BERMUDA’S WATER SUPPLY

PART II

Supply, Demand and Capacity

CONTENTS

		Page
1.	Water supply in 2008	3
2.	Sources of water	
i.	Introduction	5
ii.	Rain water catchments	5
iii.	Trucked water	7
iv.	Mains supply	8
v.	Private wells	9
vi.	Private treatment plants	9
3.	Production for public supply	9
4.	Drought of May 2009	11
5.	Production capacity and trends in demand	
i.	Current status	13
ii.	Trends in per capita supply and demand	15
iii.	Trends attributable to mains network expansion	17
iv.	Commercial demand	19
v.	Climate change	20
vi.	Re-cycling	20
vii.	Summary	21
i.	Conclusions and Recommendations	
i.	Main conclusions	21
ii.	Recommendations	23

FIGURES

1.	Water supplied in 2008 – quantities and sources	4
2.	Housing statistics and rain water harvesting data	6
3.	Water production sources in 2008 and 2009	10
4.	Residential water supply data for 2008 and May 2009	14
5.	Bermuda's national water production capacity	16
6.	Projected national demand for supplementary water	18

BERMUDA'S WATER SUPPLY

PART II. Supply, Demand and Capacity.

1. Water supply in 2008

2008, a year of average total rainfall, is considered a good baseline for assessing normal conditions in Bermuda with respect to water consumption and supply. It included dry spells, which prompted some typical spikes in demand for supplementary water, but, unlike 2009, there were no water shortages of sufficient severity to curb consumption.

The total quantity of water supplied to Bermuda in 2008, was 4.61 million Ig/day (Imperial gallons per day), of which 55% was supplied to residences. This water comprised: 1). rain caught on roofs and other catchments; 2). ground water and sea water treated at plants operated by Government and private water companies; 3) raw well water from private wells; and 4). ground water and sea water treated at private treatment plants. The proportions contributed by each of these sources are summarized in Figure 1a. After deducting the estimated quantity supplied to hotels and cruise ships of 410,000 Ig/day, the quantity available for all uses in Bermuda amounted to a 65 Ig/day per resident (This figure was calculated by dividing the total amount of water supplied to Bermuda from all sources, including rainfall, by the total population, estimated at 64,000).

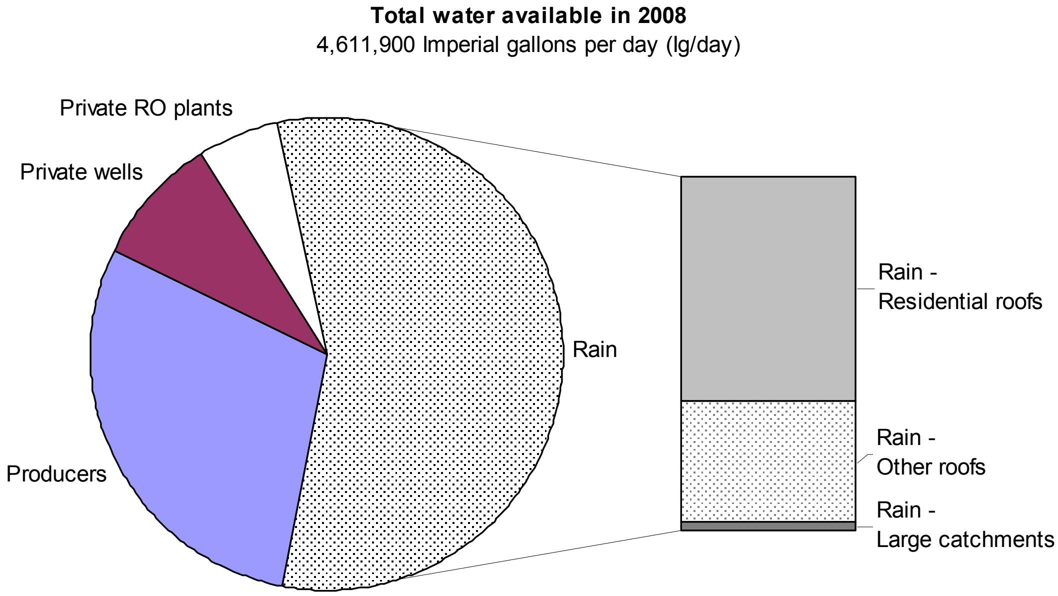
Water was provided to residences at an average rate of 2,482,900 Ig/day in 2008. This includes rain water harvested on roofs and water supplied from supplementary sources (Figure 1b). With a population of 64,000, this equates to 39 Ig/day per person. However, this figures neither accounts for changes in water storage levels in tanks, nor for tank overflows, and so can be considered, only, as an upper delimiting value of water consumption.

