, the respondents were identified through personal connections of the academic researchers, so it is possible that initial correspondence used to illicit interest in the study could have emphasized water wastage as the primary driver of the study. In addition, because the researchers' affiliation with MIT was used in initial correspondence and the introduction, the respondent set may have valued higher education and/or MIT as an institution more so than the general market segment that was the focus of the study. The researchers' actions may then have been assumed to be representative of MIT and its values, considering the direction of the study more as a recommendation than as a neutral set of questions (Bowling, 2005).

Another set of limitations involves with the representativeness of the sample set. Due to the nature of the subject introductions, though personal acquaintances, it was assumed that all households were either middle-upper class or upper class, and that the education level of the head of the household was high (four-year college degree at a minimum). Though the questionnaire included items associated with the head of household's education level and age, the researchers did not feel comfortable asking these questions of all subjects. Household income was also not addressed in the questionnaire, as the researchers anticipated in advance that this would not be a question that they would feel comfortable asking. As a result, these customer attributes were assumed to be the same for all respondents (or their difference negligible in terms of differentiation), unless a comment was made during the interview that suggested otherwise (Bowling, 2005).

Finally, it is noted that the subject population was spread across six cities (Bangalore, Mumbai, Ahmedabad, Durgapur, Jaipur and Delhi), all of which have different water supply and treatment needs, and may have had different levels of product marketing or a limitation of products offered for purchase. In addition, even within a single city, water-related issues can differ between within districts. It is possible that the survey questions did not cover certain characteristics of a household's water use (or power use) or water purifier purchasing decision that would impact future product preference. Because of this, it is recommended that further work focus on one city, or urban area, and verify the relevance and completeness of findings of this report before moving forward to group cities into the same market segment (Bowling, 2005).

6.5.2 Discrete Choice Evaluation

As previously indicated, the results of the DCE demonstrated the importance of recovery in the respondent group's water purifier selection process. The resulting WTP, however, appeared to be over-estimated. The potential for ANA and lexicographic reasoning were presented above as causes of this result, though after comparing the results of the DCE with that of the qualitative interview, it is possible that other factors contributed to the poor performance of the study. One such factor that is critical for DCE studies relates to the level of understanding of the attributes, as well as the different levels of each attribute. Care was taken during each administered in-person DCE so that the definition of each attribute was clear, and the difference between levels was understood. Given that some respondents were not aware of the wastage commonly experienced by RO systems, there may have been a misunderstanding of where current systems would fall within the range of recovery options. It is also noted that a subset of the DCE questionnaires were completed remotely, without the researcher(s) present, so there may have been some confusion over the definition of one or more of the attributes. Additionally, the word chosen for the recovery attribute ("recovered" vs. "waste") may have impacted the results. Reject water from RO water purifiers can be (and in some cases has been) used for non-potable purposes, so to refer to this water as "waste" in the choice set may have caused the respondent to believe it should not be used for any other domestic purpose.

Using "drinkable" and "non-drinkable" terms instead may have led to different results, and should be considered for future studies (Bowling, 2005).

Since the utility of the product's price was shown to be only marginally more important than power rating and the annual maintenance fee, and far less important than the system's recovery rate, future studies should consider increasing the price range to an extent where customers will be more inclined to make a trade-off with other attributes. To find this price point, a revised DCE that uses screening questions to set attribute levels, and then adjusts the hypothetical products accordingly (known as adaptive conjoint analysis, or ACA) may be useful (Kanetkar, n.d.).

Finally, the selection of attributes used in the study may have further limited the relevance of the study's results. As designed, the DCE relies on four attributes, which is only a subset of the product characteristics available to consumers during the actual product selection experience. Two attributes of note that were excluded, brand and technology type, frequently came up in conversation during the qualitative interviews, suggesting their relevance in the decision process. By excluding these parameters, the study is likely to over-estimate the preference of a future unbranded system with a new technology (not the established RO) on the brand-name, RO-dominated water purifier market (Kanetkar, n.d.).

Chapter 7. Reverse Osmosis Impact Evaluation

As indicated above, Reverse Osmosis water purification systems require a waste line for operation. The amount of water that is wasted during operation varies by product, but based on the top RO manufacturers' product information, wastage ranges from 30% to 80% of the input water volume. The following section begins with a discussion regarding the choice structure that may lead a household to purchase a water purifier (and when that may be a RO purifier), then revisits the average household consumption of water for potable and non-potable uses, and calculates the volume of water consumed and wasted for a household using an RO purifier. The impact is then reviewed on a city level, using Delhi as an example. For this portion of the evaluation, approximate volume estimates of consumption and wastage are presented, given different adoption rates of the technology based on those presented in Chapter 4, and anticipated in the near future based on the market reports of Chapter 5.

7.1 Household Choice Structure

The use of small-scale household water purifiers is a form of decentralized water treatment used to cope with an inadequate water supply. As a result, the decision to purchase a system, and what system to use, is made at the household level. Though each household may approach their decision differently, common factors that influence the structure of these decisions include the source of water and its availability and perceived quality, the cost of treatment alternatives, and information available about each treatment type. The following section describes each factor, and provides a discussion of its influence on the household's water treatment choices. Though brand and quality of after-service sales are also considered to be part of the decision process, it is assumed that they relate more to the specific product that is selected more so than the technology type given the current market options.

<u>Water Source – Availability</u>

As introduced earlier in Chapter 2, multiple water sources generally exist for domestic use. Water is supplied by the municipal corporation via distribution pipes, or through private borewells or arrangements with tankers and other water vendors if the home is not within the network. Depending on the home's location, whether it is on a private plot of land, within a society, or a flat within an apartment building, only a limited number of these sources may be available. In the case of apartment buildings and societies in an area currently without municipal service, private borewells can be installed as a temporary measure until the municipal network is extended. In the case of areas with over-exploited groundwater aquifers, further groundwater development is restricted to users with no feasible alternative, and application and approval of a no-objection certificate (NOC) is required (and often obtained) from the Central Ground Water Board prior to beginning groundwater extraction. The NOC is valid until municipal supply is available, and is sufficient to provide water to the residents, at which time groundwater extraction is no longer permitted. It is uncertain the extent that groundwater extraction under expired NOCs are enforced, and as a result it is possible that borewells might be maintained (legally or illegally) for use after municipal connection is provided for non-potable (backup or supplemental) purposes (Central Ground Water Authority, 2015a; Nandi, 2015).

Though the individual household may not be involved in the selection of the water source, it was found during the January 2016 interviews that most households were aware of their source. Water availability of these different sources, and the presence of a storage tank on RO units may impact the adoption of RO systems. Because municipal water (in the cities visited) is only available for several hours a day, subjects interviewed in January indicated that a storage system either at the building level, or the individual home level, was used in order to have water available around the clock. For homes using borewell or tanker water, storage systems were also being used to provide water "24/7" (water available 24 hours/day, 7 days/week). The availability of bottled water, and to some degree tanker water, depended on the demand and availability of the water vendor. In addition to availability of water as delivered to the building's storage system, power outages can also impact access to water. Some respondents indicated that they store water in the home for this reason, and several respondents mentioned the availability of water is a consideration when moving into a new home.

<u>Water Source – perception on quality</u>

As water quality has deteriorated across India and health impacts have been linked to contaminants within different water sources, the public's general awareness about water quality in India and the potential impacts has increased. NGO's, the government, and private water purifier companies have increased awareness through education campaigns, and residents have learned more about environmental conditions through television and the newspaper, and by observing waste and wastewater management practices in areas that could cause cross-contamination of water supply lines.

The January 2016 interviews, summarized in Chapter 6, indicated that although households typically did not have specific water quality results for their source, households primarily relying on borewell or tanker water were most likely using RO systems. In addition, several households that had a municipal supply were also using RO units. Respondents referenced water samples collected by their building, or demonstrations performed by a water purifier manufacturer representative, though in both cases, uncertainty about whether the results could be trusted, was present. Because of this, an evaluation of urban Indian residents' perception of water quality was performed using a series of surveys and studies completed over the past several years to better understand the public's perception of supplied water quality.

In a survey performed in March 2005 with households in seven major cities across India, only 54.2%[12] of households perceived the quality of their municipal water to be "quite safe" or "very safe", with the rest either unable to tell, or under the impression that the municipal water was "somewhat safe" at best (Shaban & Sharma, 2007). Another survey, performed in Bangalore, Vijaywada and Goa, found that 72% of subjects perceived water from a water purification system as the safest source of water, compared to just 13% for municipality water, 8% for water cans, and 7% for bottled water (AnalyZ Research Solutions Pvt Ltd, 2012). The 2013 TERI Environmental Survey asked respondents about the changes in the state of drinking water and surface water quality and availability, and the availability of groundwater over the past five years. For drinking water, though respondents in most cities[13] believed conditions in drinking water had improved, a significant percentage believed that they had worsened. For surface water, a majority in every city surveyed indicated conditions had worsened. The availability of groundwater was also seen to have worsened across all cities surveyed.

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[12] This value varied across cities, with Kanpur at only 11.2%, and Hyderabad at 79.4%.

[13] Hyderabad, Kolkata, Chennai, Bangalore, Mumbai and Delhi were surveyed in the TERI 2013 study. Of these cities, respondents from Hyderabad felt that drinking water quality and availability had worsened.

Cost Comparison

To understand the financial aspect of the household's decision, the costs associated with each option for improved water were evaluated. First, it is assumed in this case that the household has a desire to either treat or replace the water used for potable consumption within the home, with no replacement or treatment performed for water used for non-potable activities. Then, an average lifetime of 10 years is applied to each purifier type, with replacement parts and maintenance plans purchased on either for a set volume (3000L, as in the case of the non-electric system) or every year (as in the case of the UV and RO-based systems). The volume of potable water was kept constant for all water purifier types (either 5.0 LPCD or 7.0 LPCD depending on whether water used for cooking was treated as well) to represent drinking water consumption with the exception of bottled water, which was assumed to be less at one 20L jug per day, for practical purposes. Water for cooking was assumed boiled for treatment in this initial set of calculations. In each case, four days were taken "off" each month, where the family was away from home, and would not be relying on the water purifier or bottled water. It can either represent four whole days, or a combination of partial days, and may be higher than needed, but it was preferred to make this estimate conservative, for alternatives whose costs relied more on the volume consumed (such as the non-electric purifier and bottled water scenarios). Additional assumptions that vary by purifier type are saved in Table 7.1-1 (drinking water only treated) and Table F-1 of Appendix F (drinking and cooking water treated).

Table 7.1-1. Summary of Water Purifier Cost Elements, Capital Costs Plus 10 Years of Operation; Drinking Water Only Treated

Cost Elements	Tata Swach Non-electric system	Aquaguard Classic UV-based system	Kent RO Grand+ RO-based system
	One-Time Event Fees		
Initial Cost (avg)	999	8990	19000
	Annual Fees		
O&M Description	User cleans pre-treatment and post-treatment tanks as needed; change Tata Swach bulb every 3000 L	Pre-filter and granular activated carbon filter should be cleaned semi-annually and the activated carbon filter, and UV lamp should be replaced annually	Pre-filter and granular activated carbon filter should be cleaned quarterly and the sediment filter, activated carbon filters, RO membrane, and UV lamp should be replaced annually
Annual AMC Fee	549	1000	3000
Electricity Rating (W)	0	20	60
Treatment Time (LPM)	N/A	2	0.25
Electricity Unit Cost (Rs/KWh)	N/A	4	4
Approx Volume	25.0	25.0	25.0
Per Day Assumed Dur of Sys Op	N/A	0.21	1.67
Per Day Assumed Power Consump (KW)	N/A	0.00	0.10
Per Day Electricity Costs (Rs)	0	0.02	0.40
Lifetime	10	10	10

Sources: (Eureka Forbes, n.d.-a; Kent RO Systems Ltd., n.d.-a; Tata Chemicals Ltd., 2015)

As shown, a branded product was used to represent each category: Tata Swach for the non-electric group, Aquaguard Classic for the UV-based system, and Kent Grand+ for the RO-based system. The Annual Maintenance Contract (AMC) fee is assumed to be INR 1000 for the UV-based system, and INR 3000 for the RO-based system based on engineering judgment and a review of manufacturer and service company webpages (Kent RO Systems Ltd., 2016a). This maintenance rate was not consistent across interviewed RO users, and may vary by location and the level of demand for services. The Kent Grand+ product provides RO and UV treatment, and was used to represent the RO group because of its popularity. An RO-based product with no UV would cost less, though its maintenance would still be higher than the UV-based system. For each water purifier, the cost of water based on a municipal rate was used (the flat fee and the per kiloliter rate using Delhi's 2015 tariff structure), and for electric systems, the cost of power was also included. Though the water and electricity tariffs may change in the ten-year timeframe, the rates were kept consistent to show the general order of magnitude difference between options. See Figure 7.1-1 for the results of options for treating 5.0 LPCD (drinking water only). The Figure for treating 7.0 LPCD for both drinking and cooking is provided in Appendix F.

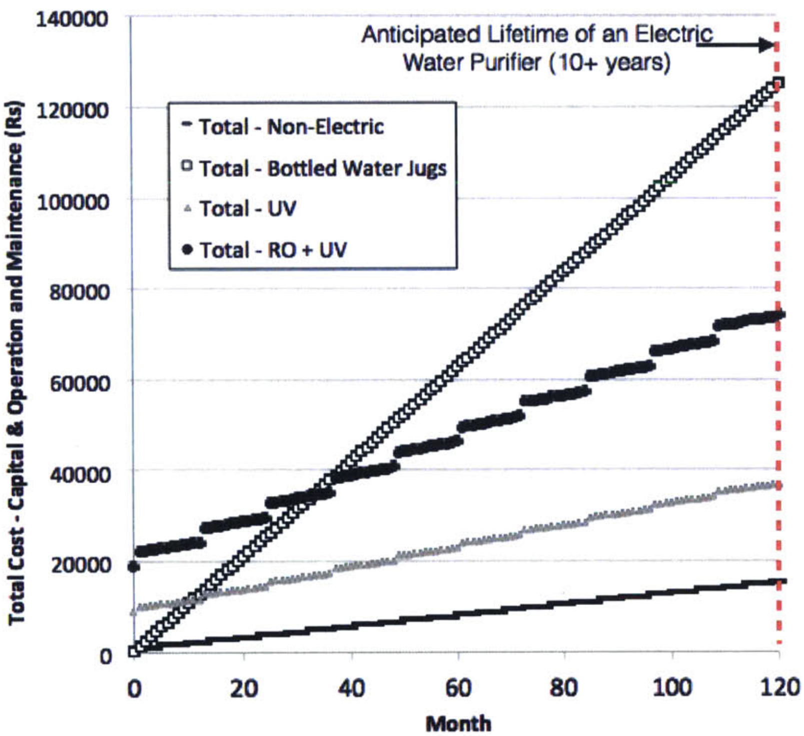

Figure 7.1-1. Cost Comparison of Water Treatment or Replacement Options, Drinking Water Only Treated (5.0 LPCD)

As demonstrated in Figure 7.1-1, bottled water has the highest cost if used as the sole source of drinking water over the full ten-year timeframe. Due to the capital cost associated with the different purifier options, however, there is a time period where bottled water is more affordable. The magnitude of the purifier purchase price and the cost of the AMC affect the duration of that time period. For the UV-based system, it takes less than a year (approximately eleven months) to become more economical than bottled water. For the RO-based system, it takes nearly three years (approximately 32 months). Though the figure presents rough costs through a ten-year timeframe, it is noted that families interviewed in January had reported using non-electric and UV-based systems for up to fifteen years, so the difference between the bottled water option and the purifiers would grow even more.

Though not included in the figure, boiling water remains a purification option. Its cost would involve electricity for heating water, which is not anticipated to exceed the capital and operational costs of a non-electric filter. Non-financial costs such as the time associated with boiling then cooling all potable water prior to consumption are difficult to estimate, and assumed in this case to extend above what is considered acceptable by the household. Since the targeted market for this RO impact evaluation has decided to either replace or improve their water through other mechanisms available in the market, boiling was not considered further.

It is noted that the water purifier options provided in Table 7.1-1 and Figure 7.1-1 do not necessarily provide the same quality of output water. Depending on the pollutants in the raw water source, water may or may not be fully treated with the non-electric system or the UV treatment system. Chapter 4 provided a background of treatment capabilities by technology type, and the next subsection briefly outlines the informational sources that consumers have in terms of distinguishing between system performance levels.

Information available about each treatment type

As previously indicated, Indian consumers receive a majority of their information on environmental issues from TV and newspaper channels. It is expected the same is true for information on more complex water treatment technologies, such as UV and RO. Private water purifier companies have been credited with decreasing instances of waterborne diseases due to the availability of household water treatment equipment. Manufacturers of water purifiers have included education in their marketing plans, including examples such as Tata's joint campaign with Brihanmumbai Municipal Corporation for "Tata Swach Wake up for Water" and Hindustan Unilver Limited's "Swachh Aadat, Swachh Bharat" campaign, encouraging people to use clean habits (one of which is drinking water only from a purifier) (Hindustan Unilever Limited, 2015; Tata Chemicals Ltd., 2011). These campaigns generally target broad adoption of water purifiers within the home, and do not focus on high-end UV or RO purifiers.

Advertisements run on TV and in newspapers are different, in that they promote improved family health associated with the use of high-end water filters, endorsed by celebrities such as Hema Malini, endorsing Kent RO systems since 2005 (Singh, 2015). In addition, manufacturers rely on their website to provide technical information on their products, such as the purpose of different treatment elements within a system. As an example, Tata's Swach Shuruaat walks the consumer through each stage of the treatment, explaining the improved purification of water throughout the treatment train (Tata Chemicals Ltd., n.d.). Manufacturers then often make recommends for the most appropriate system, given answers to questions on water source, flavor (salty or not), and price range. In addition, mobile sales have historically provided a significant portion of the sales of high-end water purifiers, possibly due to the "expert" advice provided to a household during system demonstration visits and sales calls. As observed at chain appliance stores in Bangalore and Mumbai over January, customers can also learn about the relevance of each type of system through the marketing information provided in the store. Several models included a sticker directly on the model unit and/or information in a brochure located next to the unit which identified which intake water sources could be used with each filter. Borewell water was primarily flagged for RO use, as municipal corporation water could be treated by UV. Water purifier manufacturers also commonly include certification symbols on their products and packaging, the lack of continuity in which certifications are promoted may prevent the consumer from understanding different treatment capabilities between technologies.

The government does not directly influence the household's water treatment system selection, but it does play an indirect role through overall government water supply and conservation initiatives, established drinking water standards, and specifications for household water purifiers. These are described in more detail in Chapter 8, as they tend not to impact the individual consumer's purchasing decision.

Willingness to Pay

Chapter 5.5 presented a review of willingness to pay data for improved WSS collected in India to date. The trends identified by these studies, coupled with water purifier sales data presented in Chapter 5.2, the occurrence of households avoiding the cost-recovery trade off for water purifiers in Chapter 6.3.2, and references made during the January 2016 interviews indicating the price range was too low demonstrates that urban households have accepted the price of existing RO water purifiers currently on the market, and value the anticipated treatment performance enough to consider making the purchase. Consideration should be made to the overall cost that a household must pay for water, however, based on the TERI 2013 survey data presented above in Chapter 7.1 which indicated a mixed response to willingness to pay the full cost of water.

Builder-installed purifiers

In some cases, the decision on whether to use a water purifier is made by others. For one apartment building visited during January 2016 in Jaipur, the builder had installed an RO-based water purifier inside each unit (the selected model was a Zero B unit). Each family moving into the new apartment building complex therefore had a different decision: to use the system provided to them for "free" (or included into the cost of the rent/purchase), or to discard the system. For the families we spoke with, the units were in use, and though the initial cost was covered by the builder, the annual maintenance fee still had to be paid by each household. The water source for this apartment complex was groundwater through private borewells with storage tanks. Municipal water service was not yet available in the area (the residents we spoke with had lived there up to two years), though a second tap was installed within each unit's kitchen in preparation for future service.

7.2 Individual Household – Potential Wastage Volumes

The discussion on small-scale water purifiers used in India so far has focused on the positive impacts of their use in terms of improved produced water quality and a reduced frequency of water-borne, diseases such as diarrhea, among users. Reverse Osmosis is currently viewed as the leading technology within these systems, though it comes with a drawback in the water that is rejected during the treatment process. The following section takes a closer look at what the range of recovery levels translates to in terms of the volume of water wasted – first at the household level, and then at the city level, using Delhi as an example. The implications of this waste are then discussed in terms of level of service, and overall demand for the future.

When evaluating the wastage volume from an RO system, it is important to consider whether the system is being used to treat only water used for drinking, or water used for drinking and cooking. As presented earlier in Chapter 3, estimates on total water consumption have varied, though for purposes of this evaluation, it will be assumed that water used for drinking and cooking are prioritized over water used for non-potable activities. As such, this volume was not observed to vary significantly across different conditions of water availability, so the 5.0 LPCD and 7.0 LPCD will be considered representative of current conditions for drinking water and combined drinking and cooking water volumes, respectively. Based on the range of supply norms and actual consumption values for non-potable water presented in Table 3.2-1 and Table 3.2-2, an average of 80 LPCD is assumed to be representative of the volume consumed per capita within a flat (where the anticipated growth is to occur in urban areas). Table 7.2-1 summarizes the average per capita and household consumption values to be used in the evaluation. Though the individual and total values presented are much lower than standard supply norms, their use is anticipated to provide a conservative estimate, and additional discussion regarding the impact using higher numbers will be provided later with the calculations. A household size of 5 people is assumed for the household-based volume calculations below based on the average family size, rounded to the nearest whole number (Government of India: Ministry of Statistics and Programme Implementation, 2011; Government of NCT of Delhi, 2015b).

Table 7.2-1. Summary of Selected Water Consumption Volumes, Per Capita and Per Household

	Per Capita	Per Household
Housing Type:	**Flat**	**Flat**
Volume Based On:	**Shaban & Ghosh**	**Shaban & Ghosh**
General Activity	**LPCD**	**L/HH/D**
Potable Uses	**7.0**	**35.0**
Drinking	*5.0*	*25.0*
Cooking	*2.0*	*10.0*
Non-potable uses	**80**	**400**
Washing dishes	*12.0*	*60.0*
Other	*68.0*	*340*
TOTAL Delivered	**87**	**435**

L/HH/D = Liters per household per day

Table 7.2-2 provides a summary and Table 7.2-3 provides the full evaluation with the volume of potable and non-potable water consumed per capita and per household (assuming 5 people per house), as well as the volume of water wasted by using a water purifier of various recovery levels. Volumes are calculated on daily and monthly basis, so that a comparison could be made to a monthly water bill. Cost estimates are then presented for the procurement of this excess water – first through municipal water sources (according to Delhi's 2015 tariff structure), then through additional groundwater pumping from a borewell, or the arrangement of additional tanker truck water (assuming each would be treated with the RO system). Bottled water is also presented as a replacement for all potable water (not requiring treatment), again with the volume reduced to a practical one 20L jug per day consumption rate. The columns of the table each represent a different RO system recovery level, with the 20% to 70%[14] range representing RO products currently on the market (standard and "eco-friendly"), with the 80% to 90% recovery conditions included for reference. Unlike the cost evaluation in Figure 7.1-1, for simplicity it was assumed that the household used the RO system each day of the month.

Table 7.2-2. Summary of Individual Household Wastage Volumes From Using a Water Purifier of Different Recovery Levels (5.0 LPCD, Drinking Water Only)

		Recovery %					
Description	**Units**	20%	30%	40%	50%	60%	70%
Volumes - per day (per capita)							
Vol. Potable Consumed	LPCD	5.00	5.00	5.00	5.00	5.00	5.00
Vol. Potable Wasted through RO Unit	LPCD	20.00	11.67	7.50	5.00	3.33	2.14
Vol. Non-potable Consumed	LPCD	82.0	82.0	82.0	82.0	82.0	82.0
Total Vol Consumed	LPCD	107.0	98.7	94.5	92.0	90.3	89.1
% Total Vol. Wasted	LPCD	19%	12%	8%	5%	4%	2%
Volumes - per day (HH)							
Vol. Potable Consumed	L/hh/d	25.00	25.00	25.00	25.00	25.00	25.00
Vol. Potable Wasted through RO Unit	L/hh/d	100.0	58.3	37.5	25.0	16.7	10.7
Vol. Non-potable Consumed	L/hh/d	410.0	410.0	410.0	410.0	410.0	410.0
Total Vol Consumed	L/hh/d	535.0	493.3	472.5	460.0	451.7	445.7
Volumes - per month (HH)							
Vol. Potable Consumed	L/hh/mo	660	660	660	660	660	660
Vol. Potable Wasted through RO Unit	L/hh/mo	2642	1541	991	660	440	283
Vol. Non-potable Consumed	L/hh/mo	10831	10831	10831	10831	10831	10831
Total Vol Consumed	L/hh/mo	14133	13032	12482	12152	11932	11774
	KL/hh/mo	14.13	13.03	12.48	12.15	11.93	11.77
Volumes - per year (HH)							
Vol. Potable Consumed	L/hh/yr	7925	7925	7925	7925	7925	7925
Vol. Potable Wasted through RO Unit	L/hh/yr	31700	18492	11888	7925	5283	3396
Vol. Non-potable Consumed	L/hh/yr	129970	129970	129970	129970	129970	129970
Total Vol Consumed	L/hh/yr	169595	156387	149783	145820	143178	141291
	L/hh/yr	169.60	156.39	149.78	145.82	143.18	141.29

[14] It should be noted that at least one product is available that stores reject water in a second tank, resulting in less wastage overall. Since these systems were not observed in use in January 2016, and it would be required that households have a use for the reject water year-round, it was not included in this evaluation.

Table 7.2-3. Summary of Individual Household Impact from Using a Water Purifier of Different Recovery Levels (5.0 LPCD, Drinking Water Only)

Description	Units	Recovery %							
		20%	30%	40%	50%	60%	70%	80%	90%
Volumes - per day (per capita)									
Vol. Potable Consumed	LPCD	5.00	5.00	5.00	5.00	5.00	5.00	5.00	5.00
Vol. Potable Wasted through RO Unit	LPCD	20.00	11.67	7.50	5.00	3.33	2.14	1.25	0.56
Vol. Non-potable Consumed	LPCD	82.0	82.0	82.0	82.0	82.0	82.0	82.0	82.0
Total Vol Consumed	LPCD	107.0	98.7	94.5	92.0	90.3	89.1	88.3	87.6
% Total Vol. Wasted	LPCD	19%	12%	8%	5%	4%	2%	1%	1%
Volumes - per day (HH)									
Vol. Potable Consumed	L/hh/d	25.00	25.00	25.00	25.00	25.00	25.00	25.00	25.00
Vol. Potable Wasted through RO Unit	L/hh/d	100.0	58.3	37.5	25.0	16.7	10.7	6.3	2.8
Vol. Non-potable Consumed	L/hh/d	410.0	410.0	410.0	410.0	410.0	410.0	410.0	410.0
Total Vol Consumed	L/hh/d	535.0	493.3	472.5	460.0	451.7	445.7	441.3	437.8
Volumes - per month (HH)									
Vol. Potable Consumed	L/hh/mo	660	660	660	660	660	660	660	660
Vol. Potable Wasted through RO Unit	L/hh/mo	2642	1541	991	660	440	283	165	73
Vol. Non-potable Consumed	L/hh/mo	10831	10831	10831	10831	10831	10831	10831	10831
Total Vol Consumed	L/hh/mo	14133	13032	12482	12152	11932	11774	11656	11565
	KL/hh/mo	14.13	13.03	12.48	12.15	11.93	11.77	11.66	11.56
Volumes - per year (HH)									
Vol. Potable Consumed	L/hh/yr	7925	7925	7925	7925	7925	7925	17446	17446
Vol. Potable Wasted through RO Unit	L/hh/yr	31700	18492	11888	7925	5283	3396	4362	1938
Vol. Non-potable Consumed	L/hh/yr	129970	129970	129970	129970	129970	129970	286115	286115
Total Vol Consumed	L/hh/yr	169595	156387	149783	145820	143178	141291	307922	305499
	L/hh/yr	169.60	156.39	149.78	145.82	143.18	141.29	307.92	305.50
Potential Costs - 100% Municipal (Delhi 2015 Tariff Structure)									
Flat Fee	INR	146.4	146.4	146.4	146.4	146.4	146.4	146.4	146.4
Usage, up to 20 KL	INR	62.0	57.2	54.8	53.3	52.4	51.7	51.2	50.8
Usage, from 20 - 30 KL	INR	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Usage, above 30 KL	INR	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Municipal - TOTAL Mo. Bill	**INR/mo**	208.5	203.6	201.2	199.8	198.8	198.1	197.6	197.2
Municipal - Wasted water cost, <20	**INR/mo**	11.6	6.8	4.3	2.9	1.9	1.2	0.7	0.3
Municipal - Wasted water cost, 20-30	**INR/mo**	-	-	-	-	-	-	-	-
Municipal - Wasted water cost ,>30	**INR/mo**	-	-	-	-	-	-	-	-
Municipal - TOTAL Mo. Bill (Wasted)	**INR/mo**	11.6	6.8	4.3	2.9	1.9	1.2	0.7	0.3
Potential Monthly Costs - 100% Groundwater (Pumping Costs)									
Energy moving extra water, Assume 0.5 hp pump, 0.85 pump eff, 0.85 motor eff, flow rate ~8.3 L/min	**KWhr/mo**	2.7	1.6	1.0	0.7	0.5	0.3	0.2	0.1
Monthly Electricity cost for wastage, tariff 4 INR/KW	**INR/mo**	10.9	6.3	4.1	2.7	1.8	1.2	0.7	0.3
Potential Monthly Costs - 100% Tanker - System still used to treat									
Amount of 10,000L Tankers to cover wastage	**10,000L/mo**	0.26	0.15	0.10	0.07	0.04	0.03	0.02	0.01
Cost of 10,000 Tankers (assume 1000 INR/ea)	**INR/mo**	264.2	154.1	99.1	66.0	44.0	28.3	16.5	7.3
Potential Monthly Costs - 100% Bottled Water Jugs (20L) - Used in place of all potable water in household									
No. 20L Jugs to cover reduced potable volume	**20L**	26	26	26	26	26	26	26	26
Cost of Jugs for reduced pot. vol. - (40 INR/20L)	**INR/mo**	1057	1057	1057	1057	1057	1057	1057	1057

As seen in Table 7.2-2 and Table 7.2-3, up to 31,700 L of water can be wasted each year by a single household using a water purifier with the standard 20% recovery when treating 5.0 LPCD. This total equates to approximately 19% of the total volume of water the household consumes in one year. Though this wastage can be a significant portion of the water consumed, the cost of the wasted water in terms of municipal tariffs or cost of additional pumping (in the case of a home primarily relying on groundwater from a borewell) is extremely low, each totaling less than INR 15 per month. The cost does increase when considering a household relying on water tankers for their primary supply, but even this cost is less than INR 265/month (assuming a 10,000 L tanker costs INR 1000), which is the equivalent of less than $5 US. The cost of bottled water is again presented for comparison, assuming the household's alternative is to rely exclusively on bottled water jugs for its potable water requirement. This cost is an order of magnitude greater than the cost of an additional tanker, so to revisit the comparison of bottled water fees to capital and O&M costs of the water purifier itself, the reader should refer back to Figure 7.1-1.

Since the above evaluation considered 5.0 LPCD of potable water (for drinking purposes only) and cooking was assumed to be boiled but not treated, a second evaluation was performed that took into account the additional 2.0 LPCD for cooking. Appendix G includes the summary table and full evaluation for a total of 7.0 LPCD potable water requiring treatment. As the same recovery values were used in the calculations, the total wastage for a household of five people using a water purifier with 20% recovery increased (from 31,700L in the case of the 5.0 LPCD produced water scenario to 44,380L in the case of the 7.0 LPCD produced water scenario. It should be noted that the calculated wastage volumes do not account for any additional loss in distribution through UFW. Considering a UFW rate of 35% in these wastage volumes would lead to an excess supply requirement from the municipal system of 48,769L and 68,277L per household per year for the 5.0 LPCD and 7.0 LPCD scenarios respectively. Table 7.2-4 provides a summary of wastage volumes according to different UFW rates.

Table 7.2-4. Summary of Household Annual Water Wastage Volumes at Different UFW Rates

Treatment Water Scenario	Vol. Treated	Wastage (L/HH/Yr) at Different UFW %			
		0%	15%	25%	35%
Drinking Water Only Treatment	5.0 LPCD	31700	37294	42267	48769
Drinking & Cooking Treatment	7.0 LPCD	44380	52212	59173	68277

Note: 20% Recovery was assumed for both scenarios

7.3 Delhi – Potential Wastage Volumes for SECA and SECB Social Groups

When scaling up the volumetric impact from household level calculations, it is important to clarify the target market, and the anticipated diffusion level. The population evaluated in this section consists of households in the SECA and SECB socio-economic categories, as presented earlier in Chapter 5. These socio-economic groups are estimated to overlap with HIG and MIG housing groups, and represent households with a high level of purchasing power and education. The estimated number of households form the SECA and SECB groups in Delhi is included in Appendix A as one of the twenty cities evaluated, and is also summarized below in Table 7.3-1 will then be used as a base for the potential waste volume calculations in India's capital city. This is anticipated to be somewhat conservative, given the number of households was calculated from Census 2011 data, and Delhi's urban population was projected to grow from approximately 16,753,235 people in 2011 to approximately 19,900,000 people in 2016 due to natural population increases and migration from other cities and rural areas (Delhi Development Authority, 2007; Indiastat, 2011a).

Table 7.3-1. Delhi Households, Broken down by SEC Code (2011 Census)

High TDS	Total	SECA	SECB	SECC	SECD	SECE
Number of Households	2,201,567	352,953	469,097	574,183	434,698	394,400
Percentage of Total	-	16%	21%	26%	20%	18%

As presented in the market report summary in Chapter 5, it was estimated that urban adoption of water purifiers, all varieties, had reached over 25% in Delhi. Observations from more recent surveys and studies summarized in Table 5.4-1 found the percentage to be higher, including diffusion of RO systems themselves extending up to 77% of HIG and 44% of MIG in Delhi (Ghosh et al., 2016). To evaluate the potential range of water wasted, the city-level evaluation will consider adoption levels from 10% through 100% among the SECA and SECB populations. Though a portion of this population may be limited in its overall consumption due to supply restrictions (Andey & Kelkar, 2009; Shaban & Sharma, 2007) in urban or peri-urban areas, we maintain the assumption that drinking water has the highest priority for a household, and volume reductions, if needed, are made in non-potable activities instead (Rosenberg et al., 2007). It should be noted that Ghosh also recorded RO purifier use in 27% of LIG households and 17% of slum dwellers surveyed (Ghosh et al., 2016). Though the evaluation does not include these subgroups, these groups' use of RO indicates the prevalence of the technology in Delhi, and the importance of understanding the impact on total water consumption with a high number of household units in operation.