Water provided to residences, in 2008, can be broken down as follows: rain water 67%, mains water 12%, trucked water 10% and water from private wells 11%, (see Figure 1b). Rain water supply was calculated by multiplying the total number of residential buildings by the average* residential roof catchment area and then by the annual rainfall corrected for catchment efficiency. Mains water supply information was derived from sales figures provided by the Bermuda Government and Bermuda Water Works. Private well water supply was calculated from the total numbers of brackish and fresh wells multiplied, respectively, by estimated usage, which was based on information submitted on Water Right application forms, by each well owner.

*weighted average from the three study areas as described in Section Part I, Section.3.ii

Figure 1. Water supplied in 2008 - quantities and sources.

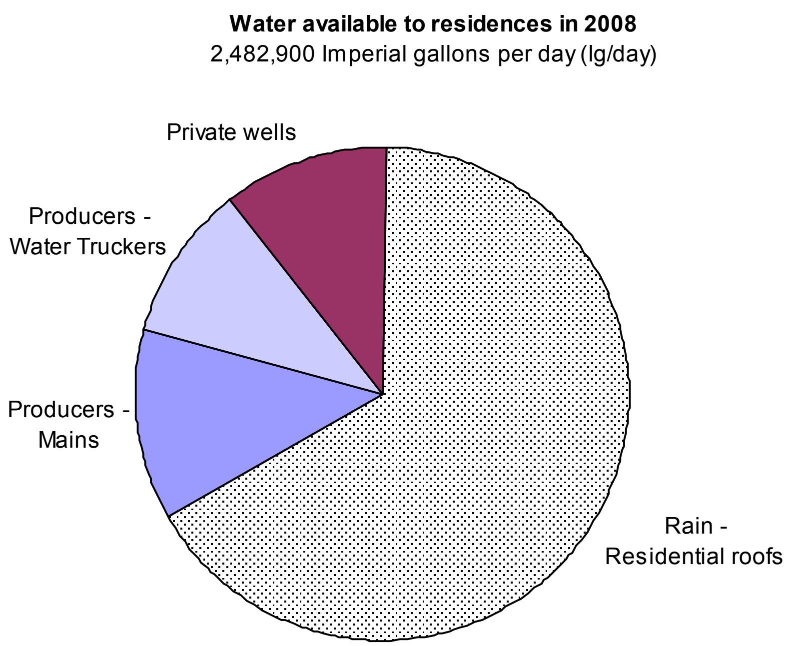
a.



Source	Rate of supply (Ig/day)	Percentage
Producers *	1,348,930	29%
Private wells	409,660	9%
Private RO plants	254,100	6%
Rain - Residential roofs	1,651,500	36%
Rain - Other roofs	887,030	19%
Rain – Large catchments	60,670	1%

Producers * - The Bermuda Government and private water companies which treat ground water and sea water for distribution by mains and water truckers.

b.



Source	Rate of supply (Ig/day)	Percentage
Producers - Mains	307,840	12%
Producers - Truckers	259,320	10%
Private wells	264,220	11%
Rain - Residential roofs	1,651,500	67%

2. Sources of water

i. Introduction

The principal source of water in Bermuda is harvested rainfall. Other, “supplementary”, water can be divided into “public supply” water (which is delivered from off-site) and water which is available on-site. The former comprises treated water sold to consumers, which is delivered by mains pipelines and by water truckers. The latter comprises raw water from private wells and treated water from private treatment plants. The distinction is important in the assessment of national water production requirements. The supply of water from private wells eases the demand on the public supply system. Private well water is not imported or exported and contributes only to self sufficiency. Consequently, demand for water from the public supply system is, for the most part, driven by consumers who have no private well. In this report, public supply water which is produced-and-delivered, as opposed to being available on-site, is referred to as “supplementary water (delivered by mains and truckers)” so as to leave no doubt as to what is meant.

An exception to the distinction, made above, would be rain water transferred by truckers, for example, from the tank at a commercial warehouse, to a residence. Such water is delivered, but is not produced by a water company. However, these transfers become increasingly rare as a drought progresses and so their impact on peak production capacity requirements can be disregarded.

ii. Rain water catchments

2008 was a year of near average rainfall with a total 56.1”, measured centrally at Prospect, compared to Bermuda’s long-term average of 57.7”. Based on the catchment area and catchment efficiency data presented in Part I, the total amount of rainfall caught in 2008 amounted to 2,599,000 Ig or 41 Ig/day per person (Figure 2). This broke down into 64% caught on residential roofs, 34% on other roofs and 2% on active ground level catchments. (Information on roof areas was provided by the Lands, Building and Surveys department of the Ministry of Works & Engineering, from the Bermuda Topographic Map Database)

Rain water caught on residential roofs in 2008 amounted to 1,660,440 Ig/day which equates to 107 Ig/day per residential building or, assuming a population of 64,000, 26 Ig/day per person (Figure 2). This is compared to an estimated average per capita demand for water at home of 30 Ig/day per person (See Part I). As explained earlier, however, the figure of 26 Ig/day per person represents captured rainfall, a portion of which would have been lost to occasional tank overflows at a significant number of residences. The average quantity of rain water actually available for consumption is, therefore, less than this amount.

At the “typical house” (Part I, Section 3) with a catchment area of 1360 sq.ft, 94 Ig/day, or 23.5 Ig/day per person, of rain water is harvested. This is the modal condition as opposed to the average. It is consistent with a national average figure for harvested

Figure 2. Housing statistics and rain water harvesting data - 2008

Population	64,000
All buildings	19,000
Houses	17,356
Condominiums	106
Residential buildings	17,250
Dwelling units (valuation numbers)	30,535
Average dwelling units per house	1.7
Average occupancy per dwelling unit	2.1

Note that average per capita water consumption at home is estimated at 30 Ig/day which in a year of normal rainfall, such as 2008, can be met by 450 sq.ft of catchment area (per capita).

The average house has 3.6 occupants who consume an average 108 Ig/day. This can be met in a year of normal rainfall by 1620 sq.ft of catchment area, which is more than the "typical" and average residential roof areas.

	Catchment area sq.ft	Catchment area sq.ft/person	Harvested rain Ig/day	Harvested rain Ig/day/person
All buildings (roofs)	37,630,000		2,538,500	
Active ground level catchments	899,000		60,600	
TOTAL	38,528,000	602	2,599,000	41
Residential buildings only (roofs)	24,480,000	382	1,660,440	26

	Occupancy	Catchment area sq.ft	Catchment area sq.ft/person	Harvested rain Ig/day	Harvested rain Ig/day/person	Balance* Ig/day
Pembroke sample area	4.1	1085	262	74	18	-49
Warwick sample area	4.8	1501	316	102	21	-41
Tuckers' Town sample area	1.6	3117	2009	211	136	+163
"Typical house"	4	1360	340	92	23	-28
Study "House 1"	3	1645	548	111	37	+21
Study "House 2"	4.5	1860	413	126	28	-14
Study "House 3"	8	3000	375	203	25	-37
Condominium (sample)	23	6270	273	425	18	-265

* Balance = harvested rainfall less water consumption per residential building (@ 30 Ig/day per person).

Information on roof areas was provided by the Lands, Building and Surveys department of the Ministry of Works & Engineering, from the Bermuda Topographic Map Database rainfall of 26 Ig/day per person, derived above, which includes the influence of houses with surplus rain water (i.e. those with greater than 450 sq.ft of catchment area per occupant and/or those with a private well. See Part I).

It can, thus, safely be said that, in a year of normal rainfall, Bermuda is in a state of net water deficit with respect to the supply of harvested rainfall at residential properties. The average supply of supplementary water to residences at a rate of 13 Ig/day per person in 2008 (Figure 4) cannot be explained in any other way.