Lastly, wastage volumes were calculated based on an average recovery rate of RO systems in use. The first scenario begins with an average of 20% recovery, which is considered representative of Kent's standard RO products (not including the Supreme system). The standard Whirlpool, Eureka Forbes Aquaguard, and Zero B products (not including any green or eco-friendly models) have a slightly higher recovery level, and are represented by the range between the 20% and 30% recovery data points. It is assumed that unbranded RO products also fall within the 20-25% recovery range. Appendix J presents the product specifications of a subset of RO purifiers currently available from the top RO branded manufacturers.

7.3.1 Potential Wastage Volumes

Figure 7.3.1-1 and Table 7.3.1-1 summarize the potential waste volumes for Delhi, based on treatment systems with recovery levels that vary from 20-50% (representing standard RO systems currently on the market) and treatment systems that represent an improvement to 70-90% recovery (all assuming 5.0 LPCD of treated potable water). In the figure, there are multiple y-axis labels: on the left are the total water wastage volumes in terms of KL/day and KL/year, given the adoption rate and average product recovery; on the right are the approximate number of equivalent households that could have been served with the water that was wasted (essentially representing an opportunity cost). The equivalent household axis labels are representative of the number that could have been served, given a household's daily demand for both potable and non-potable water, or with potable water alone (as in the case of a dual water supply, with municipal providing the household with potable water). Calculations used to create the table and graph are included in Appendix H, along with more comprehensive tables that also present the volume of potable (not including wastage) and non-potable water consumed for the range of product recovery values on a daily, monthly, and annual basis. Appendix I then contains the full set of supporting information assuming water for both drinking and cooking is treated (at 7.0 LPCD).

As shown in Figure 7.3.1-1 and Table 7.3.1-1, when considering the SECA and SECB communities in Delhi, an adoption rate of just 20% of standard RO systems (with a 20% recovery rate) results in over 16,400,000 L of water wasted every day due through the treatment of household drinking water. Though this wastage represents only 4.4% of delivered water to SECA and SECB families, this same volume could have provided nearly 37,800 households with their daily water demand[15]. The wastage volume under the same level of adoption decreases to 6,165,000 L if the average RO system has a 40% recovery. The lower wastage, however, still represents the equivalent daily demand for over 14,170 households. Increased adoption rates lead to more wastage, and more lost opportunity for servicing additional households without increasing the volume of water produced.

[15] This reference to daily household water demand, and all future references unless otherwise stated, assume total daily consumption as presented in Table 7.2-1, and discussed in Chapter 7.2. To assume water supply norms would be to greatly increase the total volume, resulting in a decrease of the number of households that could have been served with the wasted volume.

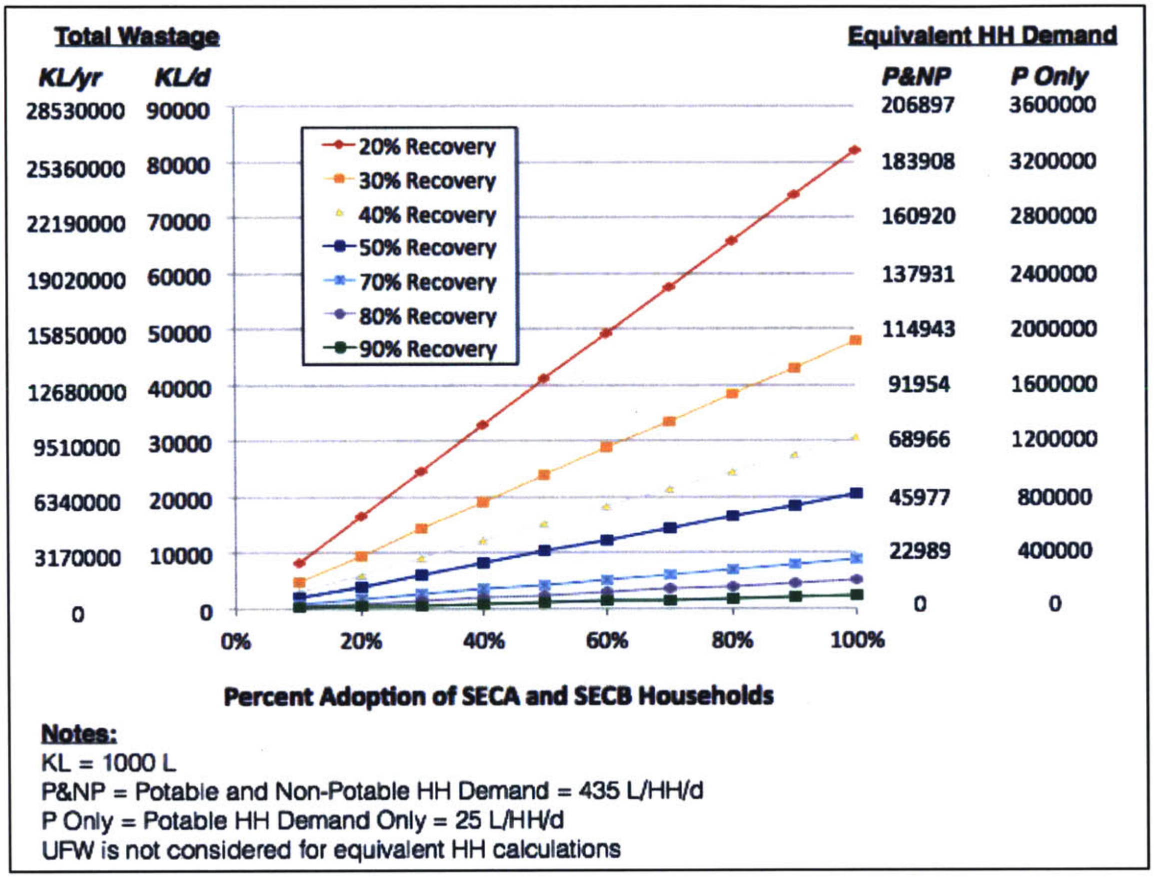

Figure 7.3.1-1. Summary of Potential Wastage Volumes and Equivalent Households That Could Have Been Served, Given a Range of Product % Recoveries and Adoption; SECA and SECB Households within Delhi, 5.0 LPCD Treated, Delhi

Table 7.3.1-1. Summary of Wasted Water Volumes and Equivalent Households That Could Have Been Served by the Wasted Volume; 5.0 LPCD Treated, Households with 5 People/Each, Delhi

Description	Units	Adoption % of Users with RO [5.0 LPCD treated; Drinking water only]									
		10%	20%	30%	40%	50%	60%	70%	80%	90%	100%
		Assuming an Average 20% Recovery									
Vol. Pot. Wasted through RO	KL/d	8220	16441	24661	32882	41102	49323	57543	65764	73984	82205
	KL/mo	250040	500080	750121	1000161	1250201	1500241	1750281	2000322	2250362	2500402
	KL/yr	3000482	3500563	5250844	7001126	8751407	10501689	12251970	14002252	15752533	17502815
% Total Vol. Wasted	%	2.2%	4.4%	6.5%	8.4%	10.3%	12.1%	13.9%	15.5%	17.1%	18.7%
Equiv. HH (P + N-P)	No. HH	18898	37795	56693	75591	94489	113386	132284	151182	170079	188977
Equiv. HH (P only)	No. HH	328820	657640	986460	1315280	1644100	1972920	2301740	2630560	2959380	3288200
		Assuming an Average 30% Recovery									
Vol. Pot. Wasted through RO	KL/d	4795	9591	14386	19181	23976	28772	33567	38362	43158	47953
	KL/mo	145857	291714	437570	583427	729284	875141	1020998	1166854	1312711	1458568
	KL/yr	1750281	2041995	3062993	4083990	5104988	6125985	7146983	8167980	9188978	10209975
% Total Vol. Wasted	%	1.3%	2.6%	3.9%	5.1%	6.3%	7.4%	8.6%	9.7%	10.8%	11.8%
Equiv. HH (P + N-P)	No. HH	11024	22047	33071	44095	55118	66142	77166	88189	99213	110237
Equiv. HH (P only)	No. HH	191812	383623	575435	767247	959058	1150870	1342682	1534493	1726305	1918117
		Assuming an Average 40% Recovery									
Vol. Pot. Wasted through RO	KL/d	3083	6165	9248	12331	15413	18496	21579	24661	27744	30827
	KL/mo	93765	187530	281295	375060	468825	562590	656356	750121	843886	937651
	KL/yr	1125181	1312711	1969067	2625422	3281778	3938133	4594489	5250844	5907200	6563555
% Total Vol. Wasted	%	0.9%	1.7%	2.5%	3.3%	4.1%	4.9%	5.7%	6.5%	7.2%	7.9%
Equiv. HH (P + N-P)	No. HH	7087	14173	21260	28347	35433	42520	49606	56693	63780	70866
Equiv. HH (P only)	No. HH	123307	246615	369922	493230	616537	739845	863152	986460	1109767	1233075
		Assuming an Average 50% Recovery									
Vol. Pot. Wasted through RO	KL/d	2055	4110	6165	8220	10276	12331	14386	16441	18496	20551
	KL/mo	62510	125020	187530	250040	312550	375060	437570	500080	562590	625101
	KL/yr	750121	875141	1312711	1750281	2187852	2625422	3062993	3500563	3938133	4375704
% Total Vol. Wasted	%	0.6%	1.1%	1.7%	2.2%	2.8%	3.3%	3.9%	4.4%	4.9%	5.4%
Equiv. HH (P + N-P)	No. HH	4724	9449	14173	18898	23622	28347	33071	37795	42520	47244
Equiv. HH (P only)	No. HH	82205	164410	246615	328820	411025	493230	575435	657640	739845	822050
		Assuming an Average 70% Recovery									
Vol. Pot. Wasted through RO	KL/d	881	1762	2642	3523	4404	5285	6165	7046	7927	8808
	KL/mo	26790	53580	80370	107160	133950	160740	187530	214320	241110	267900
	KL/yr	321480	375060	562590	750121	937651	1125181	1312711	1500241	1687771	1875302
% Total Vol. Wasted	%	0.2%	0.5%	0.7%	1.0%	1.2%	1.5%	1.7%	1.9%	2.2%	2.4%
Equiv. HH (P + N-P)	No. HH	2025	4050	6074	8099	10124	12149	14173	16198	18223	20248
Equiv. HH (P only)	No. HH	35231	70461	105692	140923	176154	211384	246615	281846	317076	352307
		Assuming an Average 80% Recovery									
Vol. Pot. Wasted through RO	KL/d	514	1028	1541	2055	2569	3083	3596	4110	4624	5138
	KL/mo	15628	31255	46883	62510	78138	93765	109393	125020	140648	156275
	KL/yr	187530	218785	328178	437570	546963	656356	765748	875141	984533	1093926
% Total Vol. Wasted	%	0.1%	0.3%	0.4%	0.6%	0.7%	0.9%	1.0%	1.1%	1.3%	1.4%
Equiv. HH (P + N-P)	No. HH	1181	2362	3543	4724	5906	7087	8268	9449	10630	11811
Equiv. HH (P only)	No. HH	20551	41102	61654	82205	102756	123307	143859	164410	184961	205512
		Assuming an Average 90% Recovery									
Vol. Pot. Wasted through RO	KL/d	228	457	685	913	1142	1370	1598.43	1827	2055	2283
	KL/mo	6946	13891	20837	27782	34728	41673	48619	55564	62510	69456
	KL/yr	83347	97238	145857	194476	243095	291714	340333	388951	437570	486189
% Total Vol. Wasted	%	0.1%	0.1%	0.2%	0.3%	0.3%	0.4%	0.4%	0.5%	0.6%	0.6%
Equiv. HH (P + N-P)	No. HH	525	1050	1575	2100	2625	3150	3675	4199	4724	5249
Equiv. HH (P only)	No. HH	9134	18268	27402	36536	45669	54803	63937	73071	82205	91339

7.3.2 Implications of Potential Wastage Volumes for Delhi's Water Supply

The following section looks further into the results presented above, exploring the potential implications of the estimated wastage volumes based on the conditions of Delhi's water supply program, as well as its other water and wastewater management programs. Table

7.3.2-1 provides an overview of results, as well as information regarding water supply and the status of groundwater development and wastewater treatment in Delhi. Volumes are provided in million liters per day (MLD) with the exception of annual groundwater availability and withdrawals, as those values are seasonal and not necessarily consistent throughout the year.

Table 7.3.2-1. Basis for Evaluation of Delhi Wastage Volumes

	Units	Delhi		
TDS Level		High		
Water Supply Norm	LPCD	225		
Water Supply & Demand	MLD	4155 total demand, 3364 supply, 455 from gw		
Status of Groundwater Withdrawals	-	Over-exploited in 20/27 tehsils; Semi-Critical in 2; Gross draft 36,919 vs. 27,318 HAM/yr Available		
Status of Wastewater Treatment	-	As of 2011, 2,867 MLD of sewage is discharged into the Yamuna River, 1,349 MLD of which was treated		
Groundwater Development Plan	-	Develop potential gw aquifers within Yamuna Flood Plans; Dual water supply in Dwarka; Recycle treated wastewater for irrigation, horticulture; Develop brackish gw for non-potable domestic use		
Total HH	HH	2201567		
SECA	HH	352953		
SECB	HH	469097		
SECA + SECB Subtotal	HH	822050		
Level of Adoption		**Avg 20% Recov**	**Avg 30% Recov**	**Avg 40% Recov**
10%	MLD	8.2	4.80	3.08
20%	MLD	16.4	9.59	6.17
30%	MLD	24.7	14.4	9.25
40%	MLD	32.9	19.2	12.3
50%	MLD	41.1	24.0	15.4
60%	MLD	49.3	28.8	18.5
70%	MLD	57.5	33.6	21.6
80%	MLD	65.8	38.4	24.7
90%	MLD	74.0	43.2	27.7
100%	MLD	82.2	48.0	30.8

MLD = Megaliters per day
Source: (Central Ground Water Board, 2011)

The wastage calculations associated with various levels of RO water purifier use across Delhi presented above consider only SECA and SECB households. As mentioned previously, RO systems have been observed to be in use within LIG and slum dwellers, which are assumed to fall below the socio-economic cutoff of the two groups reviewed. It can therefore be assumed that if small enough, the assumed wastage from a portion of the SECA or SECB population deciding never to adopt an RO system (because of lack of need or other reasons) may be replaced by households from another socio-economic segment. A review of the volumes as calculated could then be compared to Delhi's system for an overall review of impact, assuming, at least conservatively, that the remaining socio-economic groups utilize treatment technologies that recover 100% of the input water.

Volume Review

As mentioned above, the majority of RO systems currently in use are likely to have recovery rates of 20-25%. Though Kent, Eureka Forbes and ZeroB each have an "eco-friendly" RO purifier that can recover 50, 60 or 70% of the input water, it is unlikely these products currently have a high enough level of market share to increase the average recovery rate past 30%.

The percent adoption begins at 10%, which is nearly double the total percentage of Delhi's households recorded in 2011 to rely on "well water" and "other sources of water" as their primary source (4.7% from well water, 0.1% from other sources)[16] (Census of India, 2011a), but still less than the current level of RO use observed in recent studies (Ghosh et al., 2016; Shaban & Sharma, 2007). In future years, if RO system adoption continues to grow (without taking into account an increase in population which would increase the size of the total potential market) the wasted volume could represent 10% or more of the volume of supply currently sourced from extracted groundwater. Since ground water is being used to supply water in excess of current surface water supplies, and 20 of the 27 groundwater assessment units were identified as over-exploited as of 2011, (and an additional 5 units are considered semi-critical), increasing RO use demand for the excess volume requirement could lead to higher groundwater withdrawal rates and likely further deterioration of aquifers within Delhi (Central Ground Water Board, 2011).

[16] Households relying primarily on "handpumps and tubewells" were not included in the evaluation, as RO water purifiers require continuous, connected access to water through a tap, and an electricity source.

Impacts to Delhi's Sewer System

In addition to increasing total wastewater loads, low RO system recoveries lead to greater chances of cross-contamination with drinking water in areas without sufficient sewer collection and distribution infrastructure. According to approximations of generated sewage from supply rates and the standard 80% sewage assumption, Delhi's sewer network collects and treats approximately 1,349 MLD of the 2,867 MLD sewage generated within the city (Central Ground Water Board, 2011; Delhi Jal Board, 2015a). For RO systems with low recovery, the total volume required to produce the desired amount of treated water results in a higher water demand, and a higher sewer demand. Because Delhi's sewer infrastructure is limited in its treatment volume, lowering the daily demand such that the amount of untreated wastewater decreases may lower the potential for exposure to potable water[17], potentially dropping the frequency of cross-contamination.

Urbanization

With Delhi's population growth projected to take place not only in peri-urban areas that may not currently have municipal service, but also in its more central urban areas that are connected to the municipal distribution network (Delhi Development Authority, 2007), reducing consumption associated with RO wastage and improving allocation of its water supply could provide higher levels of service and lead to increased tariffs (as a portion of the water tariff is a flat fee, the more customers that are serviced, the higher the total tariff collection pool), further supporting infrastructure investments. Estimates on the equivalent number of households that could have been served demonstrate the order of magnitude of new customers could be over 100,000 households depending on the average RO recovery, the percent adoption of RO systems within the SECA and SECB subgroups, and the volume of water actually consumed by each household.

[17] This anticipated reduction in cross-contamination from lower wastewater volumes assumes that lower volumes of sewage infiltrating the soil will lead to lower amounts of microorganisms being drawn into water supply distribution pipes during times of negative pressure. This assumption may not be accurate given the volume of wastewater already impacting the soil, as the concentration of microorganisms may be sufficient to contaminate the water source without the additional load.

Potential Variation in Average Household Water Consumption

As indicated in Table 7.3.2-1, the water supply norm was 225 LPCD (Central Ground Water Board, 2011). This value could be inclusive of UFW, but it is still nearly two and a half times as high as the assumed per capita value for this evaluation (87 LPCD, as shown in Table 7.2-1). The supply norm varies beyond these two numbers, depending on the data source and year, so as a result, the evaluation of waste generated was limited to calculating treatment from drinking water (or drinking and cooking), and was considered conservative as a low estimate that was generally consistent with studies performed to date as well as Gleick's minimum per capita daily water need value. In some of the studies reviewed, all water from the kitchen tap is combined, so water used for potable uses but could be higher than what was assumed. The wastage volumes presented are therefore likely conservative and biased low (Shah, Thakar, & Panda, 2009; Water Resources Foundation, 2016).

Relevance of RO Waste for Delhi's Groundwater Development Plan

As indicated in Table 7.3.2-1, Delhi's groundwater development plans involve a shift from groundwater in over-exploited areas to those that are more sustainable, such as within the Yamuna Flood Plain. In addition, dual water supply, where potable water is provided from one source, and non-potable water is provided by a different source, is being considered in Dwarka, a densely populated area within the southwest district of the city (an area extracting over 200% of the groundwater recharge rate) (Delhi Jal Board, 2015a; www.mapsofindia.com, 2015). If dual supply is implemented, the volume of potable water provided will be important, as well as the delivery condition (intermittent, therefore likely still requiring treatment within the home, or continuous). Delhi's Master Plan for 2021 references a value of 20 GPCD (approximately 90 LPCD) for domestic non-potable water consumption. If the 60 GPCD (approximately 272 LPCD) water supply norm is used as the base, that means 40 GPCD (approximately 182 LPCD) of potable water from freshwater sources would be provided in a dual system. This value is still over twice as high as the assumed water consumed per person in the evaluation above, so if treatment is still required due to intermittent flow and/or using the same distribution network to transfer both potable and non-potable water on different cycles, the amount of potable water treated for drinking purposes is not expected to decrease. If potable water can be provided on a continuous basis, it is possible that household treatment will not be required. At that point, the household may use taste or preference as rationale for continued use of their investment, so RO wastage still may be generated.

Additional proposals such as use of recycled wastewater for irrigation and horticulture will not impact the amount of RO water generated, though if brackish water is used only for non-potable uses and not for drinking, it is possible that alternate water purifiers (such as UV-based systems) can be used in place of the RO systems, and adoption may not spread as far.

7.3.3 Additional Considerations Regarding Wastage and Reject RO Water

Unaccounted for Water

Unaccounted for water was not included in the city-level SECA and SECB wasted volume estimates. This was left out in part due to the uncertainty of the UFW value most representative of areas servicing SECA and SECB households, but also because not all households are relying entirely on municipal water as their main source. The associated additional volume required due to the UFW for purely municipality supplied water, however, would be significant, and likely cause wastage volumes (or volumes associated with delivering that volume to SECA and SECB households) to be up to one-third greater than what is shown in Table 7.3.1-1 and Figure 7.3.1-1. This increase has significant impacts on the planning of municipal water bodies, and as previously described, the amount of households that could have been served, had that water not been wasted.

Reject Water Collection and Reuse

In the water purifier waste calculations provided above, all reject water was assumed to drain directly into the sink. Based on the January 2016 interviews, however, some households capture some, if not all of the reject water, and use it for cleaning and gardening purposes otherwise considered non-potable uses within this evaluation. The calculations do not account for this reuse, which would effectively reduce the total daily demand of water for the house in addition to providing some secondary value to the RO reject water. The decision was made not to account for this in-home recycling because of the low percentage of households observed in January 2016 to be actively collecting the water for reuse. In addition, to make a reduction in the table would be to assume there is a daily use for the water that households repeatedly make. The lack of long-term collection activities observed in January in addition to the typical uncertainty that households had in terms of appropriate uses for this water led to the decision to maintain this water as a waste, and not account for its reuse.

Ground Water Impacts

Cities are increasingly looking at water consumption in total terms with plans of managing water at the municipal and private level (new NOC regulations for industries require a permit even for borewells that were installed prior to an area's designation as a groundwater projection zone), so possible restrictions on groundwater withdrawal rates for private use may cause increased tension around water that is not used entirely for potable consumption (Central Ground Water Authority, 2015b; Nandi, 2015).

7.4 Potential Wastage Volumes for SECA and SECB Social Groups Calculated for other Indian Cities (Mumbai, Bangalore and Ahmedabad)

Potential wastage volumes associated with the use of RO water purification systems by the SECA and SECB socio-economic groups of additional cities were also evaluated in order to get a sense of impact with cities in different parts of the country. Results for Bangalore, Ahmedabad and Mumbai are presented below in Table 7.4-1, Table 7.4-2 and Table 7.4-3. Supporting calculations are provided in Appendix K.

Table 7.4-1. Basis for Evaluation of Bangalore Wastage Volumes

	Units	Bangalore		
TDS Level		Medium		
Water Supply Norm	LPCD	170		
Water Supply & Demand	MLD	1275 total demand; 1315 supply, 475 from gw		
Status of Groundwater Withdrawals	-	As of March 2009, over-exploited in all taluks of Bangalore Urban District (16703 vs. 11723 HAM/yr Available)		
Status of Wastewater Treatment	-	Sewage pollution observed in the western part of the city; untreated discharge to Vrishbhavathi River Valley; Haphazard urbanization		
Groundwater Development Strategy	-	Require rain water harvesting in all buildings; Require ground water recharge at all feasible locations; Conservation and protection of all water bodies; Dual water supply with recycling of treated wastewater for non-domestic purposes; Increase ground water pricing; Permit only water-efficient domestic appliance use (for solar water heaters		
Total HH	HH	1685194		
SECA	HH	270169		
SECB	HH	359071		
SECA + SECB Subtotal	HH	629240		
Level of Adoption		**Avg 20% Recov**	**Avg 30% Recov**	**Avg 40% Recov**
10%	MLD	6.3	3.67	2.36
20%	MLD	12.6	7.34	4.72
30%	MLD	18.9	11.0	7.08
40%	MLD	25.2	14.7	9.44
50%	MLD	31.5	18.4	11.8
60%	MLD	37.8	22.0	14.2
70%	MLD	44.0	25.7	16.5
80%	MLD	50.3	29.4	18.9
90%	MLD	56.6	33.0	21.2
100%	MLD	62.9	36.7	23.6

Source: (Central Ground Water Board, 2011, 2013)

Table 7.4-2. Basis for Evaluation of Ahmedabad Wastage Volumes

	Units	Ahmedabad		
TDS Level		High		
Water Supply Norm	LPCD	160		
Water Supply & Demand	MLD	863 total demand; 760 supply, 4% from gw		
Status of Groundwater Withdrawals	-	As of 2004, over-exploited in Ahmedabad City + Daskroi Taluka (by 95.75 MCM/yr) and Gandhinagar Taluka (by 49.79 MCM/yr)		
Status of Wastewater Treatment	-	As of 2011, only one third of the sewage of the city is being partially treated; the remainder is discharged directly into the Sabmarti River		
Groundwater Development Strategy	-	Regulate groundwater development work; Require rainwater harvesting structures in all new houses/group societies; Dual water supply (30-50 LPCD potable "fresh" source, non-drinkable/non-kitchen separate source); ban use of brackish water for drinking ;improve sewage infrastructure		
Total HH	HH	1114117		
SECA	HH	178614		
SECB	HH	237389		
SECA + SECB Subtotal	HH	416004		
Level of Adoption		**Avg 20% Recov**	**Avg 30% Recov**	**Avg 40% Recov**
10%	MLD	4.16	2.43	1.56
20%	MLD	8.32	4.85	3.12
30%	MLD	12.5	7.28	4.68
40%	MLD	16.6	9.71	6.24
50%	MLD	20.8	12.1	7.80
60%	MLD	25.0	14.6	9.36
70%	MLD	29.1	17.0	10.9
80%	MLD	33.3	19.4	12.5
90%	MLD	37.4	21.8	14.0
100%	MLD	41.6	24.3	15.6

Source:(Central Ground Water Board, 2011)

Table 7.4-3. Basis for Evaluation of Mumbai Wastage Volumes

	Units	Mumbai		
TDS Level		Medium		
Water Supply Norm	LPCD	150-200		
Water Supply & Demand	MLD	3080 proj. domestic demand of 4525 total, 3230 supply		
Status of Groundwater Withdrawals	-	No measurements availble, though gw is used to supplement water supply when surface water sources are inadequate to cover demand		
Status of Wastewater Treatment	-	As of 2004, Greater Mumbai's system treated approximately 2530 MLD of 5265 MLD sewage; Sewage conveyance system is inadequate in coverage and condition		
Groundwater Development Plan	-	Limited groundwater development can take place; Regulate gw exploitation for commercial purposes; expand surface water supply; Require rain water harvesting for plots > 1000 sq m		
Total HH	HH	2495689		
SECA	HH	400106		
SECB	HH	531767		
SECA + SECB Subtotal	HH	931873		
Level of Adoption		**Avg 20% Recov**	**Avg 30% Recov**	**Avg 40% Recov**
10%	MLD	9.3	5.4	3.49
20%	MLD	18.6	10.9	6.99
30%	MLD	28.0	16.3	10.5
40%	MLD	37.3	21.7	14.0
50%	MLD	46.6	27.2	17.5
60%	MLD	55.9	32.6	21.0
70%	MLD	65.2	38.1	24.5
80%	MLD	74.5	43.5	28.0
90%	MLD	83.9	48.9	31.5
100%	MLD	93.2	54.4	34.9

Sources: (Central Ground Water Board, 2011; Municipal Corporation of Greater Mumbai, 2004)

7.5 Potential Wastage Volumes for SECA and SECB Social Groups Calculated for all of Urban India

As the sections above evaluate the potential volume of water wasted by RO water purifier use in four example cities, the problem does not stop there. A similar evaluation applied to the entire urban population of India results in potential wastage volumes of up to over 1,672

MLD if 100% of SECA and SECB homes are treating 5.0 LPCD, according to the population numbers and SEC group breakdown assumptions outlined in Table 7.5-1. Supporting calculations are provided in Appendix L. With increasing urbanization and continued adoption trends of households using multi-stage treatment systems containing RO technology to treat not only TDS, but all other contaminants, this value can increase even more. Not only does this have significant implications for the volume wasted, but it should also be noted that when these systems are being used on municipal water, money and energy spent treating that water at its point of production is also going to waste.

Table 7.5-1. Basis for Evaluation of Wastage Volumes, Urban India

DESCRIPTION	UNITS	VALUE	SOURCE	
TOTAL Population, India	Households	246,692,667	2011 CENSUS	
URBAN Population, India	Households	78,865,937	2011 CENSUS	
Avg. % SECA, Major Districts	% of Total	6.2%	SEC Evaluation based on 2011 Census, HH size of 5, and SEC breakdown of households provided by confidential water purifier manufacturer. All TDS levels considered.	
Avg. % SECB, Major Districts	% of Total	14.9%		
Estimated Total SECA + SECB	**Households**	**16,715,275**		
Avg. % SECC, Major Districts	% of Total	19.9%		
Avg. % SECD Major Districts	% of Total	23.5%		
Avg. % SECE Major Districts	% of Total	35.4%		
WASTAGE VOLUMES - 5.0 LPCD TREATED, DRINKING WATER ONLY				
Level of Adoption	**UNITS**	**Avg 20% Recov**	**Avg 30% Recov**	**Avg 40% Recov**
10%	MLD	167	98	63
20%	MLD	334	195	125
30%	MLD	501	293	188
40%	MLD	669	390	251
50%	MLD	836	488	313
60%	MLD	1003	585	376
70%	MLD	1170	683	439
80%	MLD	1337	780	501
90%	MLD	1504	878	564
100%	MLD	1672	975	627
WASTAGE VOLUMES - 7.0 LPCD TREATED, DRINKING AND COOKING WATER				
Level of Adoption	**UNITS**	**Avg 20% Recov**	**Avg 30% Recov**	**Avg 40% Recov**
10%	MLD	234	137	88
20%	MLD	468	273	176
30%	MLD	702	410	263
40%	MLD	936	546	351
50%	MLD	1170	683	439
60%	MLD	1404	819	527
70%	MLD	1638	956	614
80%	MLD	1872	1092	702
90%	MLD	2106	1229	790
100%	MLD	2340	1365	878

Chapter 8. Implications for the Future

The calculations and trends presented in Chapter 7 demonstrate the potential for a significant amount of waste associated with the increased use of RO water purifiers, which have otherwise been providing improved drinking water quality to hundreds of thousands, if not millions, of Indian households over the past decade or more. As increased adoption of these RO purifiers is anticipated in the coming years, the following reviews typical trends in product adoption that may speed up or slow down this diffusion, as well as policy and technology-based alternatives that, if applied, could change the projected impact of urban household water purification in India to a more sustainable future.

8.1 Product Diffusion – General Discussion

The calculations and trends presented in Chapter 7 use simple scaling, and while RO system adoption is likely to continue increasing over time, it is important to note that the product diffusion curve is not anticipated to be linear. As first presented by Bass, product diffusion typically occurs with two stages of consumers: initial adoption by innovators where product use begins independent of others, followed by product adoption by imitators, when customers are influenced by the actions of those that have already adopted the product. As the potential customer base converts to become adopters of the product, diffusion slows and approaches some sustainable level, exhibiting goal-seeking behavior. For consumer durables, the timing of the product purchase is driven by the number of current adopters in the social system" (Bass, 1969, p. 215). The Bass Model uses a coefficient of innovation and a coefficient of imitation, which is higher in magnitude and eventually drives the majority of diffusion. The likelihood of purchase over the life of the product is then represented by exponential growth until sales are at approximately 50%, after which growth slows as the market becomes saturated. The product's cumulative sales then take the shape of an S-curve. For products with long lifespans, the decrease in sales continues until replacements are made. Word of mouth recommendations and traditional advertising drive the imitator's initial decision (Bass, 1969; Sterman, 2000).

In terms of the purpose behind Bass' diffusion model, the intent was to facilitate the study of policies that could "shift the curve" (Bass, 2004, p. 1837) and better understand the factors that increase or decrease adoption of a product. Word of mouth factors (such as contact rate between households using a certain product) cannot necessarily be controlled by a company introducing a new technology, but price and advertising are decision variables that can be adjusted to encourage the "innovator" phase of adoption. In the RO water purifier market, one of the manufacturers, Kent, has heavily invested in marketing RO as an overall superior technology to replace UV, as well as a solution for families with high TDS levels (Sultana & Santhosi, 2012). The RO industry has grown as a result, now considered above UV as the best method available in household water purification due to the "pure and hygienic" taste of its product water (AnalyZ Research Solutions Pvt Ltd, 2012).

With the apparent strength of the current RO market, making a change to slow adoption could be made one of many ways, though all most focus on (and interrupt) a decision variable in the model. Bass talks about price and advertising, both of which could be impacted by policy decisions and government initiatives. Factors that indirectly impact Word of Mouth could include performance and satisfaction of the customer, which could be targeted with educational campaigns. In the case of attempting to promote an alternative product, Janssen and Jager present five common attributes originally identified by Everett Rogers that impact adoption: (1) relative advantage, (2) compatibility, (3) complexibilty, (4) trialability, and (5) observability. Differentiation of a new product would need to touch on one or several of these attributes in order to appear an attractive replacement, and policy decisions (including pricing and non-pricing variants) could play a role in creating the right environment. Overall, consideration must be made to the consumption patterns that are likely "locked-in" (such as the potential for continued use of a treatment system even if input water does not require it, or the lack of a collection mechanism for RO system wastewater to facilitate its reuse), and the presence of a high "switching cost" associated with a household replacing an RO water purifier with an alternative before its anticipated lifetime has been reached (Janssen & Jager, 2002). The following sections will outline potential alternatives, and address the associated challenges for each related to potential success.

Appendix M provides additional discussion and an example application of the Bass Model to the RO water purifier market to further explore design variables that could be targeted for overall reduction of wastage volumes.

8.2 Policy-Driven Alternatives

Both federal and state-level government agencies in India have created a range of policies that promote the conservation of the country's water resources. Table 8.2-1 summarizes a subset of recent programs, and the subsections that follow identify how certain policy-driven alternatives can be configured to align with these programs and help achieve the shared goal of improved (and informed) management of water resources.