Rain water harvesting continues to play a leading role in the supply of water to residences, regardless of their access to, or dependency on, supplementary water. Delivery of supplementary water under pressure, directly into residential or, for that matter, commercial plumbing systems is not permitted. It may only be delivered on-demand, in the form of top-up water, into rain water storage tanks. Consequently, demand for supplementary water is a function of the recent history of rainfall, as it affects the volume of water stored in tanks. The influence of rainfall was evident when at the height of the drought in May 2009, sales of supplementary water (delivered by mains and truckers) to residences, reached 1,039,150 Ig/day compared to the average in 2008 of only 567,160 Ig/day.

As for large ground-level rain water catchments: those that remain active currently supply less than 2% of all rainfall harvested in Bermuda. Like all catchments, they fail to supply water during a drought when consumers are most in need.

iii. Trucked water

64% of households do not have a well or a water mains connection and so rely on truckers for their supplementary water supply. There are 41 licensed water truckers in Bermuda, with an average tank capacity each of 900 Ig (Imperial gallons). In 2008, they delivered an average of 254,000 Ig/day which equates to an average 7 loads per truck per day. These data were extracted from meter readings provided by water companies, and the Bermuda Government, which supply truckers. Based on information gleaned from interviews with truckers, it is estimated that 10% of deliveries are “transfers” under normal conditions decreasing to 5% during a drought (a transfer is defined, here, as water which is transferred from non-residential rain water tanks to residential tanks).

Water is supplied to truckers at “trucker’s outlets”, which, in 2008, were operated by the Bermuda Government, Bermuda Water Waterworks, Island Water, K.C Daniels and Sousa’s Water Service. The source of trucked water provided by the small companies is treated ground water. However, that provided by the major producers - the Bermuda Government and Bermuda Water Works - is a combination of treated ground water and treated sea water. (The breakdown is discussed in more detail in the next section). 95% of deliveries of trucked water, according to Ron Smith of Island Water, are made to residences and only 5% to commercial customers.

Even amongst residences which have no access to other forms of supplementary water, there is a very large range in the demand for trucked water. Many very rarely, if ever, need it, while others purchase it on a routine basis. It is calculated that in 2008, an average of 8.6 truck loads were delivered to residences which have no mains connection or private well. This equates to 13 Ig/day per dwelling unit or 6 Ig/day per occupant.

These figures are supported by the findings of a Ministry of Works and Engineering homeowner's water survey in which the average quantity of trucked water purchased by respondents was, also, 8.6 loads per year. Since, extreme deviations from average rainfall were not experienced in 2008, the activity of the water truckers in that year, as described above, reflects the normal inadequacy in rain water supply to Bermuda households.

iv. Mains supply

There are no heavy industries in Bermuda. Major customers of the mains supply system have traditionally been multi-storey, high occupancy buildings such as large hotels, offices, and the two hospitals. Necessarily, these all have small roof areas relative to demand. In the early days, water mains were constructed with the primary objective of supplying such customers, which had larger and more constant demands for water than did residences. Recently, with the decline in the tourism industry, the related closure of hotels and a general slowdown in the economy, the relative importance of residential customers has increased significantly.

The Bermuda Government (Ministry of Works & Engineering) and Bermuda Waterworks are the only two water producers, who operate mains systems. Between them, they supply 2508 traditional residences (14% of the total) and 29 condominium developments (67% of the total). On this basis, it is calculated that 5650 dwelling units, or 19% of the total, are serviced by mains water.

In the case of the major producers, mains water and trucked water are supplied from reservoirs in which treated seawater and various grades of treated ground water are blended together. In 2008, Bermuda Waterworks had the only fully operational sea water RO (reverse osmosis) treatment plant used for public supply. Mains water, at that time, comprised 27% treated sea water and 73% treated ground water. These proportions changed significantly in 2009 with the commissioning of the Bermuda Government's 500,000 Ig/day sea water RO plant (see Section.3).

1,089,000 Ig/day were delivered by mains in 2008 and of this amount, 307,800 Ig/day (28%) were delivered to residences. This equates to residential consumption of mains water at a rate of 26 Ig/day per person. This figure was derived from sales data, provided by the Bermuda Government and Bermuda Water Works, combined with housing and dwelling occupancy data provided by the Bermuda Government (Land Valuation Department and Statistics Department).

Mains water is used to top-up rain water storage tanks. It is supplementary to rain water; so it may be concluded that the average amount of water consumed is the sum of the harvested rainfall (26 Ig/day per person) plus that supplied by mains (26 Ig/day per person). In other words, an average consumption of 52 Ig/day per person by those who have a mains supply is implied. This is 80% more than the estimated average consumption of 30 Ig/day per person at a Bermuda home. Several confounding factors are at work here, however. First, as explained earlier, 26 Ig/day per person is the average rate of capture of rain water, not the average rate of its consumption. Second, we know nothing about the occupancy or size of houses with connections. Since connections are optional, it is safe to assume that those who are particularly short of rain water, due to small roof catchment areas relative to occupancy, are more likely to opt for a connection. This skews the data, in that the occupancy of houses which have connections is probably higher than the national average, assumed above, and the per capita consumption is, therefore, lower than 52 Ig/day per person. Having said that, a significantly higher demand can be expected in households with a piped supply; because the water is more readily available and, on the face of it, is less expensive than trucked water. Also, there is the effect of incentives such as, in the case of Bermuda Waterworks, the inclusion of 1000 Ig of "free" water per month as part of the service agreement. This may encourage the drawing of more water from main connections than is necessary and, no doubt, is responsible for tank overflows, which would not have otherwise occurred.

v. Private wells

There are currently approximately 2900 houses and 105 multi-unit buildings (apartments or condominiums) with private wells. This equates to 5890 dwelling units supplied with water from private wells, or 19% of the total number of 30,540 dwelling units.

The estimated total rate of supply of water from these wells in 2008 was 264,000 Ig/day or 45 Ig/day per dwelling unit or 21 Ig/day per person. Unlike mains water or trucked water, well water is not used for tank top-up (this is not permitted). Well water may only be used for non-potable purposes and is connected directly, via a pressure tank and a separate plumbing system, to toilets and other facilities depending on the salinity of the water. Where well water is fresh (40% of wells) and can be used for washing, in addition to toilet flushing, consumption of rain water is minimal, and tanks are likely to be routinely overflowing.

Well water consumption was calculated on the basis of the number and type of facilities attached to each well, as declared on water right application forms submitted to the Department of Environmental Protection. As such, the figures are not sufficiently reliable to draw detailed conclusions as was done for mains supplies, which are metered. This is an area which requires more investigation.

vi. Private treatment plants

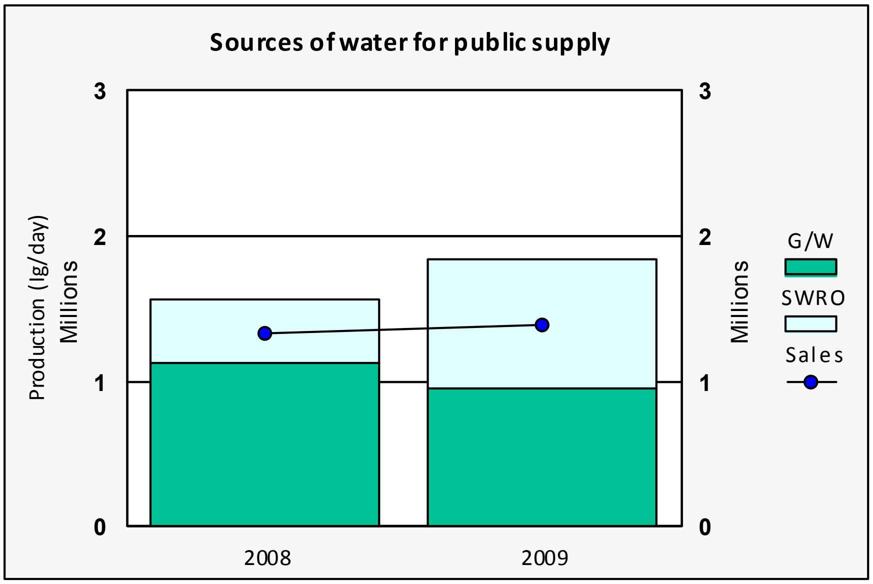
Water produced for residential consumption from small treatment units attached to private wells, is accounted for in the section on private wells, above. Private treatment plants are, for the purposes of this report, defined as moderately sized plants which are owned and operated by hotels and other commercial operations, such as concrete producers, but excluding those dedicated to production of irrigation water. They are almost exclusively RO (reverse osmosis) plants which treat brackish ground water or sea water from wells. In 2008, an estimated 254,100 Ig/day of water was produced by these plants. This was deduced from the information provided on water right application forms.