Table 8.2-1. Summary of Select Government Water Conservation Initiatives and Policies

Year: Program & Government Entity	Description
2011: National Water Mission under National Action Plan on Climate Change Ministry of Water Resources, Government of India (Government of India: Ministry of Water Resources, 2008)	"The main objective of the National Water Mission is 'conservation of water, minimizing wastage and ensuring its more equitable distribution both across and within States through integrated water resources development and management.'" (p. 3) The Mission's five goals include: • "Comprehensive water data base in public domain and assessment of impact of climate change on water resource, • Promotion of citizen and state action for water conservation, augmentation and preservation, • Focused attention to vulnerable areas including over-exploited areas, • Increasing water use efficiency by 20%, and • Promotion of basin level integrated water resources management" (p. 5) In achieving the goal of focused attention to vulnerable areas including over-exploited areas, the "promotion of water purification and desalination was one strategy, as well as involving stakeholders, as "the active participation of the stakeholders has yielded very encouraging results in water management" (p. 14). In terms of the increase in water use efficiency by 20%, the timeframe targeted is the end of 2017. A mandatory audit, including coverage of drinking water supply and consumption, is part of the plan, as well as incentives and awards for efficiency and conservation efforts. (p. v-vi) In addition, the "efficiency of urban water supply systems" are specifically mentioned as an area of improvement, as well as "efficiency labeling of water appliances and fixtures" (p. 23).
2011: Ground Water Scenario in Major Cities of India Central Ground Water Board, Ministry of Water Resources, Government of India	The report presents water supply and demand volumes (both from 2011 and projected forward) as well as groundwater conditions of certain cities in India. Each section then summarizes the groundwater development plan for that particular city. The following is a summary of proposed initiatives for four cities reviewed: Delhi, Mumbai, Bangalore, and Ahmedabad. Delhi Develop potential groundwater aquifers within Yamuna Flood Plans; Dual

(Central Ground Water Board, 2011)	water supply in Dwarka; Recycle treated wastewater for irrigation, horticulture; Develop brackish groundwater for non-potable domestic use <u>Mumbai</u> Limited groundwater development can take place; Regulate groundwater exploitation for commercial purposes; expand surface water supply; Require rain water harvesting for plots > 1000 sq m <u>Bangalore</u> Require rain water harvesting in all buildings; Require ground water recharge at all feasible locations; Conservation and protection of all water bodies; Dual water supply with recycling of treated wastewater for non-domestic purposes; Increase ground water pricing; Permit only water-efficient domestic appliance use (for solar water heaters provide subsidy); Continue to permit new groundwater structure in over-exploited areas; educational programs focused on conservation <u>Ahmedabad</u> Regulate groundwater development work; Require rainwater harvesting structures in all new houses/group societies; Dual water supply (30-50 LPCD potable "fresh" source, non-drinkable/non-kitchen separate source); ban use of brackish water for drinking; Improve sewage infrastructure
2013: India's Twelfth Five Year Plan (2012-2017) Planning Commission, Government of India (Government of India: Planning Commission, 2013)	The Plan calls for a "Paradigm Shift" in which: • Water efficiency is improved • A participatory approach will be taken to sustainably manage groundwater • All new urban water supply projects must integrate sewage systems within them There is a large focus on irrigation due to the percent of water attributed to it (approximately 80%), but urban water and waste management was emphasized in terms of the need to: • "Reinvent their water trajectory to both secure the water they need and do so in a way that minimizes the scope for conflict...[and allows them to] grow with minimal water and minimal waste" (p. 161) • Replace water demand supply program estimates based on an estimate of demand per capita and the population Essential pre-conditions for urban water and sanitations projects include: • "Plan to supply water at affordable costs to all • Invest in protection and management of local water systems • Reduce water demand and intra-city inequity in water supply and sanitation • Invest on sewage first and water supply next • Reduce costs on sewage systems so that investment can reach all • Reinvest sewage management and treatment systems for sustainability • Plan to recycle and reuse every drop of water and waste" (p. 166)

2015: Draft Water Policy - Delhi Delhi Jal Board (DJB) (Delhi Jal Board, 2015a)	The draft policy includes the following proposed statements (a subset of the longer list): • The first priority for allocating Delhi's water resources is "drinking water and human freshwater use" (p. 118) • Demand management: the policy plans to decrease per capita water consumption from 172 LPCD by a minimum of 10 LPCD every 5 years • Decentralized treatment of wastewater is promoted, and the following percentages of recycled water is planned for use: 25% by 2017, 50% by 2022, 80% or more by 2027 • Water conservation and efficiency will be promoted • Distribution losses will be targeted • Aquifer management will be put in place to attain full recovery of the 1990 groundwater levels by 2030 • Achieve access to water for all, with the minimum per capita requirement decreasing over time

8.2.1 Water Supply Volume Restrictions

As demonstrated in previous sections, water supply norms vary tremendously depending on location, and appear to also vary depending on the perceived availability of water supplies. Shortages in water supply are then referenced as the reason for providing intermittent water service to a municipality's constituents. In Delhi's Draft Water Policy, a reduction in household consumption is specifically called out as an objective with the goal of reducing the total by 10 LPCD every 5 years (Delhi Jal Board, 2015a). As Ghosh argues in an evaluation of water actually consumed by households in Delhi compared to the water supply norms that are used in developing water supply programs, water consumption is shifting from the home to the office, and the resulting consumption is far lower than the norms that are in use (Ghosh et al., 2016). Assuming intermittent water will continue through the next several years as these targets are in place, and water supply departments factor in a set volume of water per capita served in their timed release, water supply volume restrictions may be an action that can be taken by the municipalities.

There is a high level of uncertainty with this approach, however, due to the difficulty in measuring water volumes as delivered to each home. Due to the amount of unaccounted for water, the use of suction pumps on private connections, the lack of meters to accurately measure water flow and ensure targeted distribution volumes are being met, as well as uncertainty in the actual number of legal or illegal connections within the network, gross overestimates of water delivered under a limited distribution scheme to each household could result. In addition, since there have been no water consumption studies that repeatedly evaluate a family's consumption over time, and the conditions under which independent studies are performed typically prevent direct comparison in such a manner, it is possible that the average water consumption of a household in urban India is still growing, and has not yet stabilized, even for basic needs. Gleick's 50 LPCD was intended to represent the minimum daily supply of water a human needs for survival, and water consumption observations from developed worlds indicate a much higher per capita volume, it is possible that the unrestricted per capita water supply could be at or greater than high level water supply norms currently being used today. If this is the case, water restrictions will likely face resistance from consumers, and the program may not be sustainable on its own without technological advances in water-consuming equipment.

8.2.2 Water Efficiency Ratings

"Improved efficiency" is targeted throughout the documents summarized above. Usually, it is applied to water-intensive activities that use significant volumes of water (such as irrigation), though within the same initiatives, community participation is also emphasized. The establishment of a water efficiency rating program (and a complimentary standards program that requires certain efficiency minimums be met) can reduce the demand of water from water-consuming appliances used within the home. Similar to energy efficiency labels found on energy-intensive equipment (introduced by the Bureau of Energy Efficiency in 2002), a rating structure and corresponding labeling system would be created for each type of appliance that consumes water as part of operation such as washing machines, dishwashers, and water purifiers. Programs in Australia (WELS), Singapore (WELS), Portugal (ANQIPS), and the United States (WaterSense) have demonstrated some effect, and an energy efficiency program is already in effect. The new program can be incorporated into BIS standards such that it is a required component of achieving certification, and employ a five star rating system that is simple for the customer to interpret. Pricing penalties could be applied to products that do not meet minimum standards, ideally leading to a decrease in the relative attraction of the inefficient product compared to others available to the consumer at the time of purchase. An incentive program could also be set up either for consumers or for manufacturers (or both), to boost the initial adoption of water-efficient equipment. The water efficiency standards could be rolled out in phases, so that manufacturers have time to improve their technologies and offer improved products before facing an immediate fine. With the redirection of consumers towards purchasing more water-efficient systems, several outcomes may be achieved: (1) consumers currently unaware[18] of the high wastage associated with RO can become informed during their decision process, prior to making their purchase, (2) consumers considering both RO and alternatives that do not require TDS treatment may decide to purchase the more water-efficient alternative, and (3) manufacturers will be encouraged to increase their product's efficiency levels in order to remain competitive in the market (Centre for Science and Environment, 2010).

To use management of India's residential electricity demand as an example, McNeil et al evaluates the financial and environmental impacts of the standards and labeling program for refrigerators and air conditioners in India, and found that the efficiency improvement varied by type of class product, but overall could lead to reduced electricity consumption of 4.7% across the entire country by 2020. Through incorporating a life cycle cost evaluation, savings associated with the improvement could total 8.1 Billion USD in 2008 net present value (McNeil, Iyer, Meyers, Letschert, & McMahon, 2008).

Challenges associated with introducing a water efficiency program include enforcement, and the likely resistance from manufacturers. The creation of India's private industry-driven water purification market has significantly improved the health of millions of citizens. Though each treatment technology is designed to treat a specific set of contaminants, in the case of RO systems, the perception is there that the RO technology provides the highest level of treatment, and regardless of water source (and need to treat), its use will ensure the highest level of safety from hazardous contaminants. To make the perceived trade-off between protecting a family's health and the environmental cost of wasted water may not be a tradeoff customers are willing to make early into the program when only the current "eco-friendly" products are available. Low sales may trigger a low level of performance (and as discussed previously through the Bass diffusion model, may reduce the chances of adoption of the green products), and they may signal a lack of interest for higher recovery products to manufacturers.

Another limitation may be the perception of low impact associated with improving domestic water recovery rates. Drinking water is a relatively small percentage of water used

[18] During the January 2016 interviews, several respondents indicated that they were not aware of the wastage from RO units until their system was installed and operating.

within the home, so other programs may be deemed to have more of an impact due to the size of their water footprint. In addition, in certain areas, the current use of RO-based purifiers (such as the high percentages measured in 2014-2015 in Delhi) may mean that the market has already evolved to the point where the majority of the population is already using these durable products which, designed to likely last 10 to 15 years, will not need replacement for several more years (Ghosh et al., 2016).

Ultimately, it is the household that makes the decision on what water purifier to purchase. Having a water efficiency rating structure in place can provide guidance and potentially incentivize a family towards selecting a system that is more sustainable for the community at large.

8.2.3 Improved Quality of Municipal Water Supply

Though not likely a change that can be made within a short period of time, an alternative that exists for reducing the use of RO water purifiers is for cities to provide continuous water supply of adequate quality to its constituents. Though inadequate supply and resulting water shortages are often referenced as preventing continuous supply from being feasible, it is possible that future surface water development and/or sustainable groundwater development, coupled with reduced per capita water consumption and infrastructure improvements as needed will allow this to take place.

8.2.4 General Policy-related Challenges

Over the past several years, many government policies have been made that intend to improve the quality or quantity of its water resources. Water resources, however, are still deteriorating. Taking into account that groundwater extraction (including new development projects) is still being permitted in areas that have been deemed over-exploited for over five years, and projected urbanization is set to drive demand even further beyond current supply, the likelihood of policy changes on their own in achieving a change in adoption before full diffusion occurs is low. Willingness to pay studies have demonstrated an interest in paying more for improved water and sanitation services, which is a positive signal, yet respondents are generally not interested in paying for water conservation programs (Randolph & Troy, 2008), or paying the full environmental cost of water (The Energy and Resources Institute, 2013, 2014). With the common low cost recovery of water supply programs across India, the incomplete sewage capture and treatment that exists, and the need to begin the development of additional water sources to account for future demand, the budget for policy-related initiatives may not be perceived to have high priority, therefore further enforcing the need for combined policy and technology-based programs moving forward.

8.3 Technology-Driven Alternatives

Technology-driven alternatives can have a significant impact on the potential wastage generated by RO systems, if designed and marketed in such a way to encourage wide-spread adoption and either replace the current technology or greatly improve its efficiency. The following outlines a series of potential technologies, and their potential impact on current waste projections.

8.3.1 Reverse Osmosis with Waste Capture

Standard household RO systems currently in use in India include a separate waste line that drains reject water from the RO treatment process into the kitchen sink. The reject wastewater is considered undrinkable, as it includes an elevated concentration of salts, though manufacturers have identified potential uses for the water such as cleaning dishes and clothes, watering plants, and mopping. One problem with reuse, however, has been the lack of storage provided for this water. Anyone wanting to reuse the wastewater for some purpose had to manually collect it in a separate vessel(s), then manage its use from there. During the January 2016 interviews, respondents that had collected their wastewater this way reported the inconvenience associated with having to handle the water separately, and without controls. From overflowing buckets to weight restrictions, and an inability to tap into the automatic feed line for water-consuming equipment, reusing the water took a significant amount of planning.

To address the inconveniences associated with reuse, Kent created the Supreme water purifier, which is currently being marketed as the “World’s First No Water Wastage RO Purifier” system. The system, launched in the beginning of 2013 (Sushma, 2013), appears to have a recirculation loop through the RO system, TDS controller and ultrafiltration module, such that recovery of treated water achieves 50%. In addition, the RO wastewater is captured within a separate "Reject Water Tank" that is 9L in size. Though not explicitly shown in product marketing photographs, there is a waste line that prevents overflow of the second tank, so achieving a level of 100% recovery requires that the reject water be used faster than it accumulates. According to the product manual, the reject water can be used for gardening and cleaning around the home. The cost of the unit is comparable to other multi-stage RO filters, at MRP INR 20,000 (Kent RO Systems Ltd., n.d.-b).

Though it is unknown whether the Kent Supreme water purifier was offered in all retail outlets selling other Kent RO water purifiers, none of the subjects interviewed in January 2016 were using the product. Sales data provided from a confidential source also indicate lower sales compared to other RO products such as the Grand+ and Pearl models, which sold five or more times the number of units per month compared to the Supreme.

8.3.2 Electrodialysis as a Replacement for Reverse Osmosis

The RO membrane that causes low recovery provides desalination treatment, which the other technologies currently in use on the Indian water purifier market are unable to perform. Electrodialysis (ED), a technology established in the 1950's, can be used to replace the RO membrane, maintain the same level of salt removal, and greatly reduce the amount of water wasted in the process. ED as a brackish water desalination technology has been used predominantly in large-scale water and wastewater treatment systems, with design capacities up to 200,000 m^3/d (Valero, Barcelo, & Arbos, 2011). Through the use of electrodes, an applied voltage, and a stack consisting of alternating anion and cation-exchange membranes, positively and negatively charged ions are removed from the input water stream (referred to as the diluate) as it flows through the ED system. The ions become concentrated in a waste stream, typically only 10% of the input water volume due to the ability to run the system in a batch configuration, and then discharged from the system, much like the line from the RO units. When compared against RO, ED performs favorably within the brackish water TDS range, and it requires less electricity to do so (Valero et al., 2011; Wright & Winter V., 2014). As mentioned, the amount of water recovered is significantly greater than that of the RO systems currently on the market. A recent feasibility study that looked at the efficacy of using small-scale ED incorporated into a multi-stage household water treatment system (also containing UV) proved the cost could be comparable to multi-stage RO systems, and the form factor would be similar as well (Nayar et al., 2015). With the high recovery rate achievable with ED (90%), introduction and diffusion of this product into the water purifier market could significantly increase the average water purifier recovery level over time, especially as RO products currently in use require replacement.

Beyond the reduction of TDS, ED has been proven to reduce concentrations of fluoride, arsenic and nitrate, all concerns voiced during the January 2016 interviews and contaminants of concern in the groundwater of certain areas in India. In addition, the ED stack does not have the same resistance to chlorine that is found with RO (up to 1 ppm), though due to the potential of chlorine gas accumulating at the electrodes, a chemical rinse may be required. In order to reduce the formation of scale on the ED membranes, voltage reversal may be required, as is used in commercial-scale ED reversal (EDR) systems. (Amor et al., 2001; Bureau of Enviornmental Health; Private Water Systems, 2012; Valero et al., 2011).

Studies have reported that RO is capable of at least partially treating the water for bacteria (to the point that microbial treatment is included within the draft BIS RO standard) but this is not something that ED can achieve. The presence of a UV lamp, or other means of disinfection would therefore likely be required in any newly proposed water treatment system that replaces RO with ED (Bureau of Indian Standards, 2003, 2011; Valero et al., 2011). Also, there is potential with the current status of design for a chemical rinse and flow reversal to be incorporated into the design. These elements of maintenance may need to be performed on a regular basis that is more frequent than the common 3-month or 6-month maintenance schedule, so either the system's control panel will need to become more complex than the standard water purifier, maintenance contracts will need to be more involved, or homeowners will need to be properly trained on the process as well as relevant safety requirements associated with handling the rinse chemical. The risk of improper maintenance on behalf of the owner may lead to a decrease in performance, with greater costs required for replacement prior to the projected lifetime of the treatment element (Valero et al., 2011).

Regarding the equipment itself, ED components could be manufactured outside of India (as had been done for RO membranes), but after-sales service will be required for the installed water purifiers. As a result, there will be a need to develop local technical capabilities in all geographical areas where the ED-based purifiers will be sold. As of 2010, after-sales service represented over a third of the domestic water purifier market (Frost & Sullivan, 2012), and its perceived service quality has been tied to (1) reliability, (2) assurance or confidence, (3) tangibles, (4) empathy, and (5) responsiveness with (1), (3) and (5) identified as the top service qualifiers (Murali, Pugazhendhi, & Muralidharan, 2016). To do this cost effectively may require partnership with an existing water purifier manufacturer, if the design itself is not introduced by one of the top branded companies.

An additional challenge associated with the replacement of RO with ED is the need to establish ED, currently an unknown on the household Indian market, as a reliable technology worthy of the same level of trust granted to RO. To do that will likely require education campaigns, and demonstrations within households considered to be representative of the Bass Model's "innovator" community[19]. As discussed above, this innovator group would be interested in the technology itself given its distinguishing features, and may be willing to try the technology even without a significant number of previous users. Over time, as the innovator group grows and the product is demonstrated to meet the requirements of the user (outlined in Chapter 6), their adoption can help spur diffusion into the "imitator" group.

8.3.3 Desalination Bypass

Not all water sources within India require desalination as part of the treatment train. Due to the degradation of groundwater aquifers, instances of borewell water exceeding the BIS standard of 500 ppm are more common than exceedances of water supplied by municipalities from surface water bodies. Due to the high percentage of households within the target RO market with access to municipal water from their tap, incorporating a bypass into the treatment system design such that only water above a certain threshold is run through the RO membrane may reduce the total amount of water wasted by the system, and overall across an urban area with varying levels of water quality. The concept of desalination bypass appears to have been used in Eureka Forbes' Aquaguard Total Sensa water purfier (Sultana & Santhosi, 2012). Marketed with the patented BluG technology, the purifier monitors contaminants in the input

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[19] Kent, who first introduced water purifiers with the RO technology to the Indian market in 1995, used a combination of education campaigns and a celebrity endorsement (Bollywood actress and mother, Hema Malini) (Sultana & Santhosi, 2012). As Kent has established a significant presence for its brand on TV and January 2016 interviews indicated a possible level of dissatisfaction with the brand when it comes to after-sales service, it is recommended that any new technology compete on a performance basis vs. one strictly on advertising.

water, and uses RO, UV, UF, TDS control or a combination of technologies, to treat the water so that it gives you the "triple benefit of sweetness, minerals and purity" (compareindia.com, n.d.). The model was priced from INR 17,000-18,990, which is comparable to the range of products currently available. It appears to have not been successful, though, as it is not currently available through Eureka Forbes' webpage, and similar products do not appear to be offered by the manufacturer. Though the product appears to offer the consumer flexibility in treating water from various sources, additional review should be performed prior to incorporating this type of feature into a new system.

8.3.4 General Challenges for Technology-based Alternatives

In addition to the challenges presented above within each specific technology-based alternative, general challenges also exist, such as those related to brand and replacement purchases.

Brand

Regardless of the alternative proposed, the brand (or lack there of) of the product is likely to have an influence on its diffusion into the market. In an evaluation of brand and its relationship to consumer behavior, it was found that "trustworthiness, rather than expertise affects consumer choices and brand consideration more" (Erdem & Swait, 2004, p. 191). In addition, in cases with high levels of uncertainty in the product selection process, such as the case when a new, previously unknown technology is being offered, credibility has a stronger impact. The structural relationship for brand-related factors based on these findings is provided in Figure 8.3.4-1 (Erdem & Swait, 2004). Respondents from the January 2016 interviews expressed similar sentiments, as they enforced the importance of brand, and relied heavily on the expertise of a manufacturer's mobiles salesmen as well as representatives at local shops to recommend the most appropriate water purifier for their home.

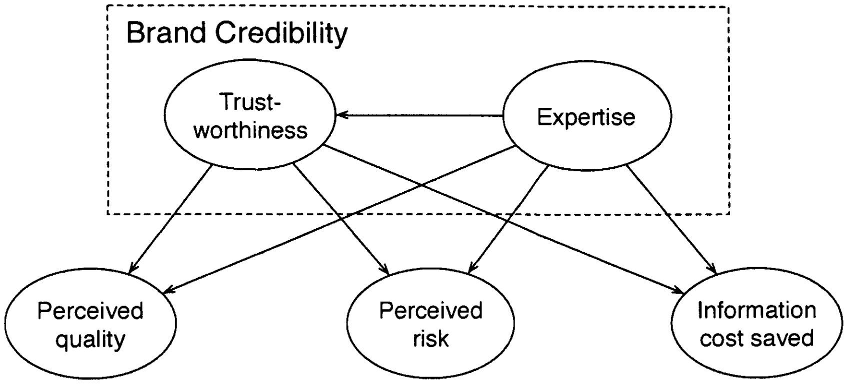

Figure 8.3.4-1. Brand Structure
Source: (Erdem & Swait, 2004)

Replacement Purchases

Taking a closer look at replacements, and understanding the dynamics associated with the customers' decision can enable a more informed strategy for introducing a product intended to replace the original model. According to the Bass diffusion model, the market is divided into adopters and potential adopters of a product. Replacement purchases are not included in the original model, though the assumption exists that once a particular potential user becomes an adopter, there is no reversal. One approach for simulating replacement purchases is to assume the install base of products is replaced according to its average lifetime. This approach takes a simple view, and assumes customers are locked into using the technology instead of considering a change when their product has expired. Considering product replacement related to discarding or upgrading a consumer's current version for a more attractive model, on the other hand, may create an opportunity for new products to enter the market. It will then be important to ensure the customer is aware of current product attributes, alternatives and their anticipated performance, the product's lifetime cost, and other external factors (such as available subsidies or water efficiency ratings described above in potential policy-related alternatives) so that an economic trade-off evaluation can be performed between replacement with a similar product, or a change to a new technology. In either case, consumer adoption of replacements will likely be highly sensitive to price, as in the case of generational product diffusion (Bass, 2004; Kamakura & Balasubramanian, 1987; Sterman, 2000).

Chapter 9. Conclusions and Future Work

9.1 Conclusions

Based on the projected volume of water wasted if a segment of the population within Delhi, Mumbai, Bangalore and Ahmedabad, or the entire urban population of India adopt and use RO-based water purifiers, water scarcity concerns previously considered to be tied mainly to an increase in population in these urban areas should be revisited. The widespread adoption of RO water purifiers predicted by the market as summarized in Chapter 5 has the distinct possibility of both improving access to water quality suitable under BIS standards, and negatively degrading the environment through its high wastage volumes and resulting consumption increase on a household level.

Perhaps most startling was the realization that the use of RO systems is apparently not limited to the small percentage of households relying on groundwater as their sole water supply, but instead has spread to households with municipal supplies as well. Chapter 7 evaluated the impact of RO adoption in a subset of different cities when RO was limited only to socio-economic group. Compared to the 10% adoption level scenario, higher adoption levels can lead to total wastage volumes that make up a measurable percentage of the excess water a city is withdrawing from over-exploited groundwater sources or the volume that remains untreated by the city's inadequate sewage system (Census of India, 2011a).

With the rising complexity and costs associated with expanding India's water supply (see Figure 9.1-1), as well as the implications for sewage and groundwater deterioration, conservation through improved water efficiency should be targeted at both the macro and micro scale, connecting federal and state government policies with the urban water supply department's mission and decisions made by the individual homeowner. An overwhelming majority of subjects interviewed in January 2016 indicated a concern for increasing water scarcity with an interest in finding out how to contribute at their own level.

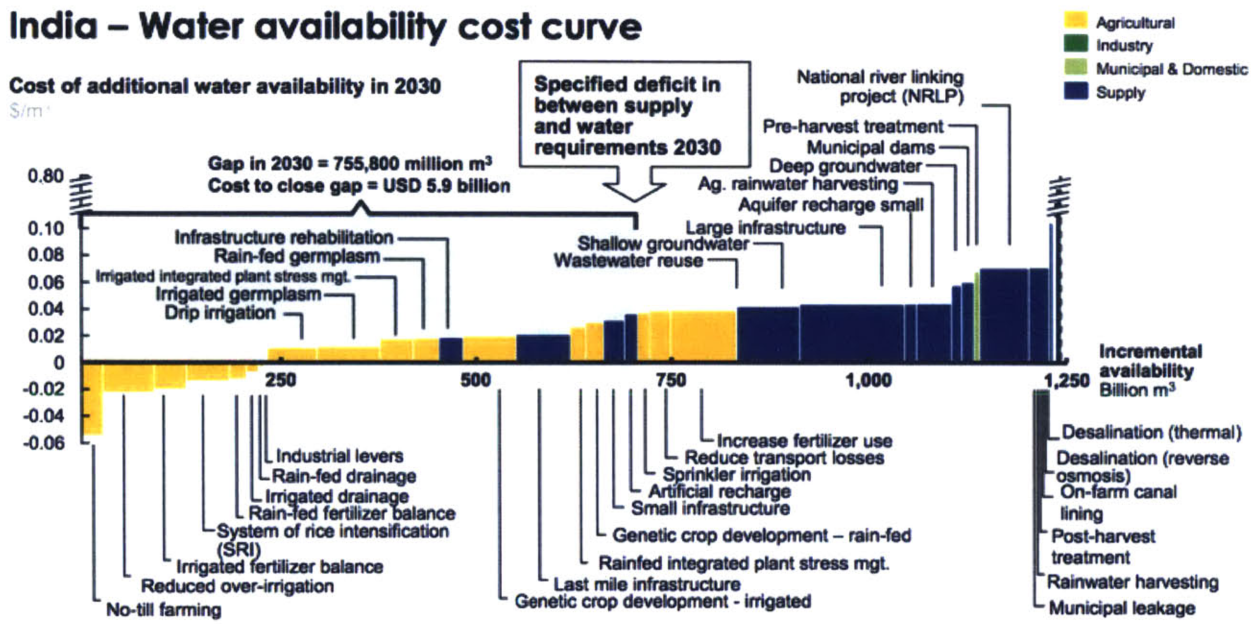

Figure 9.1-1. India's Water Availability Cost Curve
Source: (2030 Water Resources Group, 2009)

Chapter 6 describes the needs of the customers associated with household water treatment systems, and Chapter 8 presents a series of policy and technology-based alternatives that can be used to achieve a more sustainable water future. Considered in isolation, the challenges associated with each of the alternatives may limit the chance of success. Combined, however, the programs could provide a comprehensive, robust approach to tackling what appears to be an unintended effect of decentralized water purification led by private industry.

9.2 Future Work

Additional work is recommended to further evaluate and address the problem of increased water wastage due to RO systems. To begin, in-place field tests should be performed so that the order of magnitude of wastage volumes associated with RO use can be verified. In terms of water quality, a more comprehensive study should be performed to test the assumption that an alternative product can be used for households that do not require TDS treatment. With the increased prevalence of high salinity groundwater, more reliance on groundwater to supplement municipal sources (especially as household consumption and the number of families provided with water increase – further drawing down groundwater levels and

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increasing salinity), as well as the possibility of disruption from a household's water supply such that to have true water security, a household must have the capability of treating for a wider range of contaminants, including TDS, the basic assumption that households can easily change to a less environmentally-intensive technology may not be accurate. In addition, RO does appear to provide some level of protection from microorganisms, and can act as a redundant treatment step when UV is also used within the treatment system. Any replacement technology intended to fully replace RO must address the full set of contaminants, so that a change does not jeopardize the health or water security of the adopter.

Further stakeholder development should also be performed, including hierarchical structuring, such that any future program fully incorporates the needs and requirements of not only of the consumer, but also of the manufactures, suppliers, local municipality, and government agencies, and is able to achieve buy-in from all parties, especially as the solution will likely be multi-disciplinary in nature.

Appendix

A. The 2011 Socio-economic Classification (SEC) Method & Summary Tables for India 2011

Q1. Items owned/have access to at home

1. Electricity Connection
2. Ceiling Fan
3. LPG Stove
4. Two Wheeler
5. Colour TV
6. Refrigerator
7. Washing Machine
8. Personal Computer/Laptop
9. Car/Jeep/Van
10. Air Conditioner
11. Agricultural Land

Q2. Chief Earner: Education Level

1. Illiterate
2. Literate but no formal schooling/School - up to 4 years
3. School - 5 to 9 years
4. SSC/HSC
5. Some College (including a Diploma) but not Grad
6. Graduate/Post Graduate: General
7. Graduate/Post Graduate: Professional

Table A-1: SEC Classification Matrix (2011 Version) (The Market Research Society of India, 2011)

No. of Consumer Durables owned/ accessible by Household	Illiterate	Literate but no formal schooling/ School - up to 4 years	School - 5 to 9 years	SSC/HSC	Some College (including a Diploma) but not Grad	Graduate/ Post Graduate: General	Graduate/ Post Graduate: Professional
	1	2	3	4	5	6	7
0	E3	E2	E2	E2	E2	E1	D2
1	E2	E1	E1	E1	D2	D2	D2
2	E1	E1	D2	D2	D1	D1	D1
3	D2	D2	D1	D1	C2	C2	C2
4	D1	C2	C2	C1	C1	B2	B2
5	C2	C1	C1	B2	B1	B1	B1
6	C1	B2	B2	B1	A3	A3	A3
7	C1	B1	B1	A3	A3	A2	A2
8	B1	A3	A3	A3	A2	A2	A2
9+	B1	A3	A3	A2	A2	A1	A1

Table A-2: SEC Distribution for the Top 20 Cities within India

High TDS	No. of HH	SECA	SECB	SECC	SECD	SECE
Delhi	2,201,567	352,953	469,097	574,183	434,698	394,400
Vijayawada	209,648	38,070	39,513	43,607	44,930	45,680
Jaipur	614,670	111,619	115,848	127,851	131,730	133,929
Jabalpur	210,867	38,292	39,742	43,860	45,191	45,945
Chennai	936,217	150,093	199,484	244,172	184,856	167,719
Ahmedabad	1,114,117	178,614	237,389	290,569	219,982	199,589
TOTAL	5,287,087	869,641	1,101,073	1,324,242	1,061,387	987,261
Medium TDS	**No. of HH**	**SECA**	**SECB**	**SECC**	**SECD**	**SECE**
Hyderabad	1,361,994	218,354	290,206	355,217	268,925	243,995
Mumbai	2,495,689	400,106	531,767	650,892	492,773	447,091
Bangalore	1,685,194	270,169	359,071	439,509	332,741	301,894
Pune	623,086	113,147	117,434	129,602	133,534	135,762
Kolkata	897,336	143,860	191,199	234,031	177,179	160,753
Bhubaneswar	167,547	10,473	25,048	33,342	39,374	59,358
Ranchi	214,688	38,985	40,463	44,655	46,010	46,778
Lucknow	563,120	102,258	106,132	117,129	120,682	122,697
Ludhiana	322,776	58,613	60,834	67,137	69,174	70,329
Bhatinda	57,163	10,380	10,774	11,890	12,251	12,455
TOTAL	8,388,593	1,366,345	1,732,926	2,083,404	1,692,642	1,601,111
Low TDS	**No. of HH**	**SECA**	**SECB**	**SECC**	**SECD**	**SECE**
Guwahati	192,686	12,045	28,806	38,344	45,281	68,264
Nagpur	481,084	87,361	90,671	100,066	103,101	104,822
Jalandhar	172,439	10,779	25,779	34,315	40,523	61,091
Varanasi	240,363	43,648	45,302	49,996	51,512	52,372
TOTAL	1,086,572	153,832	190,557	222,721	240,418	286,549

Source: (Tata Projects, n.d.)

Table A-3: SEC Distribution for Select Districts within India [**Source**: (Tata Projects, n.d.)]

High TDS	No. of HH	SECA	SECB	SECC	SECD	SECE
Surat	1,216,264	76,028	181,827	242,037	285,822	430,894
Visakhapatnam	858,118	53,640	128,285	170,765	201,658	304,011
Vadodara	833,125	52,078	124,549	165,792	195,784	295,157
Chittoor	834,813	52,183	124,801	166,128	196,181	295,754
Haora	970,006	60,634	145,012	193,031	227,951	343,650
Ahmadnagar	908,632	56,798	135,837	180,818	213,528	321,907
Ghaziabad	936,329	58,529	139,977	186,329	220,037	331,719
Allahabad	1,190,878	74,441	178,031	236,985	279,856	421,900
Nagpur	930,714	58,178	139,138	185,212	218,718	329,730
Solapur	863,551	53,980	129,097	171,847	202,935	305,936
Bareilly	889,672	55,613	133,002	177,045	209,073	315,190
Muzaffarpur	960,212	60,022	143,548	191,082	225,650	340,181
Nadia	1,033,520	64,604	154,507	205,670	242,877	366,152
North Twenty Four Parganas	2,001,956	125,141	299,284	398,389	470,460	709,246
South Twenty Four Parganas	1,632,392	102,039	244,036	324,846	383,612	578,318
Barddhaman	1,543,513	96,484	230,749	307,159	362,725	546,830
Purba Medinipur	1,019,175	63,708	152,363	202,816	239,506	361,070
Azamgarh	922,783	57,682	137,952	183,634	216,854	326,920
Kanpur Nagar	916,254	57,274	136,976	182,334	215,320	324,607
Krishna	903,480	56,476	135,067	179,792	212,318	320,082
Gaya	878,284	54,901	131,300	174,778	206,397	311,155
Chennai	929,346	58,093	138,934	184,940	218,396	329,246
Jaipur	1,325,236	82,839	198,117	263,722	311,430	469,500
TOTAL	24,498,252	1,531,364	3,662,390	4,875,152	5,757,089	8,679,153
Medium TDS	**No. of HH**	**SECA**	**SECB**	**SECC**	**SECD**	**SECE**
Patna	1,167,693	72,991	174,565	232,371	274,408	413,686
Jalgaon	845,983	52,882	126,471	168,351	198,806	299,712
Samastipur	852,313	53,277	127,417	169,610	200,294	301,954
Rangareddy	1,059,348	66,219	158,368	210,810	248,947	375,302
Gorakhpur	888,179	55,519	132,779	176,748	208,722	314,661
Madhubani	897,476	56,100	134,169	178,598	210,907	317,955
Paschim Medinipur	1,182,691	73,929	176,808	235,356	277,932	419,000
Bangalore	1,924,310	120,287	287,677	382,938	452,213	681,738
Pune	1,885,882	117,885	281,932	375,290	443,182	668,123
Mumbai Suburban	1,871,392	116,979	279,766	372,407	439,777	662,990
Lucknow	917,968	57,381	137,232	182,676	215,722	325,214
Kolkata	899,339	56,217	134,448	178,968	211,345	318,615
TOTAL	14,392,575	899,667	2,151,632	2,864,122	3,382,255	5,098,950
Low TDS	**No. of HH**	**SECA**	**SECB**	**SECC**	**SECD**	**SECE**
Thane	2,212,030	138,272	330,690	440,194	519,827	783,670
Nashik	1,221,437	76,351	182,600	243,066	287,038	432,726
Moradabad	954,401	59,659	142,679	189,926	224,284	338,122
Malappuram	822,584	51,419	122,973	163,694	193,307	291,422
TOTAL	5,210,452	325,701	778,942	1,036,880	1,224,456	1,845,940

B. COUHES Consent Form

Evaluating the User Needs for an In-Home Water Desalination and Purification System

You have been asked to participate in a research study conducted by Catherine O'Connor and Sahil Shah from the Sloan School of Business and the Department of Mechanical Engineering at the Massachusetts Institute of Technology (M.I.T.). The purpose of the study is to learn about how families interact with their household water purification systems (specifically Reverse Osmosis (RO) units). The results of this study will be included in Catherine O'Connor and Sahil Shah's Masters theses). You were selected as a possible participant in this study because you expressed an interested in the work that was being performed. You should read the information below, and ask questions about anything you do not understand, before deciding whether or not to participate.

• This interview is voluntary. You have the right not to answer any question, and to stop the interview at any time or for any reason. We expect that the interview will take about 45 minutes.

• You will not be compensated for this interview.

• Unless you give us permission to use your name, title, and / or quote you in any publications that may result from this research, the information you tell us will be confidential.

• We would like to record and take photographs during this interview so that we can use it for reference while proceeding with this study. We will not record this interview or take photographs without your permission. If you do grant permission for this conversation to be recorded or photographed, you have the right to revoke recording or photographing permission and/or end the interview at any time.

This project will be completed by July 30th, 2016. All interview recordings and photographs will be stored in a secure work space until 1 year after that date. The tapes will then be destroyed.

I understand the procedures described above. My questions have been answered to my satisfaction, and I agree to participate in this study. I have been given a copy of this form.

(*Please check all that apply*)

[] I give permission for this interview to be recorded.
[] I give permission for photographs to be taken during this interview.
[] I give permission for the following information to be included in publications resulting from this study:
[] my name [] my title [] direct quotes from this interview

Name of Subject

Signature of Subject ______________________________ Date __________

Signature of Investigator ____________________Date ________

Please contact Sahil Shah at sahils@mit.edu with any questions or concerns.

If you feel you have been treated unfairly, or you have questions regarding your rights as a research subject, you may contact the Chairman of the Committee on the Use of Humans as Experimental Subjects, M.I.T., Room E25-143b, 77 Massachusetts Ave, Cambridge, MA 02139, phone 1-617-253-6787.

C. List of Interview Questions and Example DCE Choice Set

The following questions were used to guide each in-person and over-the-phone interview performed in January 2016. Additional commentary was also provided that extended beyond the content covered by these questions.

General Information

- Interview Date/Time
- Location (City)
- Household demographics
    - Household size (including number of children, if applicable)
    - Age of head of household
- Language used during interview
    - Interpreter's name, if applicable

Interview Questions

1. What is the primary source of drinking water? Is the source the same for water used in cooking?
2. How many hours per day is water available from this source?
3. Is the quantity of water sufficient to meet your household's needs?
4. About how much water does your household use for drinking and cooking per day?
5. Do you need to store water?
6. If yes, how much water is stored, and for how long?
7. Is a different source of water used for domestic purposes? (e.g., cleaning, washing clothes)
8. If so, how many hours per day is water available from this source?
9. With all of the combined sources, is the quantity of water sufficient to meet your household's drinking and cooking needs?
10. Does your water source change in terms of availability, quality (or anything else) throughout the year? Has it changed over the past few years? If so, could you explain how?
11. Do you sometimes use bottled water for drinking? If so, could you explain the circumstances? If at work, is this provided, or do you purchase it yourself?

You have indicated you use a Reverse Osmosis system. Can you show us the unit and demonstrate how it works?

12. How is the unit positioned?
13. What are the make and model of the RO system?
14. Do you remember the year of purchase?
15. How does the water enter the unit?
16. How does treated water exit the unit?
17. How does wastewater exit the unit? Is it treated first? If so, by what?
18. Do you collect and use the wastewater for anything? If so, what?
19. How much water does the system treat? Or, about how long does it take to treat 1L of water? Or other volume that can be measured?

20. Do you run the system only at certain times of the day, or does it run continuously, with some sort of level sensor in the storage tank?
21. Does your RO system require maintenance? If so, how often?
22. Who performs maintenance on the RO unit?
23. Would you change anything about the way maintenance is performed on the unit?
24. What prompted you to buy this treatment system?
25. What was the problem with the water quality that you were concerned about?
26. Have you tried other types of systems? If so, what type?
27. How did you learn about this product (or this type of product)?
28. About how long do you anticipate using this product before you replace it?
29. During the selection process, which features were most important to you?
30. What other products were you considering?
31. Where did you purchase the RO unit?
32. Do you remember if a payment plan was offered when purchasing the unit? If so, what type?
33. Was a service plan (in addition to warranty/cost of replacement parts) offered at the same time as the unit?
34. Do you have any questions for us, or feedback on the survey?

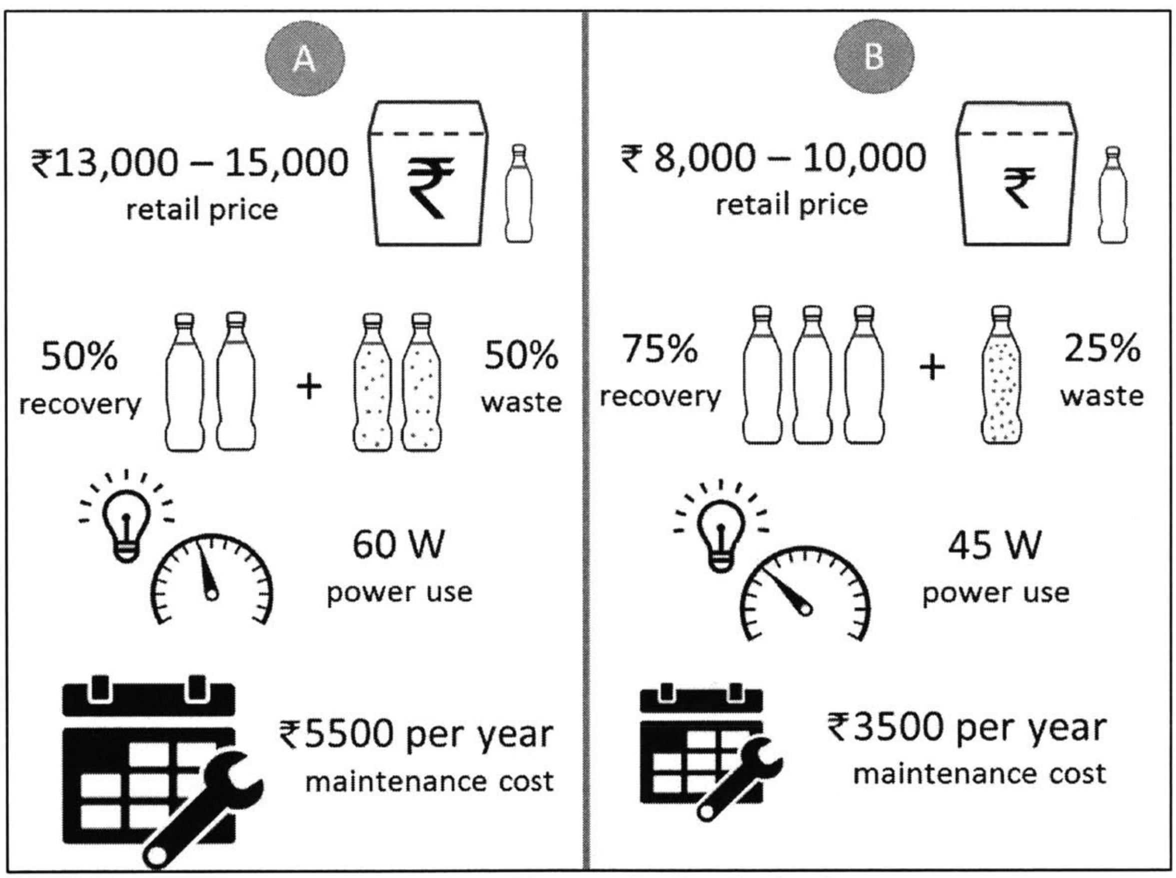


Figure C-1. Example Choice Set from Discrete Choice Evaluation

D. Summary of Use Context Statements from Initial VOC Evaluation

Table D-1. Summary of Use Context Conditions from Interview Statements, January 2016

Use Context Category	Subcategory	Considerations
Water Availability/ Quantity	Distribution/ Availability	• Households are aware of source, and the volume available from each source • Depending on housing type, water collection can be entirely manual
	Source	• **Municipal**: Not always available; often supplemented • **Groundwater**: Respondents aware of dropping groundwater table • **Bottled water**: An inconvenience; questionable quality; common backup source during service interruption • **Tanker water**: Questionable quality; known for wasting water while loading/transporting water
	Feed Water Quality	• Parameters mentioned include: hardness, high calcium, TDS, fluoride, lead, zinc • Quality impacted during rainy months when sewage mixes with drinking water source
	Water Quality Effects	• Health impacts • Clogging filters (and equipment) • Scaling on dishes
Information	Lack of	• Respondents acknowledged a lack of information of certain product characteristics (such as the RO waste line) • Subjects also relied heavily on information from corporate and social sources (each with varying levels of trust) regarding water purifier selection and maintenance requirements
Perception	Health	• Health issues such as bone strength, kidney stones, and upset stomachs were associated with water quality and treatment capabilities • Community recommendations (from parents at school) were often made if a child had an upset stomach or a cold • Minerals were a source of concern for the elders, as they get "cut down"
	System	• Some respondents found comfort with an old system • There is a difference in what type of system is acceptable for an adult vs. a child • Respondents asserted a difference in treatment level between system type (but did not mention specific parameters) - "With RO, water was getting more purified"
Marketing	Brand Position	• First mover advantage (Eureka Forbes/Aquaguard) • Brand synonymous with RO (Kent) • Perceived quality correlated with time in market

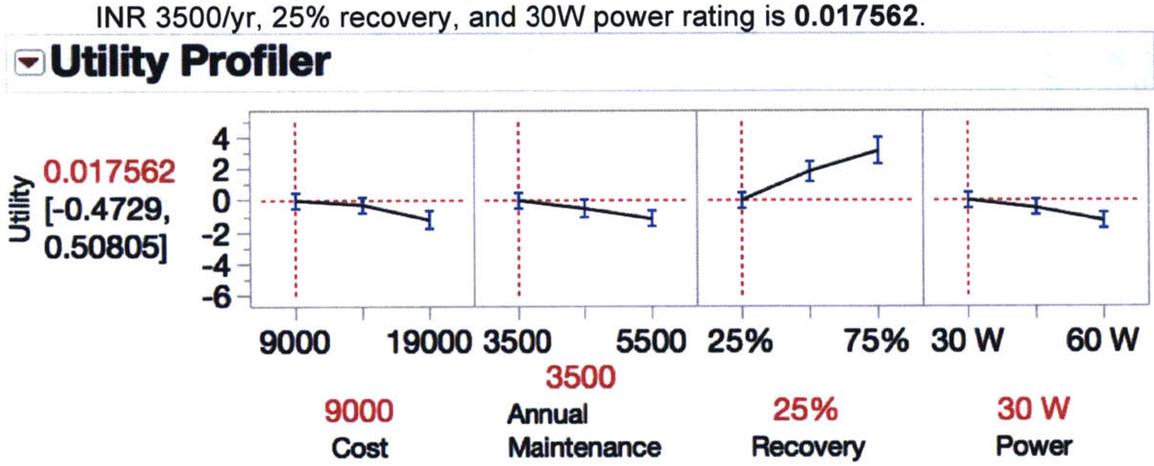
	Demonstration	• Product demonstrations are used to ensure customers of system appropriateness (though uncertainty exists as to what is being measured, and to what level)
	Features	• Sophisticated systems (with information displays and apparent system controls) are recent features • Water purifiers are typically marketed by the number of treatment stages (four+)
	Financial	• Financial incentives include referral discounts and product promotions over certain time periods • Marketing campaigns reinforce that quality is correlated with price
Adoption	Television Advertising	• Advertisements create a presence (and sense of quality) in the market • Advertisements rely heavily on celebrity endorsements • The push for adoption through advertisements is "not scientific" and creates a sense of "mystery"
	Social Networks	• RO is associated with the best care • Recommendations are made through family and friends though not necessarily located within the same city, or using the same water source • Enforces concept of being protective of family health
	Shops	• Salesperson may be considered a trusted individual, if also known in the community • Seen as having some additional knowledge of what type of system is most appropriate

E. Willingness to Pay Evaluation Process Using DCE Results

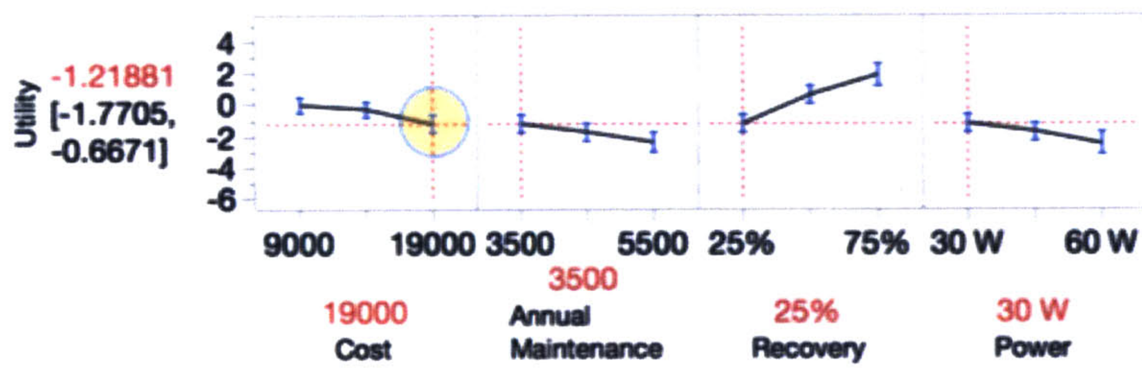
DCE results were used to determine willingness to pay levels for certain hypothetical water purifiers based on the Utility Profiler output calculated by JMP. The following outlines the procedure used to calculate each system WTP. Results are summarized in **Table E-1**, though it is noted that these results are not considered reasonable, and used to determine a general preference for certain types of products.

Process:

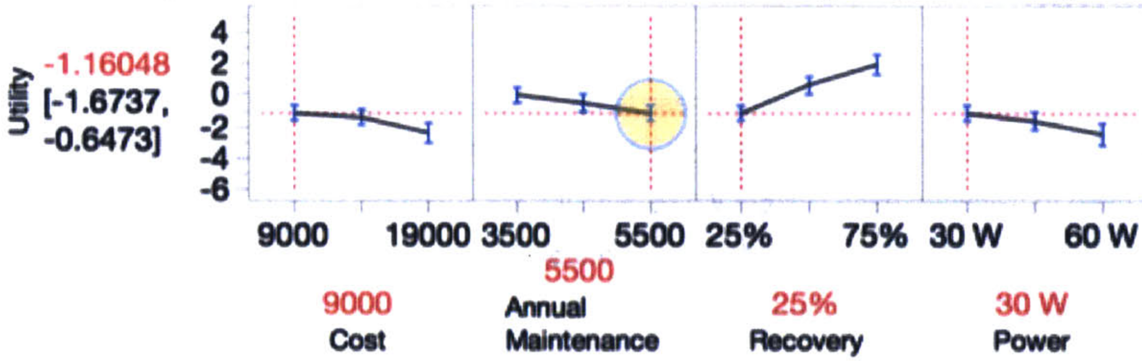
1. Determine utility (or desirability level) for the default product combination. As shown below, the utility for a water purifier that has a cost of INR 9000, annual maintenance of INR 3500/yr, 25% recovery, and 30W power rating is **0.017562**.



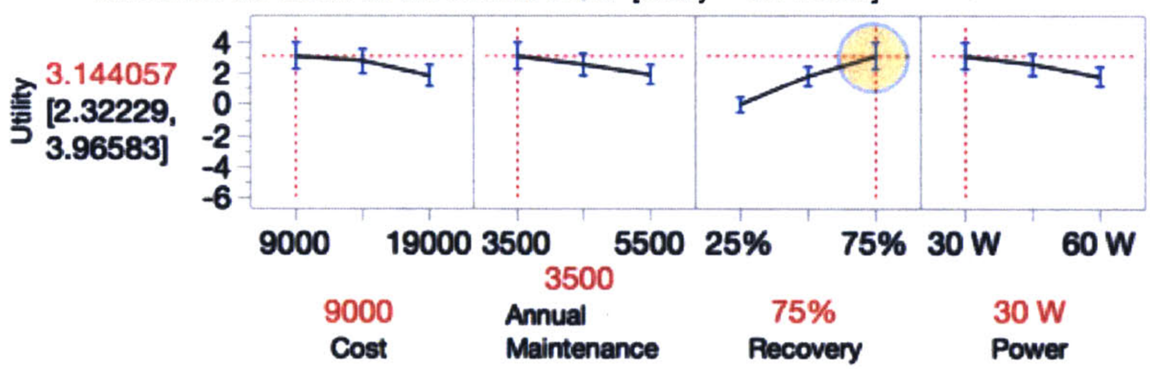
2. Determine utility value for a water purifier that has a cost of INR 19000, but is otherwise the same as the default case. [Utility = - **1.21881**]



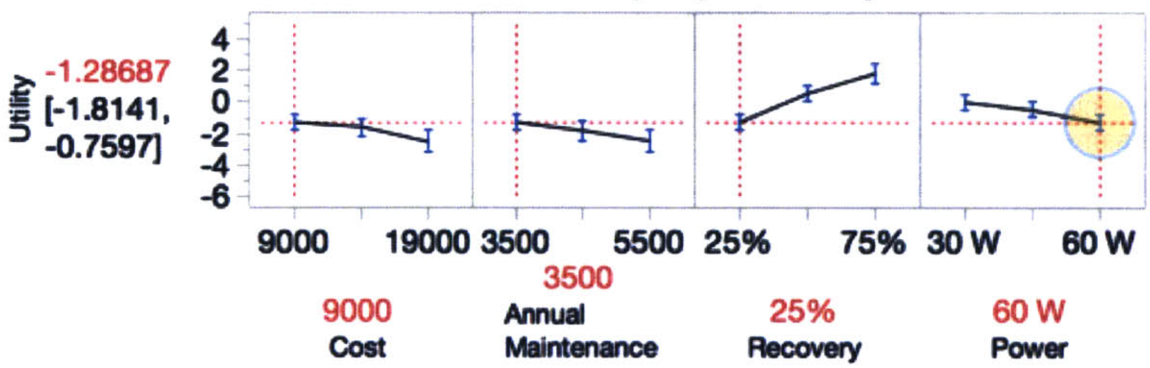
3. Determine utility value for a water purifier that has an annual maintenance fee of INR 5500/yr, but is otherwise the same as the default case. [Utility = **- 1.16048**]



4. Determine utility value for a water purifier that has a recovery level of 75%, but is otherwise the same as the default case. [Utility = **3.144057**]



5. Determine utility value for a water purifier that has a power rating of 60W, but is otherwise the same as the default case. [Utility = **-1.28687**]



6. Use the difference in cost divided by the difference in utility values for the range in cost (all other attribute levels remaining the same) to determine the INR/utility unit value for this DCE and its set of attributes.

(INR 19000-9000) / (|- 1.21881 - 0.017562|) = **INR 8088.18/1 utility unit**

7. Use the difference in utility value for systems that each vary by one parameter from the default system to determine the willingness to pay (WTP) associated with a change in attribute level.

Annual maintenance increase to INR 5500/year:
(-1.16048-0.017562) * 8088.18 = - INR 9528.22 → INR 9528 *Less for change*

Recovery rate increase to 75%:
(3.144057-0.017562) * 8088.18 = - INR 25287.66 → INR 25287 *More for change*

Power rating increase to 60W:
(-1.28687-0.017562) * 8088.18 = - INR 10550.48 → INR 10550 *Less for change*

Recovery rate increase to 50%:
(1.859809-0.017562) * 8088.18 = - INR 14900.43 → INR 14900 *More for change*

8. WTP results are summarized in **Table E-1**.

Table E-1. Calculated WTP for Select Changes in Attribute Level

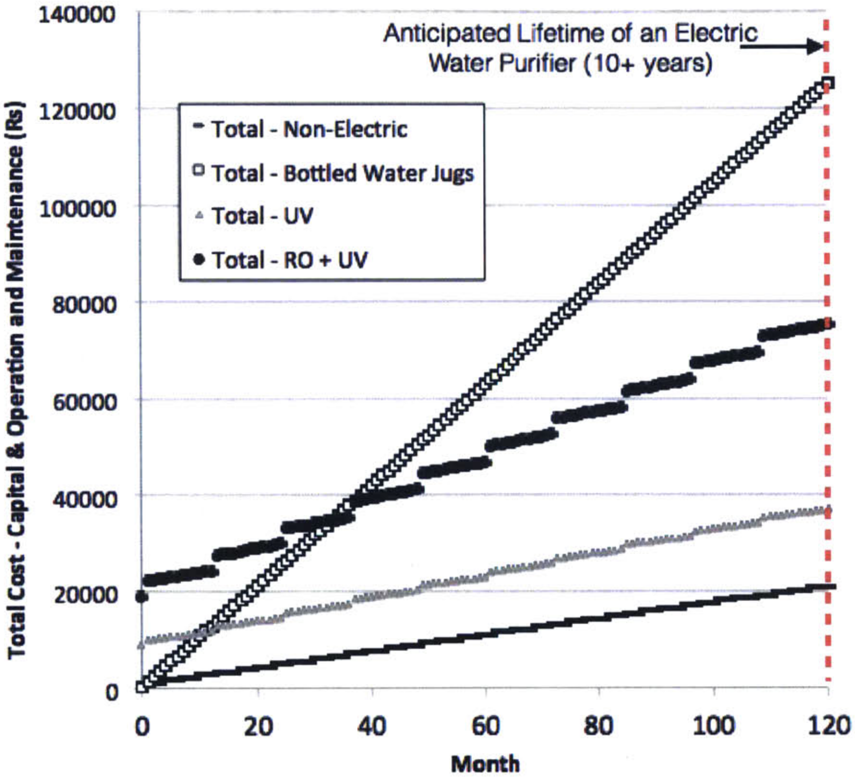
Cost (INR)	Annual Maint. (INR)	Recovery (%)	Power (W)	Utility	WTP for change in attribute (INR)	Note
9000	3500	0.25	30	0.017562	-	Used to calculate unit utility cost
14000	3500	0.25	30	-0.26556	-	-
19000	3500	0.25	30	-1.21881	-	Used to calculate unit utility cost
9000	3500	0.75	30	3.144057	25287.66	unrealistic
9000	5500	0.25	30	-1.16048	-9528.22	unrealistic
9000	3500	0.25	60	-1.28687	-10550.48	unrealistic
9000	3500	0.5	30	1.859809	14900.43	Possible

F. Cost Evaluation, Water Treatment Options for 7.0 LPCD, Combined Drinking and Cooking

Table F-1. Summary of Water Purifier Cost Elements, Capital Costs Plus 10 Years of Operation; Drinking & Cooking Water Treated (7.0 LPCD)

	Tata Swach	Aquaguard Classic	Kent RO Grand+
Cost Elements	**Non-electric system**	**UV-based system**	**RO-based system**
	One-Time Event Fees		
Initial Cost (avg)	999	8990	19000
	Annual Fees		
O&M Description	User cleans pre-treatment and post-treatment tanks as needed; change Tata Swach bulb every 3000 L	Pre-filter and granular activated carbon filter should be cleaned semi-annually and the activated carbon filter, and UV lamp should be replaced annually	Pre-filter and granular activated carbon filter should be cleaned quarterly and the sediment filter, activated carbon filters, RO membrane, and UV lamp should be replaced annually
Annual AMC Fee	549	1000	3000
Electricity Rating (W)	0	20	60
Treatment Time (LPM)	N/A	2	0.25
Electricity Unit Cost (Rs/KWh)	N/A	4	4
Approx Volume	35.0	35.0	35.0
Per Day Assumed Dur of Sys Op	N/A	0.29	2.33
Per Day Assumed Power Consump (KW)	N/A	0.01	0.14
Per Day Electricity Costs (Rs)	0	0.02	0.56
Lifetime	10	10	10

Figure F-1: Cost Comparison of Water Treatment or Replacement Options (Potable), Drinking Water and Cooking Water Treated (7.0 LPCD)



G. Calculated Wastage Volume from a Single Household, assuming 7.0 LPCD, Combined Drinking and Cooking Water, is Treated

Table G-1. Summary of Individual Household Wastage Volumes From Using a Water Purifier of Different Recovery Levels (7.0 LPCD, Drinking and Cooking Water for Treatment)

		Recovery %					
Description	**Units**	20%	30%	40%	50%	60%	70%
Volumes - per day (per capita)							
Vol. Potable Consumed	LPCD	7.00	7.00	7.00	7.00	7.00	7.00
Vol. Potable Wasted through RO Unit	LPCD	28.00	16.33	10.50	7.00	4.67	3.00
Vol. Non-potable Consumed	LPCD	80.0	80.0	80.0	80.0	80.0	80.0
Total Vol Consumed	LPCD	115.0	103.3	97.5	94.0	91.7	90.0
% Total Vol. Wasted	LPCD	24%	16%	11%	7%	5%	3%
Volumes - per day (HH)							
Vol. Potable Consumed	L/hh/d	35.00	35.00	35.00	35.00	35.00	35.00
Vol. Potable Wasted through RO Unit	L/hh/d	140.0	81.7	52.5	35.0	23.3	15.0
Vol. Non-potable Consumed	L/hh/d	400.0	400.0	400.0	400.0	400.0	400.0
Total Vol Consumed	L/hh/d	575.0	516.7	487.5	470.0	458.3	450.0
Volumes - per month (HH)							
Vol. Potable Consumed	L/hh/mo	925	925	925	925	925	925
Vol. Potable Wasted through RO Unit	L/hh/mo	3698	2157	1387	925	616	396
Vol. Non-potable Consumed	L/hh/mo	10567	10567	10567	10567	10567	10567
Total Vol Consumed	L/hh/mo	15190	13649	12878	12416	12108	11888
	KL/hh/mo	15.19	13.65	12.88	12.42	12.11	11.89
Volumes - per year (HH)							
Vol. Potable Consumed	L/hh/yr	11095	11095	11095	11095	11095	11095
Vol. Potable Wasted through RO Unit	L/hh/yr	44380	25888	16643	11095	7397	4755
Vol. Non-potable Consumed	L/hh/yr	126800	126800	126800	126800	126800	126800
Total Vol Consumed	L/hh/yr	182275	163783	154538	148990	145292	142650
	L/hh/yr	182.28	163.78	154.54	148.99	145.29	142.65

Table G-2. Summary of Individual Household Impact From Using a Water Purifier of Different Recovery Levels (7.0 LPCD, Drinking & Cooking)

		Recovery %							
Description	**Units**	20%	30%	40%	50%	60%	70%	80%	90%
Volumes - per day (per capita)									
Vol. Potable Consumed	LPCD	7.00	7.00	7.00	7.00	7.00	7.00	7.00	7.00
Vol. Potable Wasted through RO Unit	LPCD	28.00	16.33	10.50	7.00	4.67	3.00	1.75	0.78
Vol. Non-potable Consumed	LPCD	80.0	80.0	80.0	80.0	80.0	80.0	80.0	80.0
Total Vol Consumed	LPCD	115.0	103.3	97.5	94.0	91.7	90.0	88.8	87.8
% Total Vol. Wasted	LPCD	24%	16%	11%	7%	5%	3%	2%	1%
Volumes - per day (HH)									
Vol. Potable Consumed	L/hh/d	35.00	35.00	35.00	35.00	35.00	35.00	35.00	35.00
Vol. Potable Wasted through RO Unit	L/hh/d	140.0	81.7	52.5	35.0	23.3	15.0	8.8	3.9
Vol. Non-potable Consumed	L/hh/d	400.0	400.0	400.0	400.0	400.0	400.0	400.0	400.0
Total Vol Consumed	L/hh/d	575.0	516.7	487.5	470.0	458.3	450.0	443.8	438.9
Volumes - per month (HH)									
Vol. Potable Consumed	L/hh/mo	925	925	925	925	925	925	925	925
Vol. Potable Wasted through RO Unit	L/hh/mo	3698	2157	1387	925	616	396	231	103
Vol. Non-potable Consumed	L/hh/mo	10567	10567	10567	10567	10567	10567	10567	10567
Total Vol Consumed	L/hh/mo	15190	13649	12878	12416	12108	11888	11722	11594
	KL/hh/mo	15.19	13.65	12.88	12.42	12.11	11.89	11.72	11.59
Volumes - per year (HH)									
Vol. Potable Consumed	L/hh/yr	11095	11095	11095	11095	11095	11095	24424	24424
Vol. Potable Wasted through RO Unit	L/hh/yr	44380	25888	16643	11095	7397	4755	6106	2714
Vol. Non-potable Consumed	L/hh/yr	126800	126800	126800	126800	126800	126800	279136	279136
Total Vol Consumed	L/hh/yr	182275	163783	154538	148990	145292	142650	309667	306274
	L/hh/yr	182.28	163.78	154.54	148.99	145.29	142.65	309.67	306.27
Potential Costs - 100% Municipal (Delhi 2015 Tariff Structure)									
Flat Fee	INR	146.4	146.4	146.4	146.4	146.4	146.4	146.4	146.4
Usage, up to 20 KL	INR	66.7	59.9	56.5	54.5	53.2	52.2	51.5	50.9
Usage, from 20 - 30 KL	INR	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Usage, above 30 KL	INR	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Municipal - TOTAL Mo. Bill	**INR/mo**	213.1	206.3	202.9	200.9	199.6	198.6	197.9	197.3
Municipal - Wasted water cost, <20	**INR/mo**	16.2	9.5	6.1	4.1	2.7	1.7	1.0	0.5
Municipal - Wasted water cost, 20-30	**INR/mo**	-	-	-	-	-	-	-	-
Municipal - Wasted water cost ,>30	**INR/mo**	-	-	-	-	-	-	-	-
Municipal - TOTAL Mo. Bill (Wasted)	**INR/mo**	16.2	9.5	6.1	4.1	2.7	1.7	1.0	0.5
Potential Monthly Costs - 100% Groundwater (Pumping Costs)									
Energy moving extra water, Assume 0.5 hp pump, 0.85 pump eff, 0.85 motor eff, flow rate ~8.3 L/min	**KWhr/mo**	3.8	2.2	1.4	1.0	0.6	0.4	0.2	0.1
Monthly Electricity cost for wastage, tariff 4 INR/KW	**INR/mo**	15.2	8.9	5.7	3.8	2.5	1.6	1.0	0.4
Potential Monthly Costs - 100% Tanker - System still used to treat									
Amount of 10,000L Tankers to cover wastage	**10,000L/mo**	0.37	0.22	0.14	0.09	0.06	0.04	0.02	0.01
Cost of 10,000 Tankers (assume 1000 INR/ea)	**INR/mo**	369.8	215.7	138.7	92.5	61.6	39.6	23.1	10.3
Potential Monthly Costs - 100% Bottled Water Jugs (20L) - Used in place of all potable water in household									
No. 20L Jugs to cover reduced potable volume	**20L**	26	26	26	26	26	26	26	26
Cost of Jugs for reduced pot. vol. - (40 INR/20L)	**INR/mo**	1057	1057	1057	1057	1057	1057	1057	1057

H. Calculated Wastage Volumes for Delhi, assuming 5.0 LPCD, Drinking Water Only, is Treated

Table H-1. Description of Constants

Variable	Value	Units	Source
Treated Volume:	5	LPCD, Per cap volume potable consumed, Drinking water only	See Section 7.2
Untreated/Non-potable Volume:	82	LPCD, Per cap volume non-potable consumed; includes cooking	See Section 7.2
Household Size:	5	people; each household has the potential for using an RO system	(Government of NCT of Delhi, 2015b)
Water Purifier Recovery:	20-90%	% of input water that is drinkable; varies with calculations	"Standard" Recovery, (Kent RO Systems Ltd., n.d.-b)
No. of HH:	822,050	households within SECA & SECB, Delhi, 2011	(Tata Projects, n.d.)