3. Production of water for (supplementary) public supply

Water for "public supply" is defined here as that which is distributed from production facilities which are licensed by the Ministry of Health. In total there are five such licensed water producers. Three can be described as small private companies, which distribute water exclusively by truckers. On the other hand, the two largest producers - the Bermuda Government and Bermuda Waterworks - respectively supplied only 22% and 3% of their water by truckers, in 2008, with the remainder being supplied by mains.

Figure 3. Water production sources in 2008 and 2009.

a.

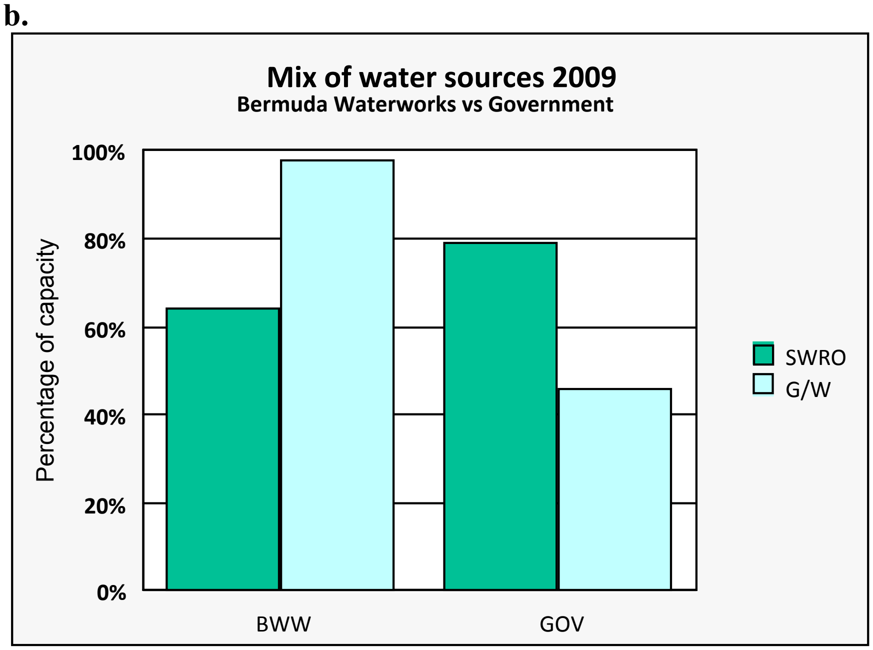


A large increase in seawater production between 2008 and 2009 was attributable to commissioning of the Bermuda Government's new sea water RO plant. Despite the significant net increase in production, sales barely increased between the two years, which must reflect escalating losses by leakage and overflow.

	2008	2009
Production* from G/W	1,132,130 (73%)	949,689 (52%)
Production* from SWRO	427,750 (27%)	892,530 (48%)
Sales	1,338.896	1,384,937
Sales as % of production	86%	75%

* Post-treatment.

b.



While, in 2009, Bermuda Waterworks maximized the exploitation of it's licensed ground water resources, the Bermuda Government maximized its sea water production.

	Bermuda Waterworks		Bermuda Government	
	Sea water RO	Ground water	Sea water RO	Ground water
Production/abstraction	496,530	359,341	396,000	744,339
Capacity/Limit	775,000	349,700	500,000	1,635,000
%	64%	96%	79%	46%

In 2008, 73% of all water produced for public supply was from ground water sources and 27% was from sea water. With the commissioning of the Government's 500,000 Ig/day sea water RO plant at the beginning of 2009, the respective percentages became 52% and 48% (Figure 3a).