<u>**Volume Calculations - Similar Formulas for Calculating Daily, Monthly, and Annual Volumes**</u>

Per HH Volume Potable Consumed = Per Capita Volume Potable Consumed * Number of People/Household

Per HH Volume Non-Potable Consumed = Per Capita Volume Non-Potable Consumed * Number of People/Household

Per HH Volume Potable Wasted through RO Unit = (Per HH Volume Potable Consumed / Recovery Rate) - Per HH Volume Potable Consumed

Per HH Total Volume Consumed = Per HH Volume Potable Consumed + Per HH Volume Non-Potable Consumed + Per HH Volume Potable Wasted through RO Unit

<u>**Opportunity Cost Calculations - Determining the Equivalent Number of Households That Could Have Been Served by the Wasted Volume**</u>

No. HH that could have been served (potable + non-potable) = Volume Potable Wasted Through RO Unit, Per Day / (Per HH Volume Potable Consumed + Per HH Volume Non-Potable Consumed)

No. HH that could have been served (potable) = Volume Potable Wasted Through RO Unit, Per Day / (Per HH Volume Potable Consumed)

Table H-2a. City-Level Impacts From SECA + SECB Groups Using Water Purifiers, 20% Recovery Level, 5.0 LPCD, Drinking Water Only

Treated Vol:	5	LPCD, drinking water only
Untreated/Non-potable Vol:	82	LPCD
Household Size:	5	people
Water Purifier Recovery:	20%	percentage of input water that is drinkable
No. of HH:	822,050	households within target market

		Adoption % of Users with RO									
Description	**Units**	10%	15%	20%	25%	30%	35%	40%	45%	50%	55%
		Volumes - Demand per day (per HH) - HH Not Using RO									
Vol. Potable Consumed	L/hh/d	25.0	25.0	25.0	25.0	25.0	25.0	25.0	25.0	25.0	25.0
Vol. Non-potable Consumed	L/hh/d	410.0	410.0	410.0	410.0	410.0	410.0	410.0	410.0	410.0	410.0
Total Vol Consumed	L/hh/d	435.0	435.0	435.0	435.0	435.0	435.0	435.0	435.0	435.0	435.0
		Volumes - Demand per day (per HH) - HH That Are Using RO									
Vol. Potable Consumed	L/hh/d	25.0	25.0	25.0	25.0	25.0	25.0	25.0	25.0	25.0	25.0
Vol. Potable Wasted through RO Unit	L/hh/d	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0
Vol. Non-potable Consumed	L/hh/d	410.0	410.0	410.0	410.0	410.0	410.0	410.0	410.0	410.0	410.0
Total Vol Consumed	L/hh/d	535.0	535.0	535.0	535.0	535.0	535.0	535.0	535.0	535.0	535.0
% Total Vol. Wasted	%	18.7%	18.7%	18.7%	18.7%	18.7%	18.7%	18.7%	18.7%	18.7%	18.7%
		Volumes - Demand per day (per HH) - TOTAL for SECA + SECB Mixed Users/Non-Users									
Vol. Potable Consumed, Not Including Wastage	KL/d	20551	20551	20551	20551	20551	20551	20551	20551	20551	20551
Vol. Potable Wasted through RO Unit	KL/d	8220	12331	16441	20551	24661	28772	32882	36992	41102	45213
Vol. Non-potable Consumed	KL/d	337040	337040	337040	337040	337040	337040	337040	337040	337040	337040
Total Vol Consumed	KL/d	365812	369922	374033	378143	382253	386363	390474	394584	398694	402804
% Total Vol. Wasted	%	2.2%	3.3%	4.4%	5.4%	6.5%	7.4%	8.4%	9.4%	10.3%	11.2%
		Volumes - per month (SECA+SECB Mixed Users/Non-Users)									
Vol. Potable Consumed	KL/mo	625101	625101	625101	625101	625101	625101	625101	625101	625101	625101
Vol. Potable Wasted through RO Unit	KL/mo	250040	375060	500080	625101	750121	875141	1000161	1125181	1250201	1375221
Vol. Non-potable Consumed	KL/mo	10251649	10251649	10251649	10251649	10251649	10251649	10251649	10251649	10251649	10251649
Total Vol Consumed	KL/mo	11126789	11251809	11376829	11501850	11626870	11751890	11876910	12001930	12126950	12251970
		Volumes - per year (SECA+SECB Mixed Users/Non-Users)									
Vol. Potable Consumed	KL/yr	7501206	4375704	4375704	4375704	4375704	4375704	4375704	4375704	4375704	4375704
Vol. Potable Wasted through RO Unit	KL/yr	3000482	2625422	3500563	4375704	5250844	6125985	7001126	7876267	8751407	9626548
Vol. Non-potable Consumed	KL/yr	123019782	71761540	71761540	71761540	71761540	71761540	71761540	71761540	71761540	71761540
Total Vol Consumed	KL/yr	133521471	78762665	79637806	80512947	81388088	82263228	83138369	84013510	84888650	85763791
		Opportunity Costs - No. HH that could not be served due to RO wastage									
Vol. Potable Wasted through RO Unit	L/d	8220500	12330750	16441000	20551250	24661500	28771750	32882000	36992250	41102500	45212750
No. HH that could have been served (P & N-P)	No. HH	18898	28347	37795	47244	56693	66142	75591	85040	94489	103937
No. HH that could have been served (P only)	No. HH	328820	493230	657640	822050	986460	1150870	1315280	1479690	1644100	1808510

Table H-2a. City-Level Impacts From SECA + SECB Groups Using Water Purifiers, 20% Recovery Level, 5.0 LPCD, Drinking Water Only

Treated Vol:	5	LPCD, drinking water only
Untreated/Non-potable Vol:	82	LPCD
Household Size:	5	people
Water Purifier Recovery:	20%	percentage of input water that is drinkable
No. of HH:	822,050	households within target market

		Adoption % of Users with RO								
Description	**Units**	60%	65%	70%	75%	80%	85%	90%	95%	100%
		Volumes - Demand per day (per HH) - HH Not Using RO								
Vol. Potable Consumed	L/hh/d	25.0	25.0	25.0	25.0	25.0	25.0	25.0	25.0	25.0
Vol. Non-potable Consumed	L/hh/d	410.0	410.0	410.0	410.0	410.0	410.0	410.0	410.0	410.0
Total Vol Consumed	L/hh/d	435.0	435.0	435.0	435.0	435.0	435.0	435.0	435.0	435.0
		Volumes - Demand per day (per HH) - HH That Are Using RO								
Vol. Potable Consumed	L/hh/d	25.0	25.0	25.0	25.0	25.0	25.0	25.0	25.0	25.0
Vol. Potable Wasted through RO Unit	L/hh/d	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0
Vol. Non-potable Consumed	L/hh/d	410.0	410.0	410.0	410.0	410.0	410.0	410.0	410.0	410.0
Total Vol Consumed	L/hh/d	535.0	535.0	535.0	535.0	535.0	535.0	535.0	535.0	535.0
% Total Vol. Wasted	%	18.7%	18.7%	18.7%	18.7%	18.7%	18.7%	18.7%	18.7%	18.7%
		Volumes - Demand per day (per HH) - TOTAL for SECA + SECB Mixed Users/Non-Users								
Vol. Potable Consumed, Not Including Wastage	KL/d	20551	20551	20551	20551	20551	20551	20551	20551	20551
Vol. Potable Wasted through RO Unit	KL/d	49323	53433	57543	61654	65764	69874	73984	78095	82205
Vol. Non-potable Consumed	KL/d	337040	337040	337040	337040	337040	337040	337040	337040	337040
Total Vol Consumed	KL/d	406915	411025	415135	419245	423356	427466	431576	435686	439797
% Total Vol. Wasted	%	12.1%	13.0%	13.9%	14.7%	15.5%	16.3%	17.1%	17.9%	18.7%
		Volumes - per month (SECA+SECB Mixed Users/Non-Users)								
Vol. Potable Consumed	KL/mo	625101	625101	625101	625101	625101	625101	625101	625101	625101
Vol. Potable Wasted through RO Unit	KL/mo	1500241	1625261	1750281	1875302	2000322	2125342	2250362	2375382	2500402
Vol. Non-potable Consumed	KL/mo	10251649	10251649	10251649	10251649	10251649	10251649	10251649	10251649	10251649
Total Vol Consumed	KL/mo	12376990	12502010	12627030	12752051	12877071	13002091	13127111	13252131	13377151
		Volumes - per year (SECA+SECB Mixed Users/Non-Users)								
Vol. Potable Consumed	KL/yr	4375704	4375704	4375704	4375704	4375704	4375704	4375704	4375704	4375704
Vol. Potable Wasted through RO Unit	KL/yr	10501689	11376829	12251970	13127111	14002252	14877392	15752533	16627674	17502815
Vol. Non-potable Consumed	KL/yr	71761540	71761540	71761540	71761540	71761540	71761540	71761540	71761540	71761540
Total Vol Consumed	KL/yr	86638932	87514073	88389213	89264354	90139495	91014636	91889776	92764917	93640058
		Opportunity Costs - No. HH that could not be served due to RO wastage								
Vol. Potable Wasted through RO Unit	L/d	49323000	53433250	57543500	61653750	65764000	69874250	73984500	78094750	82205000
No. HH that could have been served (P & N-P)	No. HH	113386	122835	132284	141733	151182	160630	170079	179528	188977
No. HH that could have been served (P only)	No. HH	1972920	2137330	2301740	2466150	2630560	2794970	2959380	3123790	3288200

Table H-2b. City-Level Impacts From SECA + SECB Groups Using Water Purifiers, 30% Recovery Level, 5.0 LPCD, Drinking Water Only

Treated Vol:	5	LPCD, drinking water only
Untreated/Non-potable Vol:	82	LPCD
Household Size:	5	people
Water Purifier Recovery:	30%	percentage of input water that is drinkable
No. of HH:	822,050	households within target market

		Adoption % of Users with RO									
Description	**Units**	10%	15%	20%	25%	30%	35%	40%	45%	50%	55%
		Volumes - Demand per day (per HH) - HH Not Using RO									
Vol. Potable Consumed	L/hh/d	25.0	25.0	25.0	25.0	25.0	25.0	25.0	25.0	25.0	25.0
Vol. Non-potable Consumed	L/hh/d	410.0	410.0	410.0	410.0	410.0	410.0	410.0	410.0	410.0	410.0
Total Vol Consumed	L/hh/d	435.0	435.0	435.0	435.0	435.0	435.0	435.0	435.0	435.0	435.0
		Volumes - Demand per day (per HH) - HH That Are Using RO									
Vol. Potable Consumed	L/hh/d	25.0	25.0	25.0	25.0	25.0	25.0	25.0	25.0	25.0	25.0
Vol. Potable Wasted through RO Unit	L/hh/d	58.3	58.3	58.3	58.3	58.3	58.3	58.3	58.3	58.3	58.3
Vol. Non-potable Consumed	L/hh/d	410.0	410.0	410.0	410.0	410.0	410.0	410.0	410.0	410.0	410.0
Total Vol Consumed	L/hh/d	493.3	493.3	493.3	493.3	493.3	493.3	493.3	493.3	493.3	493.3
% Total Vol. Wasted	%	11.8%	11.8%	11.8%	11.8%	11.8%	11.8%	11.8%	11.8%	11.8%	11.8%
		Volumes - Demand per day (per HH) - TOTAL for SECA + SECB Mixed Users/Non-Users									
Vol. Potable Consumed, Not Including Wastage	KL/d	20551	20551	20551	20551	20551	20551	20551	20551	20551	20551
Vol. Potable Wasted through RO Unit	KL/d	4795	7193	9591	11988	14386	16784	19181	21579	23976	26374
Vol. Non-potable Consumed	KL/d	337040	337040	337040	337040	337040	337040	337040	337040	337040	337040
Total Vol Consumed	KL/d	362387	364785	367182	369580	371978	374375	376773	379171	381568	383966
% Total Vol. Wasted	%	1.3%	2.0%	2.6%	3.2%	3.9%	4.5%	5.1%	5.7%	6.3%	6.9%
		Volumes - per month (SECA+SECB Mixed Users/Non-Users)									
Vol. Potable Consumed	KL/mo	625101	625101	625101	625101	625101	625101	625101	625101	625101	625101
Vol. Potable Wasted through RO Unit	KL/mo	145857	218785	291714	364642	437570	510499	583427	656356	729284	802212
Vol. Non-potable Consumed	KL/mo	10251649	10251649	10251649	10251649	10251649	10251649	10251649	10251649	10251649	10251649
Total Vol Consumed	KL/mo	11022606	11095534	11168463	11241391	11314319	11387248	11460176	11533105	11606033	11678961
		Volumes - per year (SECA+SECB Mixed Users/Non-Users)									
Vol. Potable Consumed	KL/yr	7501206	4375704	4375704	4375704	4375704	4375704	4375704	4375704	4375704	4375704
Vol. Potable Wasted through RO Unit	KL/yr	1750281	1531496	2041995	2552494	3062993	3573491	4083990	4594489	5104988	5615486
Vol. Non-potable Consumed	KL/yr	123019782	71761540	71761540	71761540	71761540	71761540	71761540	71761540	71761540	71761540
Total Vol Consumed	KL/yr	132271270	77668739	78179238	78689737	79200236	79710734	80221233	80731732	81242231	81752730
		Opportunity Costs - No. HH that could not be served due to RO wastage									
Vol. Potable Wasted through RO Unit	L/d	4795292	7192937	9590583	11988229	14385875	16783521	19181167	21578812	23976458	26374104
No. HH that could have been served (P & N-P)	No. HH	11024	16535	22047	27559	33071	38583	44095	49606	55118	60630
No. HH that could have been served (P only)	No. HH	191812	287717	383623	479529	575435	671341	767247	863152	959058	1054964

Table H-2b. City-Level Impacts From SECA + SECB Groups Using Water Purifiers, 30% Recovery Level, 5.0 LPCD, Drinking Water Only

Treated Vol:	5	LPCD, drinking water only
Untreated/Non-potable Vol:	82	LPCD
Household Size:	5	people
Water Purifier Recovery:	30%	percentage of input water that is drinkable
No. of HH:	822,050	households within target market

		Adoption % of Users with RO								
Description	**Units**	60%	65%	70%	75%	80%	85%	90%	95%	100%
		Volumes - Demand per day (per HH) - HH Not Using RO								
Vol. Potable Consumed	L/hh/d	25.0	25.0	25.0	25.0	25.0	25.0	25.0	25.0	25.0
Vol. Non-potable Consumed	L/hh/d	410.0	410.0	410.0	410.0	410.0	410.0	410.0	410.0	410.0
Total Vol Consumed	L/hh/d	435.0	435.0	435.0	435.0	435.0	435.0	435.0	435.0	435.0
		Volumes - Demand per day (per HH) - HH That Are Using RO								
Vol. Potable Consumed	L/hh/d	25.0	25.0	25.0	25.0	25.0	25.0	25.0	25.0	25.0
Vol. Potable Wasted through RO Unit	L/hh/d	58.3	58.3	58.3	58.3	58.3	58.3	58.3	58.3	58.3
Vol. Non-potable Consumed	L/hh/d	410.0	410.0	410.0	410.0	410.0	410.0	410.0	410.0	410.0
Total Vol Consumed	L/hh/d	493.3	493.3	493.3	493.3	493.3	493.3	493.3	493.3	493.3
% Total Vol. Wasted	%	11.8%	11.8%	11.8%	11.8%	11.8%	11.8%	11.8%	11.8%	11.8%
		Volumes - Demand per day (per HH) - TOTAL for SECA + SECB Mixed Users/Non-Users								
Vol. Potable Consumed, Not Including Wastage	KL/d	20551	20551	20551	20551	20551	20551	20551	20551	20551
Vol. Potable Wasted through RO Unit	KL/d	28772	31169	33567	35965	38362	40760	43158	45555	47953
Vol. Non-potable Consumed	KL/d	337040	337040	337040	337040	337040	337040	337040	337040	337040
Total Vol Consumed	KL/d	386363	388761	391159	393556	395954	398352	400749	403147	405545
% Total Vol. Wasted	%	7.4%	8.0%	8.6%	9.1%	9.7%	10.2%	10.8%	11.3%	11.8%
		Volumes - per month (SECA+SECB Mixed Users/Non-Users)								
Vol. Potable Consumed	KL/mo	625101	625101	625101	625101	625101	625101	625101	625101	625101
Vol. Potable Wasted through RO Unit	KL/mo	875141	948069	1020998	1093926	1166854	1239783	1312711	1385639	1458568
Vol. Non-potable Consumed	KL/mo	10251649	10251649	10251649	10251649	10251649	10251649	10251649	10251649	10251649
Total Vol Consumed	KL/mo	11751890	11824818	11897747	11970675	12043603	12116532	12189460	12262389	12335317
		Volumes - per year (SECA+SECB Mixed Users/Non-Users)								
Vol. Potable Consumed	KL/yr	4375704	4375704	4375704	4375704	4375704	4375704	4375704	4375704	4375704
Vol. Potable Wasted through RO Unit	KL/yr	6125985	6636484	7146983	7657481	8167980	8678479	9188978	9699476	10209975
Vol. Non-potable Consumed	KL/yr	71761540	71761540	71761540	71761540	71761540	71761540	71761540	71761540	71761540
Total Vol Consumed	KL/yr	82263228	82773727	83284226	83794725	84305223	84815722	85326221	85836720	86347218
		Opportunity Costs - No. HH that could not be served due to RO wastage								
Vol. Potable Wasted through RO Unit	L/d	28771750	31169396	33567042	35964687	38362333	40759979	43157625	45555271	47952917
No. HH that could have been served (P & N-P)	No. HH	66142	71654	77166	82677	88189	93701	99213	104725	110237
No. HH that could have been served (P only)	No. HH	1150870	1246776	1342682	1438587	1534493	1630399	1726305	1822211	1918117

Table H-2c. City-Level Impacts From SECA + SECB Groups Using Water Purifiers, 40% Recovery Level, 5.0 LPCD, Drinking Water Only

Treated Vol:	5	LPCD, drinking water only
Untreated/Non-potable Vol:	82	LPCD
Household Size:	5	people
Water Purifier Recovery:	40%	percentage of input water that is drinkable
No. of HH:	822,050	households within target market

		Adoption % of Users with RO									
Description	**Units**	10%	15%	20%	25%	30%	35%	40%	45%	50%	55%
		Volumes - Demand per day (per HH) - HH Not Using RO									
Vol. Potable Consumed	L/hh/d	25.0	25.0	25.0	25.0	25.0	25.0	25.0	25.0	25.0	25.0
Vol. Non-potable Consumed	L/hh/d	410.0	410.0	410.0	410.0	410.0	410.0	410.0	410.0	410.0	410.0
Total Vol Consumed	L/hh/d	435.0	435.0	435.0	435.0	435.0	435.0	435.0	435.0	435.0	435.0
		Volumes - Demand per day (per HH) - HH That Are Using RO									
Vol. Potable Consumed	L/hh/d	25.0	25.0	25.0	25.0	25.0	25.0	25.0	25.0	25.0	25.0
Vol. Potable Wasted through RO Unit	L/hh/d	37.5	37.5	37.5	37.5	37.5	37.5	37.5	37.5	37.5	37.5
Vol. Non-potable Consumed	L/hh/d	410.0	410.0	410.0	410.0	410.0	410.0	410.0	410.0	410.0	410.0
Total Vol Consumed	L/hh/d	472.5	472.5	472.5	472.5	472.5	472.5	472.5	472.5	472.5	472.5
% Total Vol. Wasted	%	7.9%	7.9%	7.9%	7.9%	7.9%	7.9%	7.9%	7.9%	7.9%	7.9%
		Volumes - Demand per day (per HH) - TOTAL for SECA + SECB Mixed Users/Non-Users									
Vol. Potable Consumed, Not Including Wastage	KL/d	20551	20551	20551	20551	20551	20551	20551	20551	20551	20551
Vol. Potable Wasted through RO Unit	KL/d	3083	4624	6165	7707	9248	10789	12331	13872	15413	16955
Vol. Non-potable Consumed	KL/d	337040	337040	337040	337040	337040	337040	337040	337040	337040	337040
Total Vol Consumed	KL/d	360674	362216	363757	365298	366840	368381	369922	371464	373005	374547
% Total Vol. Wasted	%	0.9%	1.3%	1.7%	2.1%	2.5%	2.9%	3.3%	3.7%	4.1%	4.5%
		Volumes - per month (SECA+SECB Mixed Users/Non-Users)									
Vol. Potable Consumed	KL/mo	625101	625101	625101	625101	625101	625101	625101	625101	625101	625101
Vol. Potable Wasted through RO Unit	KL/mo	93765	140648	187530	234413	281295	328178	375060	421943	468825	515708
Vol. Non-potable Consumed	KL/mo	10251649	10251649	10251649	10251649	10251649	10251649	10251649	10251649	10251649	10251649
Total Vol Consumed	KL/mo	10970514	11017397	11064279	11111162	11158044	11204927	11251809	11298692	11345574	11392457
		Volumes - per year (SECA+SECB Mixed Users/Non-Users)									
Vol. Potable Consumed	KL/yr	7501206	4375704	4375704	4375704	4375704	4375704	4375704	4375704	4375704	4375704
Vol. Potable Wasted through RO Unit	KL/yr	1125181	984533	1312711	1640889	1969067	2297244	2625422	2953600	3281778	3609955
Vol. Non-potable Consumed	KL/yr	123019782	71761540	71761540	71761540	71761540	71761540	71761540	71761540	71761540	71761540
Total Vol Consumed	KL/yr	131646169	77121777	77449954	77778132	78106310	78434488	78762665	79090843	79419021	79747199
		Opportunity Costs - No. HH that could not be served due to RO wastage									
Vol. Potable Wasted through RO Unit	L/d	3082687	4624031	6165375	7706719	9248062	10789406	12330750	13872094	15413437	16954781
No. HH that could have been served (P & N-P)	No. HH	7087	10630	14173	17717	21260	24803	28347	31890	35433	38977
No. HH that could have been served (P only)	No. HH	123307	184961	246615	308269	369922	431576	493230	554884	616537	678191

Table H-2c. City-Level Impacts From SECA + SECB Groups Using Water Purifiers, 40% Recovery Level, 5.0 LPCD, Drinking Water Only

Treated Vol:	5	LPCD, drinking water only
Untreated/Non-potable Vol:	82	LPCD
Household Size:	5	people
Water Purifier Recovery:	40%	percentage of input water that is drinkable
No. of HH:	822,050	households within target market

		Adoption % of Users with RO								
Description	**Units**	60%	65%	70%	75%	80%	85%	90%	95%	100%
		Volumes - Demand per day (per HH) - HH Not Using RO								
Vol. Potable Consumed	L/hh/d	25.0	25.0	25.0	25.0	25.0	25.0	25.0	25.0	25.0
Vol. Non-potable Consumed	L/hh/d	410.0	410.0	410.0	410.0	410.0	410.0	410.0	410.0	410.0
Total Vol Consumed	L/hh/d	435.0	435.0	435.0	435.0	435.0	435.0	435.0	435.0	435.0
		Volumes - Demand per day (per HH) - HH That Are Using RO								
Vol. Potable Consumed	L/hh/d	25.0	25.0	25.0	25.0	25.0	25.0	25.0	25.0	25.0
Vol. Potable Wasted through RO Unit	L/hh/d	37.5	37.5	37.5	37.5	37.5	37.5	37.5	37.5	37.5
Vol. Non-potable Consumed	L/hh/d	410.0	410.0	410.0	410.0	410.0	410.0	410.0	410.0	410.0
Total Vol Consumed	L/hh/d	472.5	472.5	472.5	472.5	472.5	472.5	472.5	472.5	472.5
% Total Vol. Wasted	%	7.9%	7.9%	7.9%	7.9%	7.9%	7.9%	7.9%	7.9%	7.9%
		Volumes - Demand per day (per HH) - TOTAL for SECA + SECB Mixed Users/Non-Users								
Vol. Potable Consumed, Not Including Wastage	KL/d	20551	20551	20551	20551	20551	20551	20551	20551	20551
Vol. Potable Wasted through RO Unit	KL/d	18496	20037	21579	23120	24661	26203	27744	29286	30827
Vol. Non-potable Consumed	KL/d	337040	337040	337040	337040	337040	337040	337040	337040	337040
Total Vol Consumed	KL/d	376088	377629	379171	380712	382253	383795	385336	386877	388419
% Total Vol. Wasted	%	4.9%	5.3%	5.7%	6.1%	6.5%	6.8%	7.2%	7.6%	7.9%
		Volumes - per month (SECA+SECB Mixed Users/Non-Users)								
Vol. Potable Consumed	KL/mo	625101	625101	625101	625101	625101	625101	625101	625101	625101
Vol. Potable Wasted through RO Unit	KL/mo	562590	609473	656356	703238	750121	797003	843886	890768	937651
Vol. Non-potable Consumed	KL/mo	10251649	10251649	10251649	10251649	10251649	10251649	10251649	10251649	10251649
Total Vol Consumed	KL/mo	11439339	11486222	11533105	11579987	11626870	11673752	11720635	11767517	11814400
		Volumes - per year (SECA+SECB Mixed Users/Non-Users)								
Vol. Potable Consumed	KL/yr	4375704	4375704	4375704	4375704	4375704	4375704	4375704	4375704	4375704
Vol. Potable Wasted through RO Unit	KL/yr	3938133	4266311	4594489	4922667	5250844	5579022	5907200	6235378	6563555
Vol. Non-potable Consumed	KL/yr	71761540	71761540	71761540	71761540	71761540	71761540	71761540	71761540	71761540
Total Vol Consumed	KL/yr	80075376	80403554	80731732	81059910	81388088	81716265	82044443	82372621	82700799
		Opportunity Costs - No. HH that could not be served due to RO wastage								
Vol. Potable Wasted through RO Unit	L/d	18496125	20037469	21578812	23120156	24661500	26202844	27744187	29285531	30826875
No. HH that could have been served (P & N-P)	No. HH	42520	46063	49606	53150	56693	60236	63780	67323	70866
No. HH that could have been served (P only)	No. HH	739845	801499	863152	924806	986460	1048114	1109767	1171421	1233075

Table H-2d. City-Level Impacts From SECA + SECB Groups Using Water Purifiers, 50% Recovery Level, 5.0 LPCD, Drinking Water Only

Treated Vol:	5	LPCD, drinking water only
Untreated/Non-potable Vol:	82	LPCD
Household Size:	5	people
Water Purifier Recovery:	50%	percentage of input water that is drinkable
No. of HH:	822,050	households within target market

Description	Units	Adoption % of Users with RO									
		10%	15%	20%	25%	30%	35%	40%	45%	50%	55%
		Volumes - Demand per day (per HH) - HH Not Using RO									
Vol. Potable Consumed	L/hh/d	25.0	25.0	25.0	25.0	25.0	25.0	25.0	25.0	25.0	25.0
Vol. Non-potable Consumed	L/hh/d	410.0	410.0	410.0	410.0	410.0	410.0	410.0	410.0	410.0	410.0
Total Vol Consumed	L/hh/d	435.0	435.0	435.0	435.0	435.0	435.0	435.0	435.0	435.0	435.0
		Volumes - Demand per day (per HH) - HH That Are Using RO									
Vol. Potable Consumed	L/hh/d	25.0	25.0	25.0	25.0	25.0	25.0	25.0	25.0	25.0	25.0
Vol. Potable Wasted through RO Unit	L/hh/d	25.0	25.0	25.0	25.0	25.0	25.0	25.0	25.0	25.0	25.0
Vol. Non-potable Consumed	L/hh/d	410.0	410.0	410.0	410.0	410.0	410.0	410.0	410.0	410.0	410.0
Total Vol Consumed	L/hh/d	460.0	460.0	460.0	460.0	460.0	460.0	460.0	460.0	460.0	460.0
% Total Vol. Wasted	%	5.4%	5.4%	5.4%	5.4%	5.4%	5.4%	5.4%	5.4%	5.4%	5.4%
		Volumes - Demand per day (per HH) - TOTAL for SECA + SECB Mixed Users/Non-Users									
Vol. Potable Consumed, Not Including Wastage	KL/d	20551	20551	20551	20551	20551	20551	20551	20551	20551	20551
Vol. Potable Wasted through RO Unit	KL/d	2055	3083	4110	5138	6165	7193	8220	9248	10276	11303
Vol. Non-potable Consumed	KL/d	337040	337040	337040	337040	337040	337040	337040	337040	337040	337040
Total Vol Consumed	KL/d	359647	360674	361702	362730	363757	364785	365812	366840	367867	368895
% Total Vol. Wasted	%	0.6%	0.9%	1.1%	1.4%	1.7%	2.0%	2.2%	2.5%	2.8%	3.1%
		Volumes - per month (SECA+SECB Mixed Users/Non-Users)									
Vol. Potable Consumed	KL/mo	625101	625101	625101	625101	625101	625101	625101	625101	625101	625101
Vol. Potable Wasted through RO Unit	KL/mo	62510	93765	125020	156275	187530	218785	250040	281295	312550	343805
Vol. Non-potable Consumed	KL/mo	10251649	10251649	10251649	10251649	10251649	10251649	10251649	10251649	10251649	10251649
Total Vol Consumed	KL/mo	10939259	10970514	11001769	11033024	11064279	11095534	11126789	11158044	11189299	11220554
		Volumes - per year (SECA+SECB Mixed Users/Non-Users)									
Vol. Potable Consumed	KL/yr	7501206	4375704	4375704	4375704	4375704	4375704	4375704	4375704	4375704	4375704
Vol. Potable Wasted through RO Unit	KL/yr	750121	656356	875141	1093926	1312711	1531496	1750281	1969067	2187852	2406637
Vol. Non-potable Consumed	KL/yr	123019782	71761540	71761540	71761540	71761540	71761540	71761540	71761540	71761540	71761540
Total Vol Consumed	KL/yr	131271109	76793599	77012384	77231169	77449954	77668739	77887525	78106310	78325095	78543880
		Opportunity Costs - No. HH that could not be served due to RO wastage									
Vol. Potable Wasted through RO Unit	L/d	2055125	3082687	4110250	5137812	6165375	7192937	8220500	9248062	10275625	11303187
No. HH that could have been served (P & N-P)	No. HH	4724	7087	9449	11811	14173	16535	18898	21260	23622	25984
No. HH that could have been served (P only)	No. HH	82205	123307	164410	205512	246615	287717	328820	369922	411025	452127

Table H-2d. City-Level Impacts From SECA + SECB Groups Using Water Purifiers, 50% Recovery Level, 5.0 LPCD, Drinking Water Only

Treated Vol:	5	LPCD, drinking water only
Untreated/Non-potable Vol:	82	LPCD
Household Size:	5	people
Water Purifier Recovery:	50%	percentage of input water that is drinkable
No. of HH:	822,050	households within target market

		Adoption % of Users with RO								
Description	**Units**	60%	65%	70%	75%	80%	85%	90%	95%	100%
		Volumes - Demand per day (per HH) - HH Not Using RO								
Vol. Potable Consumed	L/hh/d	25.0	25.0	25.0	25.0	25.0	25.0	25.0	25.0	25.0
Vol. Non-potable Consumed	L/hh/d	410.0	410.0	410.0	410.0	410.0	410.0	410.0	410.0	410.0
Total Vol Consumed	L/hh/d	435.0	435.0	435.0	435.0	435.0	435.0	435.0	435.0	435.0
		Volumes - Demand per day (per HH) - HH That Are Using RO								
Vol. Potable Consumed	L/hh/d	25.0	25.0	25.0	25.0	25.0	25.0	25.0	25.0	25.0
Vol. Potable Wasted through RO Unit	L/hh/d	25.0	25.0	25.0	25.0	25.0	25.0	25.0	25.0	25.0
Vol. Non-potable Consumed	L/hh/d	410.0	410.0	410.0	410.0	410.0	410.0	410.0	410.0	410.0
Total Vol Consumed	L/hh/d	460.0	460.0	460.0	460.0	460.0	460.0	460.0	460.0	460.0
% Total Vol. Wasted	%	5.4%	5.4%	5.4%	5.4%	5.4%	5.4%	5.4%	5.4%	5.4%
		Volumes - Demand per day (per HH) - TOTAL for SECA + SECB Mixed Users/Non-Users								
Vol. Potable Consumed, Not Including Wastage	KL/d	20551	20551	20551	20551	20551	20551	20551	20551	20551
Vol. Potable Wasted through RO Unit	KL/d	12331	13358	14386	15413	16441	17469	18496	19524	20551
Vol. Non-potable Consumed	KL/d	337040	337040	337040	337040	337040	337040	337040	337040	337040
Total Vol Consumed	KL/d	369922	370950	371978	373005	374033	375060	376088	377115	378143
% Total Vol. Wasted	%	3.3%	3.6%	3.9%	4.1%	4.4%	4.7%	4.9%	5.2%	5.4%
		Volumes - per month (SECA+SECB Mixed Users/Non-Users)								
Vol. Potable Consumed	KL/mo	625101	625101	625101	625101	625101	625101	625101	625101	625101
Vol. Potable Wasted through RO Unit	KL/mo	375060	406315	437570	468825	500080	531335	562590	593845	625101
Vol. Non-potable Consumed	KL/mo	10251649	10251649	10251649	10251649	10251649	10251649	10251649	10251649	10251649
Total Vol Consumed	KL/mo	11251809	11283064	11314319	11345574	11376829	11408084	11439339	11470595	11501850
		Volumes - per year (SECA+SECB Mixed Users/Non-Users)								
Vol. Potable Consumed	KL/yr	4375704	4375704	4375704	4375704	4375704	4375704	4375704	4375704	4375704
Vol. Potable Wasted through RO Unit	KL/yr	2625422	2844207	3062993	3281778	3500563	3719348	3938133	4156918	4375704
Vol. Non-potable Consumed	KL/yr	71761540	71761540	71761540	71761540	71761540	71761540	71761540	71761540	71761540
Total Vol Consumed	KL/yr	78762665	78981451	79200236	79419021	79637806	79856591	80075376	80294162	80512947
		Opportunity Costs - No. HH that could not be served due to RO wastage								
Vol. Potable Wasted through RO Unit	L/d	12330750	13358312	14385875	15413437	16441000	17468562	18496125	19523687	20551250
No. HH that could have been served (P & N-P)	No. HH	28347	30709	33071	35433	37795	40158	42520	44882	47244
No. HH that could have been served (P only)	No. HH	493230	534332	575435	616537	657640	698742	739845	780947	822050

Table H-2e. City-Level Impacts From SECA + SECB Groups Using Water Purifiers, 70% Recovery Level, 5.0 LPCD, Drinking Water Only

Treated Vol:	5	LPCD, drinking water only
Untreated/Non-potable Vol:	82	LPCD
Household Size:	5	people
Water Purifier Recovery:	70%	percentage of input water that is drinkable
No. of HH:	822,050	households within target market

		Adoption % of Users with RO									
Description	**Units**	10%	15%	20%	25%	30%	35%	40%	45%	50%	55%
		Volumes - Demand per day (per HH) - HH Not Using RO									
Vol. Potable Consumed	L/hh/d	25.0	25.0	25.0	25.0	25.0	25.0	25.0	25.0	25.0	25.0
Vol. Non-potable Consumed	L/hh/d	410.0	410.0	410.0	410.0	410.0	410.0	410.0	410.0	410.0	410.0
Total Vol Consumed	L/hh/d	435.0	435.0	435.0	435.0	435.0	435.0	435.0	435.0	435.0	435.0
		Volumes - Demand per day (per HH) - HH That Are Using RO									
Vol. Potable Consumed	L/hh/d	25.0	25.0	25.0	25.0	25.0	25.0	25.0	25.0	25.0	25.0
Vol. Potable Wasted through RO Unit	L/hh/d	10.7	10.7	10.7	10.7	10.7	10.7	10.7	10.7	10.7	10.7
Vol. Non-potable Consumed	L/hh/d	410.0	410.0	410.0	410.0	410.0	410.0	410.0	410.0	410.0	410.0
Total Vol Consumed	L/hh/d	445.7	445.7	445.7	445.7	445.7	445.7	445.7	445.7	445.7	445.7
% Total Vol. Wasted	%	2.4%	2.4%	2.4%	2.4%	2.4%	2.4%	2.4%	2.4%	2.4%	2.4%
		Volumes - Demand per day (per HH) - TOTAL for SECA + SECB Mixed Users/Non-Users									
Vol. Potable Consumed, Not Including Wastage	KL/d	20551	20551	20551	20551	20551	20551	20551	20551	20551	20551
Vol. Potable Wasted through RO Unit	KL/d	881	1321	1762	2202	2642	3083	3523	3963	4404	4844
Vol. Non-potable Consumed	KL/d	337040	337040	337040	337040	337040	337040	337040	337040	337040	337040
Total Vol Consumed	KL/d	358473	358913	359353	359794	360234	360674	361115	361555	361996	362436
% Total Vol. Wasted	%	0.2%	0.4%	0.5%	0.6%	0.7%	0.9%	1.0%	1.1%	1.2%	1.3%
		Volumes - per month (SECA+SECB Mixed Users/Non-Users)									
Vol. Potable Consumed	KL/mo	625101	625101	625101	625101	625101	625101	625101	625101	625101	625101
Vol. Potable Wasted through RO Unit	KL/mo	26790	40185	53580	66975	80370	93765	107160	120555	133950	147345
Vol. Non-potable Consumed	KL/mo	10251649	10251649	10251649	10251649	10251649	10251649	10251649	10251649	10251649	10251649
Total Vol Consumed	KL/mo	10903539	10916934	10930329	10943724	10957119	10970514	10983909	10997304	11010699	11024094
		Volumes - per year (SECA+SECB Mixed Users/Non-Users)									
Vol. Potable Consumed	KL/yr	7501206	4375704	4375704	4375704	4375704	4375704	4375704	4375704	4375704	4375704
Vol. Potable Wasted through RO Unit	KL/yr	321480	281295	375060	468825	562590	656356	750121	843886	937651	1031416
Vol. Non-potable Consumed	KL/yr	123019782	71761540	71761540	71761540	71761540	71761540	71761540	71761540	71761540	71761540
Total Vol Consumed	KL/yr	130842469	76418538	76512304	76606069	76699834	76793599	76887364	76981129	77074894	77168659
		Opportunity Costs - No. HH that could not be served due to RO wastage									
Vol. Potable Wasted through RO Unit	L/d	880768	1321152	1761536	2201920	2642304	3082687	3523071	3963455	4403839	4844223
No. HH that could have been served (P & N-P)	No. HH	2025	3037	4050	5062	6074	7087	8099	9111	10124	11136
No. HH that could have been served (P only)	No. HH	35231	52846	70461	88077	105692	123307	140923	158538	176154	193769