Average production of water for public supply from all sources increased from 1,600,000 Ig/day in 2008 to 1,842,200 Ig/day in 2009. The latter figure amounted to 61% of current licensed production capacity of 3,004,000 Ig/day (Figure 5). The unused 1,161,800 Ig/day of potential capacity is largely accounted for by unexploited ground water production capacity. This under-exploitation was exacerbated by the fact that production of treated sea water to some extent substituted for the production of treated ground water, rather than just supplementing it. (Figure 3a).

Although total water production for public supply increased between 2008 and 2009 by 18%, sales increased by only 3.4%. The diminutive increase in sales, despite a drought at the beginning of 2009, can be attributed to high rainfall later in the year, which brought total sales for the year close to that of a normal year. Meanwhile, the disproportionate increase in production in 2009 relative to sales must mainly be accounted for by an increase of "losses" (leaks and overflows), primarily in the Government's system.

As a consequence of the contractual commitment by the Bermuda Government to produce treated sea water at a constant rate close to the capacity of the new plant, it falls to ground water production facilities to meet unpredictable rainfall-related peaks in demand. The challenges that this presents, in terms of synchronizing the inflow of abstracted ground water with fluctuating demand, is borne out by the scale of the losses mentioned above.

Sea water desalination is an energy hungry process compared with treatment of much lower salinity ground water. Exploitation of treated ground water for base load supply, while reserving costly treated sea water for peaking supply, makes eminent sense under normal circumstances. This reasoning is apparent in the strategy which has been adopted by Bermuda Waterworks. In 2009 the company exploited 96% of the ground water abstraction capacity available to it, while holding its sea water production to 64% of capacity. By comparison, the Bermuda Government produced treated sea water at 79% of capacity and abstracted ground water at only only 46% of its licensed capacity (Figure 3b). The figure of 79% for sea water production would have been much higher had the Bermuda Government's sea water RO plant been fully operational at the very beginning of 2009.

4. Drought of May 2009

The "Drought of May 2009", was the culmination of a long episode of accumulating rainfall deficit which began on 21st August 2008 (Part I, Figure 15). The frequency of recurrence of a drought of this duration and severity is approximately once in twenty years (based on Macky's (1957) analyses of droughts). The impact of droughts, in Bermuda, is intensified by the extent of the dependency on rain water harvesting. Rainfall deficits rapidly translate into increasing demand, which cannot be met in the absence of adequate standby water production capacity and the capability to distribute it. In the months leading up to May 2009, water tanks had become progressively depleted. This is illustrated by the spreadsheet simulations of water tanks storage level represented in Part I, Figures 12 and 13. The May 2009 rainfall of only 1.3 inches, provided harvested rain water to residences at a rate of only 7 Ig/day per person compared to the average in 2008 of 26 Ig/day per person creating a deficit of approximately 20 Ig/day per person (Figure 4).

To compensate for the shortfall in rainfall, total supply (sales) of supplementary water (delivered by mains and truckers) to residential and non-residential customers increased from an average of 1,348,900 Ig/day in 2008 to 1,697,500 Ig/day in May 2009. The portion of this which was supplied to residences increased from 567,160 Ig/day to 1,039,150 Ig/day. Those with mains connections increased their purchase of water from an average of 26 Ig/day per person in 2008 to 46 Ig/day per person in May 2009 (based on occupancy of 3.7 occupants per residence). Meanwhile, the supply of trucked water to residences with no mains connection and no well, increased from an average of 6 Ig/day per person in 2008 to an average of 13 Ig/day per person in May 2009.

These figures suggest that some households, in May 2009, were managing on 20 Ig/day per person (7 Ig of rain water and 13 Ig of trucked water) compared to an average of 32 Ig/day per person (26 Ig of rain water and 6 Ig of trucked water) in 2008 (Figure 4). An unfulfilled demand of 12 Ig/day per person is implied. However, what is not taken into account, here, is the exploitation of stored water from tanks at those houses which had ample reserves, such as did House 1 (Part I, Figure 12). Average consumption of harvested rain water was, therefore, in fact greater than the amount which was harvested in May (7 Ig/day per person) and unfulfilled demand was less than 12 Ig/day per person at households with no direct access to a supplementary supply.