Table H-2e. City-Level Impacts From SECA + SECB Groups Using Water Purifiers, 70% Recovery Level, 5.0 LPCD, Drinking Water Only

Treated Vol:	5	LPCD, drinking water only
Untreated/Non-potable Vol:	82	LPCD
Household Size:	5	people
Water Purifier Recovery:	70%	percentage of input water that is drinkable
No. of HH:	822,050	households within target market

		Adoption % of Users with RO								
Description	**Units**	60%	65%	70%	75%	80%	85%	90%	95%	100%
		Volumes - Demand per day (per HH) - HH Not Using RO								
Vol. Potable Consumed	L/hh/d	25.0	25.0	25.0	25.0	25.0	25.0	25.0	25.0	25.0
Vol. Non-potable Consumed	L/hh/d	410.0	410.0	410.0	410.0	410.0	410.0	410.0	410.0	410.0
Total Vol Consumed	L/hh/d	435.0	435.0	435.0	435.0	435.0	435.0	435.0	435.0	435.0
		Volumes - Demand per day (per HH) - HH That Are Using RO								
Vol. Potable Consumed	L/hh/d	25.0	25.0	25.0	25.0	25.0	25.0	25.0	25.0	25.0
Vol. Potable Wasted through RO Unit	L/hh/d	10.7	10.7	10.7	10.7	10.7	10.7	10.7	10.7	10.7
Vol. Non-potable Consumed	L/hh/d	410.0	410.0	410.0	410.0	410.0	410.0	410.0	410.0	410.0
Total Vol Consumed	L/hh/d	445.7	445.7	445.7	445.7	445.7	445.7	445.7	445.7	445.7
% Total Vol. Wasted	%	2.4%	2.4%	2.4%	2.4%	2.4%	2.4%	2.4%	2.4%	2.4%
		Volumes - Demand per day (per HH) - TOTAL for SECA + SECB Mixed Users/Non-Users								
Vol. Potable Consumed, Not Including Wastage	KL/d	20551	20551	20551	20551	20551	20551	20551	20551	20551
Vol. Potable Wasted through RO Unit	KL/d	5285	5725	6165	6606	7046	7487	7927	8367	8808
Vol. Non-potable Consumed	KL/d	337040	337040	337040	337040	337040	337040	337040	337040	337040
Total Vol Consumed	KL/d	362876	363317	363757	364198	364638	365078	365519	365959	366399
% Total Vol. Wasted	%	1.5%	1.6%	1.7%	1.8%	1.9%	2.1%	2.2%	2.3%	2.4%
		Volumes - per month (SECA+SECB Mixed Users/Non-Users)								
Vol. Potable Consumed	KL/mo	625101	625101	625101	625101	625101	625101	625101	625101	625101
Vol. Potable Wasted through RO Unit	KL/mo	160740	174135	187530	200925	214320	227715	241110	254505	267900
Vol. Non-potable Consumed	KL/mo	10251649	10251649	10251649	10251649	10251649	10251649	10251649	10251649	10251649
Total Vol Consumed	KL/mo	11037489	11050884	11064279	11077674	11091069	11104464	11117859	11131254	11144649
		Volumes - per year (SECA+SECB Mixed Users/Non-Users)								
Vol. Potable Consumed	KL/yr	4375704	4375704	4375704	4375704	4375704	4375704	4375704	4375704	4375704
Vol. Potable Wasted through RO Unit	KL/yr	1125181	1218946	1312711	1406476	1500241	1594006	1687771	1781536	1875302
Vol. Non-potable Consumed	KL/yr	71761540	71761540	71761540	71761540	71761540	71761540	71761540	71761540	71761540
Total Vol Consumed	KL/yr	77262424	77356189	77449954	77543719	77637484	77731250	77825015	77918780	78012545
		Opportunity Costs - No. HH that could not be served due to RO wastage								
Vol. Potable Wasted through RO Unit	L/d	5284607	5724991	6165375	6605759	7046143	7486527	7926911	8367295	8807679
No. HH that could have been served (P & N-P)	No. HH	12149	13161	14173	15186	16198	17210	18223	19235	20248
No. HH that could have been served (P only)	No. HH	211384	229000	246615	264230	281846	299461	317076	334692	352307

Table H-2f. City-Level Impacts From SECA + SECB Groups Using Water Purifiers, 80% Recovery Level, 5.0 LPCD, Drinking Water Only

Treated Vol:	5	LPCD, drinking water only
Untreated/Non-potable Vol:	82	LPCD
Household Size:	5	people
Water Purifier Recovery:	80%	percentage of input water that is drinkable
No. of HH:	822,050	households within target market

Description	**Units**	**Adoption % of Users with RO** 10%	15%	20%	25%	30%	35%	40%	45%	50%	55%
		Volumes - Demand per day (per HH) - HH Not Using RO									
Vol. Potable Consumed	L/hh/d	25.0	25.0	25.0	25.0	25.0	25.0	25.0	25.0	25.0	25.0
Vol. Non-potable Consumed	L/hh/d	410.0	410.0	410.0	410.0	410.0	410.0	410.0	410.0	410.0	410.0
Total Vol Consumed	L/hh/d	435.0	435.0	435.0	435.0	435.0	435.0	435.0	435.0	435.0	435.0
		Volumes - Demand per day (per HH) - HH That Are Using RO									
Vol. Potable Consumed	L/hh/d	25.0	25.0	25.0	25.0	25.0	25.0	25.0	25.0	25.0	25.0
Vol. Potable Wasted through RO Unit	L/hh/d	6.3	6.3	6.3	6.3	6.3	6.3	6.3	6.3	6.3	6.3
Vol. Non-potable Consumed	L/hh/d	410.0	410.0	410.0	410.0	410.0	410.0	410.0	410.0	410.0	410.0
Total Vol Consumed	L/hh/d	441.3	441.3	441.3	441.3	441.3	441.3	441.3	441.3	441.3	441.3
% Total Vol. Wasted	%	1.4%	1.4%	1.4%	1.4%	1.4%	1.4%	1.4%	1.4%	1.4%	1.4%
		Volumes - Demand per day (per HH) - TOTAL for SECA + SECB Mixed Users/Non-Users									
Vol. Potable Consumed, Not Including Wastage	KL/d	20551	20551	20551	20551	20551	20551	20551	20551	20551	20551
Vol. Potable Wasted through RO Unit	KL/d	514	771	1028	1284	1541	1798	2055	2312	2569	2826
Vol. Non-potable Consumed	KL/d	337040	337040	337040	337040	337040	337040	337040	337040	337040	337040
Total Vol Consumed	KL/d	358106	358362	358619	358876	359133	359390	359647	359904	360161	360418
% Total Vol. Wasted	%	0.1%	0.2%	0.3%	0.4%	0.4%	0.5%	0.6%	0.6%	0.7%	0.8%
		Volumes - per month (SECA+SECB Mixed Users/Non-Users)									
Vol. Potable Consumed	KL/mo	625101	625101	625101	625101	625101	625101	625101	625101	625101	625101
Vol. Potable Wasted through RO Unit	KL/mo	15628	23441	31255	39069	46883	54696	62510	70324	78138	85951
Vol. Non-potable Consumed	KL/mo	10251649	10251649	10251649	10251649	10251649	10251649	10251649	10251649	10251649	10251649
Total Vol Consumed	KL/mo	10892377	10900190	10908004	10915818	10923632	10931445	10939259	10947073	10954887	10962700
		Volumes - per year (SECA+SECB Mixed Users/Non-Users)									
Vol. Potable Consumed	KL/yr	7501206	4375704	4375704	4375704	4375704	4375704	4375704	4375704	4375704	4375704
Vol. Potable Wasted through RO Unit	KL/yr	187530	164089	218785	273481	328178	382874	437570	492267	546963	601659
Vol. Non-potable Consumed	KL/yr	123019782	71761540	71761540	71761540	71761540	71761540	71761540	71761540	71761540	71761540
Total Vol Consumed	KL/yr	130708518	76301332	76356028	76410725	76465421	76520117	76574814	76629510	76684206	76738902
		Opportunity Costs - No. HH that could not be served due to RO wastage									
Vol. Potable Wasted through RO Unit	L/d	513781	770672	1027562	1284453	1541344	1798234	2055125	2312016	2568906	2825797
No. HH that could have been served (P & N-P)	No. HH	1181	1772	2362	2953	3543	4134	4724	5315	5906	6496
No. HH that could have been served (P only)	No. HH	20551	30827	41102	51378	61654	71929	82205	92481	102756	113032

Table H-2f. City-Level Impacts From SECA + SECB Groups Using Water Purifiers, 80% Recovery Level, 5.0 LPCD, Drinking Water Only

Treated Vol:	5	LPCD, drinking water only
Untreated/Non-potable Vol:	82	LPCD
Household Size:	5	people
Water Purifier Recovery:	80%	percentage of input water that is drinkable
No. of HH:	822,050	households within target market

		Adoption % of Users with RO								
Description	**Units**	60%	65%	70%	75%	80%	85%	90%	95%	100%
		Volumes - Demand per day (per HH) - HH Not Using RO								
Vol. Potable Consumed	L/hh/d	25.0	25.0	25.0	25.0	25.0	25.0	25.0	25.0	25.0
Vol. Non-potable Consumed	L/hh/d	410.0	410.0	410.0	410.0	410.0	410.0	410.0	410.0	410.0
Total Vol Consumed	L/hh/d	435.0	435.0	435.0	435.0	435.0	435.0	435.0	435.0	435.0
		Volumes - Demand per day (per HH) - HH That Are Using RO								
Vol. Potable Consumed	L/hh/d	25.0	25.0	25.0	25.0	25.0	25.0	25.0	25.0	25.0
Vol. Potable Wasted through RO Unit	L/hh/d	6.3	6.3	6.3	6.3	6.3	6.3	6.3	6.3	6.3
Vol. Non-potable Consumed	L/hh/d	410.0	410.0	410.0	410.0	410.0	410.0	410.0	410.0	410.0
Total Vol Consumed	L/hh/d	441.3	441.3	441.3	441.3	441.3	441.3	441.3	441.3	441.3
% Total Vol. Wasted	%	1.4%	1.4%	1.4%	1.4%	1.4%	1.4%	1.4%	1.4%	1.4%
		Volumes - Demand per day (per HH) - TOTAL for SECA + SECB Mixed Users/Non-Users								
Vol. Potable Consumed, Not Including Wastage	KL/d	20551	20551	20551	20551	20551	20551	20551	20551	20551
Vol. Potable Wasted through RO Unit	KL/d	3083	3340	3596	3853	4110	4367	4624	4881	5138
Vol. Non-potable Consumed	KL/d	337040	337040	337040	337040	337040	337040	337040	337040	337040
Total Vol Consumed	KL/d	360674	360931	361188	361445	361702	361959	362216	362473	362730
% Total Vol. Wasted	%	0.9%	0.9%	1.0%	1.1%	1.1%	1.2%	1.3%	1.3%	1.4%
		Volumes - per month (SECA+SECB Mixed Users/Non-Users)								
Vol. Potable Consumed	KL/mo	625101	625101	625101	625101	625101	625101	625101	625101	625101
Vol. Potable Wasted through RO Unit	KL/mo	93765	101579	109393	117206	125020	132834	140648	148461	156275
Vol. Non-potable Consumed	KL/mo	10251649	10251649	10251649	10251649	10251649	10251649	10251649	10251649	10251649
Total Vol Consumed	KL/mo	10970514	10978328	10986142	10993955	11001769	11009583	11017397	11025210	11033024
		Volumes - per year (SECA+SECB Mixed Users/Non-Users)								
Vol. Potable Consumed	KL/yr	4375704	4375704	4375704	4375704	4375704	4375704	4375704	4375704	4375704
Vol. Potable Wasted through RO Unit	KL/yr	656356	711052	765748	820444	875141	929837	984533	1039230	1093926
Vol. Non-potable Consumed	KL/yr	71761540	71761540	71761540	71761540	71761540	71761540	71761540	71761540	71761540
Total Vol Consumed	KL/yr	76793599	76848295	76902991	76957688	77012384	77067080	77121777	77176473	77231169
		Opportunity Costs - No. HH that could not be served due to RO wastage								
Vol. Potable Wasted through RO Unit	L/d	3082687	3339578	3596469	3853359	4110250	4367141	4624031	4880922	5137812
No. HH that could have been served (P & N-P)	No. HH	7087	7677	8268	8858	9449	10039	10630	11221	11811
No. HH that could have been served (P only)	No. HH	123307	133583	143859	154134	164410	174686	184961	195237	205512

Table H-2g. City-Level Impacts From SECA + SECB Groups Using Water Purifiers, 90% Recovery Level, 5.0 LPCD, Drinking Water Only

Treated Vol:	5	LPCD, drinking water only
Untreated/Non-potable Vol:	82	LPCD
Household Size:	5	people
Water Purifier Recovery:	90%	percentage of input water that is drinkable
No. of HH:	822,050	households within target market

		Adoption % of Users with RO									
Description	**Units**	10%	15%	20%	25%	30%	35%	40%	45%	50%	55%
		Volumes - Demand per day (per HH) - HH Not Using RO									
Vol. Potable Consumed	L/hh/d	25.0	25.0	25.0	25.0	25.0	25.0	25.0	25.0	25.0	25.0
Vol. Non-potable Consumed	L/hh/d	410.0	410.0	410.0	410.0	410.0	410.0	410.0	410.0	410.0	410.0
Total Vol Consumed	L/hh/d	435.0	435.0	435.0	435.0	435.0	435.0	435.0	435.0	435.0	435.0
		Volumes - Demand per day (per HH) - HH That Are Using RO									
Vol. Potable Consumed	L/hh/d	25.0	25.0	25.0	25.0	25.0	25.0	25.0	25.0	25.0	25.0
Vol. Potable Wasted through RO Unit	L/hh/d	2.8	2.8	2.8	2.8	2.8	2.8	2.8	2.8	2.8	2.8
Vol. Non-potable Consumed	L/hh/d	410.0	410.0	410.0	410.0	410.0	410.0	410.0	410.0	410.0	410.0
Total Vol Consumed	L/hh/d	437.8	437.8	437.8	437.8	437.8	437.8	437.8	437.8	437.8	437.8
% Total Vol. Wasted	%	0.6%	0.6%	0.6%	0.6%	0.6%	0.6%	0.6%	0.6%	0.6%	0.6%
		Volumes - Demand per day (per HH) - TOTAL for SECA + SECB Mixed Users/Non-Users									
Vol. Potable Consumed, Not Including Wastage	KL/d	20551	20551	20551	20551	20551	20551	20551	20551	20551	20551
Vol. Potable Wasted through RO Unit	KL/d	228	343	457	571	685	799	913	1028	1142	1256
Vol. Non-potable Consumed	KL/d	337040	337040	337040	337040	337040	337040	337040	337040	337040	337040
Total Vol Consumed	KL/d	357820	357934	358048	358163	358277	358391	358505	358619	358733	358848
% Total Vol. Wasted	%	0.1%	0.1%	0.1%	0.2%	0.2%	0.2%	0.3%	0.3%	0.3%	0.3%
		Volumes - per month (SECA+SECB Mixed Users/Non-Users)									
Vol. Potable Consumed	KL/mo	625101	625101	625101	625101	625101	625101	625101	625101	625101	625101
Vol. Potable Wasted through RO Unit	KL/mo	6946	10418	13891	17364	20837	24309	27782	31255	34728	38201
Vol. Non-potable Consumed	KL/mo	10251649	10251649	10251649	10251649	10251649	10251649	10251649	10251649	10251649	10251649
Total Vol Consumed	KL/mo	10883695	10887167	10890640	10894113	10897586	10901058	10904531	10908004	10911477	10914950
		Volumes - per year (SECA+SECB Mixed Users/Non-Users)									
Vol. Potable Consumed	KL/yr	7501206	4375704	4375704	4375704	4375704	4375704	4375704	4375704	4375704	4375704
Vol. Potable Wasted through RO Unit	KL/yr	83347	72928	97238	121547	145857	170166	194476	218785	243095	267404
Vol. Non-potable Consumed	KL/yr	123019782	71761540	71761540	71761540	71761540	71761540	71761540	71761540	71761540	71761540
Total Vol Consumed	KL/yr	130604335	76210172	76234481	76258791	76283100	76307409	76331719	76356028	76380338	76404647
		Opportunity Costs - No. HH that could not be served due to RO wastage									
Vol. Potable Wasted through RO Unit	L/d	228347	342521	456694	570868	685042	799215	913389	1027562	1141736	1255910
No. HH that could have been served (P & N-P)	No. HH	525	787	1050	1312	1575	1837	2100	2362	2625	2887
No. HH that could have been served (P only)	No. HH	9134	13701	18268	22835	27402	31969	36536	41102	45669	50236

Table H-2g. City-Level Impacts From SECA + SECB Groups Using Water Purifiers, 90% Recovery Level, 5.0 LPCD, Drinking Water Only

Treated Vol:	5	LPCD, drinking water only
Untreated/Non-potable Vol:	82	LPCD
Household Size:	5	people
Water Purifier Recovery:	90%	percentage of input water that is drinkable
No. of HH:	822,050	households within target market

		Adoption % of Users with RO								
Description	**Units**	60%	65%	70%	75%	80%	85%	90%	95%	100%
		Volumes - Demand per day (per HH) - HH Not Using RO								
Vol. Potable Consumed	L/hh/d	25.0	25.0	25.0	25.0	25.0	25.0	25.0	25.0	25.0
Vol. Non-potable Consumed	L/hh/d	410.0	410.0	410.0	410.0	410.0	410.0	410.0	410.0	410.0
Total Vol Consumed	L/hh/d	435.0	435.0	435.0	435.0	435.0	435.0	435.0	435.0	435.0
		Volumes - Demand per day (per HH) - HH That Are Using RO								
Vol. Potable Consumed	L/hh/d	25.0	25.0	25.0	25.0	25.0	25.0	25.0	25.0	25.0
Vol. Potable Wasted through RO Unit	L/hh/d	2.8	2.8	2.8	2.8	2.8	2.8	2.8	2.8	2.8
Vol. Non-potable Consumed	L/hh/d	410.0	410.0	410.0	410.0	410.0	410.0	410.0	410.0	410.0
Total Vol Consumed	L/hh/d	437.8	437.8	437.8	437.8	437.8	437.8	437.8	437.8	437.8
% Total Vol. Wasted	%	0.6%	0.6%	0.6%	0.6%	0.6%	0.6%	0.6%	0.6%	0.6%
		Volumes - Demand per day (per HH) - TOTAL for SECA + SECB Mixed Users/Non-Users								
Vol. Potable Consumed, Not Including Wastage	KL/d	20551	20551	20551	20551	20551	20551	20551	20551	20551
Vol. Potable Wasted through RO Unit	KL/d	1370	1484	1598	1713	1827	1941	2055	2169	2283
Vol. Non-potable Consumed	KL/d	337040	337040	337040	337040	337040	337040	337040	337040	337040
Total Vol Consumed	KL/d	358962	359076	359190	359304	359419	359533	359647	359761	359875
% Total Vol. Wasted	%	0.4%	0.4%	0.4%	0.5%	0.5%	0.5%	0.6%	0.6%	0.6%
		Volumes - per month (SECA+SECB Mixed Users/Non-Users)								
Vol. Potable Consumed	KL/mo	625101	625101	625101	625101	625101	625101	625101	625101	625101
Vol. Potable Wasted through RO Unit	KL/mo	41673	45146	48619	52092	55564	59037	62510	65983	69456
Vol. Non-potable Consumed	KL/mo	10251649	10251649	10251649	10251649	10251649	10251649	10251649	10251649	10251649
Total Vol Consumed	KL/mo	10918422	10921895	10925368	10928841	10932314	10935786	10939259	10942732	10946205
		Volumes - per year (SECA+SECB Mixed Users/Non-Users)								
Vol. Potable Consumed	KL/yr	4375704	4375704	4375704	4375704	4375704	4375704	4375704	4375704	4375704
Vol. Potable Wasted through RO Unit	KL/yr	291714	316023	340333	364642	388951	413261	437570	461880	486189
Vol. Non-potable Consumed	KL/yr	71761540	71761540	71761540	71761540	71761540	71761540	71761540	71761540	71761540
Total Vol Consumed	KL/yr	76428957	76453266	76477576	76501885	76526195	76550504	76574814	76599123	76623432
		Opportunity Costs - No. HH that could not be served due to RO wastage								
Vol. Potable Wasted through RO Unit	L/d	1370083	1484257	1598431	1712604	1826778	1940951	2055125	2169299	2283472
No. HH that could have been served (P & N-P)	No. HH	3150	3412	3675	3937	4199	4462	4724	4987	5249
No. HH that could have been served (P only)	No. HH	54803	59370	63937	68504	73071	77638	82205	86772	91339

I. Calculated Wastage Volumes for Delhi, assuming 7.0 LPCD, Combined Drinking and Cooking Water, is Treated

Table I-1. Summary of Wasted Water Volumes and Equivalent Households That Could Have Been Served by the Wasted Volume; 7.0 LPCD Treated; Households With 5 People/Each, Delhi

Description	Units	Adoption % of Users with RO [7.0 LPCD treated; Drinking & Cooking Water]								
		20%	30%	40%	50%	60%	70%	80%	90%	100%
		Assuming an Average 20% Recovery								
Vol. Pot. Wasted through RO	KL/d	23017	34526	46035	57543	69052	80561	92070	103578	115087
	KL/mo	700113	1050169	1400225	1750281	2100338	2450394	2800450	3150507	3500563
	KL/yr	4900788	7351182	9801576	12251970	14702364	17152758	19603152	22053546	24503940
% Total Vol. Wasted	%	6.0%	8.8%	11.4%	13.9%	16.2%	18.4%	20.5%	22.5%	24.3%
Equiv. HH (P + N-P)	No. HH	52914	79370	105827	132284	158741	185197	211654	238111	264568
Equiv. HH (P only)	No. HH	657640	986460	1315280	1644100	1972920	2301740	2630560	2959380	3288200
		Assuming an Average 30% Recovery								
Vol. Pot. Wasted through RO	KL/d	13427	20140	26854	33567	40280	46994	53707	60421	67134
	KL/mo	408399	612599	816798	1020998	1225197	1429397	1633596	1837796	2041995
	KL/yr	2858793	4288190	5717586	7146983	8576379	10005776	11435172	12864569	14293965
% Total Vol. Wasted	%	3.6%	5.3%	7.0%	8.6%	10.1%	11.6%	13.1%	14.5%	15.8%
Equiv. HH (P + N-P)	No. HH	30866	46299	61732	77166	92599	108032	123465	138898	154331
Equiv. HH (P only)	No. HH	383623	575435	767247	959058	1150870	1342682	1534493	1726305	1918117
		Assuming an Average 40% Recovery								
Vol. Pot. Wasted through RO	KL/d	8632	12947	17263	21579	25895	30210	34526	38842	43158
	KL/mo	262542	393813	525084	656356	787627	918898	1050169	1181440	1312711
	KL/yr	1837796	2756693	3675591	4594489	5513387	6432284	7351182	8270080	9188978
% Total Vol. Wasted	%	2.4%	3.5%	4.6%	5.7%	6.8%	7.8%	8.8%	9.8%	10.8%
Equiv. HH (P + N-P)	No. HH	19843	29764	39685	49606	59528	69449	79370	89292	99213
Equiv. HH (P only)	No. HH	246615	369922	493230	616537	739845	863152	986460	1109767	1233075
		Assuming an Average 50% Recovery								
Vol. Pot. Wasted through RO	KL/d	5754	8632	11509	14386	17263	20140	23017	25895	28772
	KL/mo	175028	262542	350056	437570	525084	612599	700113	787627	875141
	KL/yr	1225197	1837796	2450394	3062993	3675591	4288190	4900788	5513387	6125985
% Total Vol. Wasted	%	1.6%	2.4%	3.1%	3.9%	4.6%	5.3%	6.0%	6.8%	7.4%
Equiv. HH (P + N-P)	No. HH	13228	19843	26457	33071	39685	46299	52914	59528	66142
Equiv. HH (P only)	No. HH	164410	246615	328820	411025	493230	575435	657640	739845	822050
		Assuming an Average 70% Recovery								
Vol. Pot. Wasted through RO	KL/d	2466	3699	4932	6165	7398	8632	9865	11098	12331
	KL/mo	75012	112518	150024	187530	225036	262542	300048	337554	375060
	KL/yr	525084	787627	1050169	1312711	1575253	1837796	2100338	2362880	2625422
% Total Vol. Wasted	%	0.7%	1.0%	1.4%	1.7%	2.0%	2.4%	2.7%	3.0%	3.3%
Equiv. HH (P + N-P)	No. HH	5669	8504	11339	14173	17008	19843	22677	25512	28347
Equiv. HH (P only)	No. HH	70461	105692	140923	176154	211384	246615	281846	317076	352307
		Assuming an Average 80% Recovery								
Vol. Pot. Wasted through RO	KL/d	1439	2158	2877	3596	4316	5035	5754	6474	7193
	KL/mo	43757	65636	87514	109393	131271	153150	175028	196907	218785
	KL/yr	306299	459449	612599	765748	918898	1072047	1225197	1378347	1531496
% Total Vol. Wasted	%	0.4%	0.6%	0.8%	1.0%	1.2%	1.4%	1.6%	1.8%	2.0%
Equiv. HH (P + N-P)	No. HH	3307	4961	6614	8268	9921	11575	13228	14882	16535
Equiv. HH (P only)	No. HH	41102	61654	82205	102756	123307	143859	164410	184961	205512
		Assuming an Average 90% Recovery								
Vol. Pot. Wasted through RO	KL/d	639	959	1279	1598	1918	2238	2557	2877	3197
	KL/mo	19448	29171	38895	48619	58343	68067	77790	87514	97238
	KL/yr	136133	204200	272266	340333	408399	476466	544532	612599	680665
% Total Vol. Wasted	%	0.2%	0.3%	0.4%	0.4%	0.5%	0.6%	0.7%	0.8%	0.9%
Equiv. HH (P + N-P)	No. HH	1470	2205	2940	3675	4409	5144	5879	6614	7349
Equiv. HH (P only)	No. HH	18268	27402	36536	45669	54803	63937	73071	82205	91339

J. Specifications for Example Reverse Osmosis Water Purifiers

Table J-1. Example Product Specifications, RO-Based Units

Product Specifications	Aquaguard Enhance Green RO	Aquaguard Enhance RO + UV	Aquaguard Reviva RO + UV + TDS Controller	Kent Grand+
Price	INR 13,999	INR 17,999	INR 14,990	INR 19,000
Purifying Technology	Reverse Osmosis (RO)	Reverse Osmosis (RO) & Ultra Violet (UV)	Reverse Osmosis (RO) & Ultra Violet (UV)	Reverse Osmosis (RO) & Ultra Violet (UV) & Ultrafiltration (UF) with TDS Controller
Recommended for	Water sourced from borewells, with high TDS giving it a salty/khara/brackish taste.	Water from many sources – municipal, borewells, tankers.	Water from many sources – municipal, borewells, tankers.	Water from all sources such as borewells, tanks or tap-water
Filtration / Purification Modules	i-Filter, Chemi Block, EMLE, RO Membrane, Taste Enhancer Cartridge	I-Filter, Chemi block, EMLE, Reverse Osmosis Membrane, Ultra Violet, Taste Enhancer Cartridge, TDS Regulator	I-Filter, Chemi block, EMLE, Reverse Osmosis Membrane, Ultra Violet, Taste Enhancer Cartridge, TDS Regulator	Sediment Activated Carbon, UF, Post Carbon
Installation Type	Table Top, Wall Mounting	Table Top, Wall Mounting	Table Top and Wall Mounting	Wall mounting
Purified Water Flow Rate	15 litre/hour	15 litre/hour	15 liters/hour	15 liters/hour
Storage Tank	7 Litres	7 Litres	8 Liters	8 Liters
% Water Recovery	40% (approx)	25% (approx)	25% (approx)	20% (Standard RO)*
Dimensions (W X D X H) in mm	316 x 251 x 462	316 x 251 x 462	320 X 275 X 410	260 x 410 x 520
Net weight	8.2 Kg	8.2 Kg	9.0 Kg	9.40 kgs
Operating/Input Voltage	230 V AC/50 Hz	230 V AC/50HZ	230 V AC/50HZ	24V DC / 100-300V AC (50 Hz)
Power Rating/Consumption	35 Watts	40 Watts	45 Watts	60 Watts
Ultraviolet Lamp	NA	11 Watts	4 Watts	11 Watts
RO Membrane	75 GPD	75 GPD	75 GPD	75 GPD
Certifications	Certified by more than 135 national and international leading labs	Certified by more than 135 national and international leading labs	Certified by more than 135 national and international leading labs	NSF & WQA Gold Seal Certified & CE Certified

Notes:
* % Water Recovery not provided on individual Kent RO product specifications page. Assumed recovery was represented by the reference to the standard RO from 24 June 2015 blog post "Reducing Water Wastage in RO Purifiers".

Table J-1. Example Product Specifications, RO-Based Units

Product Specifications	Kent Pearl	Kent Supreme	ZeroB Wave	ZeroB eco RO
Price	INR 19,500	INR 20,000	INR 15,295	INR 21,490
Purifying Technology	Reverse Osmosis (RO) & Ultra Violet (UV) & Ultrafiltration (UF) with TDS Controller	Reverse Osmosis (RO) & Ultra Violet (UV) & Ultrafiltration (UF) with TDS Controller	Reverse Osmosis (RO)	Reverse Osmosis (RO)
Recommended for	Water from all sources such as borewells, tanks or tap-water	Water from all sources such as borewells, tanks or tap-water	No distinction, though hardness < 500 ppm, Max TDS 1300 ppm	No distinction, though hardness < 500 ppm, Max TDS 1300 ppm
Filtration / Purification Modules	Sediment Activated Carbon, UF, Post Carbon	Sediment Activated Carbon, UF, Post Carbon	Filter bag, bacteriostatic activated carbon pre-filter, sediment cartridge, bacteriostatic activated carbon post-filter,	Integrated filter bag, bacteriostatic silver impregnated activated carbon filter, E-SAN Block filter, Electrolytic Silver Impregnated Carbon
Installation Type	Table Top and Wall Mounting	Wall mounting	Counter top	Wall mounting
Purified Water Flow Rate	15 liters/hour	15 liters/hour	5-7 liters/hour	10 liters/hour
Storage Tank	8 Liters	9 Liters - purified water; 9 Liters - rejected water	7 Liters	6 Liters
% Water Recovery	20% (Standard RO)*	50%	25-30% (at 750 ppm TDS)	60-70% (at 750 ppm TDS)
Dimensions (W X D X H) in mm	330 x 405 x 470	270 x 430 x 630	320 x 330 x 400	230 x 275 x 370
Net weight	10.80 kgs	10.90 kgs	11.0 kgs	12.0 kgs
Operating/Input Voltage	24V DC / 100-300V AC (50 Hz)	24V DC / 100-300V AC (50 Hz)	230 +/- 10% V AC (50 Hz)	230 +/- 20% V AC (50 Hz)
Power Rating/Consumption	60 Watts	60 Watts	24 Watts	30 Watts
Ultraviolet Lamp	11 Watts	11 Watts	NA	NA
RO Membrane	75 GPD	75 GPD	50 GPD	80 GPD
Certifications	NSF & WQA Gold Seal Certified & CE Certified	NSF & WQA Gold Seal Certified & CE Certified	Product meets USEPA Drinking water standards and IS 10500	Product meets USEPA Drinking water standards and IS 10500

Notes:
* % Water Recovery not provided on individual Kent RO product specifications page. Assumed recovery was represented by the reference to the standard RO from 24 June 2015 blog post "Reducing Water Wastage in RO Purifiers".

Table J-1. Example Product Specifications, RO-Based Units

Product Specifications	Tata Swach Ultima Silver RO+UV	Tata Swach Platina Silver RO	Tata Swach Nova Silver RO	Whirlpool Minerala 90 Platinum
Price	INR 18,999	INR 14,999	INR 10,999	INR 17,500
Purifying Technology	Reverse Osmosis (RO) & Ultra Violet (UV)	Reverse Osmosis (RO)	Reverse Osmosis (RO)	Reverse Osmosis (RO)
Recommended for	Suitable for purification of tap water upto 2000ppm TDS and hardness below 500ppm	Suitable for purification of tap water upto 2000ppm TDS and hardness below 500ppm	Suitable for purification of tap water upto 2000ppm TDS and hardness below 500ppm	Works up to TDS levels of 2500 ppm
Filtration / Purification Modules	Sediment filter cartidges (coarse and fine), bacteriostatic silver impregnated activated carbon pre- and post-filters	Sediment filter cartidges (coarse and fine), bacteriostatic silver impregnated activated carbon pre- and post-filters	Sediment filter cartidges (coarse), bacteriostatic silver impregnated activated carbon pre- and post-filters	Pre-filter, sediment filter, pre-carbon filter, MES filter which adds minerals after filtration
Installation Type	Wall mounting	Wall mounting	Wall mounting	Wall mounting
Purified Water Flow Rate	15 Liters/hour	12 Liters/hour	8 Liters/hour	13.5 Liters/hour
Storage Tank	7 Liters	7 Liters	4 Liters	8.5 Liters
% Water Recovery	-	-	-	25%
Dimensions (W X D X H) in mm	420 x 168 x 537	420 x 168 x 537	392 x 240 x 440	534 x 276 x 412
Net weight	11.5 Kgs	10.05 Kgs	10.5 kgs	10.0 kgs
Operating/Input Voltage	160-270 V AC	160-270 V AC	160-270 V AC	160-260 V AC
Power Rating/Consumption	-	-	-	36 Watts
Ultraviolet Lamp	11 Watts	NA	NA	NA
RO Membrane	-	-	50 GPD	75 GPD
Certifications	NSF International Listed RO Membrane	NSF International Listed RO Membrane	NSF International Listed RO Membrane	Filters compliant to NSF 42 & NSF 58 Standards; Made in USA

Notes:
* % Water Recovery not provided on individual Kent RO product specifications page. Assumed recovery was represented by the reference to the standard RO from 24 June 2015 blog post "Reducing Water Wastage in RO Purifiers".

Source: (Eureka Forbes, n.d.-b; Kent RO Systems Ltd., n.d.-b; Tata Chemicals Ltd., n.d.; Whirlpool of India Limited, n.d.; Zero B, n.d.)

K. Calculated Wastage Volumes for Bangalore, Ahmedabad and Mumbai, assuming 5.0 LPCD, Drinking Water Only, is Treated

Table K-1. Summary of Wasted Water Volumes and Equivalent Households That Could Have Been Served by the Wasted Volume; 5.0 LPCD Treated; Households With 5 People/Each, Bangalore

Description	Units	Adoption % of Users with RO [5.0 LPCD treated; Drinking water only]									
		10%	20%	30%	40%	50%	60%	70%	80%	90%	100%
		Assuming an Average 20% Recovery									
Vol. Pot. Wasted through RO	KL/d	6292	12585	18877	25170	31462	37754	44047	50339	56632	62924
	KL/mo	191394	382788	574181	765575	956969	1148363	1339757	1531150	1722544	1913938
	KL/yr	2296726	2679513	4019270	5359026	6698783	8038539	9378296	10718052	12057809	13397565
% Total Vol. Wasted	%	2.2%	4.4%	6.5%	8.4%	10.3%	12.1%	13.9%	15.5%	17.1%	18.7%
Equiv. HH (P + N-P)	No. HH	14465	28931	43396	57861	72326	86792	101257	115722	130188	144653
Equiv. HH (P only)	No. HH	251696	503392	755088	1006784	1258480	1510176	1761872	2013568	2265264	2516959
		Assuming an Average 30% Recovery									
Vol. Pot. Wasted through RO	KL/d	3671	7341	11012	14682	18353	22023	25694	29365	33035	36706
	KL/mo	111646	223293	334939	446586	558232	669878	781525	893171	1004817	1116464
	KL/yr	1339757	1563049	2344574	3126099	3907623	4689148	5470673	6252197	7033722	7815247
% Total Vol. Wasted	%	1.3%	2.6%	3.9%	5.1%	6.3%	7.4%	8.6%	9.7%	10.8%	11.8%
Equiv. HH (P + N-P)	No. HH	8438	16876	25314	33752	42190	50628	59067	67505	75943	84381
Equiv. HH (P only)	No. HH	146823	293645	440468	587291	734113	880936	1027758	1174581	1321404	1468226
		Assuming an Average 40% Recovery									
Vol. Pot. Wasted through RO	KL/d	2360	4719	7079	9439	11798	14158	16518	18877	21237	23596
	KL/mo	71773	143545	215318	287091	358863	430636	502409	574181	645954	717727
	KL/yr	861272	1004817	1507226	2009635	2512044	3014452	3516861	4019270	4521678	5024087
% Total Vol. Wasted	%	0.9%	1.7%	2.5%	3.3%	4.1%	4.9%	5.7%	6.5%	7.2%	7.9%
Equiv. HH (P + N-P)	No. HH	5424	10849	16273	21698	27122	32547	37971	43396	48820	54245
Equiv. HH (P only)	No. HH	94386	188772	283158	377544	471930	566316	660702	755088	849474	943860
		Assuming an Average 50% Recovery									
Vol. Pot. Wasted through RO	KL/d	1573	3146	4719	6292	7865	9439	11012	12585	14158	15731
	KL/mo	47848	95697	143545	191394	239242	287091	334939	382788	430636	478484
	KL/yr	574181	669878	1004817	1339757	1674696	2009635	2344574	2679513	3014452	3349391
% Total Vol. Wasted	%	0.6%	1.1%	1.7%	2.2%	2.8%	3.3%	3.9%	4.4%	4.9%	5.4%
Equiv. HH (P + N-P)	No. HH	3616	7233	10849	14465	18082	21698	25314	28931	32547	36163
Equiv. HH (P only)	No. HH	62924	125848	188772	251696	314620	377544	440468	503392	566316	629240
		Assuming an Average 70% Recovery									
Vol. Pot. Wasted through RO	KL/d	674	1348	2023	2697	3371	4045	4719	5393	6068	6742
	KL/mo	20506	41013	61519	82026	102532	123039	143545	164052	184558	205065
	KL/yr	246078	287091	430636	574181	717727	861272	1004817	1148363	1291908	1435453
% Total Vol. Wasted	%	0.2%	0.5%	0.7%	1.0%	1.2%	1.5%	1.7%	1.9%	2.2%	2.4%
Equiv. HH (P + N-P)	No. HH	1550	3100	4650	6199	7749	9299	10849	12399	13949	15499
Equiv. HH (P only)	No. HH	26967	53935	80902	107870	134837	161805	188772	215739	242707	269674
		Assuming an Average 80% Recovery									
Vol. Pot. Wasted through RO	KL/d	393	787	1180	1573	1966	2360	2753	3146	3539	3933
	KL/mo	11962	23924	35886	47848	59811	71773	83735	95697	107659	119621
	KL/yr	143545	167470	251204	334939	418674	502409	586143	669878	753613	837348
% Total Vol. Wasted	%	0.1%	0.3%	0.4%	0.6%	0.7%	0.9%	1.0%	1.1%	1.3%	1.4%
Equiv. HH (P + N-P)	No. HH	904	1808	2712	3616	4520	5424	6329	7233	8137	9041
Equiv. HH (P only)	No. HH	15731	31462	47193	62924	78655	94386	110117	125848	141579	157310
		Assuming an Average 90% Recovery									
Vol. Pot. Wasted through RO	KL/d	175	350	524	699	874	1049	1223.52	1398	1573	1748
	KL/mo	5316	10633	15949	21266	26582	31899	37215	42532	47848	53165
	KL/yr	63798	74431	111646	148862	186077	223293	260508	297724	334939	372155
% Total Vol. Wasted	%	0.1%	0.1%	0.2%	0.3%	0.3%	0.4%	0.4%	0.5%	0.6%	0.6%
Equiv. HH (P + N-P)	No. HH	402	804	1205	1607	2009	2411	2813	3215	3616	4018
Equiv. HH (P only)	No. HH	6992	13983	20975	27966	34958	41949	48941	55932	62924	69916

Table K-2. Summary of Wasted Water Volumes and Equivalent Households That Could Have Been Served by the Wasted Volume; 5.0 LPCD Treated; Households With 5 People/Each, Ahmedabad

Description	Units	Adoption % of Users with RO [5.0 LPCD treated; Drinking water only]									
		10%	20%	30%	40%	50%	60%	70%	80%	90%	100%
		Assuming an Average 20% Recovery									
Vol. Pot. Wasted through RO	KL/d	4160	8320	12480	16640	20800	24960	29120	33280	37440	41600
	KL/mo	126534	253069	379603	506138	632672	759207	885741	1012276	1138810	1265344
	KL/yr	1518413	1771482	2657223	3542964	4428705	5314446	6200188	7085929	7971670	8857411
% Total Vol. Wasted	%	2.2%	4.4%	6.5%	8.4%	10.3%	12.1%	13.9%	15.5%	17.1%	18.7%
Equiv. HH (P + N-P)	No. HH	9563	19127	28690	38253	47817	57380	66943	76506	86070	95633
Equiv. HH (P only)	No. HH	166401	332803	499204	665606	832007	998409	1164810	1331212	1497613	1664015
		Assuming an Average 30% Recovery									
Vol. Pot. Wasted through RO	KL/d	2427	4853	7280	9707	12133	14560	16987	19414	21840	24267
	KL/mo	73812	147624	221435	295247	369059	442871	516682	590494	664306	738118
	KL/yr	885741	1033365	1550047	2066729	2583411	3100094	3616776	4133458	4650141	5166823
% Total Vol. Wasted	%	1.3%	2.6%	3.9%	5.1%	6.3%	7.4%	8.6%	9.7%	10.8%	11.8%
Equiv. HH (P + N-P)	No. HH	5579	11157	16736	22314	27893	33472	39050	44629	50207	55786
Equiv. HH (P only)	No. HH	97068	194135	291203	388270	485338	582405	679473	776540	873608	970675
		Assuming an Average 40% Recovery									
Vol. Pot. Wasted through RO	KL/d	1560	3120	4680	6240	7800	9360	10920	12480	14040	15600
	KL/mo	47450	94901	142351	189802	237252	284702	332153	379603	427054	474504
	KL/yr	569405	664306	996459	1328612	1660765	1992917	2325070	2657223	2989376	3321529
% Total Vol. Wasted	%	0.9%	1.7%	2.5%	3.3%	4.1%	4.9%	5.7%	6.5%	7.2%	7.9%
Equiv. HH (P + N-P)	No. HH	3586	7172	10759	14345	17931	21517	25104	28690	32276	35862
Equiv. HH (P only)	No. HH	62401	124801	187202	249602	312003	374403	436804	499204	561605	624005
		Assuming an Average 50% Recovery									
Vol. Pot. Wasted through RO	KL/d	1040	2080	3120	4160	5200	6240	7280	8320	9360	10400
	KL/mo	31634	63267	94901	126534	158168	189802	221435	253069	284702	316336
	KL/yr	379603	442871	664306	885741	1107176	1328612	1550047	1771482	1992917	2214353
% Total Vol. Wasted	%	0.6%	1.1%	1.7%	2.2%	2.8%	3.3%	3.9%	4.4%	4.9%	5.4%
Equiv. HH (P + N-P)	No. HH	2391	4782	7172	9563	11954	14345	16736	19127	21517	23908
Equiv. HH (P only)	No. HH	41600	83201	124801	166401	208002	249602	291203	332803	374403	416004
		Assuming an Average 70% Recovery									
Vol. Pot. Wasted through RO	KL/d	446	891	1337	1783	2229	2674	3120	3566	4011	4457
	KL/mo	13557	27115	40672	54229	67786	81344	94901	108458	122015	135573
	KL/yr	162687	189802	284702	379603	474504	569405	664306	759207	854107	949008
% Total Vol. Wasted	%	0.2%	0.5%	0.7%	1.0%	1.2%	1.5%	1.7%	1.9%	2.2%	2.4%
Equiv. HH (P + N-P)	No. HH	1025	2049	3074	4099	5123	6148	7172	8197	9222	10246
Equiv. HH (P only)	No. HH	17829	35657	53486	71315	89144	106972	124801	142630	160459	178287
		Assuming an Average 80% Recovery									
Vol. Pot. Wasted through RO	KL/d	260	520	780	1040	1300	1560	1820	2080	2340	2600
	KL/mo	7908	15817	23725	31634	39542	47450	55359	63267	71176	79084
	KL/yr	94901	110718	166076	221435	276794	332153	387512	442871	498229	553588
% Total Vol. Wasted	%	0.1%	0.3%	0.4%	0.6%	0.7%	0.9%	1.0%	1.1%	1.3%	1.4%
Equiv. HH (P + N-P)	No. HH	598	1195	1793	2391	2989	3586	4184	4782	5379	5977
Equiv. HH (P only)	No. HH	10400	20800	31200	41600	52000	62401	72801	83201	93601	104001
		Assuming an Average 90% Recovery									
Vol. Pot. Wasted through RO	KL/d	116	231	347	462	578	693	808.90	924	1040	1156
	KL/mo	3515	7030	10545	14059	17574	21089	24604	28119	31634	35148
	KL/yr	42178	49208	73812	98416	123020	147624	172227	196831	221435	246039
% Total Vol. Wasted	%	0.1%	0.1%	0.2%	0.3%	0.3%	0.4%	0.4%	0.5%	0.6%	0.6%
Equiv. HH (P + N-P)	No. HH	266	531	797	1063	1328	1594	1860	2125	2391	2656
Equiv. HH (P only)	No. HH	4622	9245	13867	18489	23111	27734	32356	36978	41600	46223

Table K-3. Summary of Wasted Water Volumes and Equivalent Households That Could Have Been Served by the Wasted Volume; 5.0 LPCD Treated; Households With 5 People/Each, Mumbai

Description	Units	Adoption % of Users with RO [5.0 LPCD treated; Drinking water only]									
		10%	20%	30%	40%	50%	60%	70%	80%	90%	100%
		Assuming an Average 20% Recovery									
Vol. Pot. Wasted through RO	KL/d	9319	18637	27956	37275	46594	55912	65231	74550	83869	93187
	KL/mo	283445	566890	850334	1133779	1417224	1700669	1984114	2267558	2551003	2834448
	KL/yr	3401337	3968227	5952341	7936454	9920568	11904681	13888795	15872908	17857022	19841135
% Total Vol. Wasted	%	2.2%	4.4%	6.5%	8.4%	10.3%	12.1%	13.9%	15.5%	17.1%	18.7%
Equiv. HH (P + N-P)	No. HH	21422	42845	64267	85689	107112	128534	149957	171379	192801	214224
Equiv. HH (P only)	No. HH	372749	745499	1118248	1490997	1863747	2236496	2609245	2981995	3354744	3727493
		Assuming an Average 30% Recovery									
Vol. Pot. Wasted through RO	KL/d	5436	10872	16308	21744	27180	32616	38051	43487	48923	54359
	KL/mo	165343	330686	496028	661371	826714	992057	1157400	1322742	1488085	1653428
	KL/yr	1984114	2314799	3472199	4629598	5786998	6944397	8101797	9259196	10416596	11573996
% Total Vol. Wasted	%	1.3%	2.6%	3.9%	5.1%	6.3%	7.4%	8.6%	9.7%	10.8%	11.8%
Equiv. HH (P + N-P)	No. HH	12496	24993	37489	49986	62482	74978	87475	99971	112467	124964
Equiv. HH (P only)	No. HH	217437	434874	652311	869748	1087185	1304623	1522060	1739497	1956934	2174371
		Assuming an Average 40% Recovery									
Vol. Pot. Wasted through RO	KL/d	3495	6989	10484	13978	17473	20967	24462	27956	31451	34945
	KL/mo	106292	212584	318875	425167	531459	637751	744043	850334	956626	1062918
	KL/yr	1275502	1488085	2232128	2976170	3720213	4464255	5208298	5952341	6696383	7440426
% Total Vol. Wasted	%	0.9%	1.7%	2.5%	3.3%	4.1%	4.9%	5.7%	6.5%	7.2%	7.9%
Equiv. HH (P + N-P)	No. HH	8033	16067	24100	32134	40167	48200	56234	64267	72301	80334
Equiv. HH (P only)	No. HH	139781	279562	419343	559124	698905	838686	978467	1118248	1258029	1397810
		Assuming an Average 50% Recovery									
Vol. Pot. Wasted through RO	KL/d	2330	4659	6989	9319	11648	13978	16308	18637	20967	23297
	KL/mo	70861	141722	212584	283445	354306	425167	496028	566890	637751	708612
	KL/yr	850334	992057	1488085	1984114	2480142	2976170	3472199	3968227	4464255	4960284
% Total Vol. Wasted	%	0.6%	1.1%	1.7%	2.2%	2.8%	3.3%	3.9%	4.4%	4.9%	5.4%
Equiv. HH (P + N-P)	No. HH	5356	10711	16067	21422	26778	32134	37489	42845	48200	53556
Equiv. HH (P only)	No. HH	93187	186375	279562	372749	465937	559124	652311	745499	838686	931873
		Assuming an Average 70% Recovery									
Vol. Pot. Wasted through RO	KL/d	998	1997	2995	3994	4992	5991	6989	7987	8986	9984
	KL/mo	30369	60738	91107	121476	151845	182215	212584	242953	273322	303691
	KL/yr	364429	425167	637751	850334	1062918	1275502	1488085	1700669	1913252	2125836
% Total Vol. Wasted	%	0.2%	0.5%	0.7%	1.0%	1.2%	1.5%	1.7%	1.9%	2.2%	2.4%
Equiv. HH (P + N-P)	No. HH	2295	4591	6886	9181	11476	13772	16067	18362	20657	22953
Equiv. HH (P only)	No. HH	39937	79875	119812	159750	199687	239625	279562	319499	359437	399374
		Assuming an Average 80% Recovery									
Vol. Pot. Wasted through RO	KL/d	582	1165	1747	2330	2912	3495	4077	4659	5242	5824
	KL/mo	17715	35431	53146	70861	88576	106292	124007	141722	159438	177153
	KL/yr	212584	248014	372021	496028	620035	744043	868050	992057	1116064	1240071
% Total Vol. Wasted	%	0.1%	0.3%	0.4%	0.6%	0.7%	0.9%	1.0%	1.1%	1.3%	1.4%
Equiv. HH (P + N-P)	No. HH	1339	2678	4017	5356	6694	8033	9372	10711	12050	13389
Equiv. HH (P only)	No. HH	23297	46594	69890	93187	116484	139781	163078	186375	209671	232968
		Assuming an Average 90% Recovery									
Vol. Pot. Wasted through RO	KL/d	259	518	777	1035	1294	1553	1811.98	2071	2330	2589
	KL/mo	7873	15747	23620	31494	39367	47241	55114	62988	70861	78735
	KL/yr	94482	110229	165343	220457	275571	330686	385800	440914	496028	551143
% Total Vol. Wasted	%	0.1%	0.1%	0.2%	0.3%	0.3%	0.4%	0.4%	0.5%	0.6%	0.6%
Equiv. HH (P + N-P)	No. HH	595	1190	1785	2380	2975	3570	4165	4761	5356	5951
Equiv. HH (P only)	No. HH	10354	20708	31062	41417	51771	62125	72479	82833	93187	103541

L. Calculated Wastage Volumes for Urban India

Table L-1. Summary of Wasted Water Volumes and Equivalent Households That Could Have Been Served by the Wasted Volume; 5.0 LPCD Treated; Households With 5 People/Each, Urban India (SECA and SECB households)

Description	Units	Adoption % of Users with RO [5.0 LPCD treated; Drinking water only]									
		10%	20%	30%	40%	50%	60%	70%	80%	90%	100%
		Assuming an Average 20% Recovery									
Vol. Pot. Wasted through RO	KL/d	167153	334305	501458	668611	835764	1002916	1170069	1337222	1504375	1671527
	KL/mo	5084229	10168459	15252688	20336917	25421147	30505376	35589605	40673835	45758064	50842293
	KL/yr	61010752	71179211	106768816	142358421	177948027	213537632	249127238	284716843	320306448	355896054
% Total Vol. Wasted	%	2.2%	4.4%	6.5%	8.4%	10.3%	12.1%	13.9%	15.5%	17.1%	18.7%
Equiv. HH (P + N-P)	No. HH	384259	768518	1152778	1537037	1921296	2305555	2689814	3074073	3458333	3842592
Equiv. HH (P only)	No. HH	6686110	13372220	20058329	26744439	33430549	40116659	46802769	53488879	60174988	66861098
		Assuming an Average 30% Recovery									
Vol. Pot. Wasted through RO	KL/d	97506	195012	292517	390023	487529	585035	682540	780046	877552	975058
	KL/mo	2965800	5931601	8897401	11863202	14829002	17794803	20760603	23726404	26692204	29658004
	KL/yr	35589605	41521206	62281809	83042413	103803016	124563619	145324222	166084825	186845428	207606031
% Total Vol. Wasted	%	1.3%	2.6%	3.9%	5.1%	6.3%	7.4%	8.6%	9.7%	10.8%	11.8%
Equiv. HH (P + N-P)	No. HH	224151	448302	672454	896605	1120756	1344907	1569058	1793210	2017361	2241512
Equiv. HH (P only)	No. HH	3900231	7800461	11700692	15600923	19501154	23401384	27301615	31201846	35102077	39002307
		Assuming an Average 40% Recovery									
Vol. Pot. Wasted through RO	KL/d	62682	125365	188047	250729	313411	376094	438776	501458	564141	626823
	KL/mo	1906586	3813172	5719758	7626344	9532930	11439516	13346102	15252688	17159274	19065860
	KL/yr	22879032	26692204	40038306	53384408	66730510	80076612	93422714	106768816	120114918	133461020
% Total Vol. Wasted	%	0.9%	1.7%	2.5%	3.3%	4.1%	4.9%	5.7%	6.5%	7.2%	7.9%
Equiv. HH (P + N-P)	No. HH	144097	288194	432292	576389	720486	864583	1008680	1152778	1296875	1440972
Equiv. HH (P only)	No. HH	2507291	5014582	7521874	10029165	12536456	15043747	17551038	20058329	22565621	25072912
		Assuming an Average 50% Recovery									
Vol. Pot. Wasted through RO	KL/d	41788	83576	125365	167153	208941	250729	292517	334305	376094	417882
	KL/mo	1271057	2542115	3813172	5084229	6355287	7626344	8897401	10168459	11439516	12710573
	KL/yr	15252688	17794803	26692204	35589605	44487007	53384408	62281809	71179211	80076612	88974013
% Total Vol. Wasted	%	0.6%	1.1%	1.7%	2.2%	2.8%	3.3%	3.9%	4.4%	4.9%	5.4%
Equiv. HH (P + N-P)	No. HH	96065	192130	288194	384259	480324	576389	672454	768518	864583	960648
Equiv. HH (P only)	No. HH	1671527	3343055	5014582	6686110	8357637	10029165	11700692	13372220	15043747	16715275
		Assuming an Average 70% Recovery									
Vol. Pot. Wasted through RO	KL/d	17909	35818	53728	71637	89546	107455	125365	143274	161183	179092
	KL/mo	544739	1089478	1634217	2178955	2723694	3268433	3813172	4357911	4902650	5447389
	KL/yr	6536866	7626344	11439516	15252688	19065860	22879032	26692204	30505376	34318548	38131720
% Total Vol. Wasted	%	0.2%	0.5%	0.7%	1.0%	1.2%	1.5%	1.7%	1.9%	2.2%	2.4%
Equiv. HH (P + N-P)	No. HH	41171	82341	123512	164683	205853	247024	288194	329365	370536	411706
Equiv. HH (P only)	No. HH	716369	1432738	2149107	2865476	3581845	4298213	5014582	5730951	6447320	7163689
		Assuming an Average 80% Recovery									
Vol. Pot. Wasted through RO	KL/d	10447	20894	31341	41788	52235	62682	73129	83576	94023	104470
	KL/mo	317764	635529	953293	1271057	1588822	1906586	2224350	2542115	2859879	3177643
	KL/yr	3813172	4448701	6673051	8897401	11121752	13346102	15570452	17794803	20019153	22243503
% Total Vol. Wasted	%	0.1%	0.3%	0.4%	0.6%	0.7%	0.9%	1.0%	1.1%	1.3%	1.4%
Equiv. HH (P + N-P)	No. HH	24016	48032	72049	96065	120081	144097	168113	192130	216146	240162
Equiv. HH (P only)	No. HH	417882	835764	1253646	1671527	2089409	2507291	2925173	3343055	3760937	4178819
		Assuming an Average 90% Recovery									
Vol. Pot. Wasted through RO	KL/d	4643	9286	13929	18573	23216	27859	32501.92	37145	41788	46431
	KL/mo	141229	282457	423686	564914	706143	847372	988600	1129829	1271057	1412286
	KL/yr	1694743	1977200	2965800	3954401	4943001	5931601	6920201	7908801	8897401	9886001
% Total Vol. Wasted	%	0.1%	0.1%	0.2%	0.3%	0.3%	0.4%	0.4%	0.5%	0.6%	0.6%
Equiv. HH (P + N-P)	No. HH	10674	21348	32022	42695	53369	64043	74717	85391	96065	106739
Equiv. HH (P only)	No. HH	185725	371451	557176	742901	928626	1114352	1300077	1485802	1671527	1857253

Table L-2. Summary of Wasted Water Volumes and Equivalent Households That Could Have Been Served by the Wasted Volume; 7.0 LPCD Treated; Households With 5 People/Each, Urban India (SECA and SECB households)

Description	Units	Adoption % of Users with RO [7.0 LPCD treated; Drinking & Cooking Water]									
		10%	20%	30%	40%	50%	60%	70%	80%	90%	100%
		Assuming an Average 20% Recovery									
Vol. Pot. Wasted through RO	KL/d	234014	468028	702042	936055	1170069	1404083	1638097	1872111	2106125	2340138
	KL/mo	7117921	14235842	21353763	28471684	35589605	42707526	49825448	56943369	64061290	71179211
	KL/yr	85415053	99650895	149476343	199301790	249127238	298952685	348778133	398603580	448429028	498254475
% Total Vol. Wasted	%	3.1%	6.0%	8.8%	11.4%	13.9%	16.2%	18.4%	20.5%	22.5%	24.3%
Equiv. HH (P + N-P)	No. HH	537963	1075926	1613889	2151851	2689814	3227777	3765740	4303703	4841666	5379629
Equiv. HH (P only)	No. HH	6686110	13372220	20058329	26744439	33430549	40116659	46802769	53488879	60174988	66861098
		Assuming an Average 30% Recovery									
Vol. Pot. Wasted through RO	KL/d	136508	273016	409524	546032	682540	819048	955557	1092065	1228573	1365081
	KL/mo	4152121	8304241	12456362	16608483	20760603	24912724	29064844	33216965	37369086	41521206
	KL/yr	49825448	58129689	87194533	116259378	145324222	174389066	203453911	232518755	261583599	290648444
% Total Vol. Wasted	%	1.8%	3.6%	5.3%	7.0%	8.6%	10.1%	11.6%	13.1%	14.5%	15.8%
Equiv. HH (P + N-P)	No. HH	313812	627623	941435	1255247	1569058	1882870	2196682	2510493	2824305	3138117
Equiv. HH (P only)	No. HH	3900231	7800461	11700692	15600923	19501154	23401384	27301615	31201846	35102077	39002307
		Assuming an Average 40% Recovery									
Vol. Pot. Wasted through RO	KL/d	87755	175510	263266	351021	438776	526531	614286	702042	789797	877552
	KL/mo	2669220	5338441	8007661	10676882	13346102	16015322	18684543	21353763	24022984	26692204
	KL/yr	32030645	37369086	56053628	74738171	93422714	112107257	130791800	149476343	168160885	186845428
% Total Vol. Wasted	%	1.2%	2.4%	3.5%	4.6%	5.7%	6.8%	7.8%	8.8%	9.8%	10.8%
Equiv. HH (P + N-P)	No. HH	201736	403472	605208	806944	1008680	1210416	1412153	1613889	1815625	2017361
Equiv. HH (P only)	No. HH	2507291	5014582	7521874	10029165	12536456	15043747	17551038	20058329	22565621	25072912
		Assuming an Average 50% Recovery									
Vol. Pot. Wasted through RO	KL/d	58503	117007	175510	234014	292517	351021	409524	468028	526531	585035
	KL/mo	1779480	3558961	5338441	7117921	8897401	10676882	12456362	14235842	16015322	17794803
	KL/yr	21353763	24912724	37369086	49825448	62281809	74738171	87194533	99650895	112107257	124563619
% Total Vol. Wasted	%	0.8%	1.6%	2.4%	3.1%	3.9%	4.6%	5.3%	6.0%	6.8%	7.4%
Equiv. HH (P + N-P)	No. HH	134491	268981	403472	537963	672454	806944	941435	1075926	1210416	1344907
Equiv. HH (P only)	No. HH	1671527	3343055	5014582	6686110	8357637	10029165	11700692	13372220	15043747	16715275
		Assuming an Average 70% Recovery									
Vol. Pot. Wasted through RO	KL/d	25073	50146	75219	100292	125365	150437	175510	200583	225656	250729
	KL/mo	762634	1525269	2287903	3050538	3813172	4575806	5338441	6101075	6863710	7626344
	KL/yr	9151613	10676882	16015322	21353763	26692204	32030645	37369086	42707526	48045967	53384408
% Total Vol. Wasted	%	0.3%	0.7%	1.0%	1.4%	1.7%	2.0%	2.4%	2.7%	3.0%	3.3%
Equiv. HH (P + N-P)	No. HH	57639	115278	172917	230556	288194	345833	403472	461111	518750	576389
Equiv. HH (P only)	No. HH	716369	1432738	2149107	2865476	3581845	4298213	5014582	5730951	6447320	7163689
		Assuming an Average 80% Recovery									
Vol. Pot. Wasted through RO	KL/d	14626	29252	43878	58503	73129	87755	102381	117007	131633	146259
	KL/mo	444870	889740	1334610	1779480	2224350	2669220	3114090	3558961	4003831	4448701
	KL/yr	5338441	6228181	9342271	12456362	15570452	18684543	21798633	24912724	28026814	31140905
% Total Vol. Wasted	%	0.2%	0.4%	0.6%	0.8%	1.0%	1.2%	1.4%	1.6%	1.8%	2.0%
Equiv. HH (P + N-P)	No. HH	33623	67245	100868	134491	168113	201736	235359	268981	302604	336227
Equiv. HH (P only)	No. HH	417882	835764	1253646	1671527	2089409	2507291	2925173	3343055	3760937	4178819
		Assuming an Average 90% Recovery									
Vol. Pot. Wasted through RO	KL/d	6500	13001	19501	26002	32502	39002	45503	52003	58503	65004
	KL/mo	197720	395440	593160	790880	988600	1186320	1384040	1581760	1779480	1977200
	KL/yr	2372640	2768080	4152121	5536161	6920201	8304241	9688281	11072322	12456362	13840402
% Total Vol. Wasted	%	0.1%	0.2%	0.3%	0.4%	0.4%	0.5%	0.6%	0.7%	0.8%	0.9%
Equiv. HH (P + N-P)	No. HH	14943	29887	44830	59774	74717	89660	104604	119547	134491	149434
Equiv. HH (P only)	No. HH	185725	371451	557176	742901	928626	1114352	1300077	1485802	1671527	1857253

M. Additional Discussion of the Bass Model as it Applies to the RO Water Purifier Market

For purposes of discussion, Figure M-1 includes a simple system dynamics model for the RO market adapted from the traditional Bass Model presented by Sterman (Sterman, 2000) so that it accounts for market growth, and provides the reader with an intuitive understanding of how the model is used in the calculation for percent adoption of RO products, and the volume wasted associated with its current level of use. First, the overall format using the numbered features from the diagram is described, additional general information is provided regarding the way the model is configured, and then factors that contribute to growth of the market are explored in more detail through the use of model simulations.

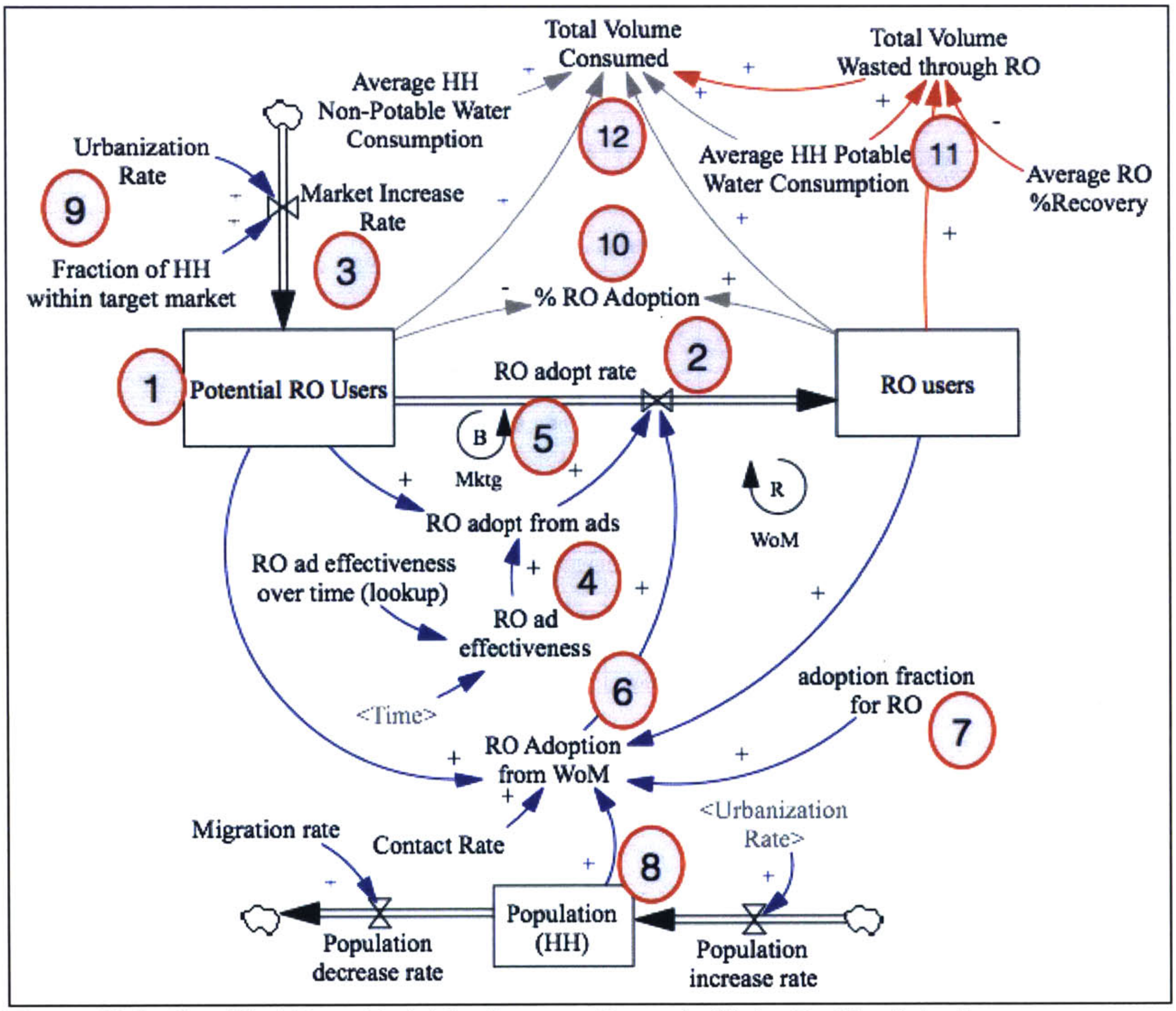


Figure M-1. Simplified Bass Model for Reverse Osmosis Water Purifier Adoption

M.1 General Model Discussion

Overall purpose of the Model

The model shown above is intended to represent the adoption of RO water purifiers over time due to the influence of advertisements and word of mouth. The model represents one city, Delhi, India. Adjusting the value or equations of different variables and running a series of simulations under different conditions can provide an improved understand the types of responses to be expected under different model conditions. Results are plotted out over time, so trends such as the time to reach market capacity or the total market captured by a certain timeframe can be used as points of comparison between different simulations.

The intent of the model timeframe is to begin when the market is small, and growth is slow. Over time, as more adopters purchase the RO systems and WoM (Word of Mouth) takes over from advertising as the driver for adoption, the rate of adoption significantly increases until 50% of the market has been achieved. Growth will then slow, as the market becomes saturated, and the rate of urbanization becomes the limiting factor.

Basic Assumptions

Throughout the model development and simulation period, the following is assumed:

- The value of each variable represents the average condition across the population
- Each household uses one RO water purifier at a time
- The number of adopters represents the number of units sold over time
- In the initial model, replacement purchases are not included, assuming adopters could continue using their water purifier throughout the rest of the simulation duration
- The adoption of RO was estimated based on the approximate use rate of ROs in Delhi across a series of different studies (<5% in 2005, <25% in 2010, ~50% or higher in 2014/2015). See Chapter 5.4 for more detail on those studies.

Features of the Model

(1) **Stocks/Box Variables**: Potential Water Purifier Users, RO Users

  a. ***Purpose***: Stock variables represent accumulated values over time. Together, the stock variables in a model are intended to equal 100%. Since non-electric and UV water purifiers do not waste water, they are theoretically lumped in together with the potential water purifier user group.

  b. ***Formulas***: Stock = Initial value + Integral (all inflows – all outflows)

(2) **Flow**: RO Adoption Rate

  a. ***Purpose***: This flow represents the rate at which users that were potential purifier users are purchasing RO units.

  b. ***Formulas***: RO Adopt. Rate = RO adopt from ads + RO Adoption from WoM

(3) **Flow**: Market Increase Rate

  a. ***Purpose***: This flow represents the rate at which users enter the market and become potential water purifier users. In this simple model, the flow depends on the urbanization rate and the fraction of households (HH) within the target market.

b. ***Formulas***: Market Increase rate = Urbanization rate * Fraction of HH within target market

(4) **Endogenous Variable**: RO Ad Effectiveness

a. ***Purpose***: Endogenous variables are changed over time by the variables that feed into them. This variable represents the effectiveness of RO advertisements in converting a potential user into an RO adopter. It is multiplied against the stock of potential water purifier users to determine the rate at which conversion occurs due to ads. To determine its value at a given time, a lookup table (RO ad effectiveness over time (lookup)) is used. Due to Kent's advertising contract with celebrity Hema Malini in 2005 (Singh, 2015), the RO effectiveness values in the lookup table were set to equal 0.0001/month until month 66 (which accounts for some delay in effectiveness after the ads began), when the new advertisements were increased to 0.001/month.

b. ***Formulas***: constant value

(5) **Loop Labels**: Marketing (a Balancing loop), WoM (a Reinforcing loop)

a. ***Purpose***: Loop labels display the type of loop (balancing, which drains a stock, or reinforcing, which continues to increase a stock) and a brief name that summarizes the overall activity set of the loop.

b. ***Formulas***: N/A, but to determine if a loop is balancing or reinforcing, we look to Marketing as an example. With + Potential Water Purifier Users → + RO adoption from ads → + RO adoption rate → - Potential Water Purifier Users. The Potential Water Purifier Users stock is drained as users convert, and the loop is therefore a balancing loop.

(6) **Endogenous Variable**: RO Adoption from WoM

a. ***Purpose***: Endogenous variables have values that change with the model. The RO Adoption from WoM variable represents the rate at which potential adopters are converted to adopters based on the word of mouth, though contacts with others that can influence the change.

b. ***Formulas***: Contact Rate*adoption fraction for RO*RO users*Potential Water Purifier Users/Population

(7) **Exogenous Variables**: Adoption fraction for RO, Contact Rate

a. ***Purpose***: In combination with the Population, discussed in (8), these factors contribute towards adoption from Word of Mouth. The Adoption fraction for RO is the frequency of which contacts influence the purchase and the contact rate is the rate at which households interact with each other on a per month basis.

b. ***Formulas***: constant values for exogenous variables

(8) **Stock structure**: Population (HH)

a. ***Purpose***: The population stock variable changes over time due to urbanization and migration from the city. For simplicity, births and deaths were omitted from the model, and urbanization was set to zero. The population value is used to represent the number of households that could be in contact, which ensures the RO adoption from WoM does not assume all contacts with other households involve an RO user.

b. ***Formulas***: Population = Initial Population + Integral (Population Increase Rate – Population Decrease Rate), with Population Increase Rate = Urbanization Rate, Population Decrease Rate = Migration Rate

(9) **Exogenous Variables**: Urbanization Rate, Fraction of HH within Target Market

a. ***Purpose***: These variables are used to determine the market increase rate. The Urbanization rate is the population (represented in terms of households) that move to the city every month. The Fraction of households within target market represents the percentage of households moving to a city that are financially capable and have a desire to purchase a water purifier. For purposes of this evaluation, the original value of this variable was assumed to be equivalent to the total percentage of SECA and SECB households already residing within the city, and as mentioned above, urbanization was set to zero.

b. ***Formulas***: constant values

(10) **Variable Used as a Point of Measurement**: % RO Adoption

a. ***Purpose***: The % RO Adoption variable is not used by the model itself, but acts as a point of measurement for the % of RO adopters (out of the total potential + active RO users) at a given time.

b. ***Formulas***: % RO Adoption = RO users / (RO users + Potential Water Purifier Users)

(11) **Variable Set Used to Measure Impact**: Average HH Potable Water Consumption, Average % Recovery, Total Volume Wasted through RO

a. ***Purpose***: These variables are not used by the model itself, but together provide a form of measuring the impact of the number of ROs in operation (assumed to be equivalent to the number of RO users) in terms of volume of water wasted per day. The Average household potable water consumption and average RO % recovery variables are initially set up to be exogenous.

b. ***Formulas***: Average volume wasted through RO = RO users * (Average HH potable water consumption/Average RO %Recovery – Average HH potable water consumption)

(12) **Variable Set Used to Measure Impact**: Average HH Non-Potable Water Consumption, Total Volume Consumed

a. **Purpose**: These variables are not used by the model itself, but together provide a form of measuring the impact of all Potential RO users and RO users in terms of volume of water consumed per day. The Average HH Non-Potable Water Consumption variable is initially set up to be exogenous.

b. **Formulas**: Total Volume Consumed = (Potential RO Users + RO Users)*(Average HH Non-Potable Water Consumption + Average HH Potable Water Consumption) + Total Volume Wasted through RO

Signs used in the model

- \+ The addition sign signifies an increase in the associated variable or flow resulting from an increase in the variable from which the signed arrow originates.
- \- The subtraction sign signifies a decrease in the associated variable or flow resulting from an increase in the variable from which the signed arrow originates.

Time Intervals and Total Duration of the model

- The model was configured with months as the unit of time.
- The total model timeframe is 360 months in duration, with t = 0 assumed to represent year 2000, when the RO market was still very small.
- The model calculates variable and flow values every 0.125 months.

M.2 Baseline Model Simulations

Baseline Constant Values and Simulation Results

The initial model simulation was run with the structure shown in **Figure M-2**. **Table M-2** below summarizes the value for each constant, and **Figures M-2a and M-2b** illustrate model results in terms of the number of potential and converted RO users over time, and the volume consumed (and wasted) under the different RO %Recovery conditions. The model constants were determined by trying to fit adoption rates of < 5% at month 60, <15% at month 120 (assuming the 25% water filter adoption level in 2010 included all filter types, with RO representing slightly more than the majority), and ~50% at month 180 based on diffusion estimates from Chapter 5. For purposes of this exercise, adoption is assumed to take the shape of an S-curve, reaching near 100% product adoption at approximately month 270 (year 22.5, or the middle of year 2023), with the number of RO Users exceeding the number of Potential RO Users by month 144 (year 12, the end of 2012).

Table M-2. Constant Values used in the Baseline Model Simulations

		Units	Baseline_20%Recov	Baseline_30%Recov	Baseline_40%Recov
Initial Population		HH	2,201,570	2,201,570	2,201,570
Fraction of HH within target		%	37%	37%	37%
Urbanization Rate		HH/mo	0	0	0
Initial Population of RO Users		HH	1	1	1
RO Ad Effectiveness	0-66 mos.	1/mo	0.0001	0.0001	0.0001
	66+ mos	1/mo	0.001	0.001	0.001
Contact Rate		HH/HH/mo	5	5	5
Adoption Fraction for RO		1/mo	0.02	0.02	0.02
Average HH Non-Potable Water Consumption		L/HH/d	410	410	410
Average HH Potable Water Consumption		L/HH/d	25	25	25
Average RO % Recovery		%	20%	30%	40%

Note: Cells in yellow were changed as compared to the baseline condition

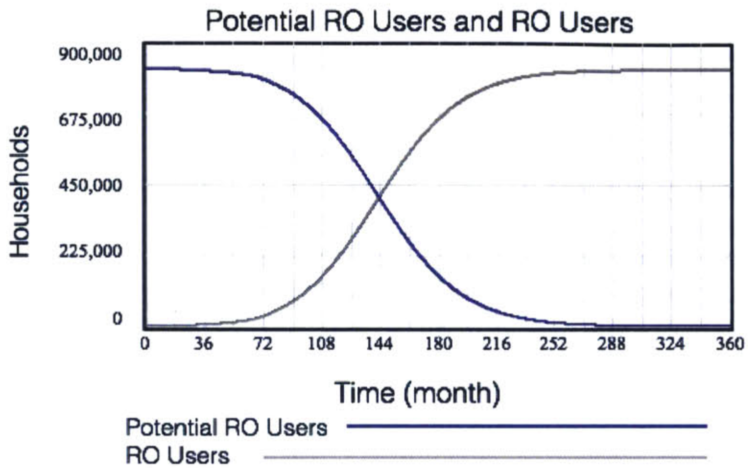


Figure M-2a: Potential RO Users and RO Users Over Time, Baseline Conditions

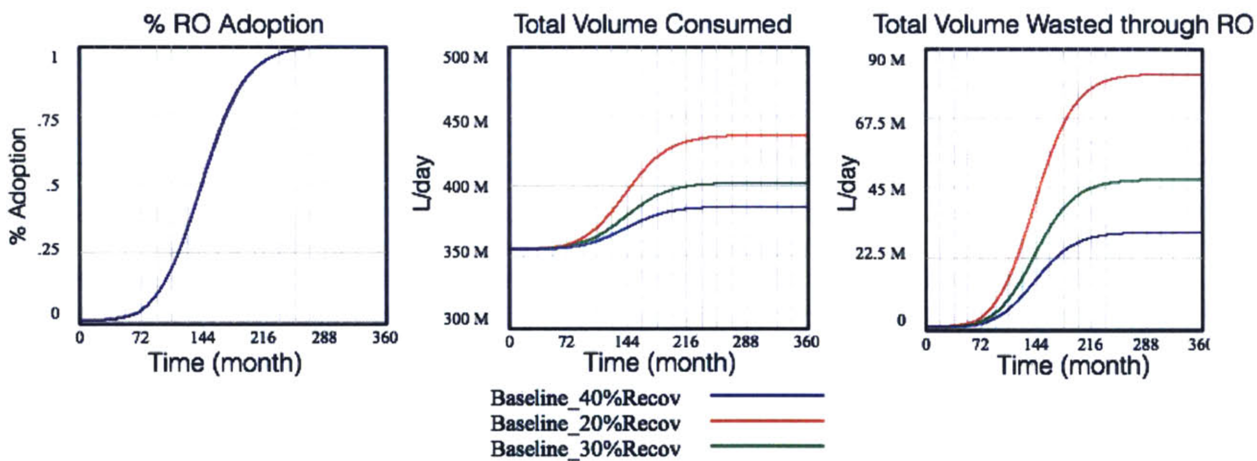


Figure M-2b: % RO Adoption, Total Volume Consumed, and Total Volume Wasted through RO, Baseline Conditions

As shown above in **Figure M-2b** and discussed in Chapter 7, the total volume consumed by the modeled population (SECA and SECB households) is a factor of the number of RO users, and the average RO % Recovery level. As previously indicated, urbanization and migration have been sets to 0, so the population remains constant throughout these baseline simulations.

As one model is needed as a point of comparison for future simulations, one of the three simulations presented above will be considered representative of baseline conditions: the **Baseline_30%Recov** simulation.

Baseline model limitations

The model as shown is overly simplistic. It does not account for certain elements that are likely in play, such as the replacement of purifiers either at end of its useful lifetime, or before, the possibility of the average RO % Recovery rate improving over time, the effectiveness of advertising, or the change in behavior of potential RO users (or RO adopters). Changes will be discussed in next section regarding potential model variations and additions.

Baseline model sensitivity review

The model will be used to represent anticipated conditions in comparison with different alternative simulations. As mentioned previously, the intent for this model is to demonstrate potential changes in the shape of the resulting curves (adoption, total volume consumed, total volume wasted), and baseline constants were selected such that they matched the approximate diffusion trend to date of RO products: <5% in 2005, <25% in 2010, and ~50% in 2015.

M.3 Alternative Evaluation Using Model Simulations

A series of simulations are presented below as a means of evaluating the potential impact of the proposed policy-based or technology-based alternatives discussed in Chapter 8. Since changes to constant values used in the evaluation below are not based on published data, results will be used only to demonstrate the general type of change expected from an increase or decrease in variable values.

M.3.1 Policy-Based Alternatives

As presented in Chapter 8, policy-based alternatives covered water supply volume restrictions, water efficiency ratings, and the possibility of improved water quality supplied by the municipality. It is assumed that all alternatives are implemented after month 192 (year 2016). **Table M-3** provides a summary of the constants used to simulate each alternative and **Figure M-3a** and **Figure M-3b** present results. The following sections provide a discussion related to each proposed alternative.

Table M-3. Constant Values used in the Policy-Based Alternative Simulations

		Units	Baseline_30%Recov	SupplyVolRestrict	WaterEfficiencyRatings	ImprovedWQ_Muni
Initial Population		HH	2,201,570	2,201,570	2,201,570	2,201,570
Fraction of HH within target		%	37%	37%	37%	37%
Urbanization Rate		HH/mo	0	0	0	0
Initial Population of RO Users		HH	1	1	1	1
RO Ad Effectiveness	0-66 mos.	1/mo	0.0001	0.0001	0.0001	0.0001
	66-192 mos	1/mo	0.001	0.001	0.001	0.001
	192+ mos	1/mo		0.0001		0.0001
Contact Rate		HH/HH/mo	5	5	5	5
Adoption Fraction for RO	0-192 mos.	1/mo	0.02	0.02	0.02	0.02
	192+ mos	1/mo		0.01		0.001
Average HH Non-Potable Water Consumption		L/HH/d	410	*Limit 435/HH total HH consumption	410	410
Average HH Potable Water Consumption		L/HH/d	25	25	25	25
Average RO % Recovery	0-192 mos.	%	30%	30%	30%	30%
	216 mos.	%			35%	
	240 mos.	%			40%	
	264 mos.	%			50%	
	288+ mos.	%			60%	
RO Use %	0-192 mos.	%	100%	100%	100%	100%
	192-360 mos.	%				20%

Note: Cells in yellow were changed as compared to the baseline condition

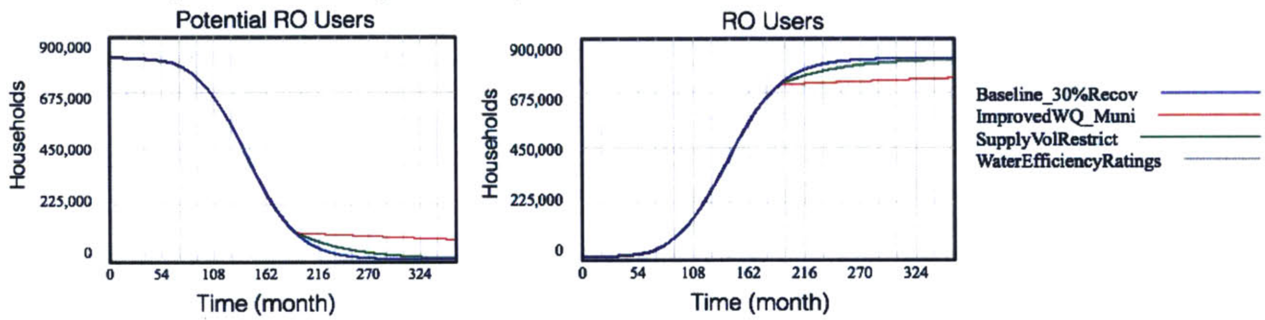


Figure M-3a: Potential RO Users and RO Users Over Time, Policy-Based Alternatives

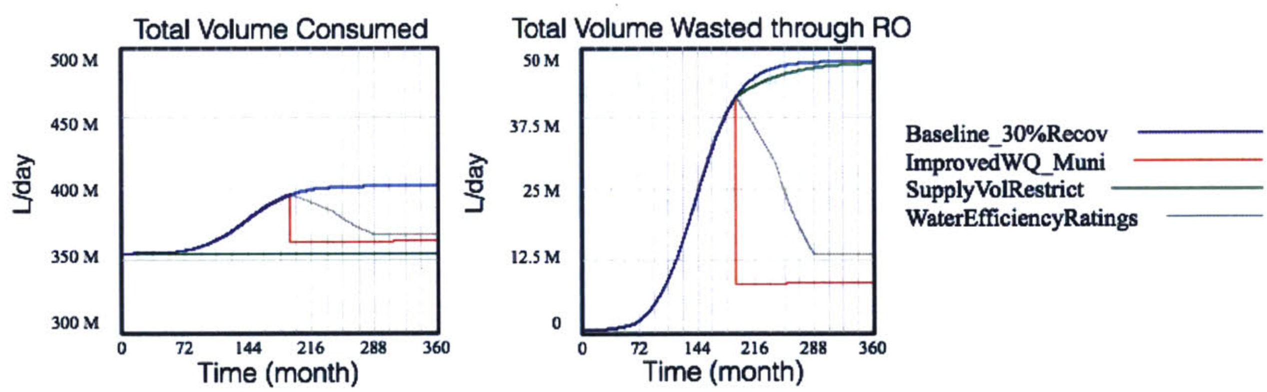


Figure M-3b: Total Volume Consumed, and Total Volume Wasted through RO, Policy-Based Alternatives

Water Supply Volume Restrictions

The first simulation involved a supply volume restriction. As shown in yellow in **Table M-3**, the condition was simulated by decreasing the RO advertising effectiveness and the Adoption Fraction for RO that leads to adoption through word of mouth, as it was assumed potential adopters would be less inclined to purchase a product that causes a limitation to the volume of water consumed at home. The limit of 425 L/HH/day is enforced in this scenario (which assumes 5.0 LPCD treated and 82 LPCD untreated), so as shown in **Figure M-3b**, the lowest total consumption can be met through these conditions, though there is little change in the volume that is wasted through RO units (apart from an apparent reduction in the number of users as the curve begins to levels off). As mentioned in Chapter 8, it is unlikely this approach will be accepted without resistance unless the fixed volume is based on a value high enough to ensure all of the household water requirements are filled.

Water Efficiency Ratings

The incorporation of a water efficiency rating policy was simulated by an increase in the average RO % recovery over time, as shown in **Table M-3**. This adjustment in percent recovery assumes that existing RO products are not effected, and continue to be used, and new products are created that achieve a higher recovery level (as required by the policy) and meet the customers' requirements such that the word of mouth and advertising rates from the standard RO products apply to these new products as well. As demonstrated in the results from **Figure M-3a and M-3b**, water efficiency ratings do not impact the adoption of RO units, but the improvement in recovery provides a noticeable reduction in the volume wasted by RO (and the total water consumed) as the overall efficiency improves.

It should be noted that the method in which this simulation was modeled assumes that a sufficient number of products are replaced before their product lifetime has finished, due to customers having an interest in the higher efficiency product. The two-year timeframe is likely not sufficient to make significant changes in average RO % Recovery without these substitutions.

Improved Water Quality of Municipal Water Supply

The largest potential impact from the group of policy-related alternatives simulated is represented by improved water quality supplied by the municipality. In this scenario, intermittent water supply with low water quality provided by the municipality continues for the first 192 months (16 years), after which infrastructure improvements are made, and continuous water meeting BIS drinking water quality standards is delivered to the connected homes. Once the improvement is made, RO ad effectiveness and the adoption fraction for RO impacting word of mouth purchases drop, and the number of existing RO users decrease use of their ROs to 20% (representing households on borewell water plus a fraction that may not yet trust the water quality). These changes occur because there is no longer a need to store water in tanks (which has been a source of microbial contamination in the past), be concerned about the quality of water degrading due to intermittent operation, or treat water for other purposes in the home, as the municipality has taken over all treatment requirements.

Though this scenario provides the best long-term results in terms of reduced water wastage **(Figure M-3b)**, the cost of the required infrastructure improvements and supply augmentation where needed is substantial, and unlikely to occur in the short-term time period modeled, or be available across the entire city all at once.

M.3.2 Technology-Based Alternatives

As presented in Chapter 8, technology-based alternatives included RO with waste capture, electrodialysis (ED) as a replacement for RO, and desalination bypass (such that only water with an elevated TDS reading would be treated through the RO membrane). It is assumed that all alternatives are implemented after month 192 (year 2016). Two of the technical alternatives were simulated in a way that provides immediate results, and one alternative (ED) was simulated in a way that required diffusion of a new technology[20]. This choice will be discussed in more detail below. **Table M-4** provides a summary of the constants used to simulate each alternative and **Figure M-4a** and **Figure M-4b** present results. The following sections provide a discussion related to each proposed alternative.

[20] In addition, product retirement was only considered in the ED simulation, as it was assumed that RO users would replace their product with another RO unit, unless another technology (such as ED) was available. Changing products to one that was more efficient or had an integrated storage tank for reject water was not modeled specifically, as discussed below.

Table M-4. Constant Values used in the Technology-Based Alternative Simulations

		Units	Baseline_30%Recov	RO_w_WasteCapture	ED_Replacement	Desalination_Bypass
Initial Population		HH	2,201,570	2,201,570	2,201,570	2,201,570
Fraction of HH within target		%	0.37	0.37	0.37	0.37
Urbanization Rate		HH/mo	0	0	0	0
Initial Population of RO Users		HH	1	1	1	1
RO Ad Effectiveness	0-66 mos.	1/mo	0.0001	0.0001	0.0001	0.0001
	66-192 mos	1/mo	0.001	0.001	0.001	0.001
	192+ mos	1/mo			0.0001	
Contact Rate		HH/HH/mo	5	5	5	5
Adoption Fraction for RO	0-192 mos.	1/mo	0.02	0.02	0.02	0.02
	192+ mos	1/mo			0.01	
Average HH Non-Potable Water		L/HH/d	410	410	410	410
Average HH Potable Water		L/HH/d	25	25	25	25
Average RO % Recovery (or in the case of RO Capture, reuse)	0-192 mos.	%	30%	30%	30%	30%
	216 mos.	%		90%	35%	
	240 mos.	%			40%	
	264 mos.	%			50%	
	288+ mos.	%			60%	
Initial Population of ED Users		HH	-	-	1	-
Adoption Fraction for ED	0-192 mos.	1/mo	-	-	0	-
	192-360 mos.	1/mo			0.02	
ED ad Effectiveness	0-192 mos.	1/mo	-	-	-	-
	192+ mos	1/mo			0.001	
Average ED % Recovery	0-192 mos.	%	-	-	-	-
	192-360 mos.	%			90%	
RO Use %	0-192 mos.	%	100%	100%	100%	100%
	192-360 mos.	%				20%

Note: Cells in yellow were changed as compared to the baseline condition

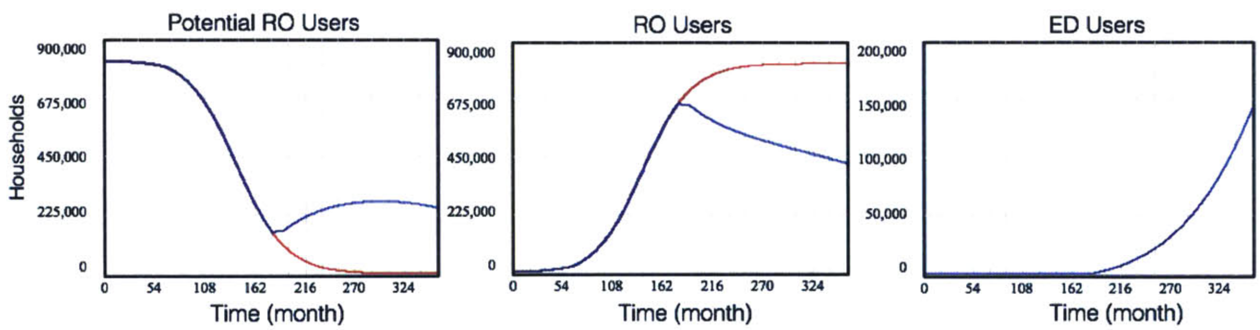


Figure M-4a: Potential RO Users and RO Users Over Time, Technology-Based Alternatives

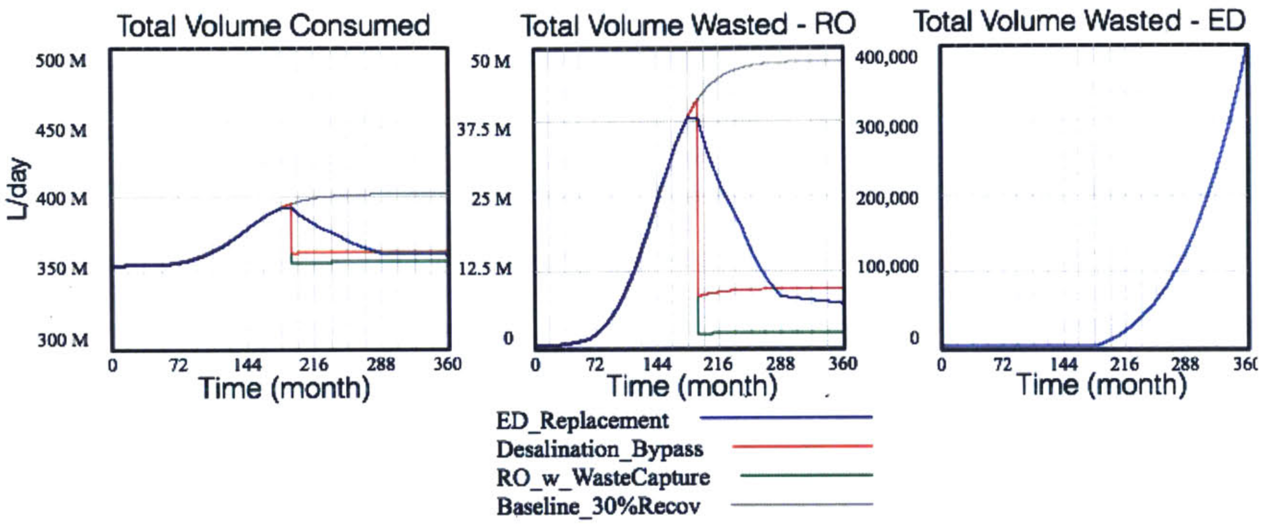


Figure M-4b: Total Volume Consumed, and Total Volume Wasted through RO or ED, Technology-Based Alternatives

<u>RO with Waste Capture</u>

As shown in **Table M-4**, RO with waste capture was simulated by changing the average RO %Recovery from 30% to 90%. The impact shown in **Figure M-4b**, the best of all technical alternatives considered, was immediate, though as noted above, the immediate response was a choice made in how the scenario as simulated. RO with waste capture involves reuse of nearly all of the RO reject water (10% is assumed to be disposed of due to lack of use), and it can be achieved either by constructing a new product entirely with a second tank (such as Kent's Supreme product), or by creating a supplemental product or system that captures the water and stores it for convenient reuse. The supplemental/add-on product could be available in the short-term and be used immediately, though adoption of the supplemental product or method (such as in the case of a wide-scale educational program based on using products already available in the home) would be required. Relying on adoption of new water purifiers with an integrated storage compartment for reject water (like the Kent Supreme) would take longer, unless users are willing to replace their products before the average lifetime has been met.

<u>Electrodialysis as a replacement for RO</u>

Electrodialysis was the only technology simulated that did not include RO technology. Because of this, diffusion of the new technology based on advertisements and word of mouth was incorporated into the simulation (whereas the other technical alternatives were assumed to be more immediate in their adoption). As outlined in **Table M-4**, it was assumed that RO ad effectiveness and adoption fraction for RO were decreased, while the equivalent variables for ED were based on what had led to significant growth of RO between months 66 and 192. An initial population of ED users was 1 household, to be conservative. The average ED % recovery was assumed to be 90%. It is noted that changes were also made to the average RO % recovery level, as it was assumed that the introduction of ED with its high recovery would prompt further development and adoption of "eco-friendly" RO products because of the pressure of competition. Finally, another addition to the ED model that was not used elsewhere was the integration of an RO retirement flow rate out of RO users, returning to the Potential RO Users stock. This flow represented product retirement after the average lifetime of 10 years, and allowed the user to reconsider the choice of water purifiers providing desalination. The decrease in RO users observed in **Figure M-4a** resulted from this change.

As demonstrated in **Figure M-4a**, the ED scenario was the only technical alternative that reduced the overall number of RO adopters over the long term, though this could have been a function of the assumptions made while modeling each scenario. **Figure M-4b** then illustrates a more gradual decrease in the volume of water wasted per day, which eventually begins to level off above the RO with waste capture scenario (due to the remaining RO users).

<u>**Desalination Bypass**</u>

Desalination bypass involves the use of the RO membrane to desalinate only water that has exceeded a preset TDS level in the input water; water with a lower TDS level will bypass the RO membrane, and be treated by the remaining treatment stages prior to discharge into the storage tank. As shown in **Table M-4**, this alternative was simulated by changing the RO use percentage to 20% (to cover households relying primarily on groundwater and other sources, as well as some percentage for those not comfortable with the change), and assumed an immediate change could be observed at 192 months (the end of 2016). Similar to the RO with waste capture alternative, this alternative was modeled to have an immediate effect due to the possibility of replacement (RO already has established trust as a technology, and the bypass may not impact that level of trust), and in order to demonstrate the best-case condition, assuming that only 20% of users required desalination. As demonstrated in **Figure M-4b**, this scenario achieved lower volumes of waste compared to the baseline RO condition, but as modeled, did not perform as well as the ED replacement or the RO system with waste capture.

M.3.3 Comprehensive Model

Throughout the alternative simulations described above, additions were required to the model originally provided in **Figure M-1**. **Figure M-5** presents the comprehensive model developed through the evaluation, incorporating structural changes described in **Table M-3** and **Table M-4**.

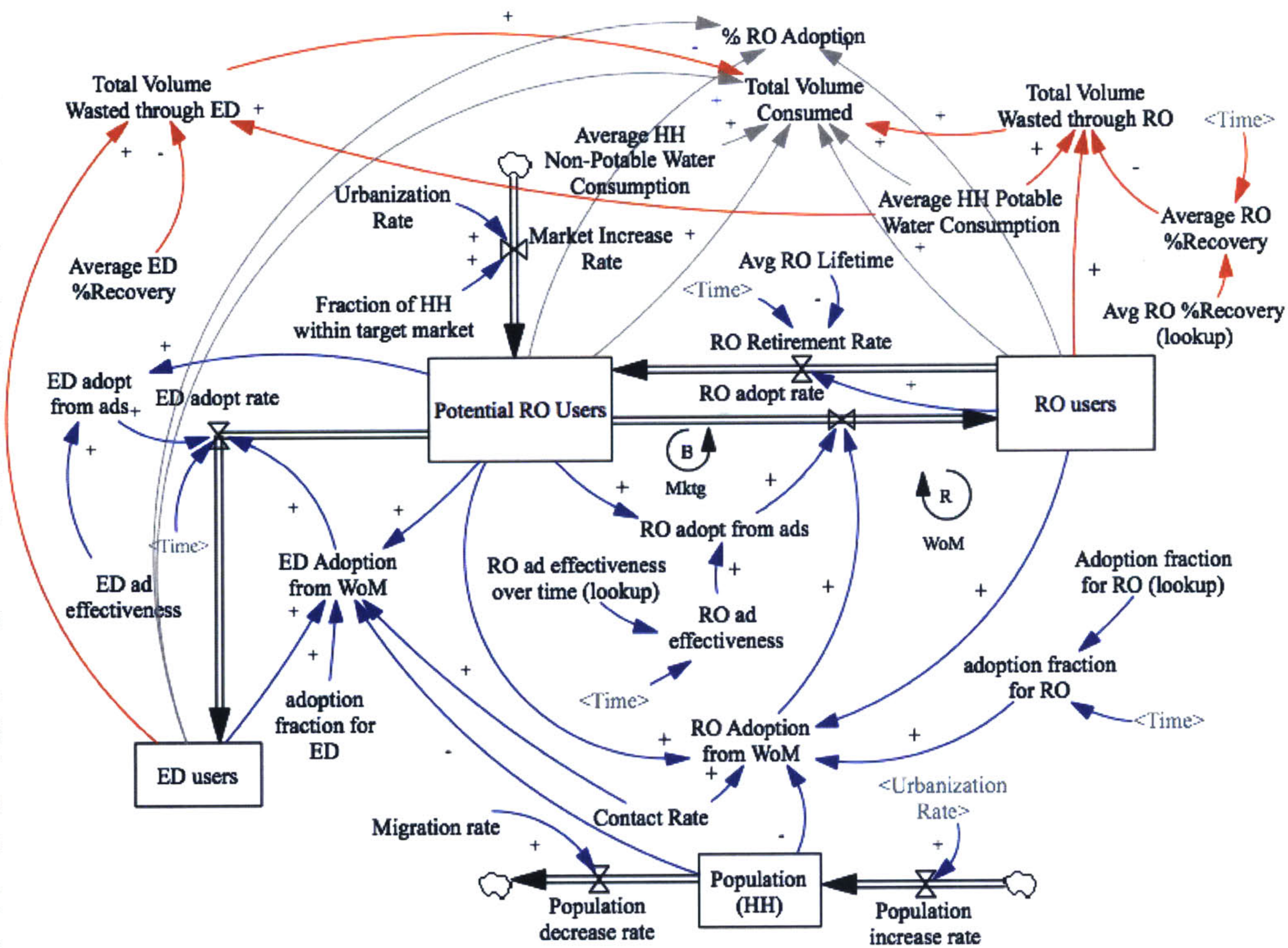


Figure M-5. Comprehensive Bass Model for Reverse Osmosis Water Purifier Adoption

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Icons sourced from the Noun Project for Figure 3-1 include "Factory" icon by Krisada, "Factory" [used as a wastewater treatment plant] icon by Creative Stall, "Water Purifier" icon by Shashank Singh, "Clock" icon by James Rainsford, "Bucket" icon by Philipp Koerner, "Toilet" icon by Matt Brooks, "Bathtub" icon by Mint Shirt, "Shower" icon by Creative Stall, "Outfall" icon by Luis Prado, "House" icon by Ashwin Dinesh, "User" icon by Cees de Vries, "Water Truck" icon by Rohan Gupta, "Network" icon by Alina Alvarez, "Potable Water Source" icon by OCHA Visual Information Unit, "Pump" by Adam Zubin, "Water Bottle" icon by Nikita Kozin, "Water" icon by Marli du Plessis, "Well" icon by OCHA Visual Information Unit, "Water Tank" icon by Adam Zubin, "Hot Water" icon by Nathan Stang, and "Water-Tower" icon by Katie Wright.