Those with connections on average increased their consumption of mains water by 20 Ig/day per person (from 26 to 46 Ig/day per person) to directly counteract the household deficit of harvested rainfall of 20 Ig/day per person (Figure 4). The drought, evidently, had no impact on their water consumption and, apparently, the cost of supplementary water did not come into play. The fact that supply met demand indicates that there were no restrictions or interruptions in the flow of mains water to the majority of customers. (Only the limited number of customers on the Government mains systems at the east and west end suffered interruptions). This is important evidence that central production capacity was not stressed.

By May 2009, households reliant on trucked water were experiencing an average delay in delivery of 5 days or more, depending on their location. In previous years, this would have been attributed to depletion of reservoirs. However, with the timely commissioning of the Bermuda Government's 500,000 Ig/day seawater RO plant early in 2009, water production capacity was not lacking.

The total delivery rate of 515,680 Ig/day by truckers in May 2009 (including 5% as transfers of rain water) amounted to an average of 14 loads/day per truck. While some truckers can achieve 20 loads per day, or more, it has been established, based on interviews with truckers, that 14 loads per day is a realistic maximum that can be sustained over one month. It must be concluded, therefore, that a deficiency in water trucking capacity contributed to household water shortages in May 2009. However, a factor which more immediately contributed to a bottleneck in water truck deliveries, was the progressive attrition of supply points (truckers' outlets) as water resources at the east and west end of the island were exploited to their maximum capacity and had to be shut down or throttled back. Delivery distance then became more of an issue, with centrally located households receiving preferential treatment, to the detriment of those at the extremities of the island.

Additional numbers of water trucks would arguably alleviate delivery backlogs. This would, however, create hardship for truckers, in the form of excessive competition under normal, non-drought conditions. Furthermore, it would not resolve pressing distribution challenges, which are attributable to the centralized massing of water production facilities and associated truckers' outlets. When queues of trucks form, as happened at the Bermuda Government's Prospect outlets in May 2009, the immediate solution plainly cannot be to increase the number of trucks. (One trucker from the east end reported that he did less business than normal in May 2009 because of lack of access to water sources close to his customers).

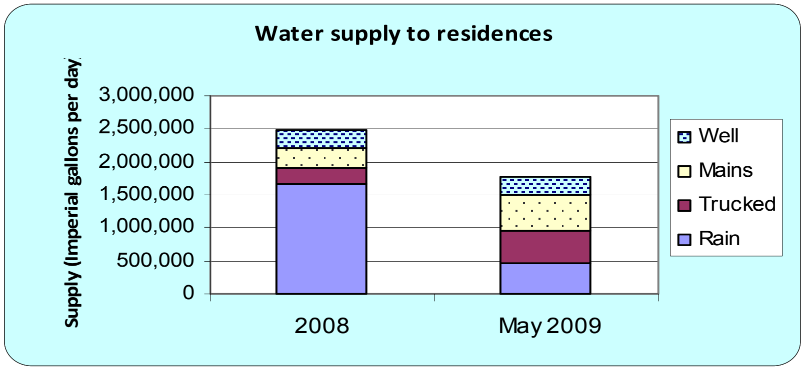
5. Production capacity and trends in demand.

i. Current status

Virtually every household, business and institution in Bermuda has rainfall harvesting integrated into their water supply system, in accordance with the law. Demand for water fluctuates in response to cumulative rainfall surpluses and deficits which, respectively, build and deplete water storage volumes in tanks. Production capacity must be taken off-line and standby capacity must be brought on-line, as dictated by rainfall-related demand. Illustrative of these circumstances was the increase in total sales of supplementary water (delivered by mains and truckers) from an average of 1,348,900 Ig/day in 2008 to 1,697,500 Ig/day at the height of the drought in May 2009, a 26% increase. The point is made even more graphically by the erratic fluctuation in demand for trucked water recorded by Island Water, as shown in Part I, Figure 14

Rain water caught on residential roofs declined from an average in 2008 of 1,651,500 Ig/day to 465,260 Ig/day in May 2009. The inferred May 2009 deficit (relative to the 2008 average) in harvested rain water of 1,186,240 Ig/day was met by an increase in supplementary supply/distribution of only 472,000 Ig/day, representing a hypothetical shortfall in supply of 714,000 Ig/day, which is largely attributable to the distribution challenges described in Section 4. (see Figure 4). While many households continued to live exclusively off rain water stored in their tanks, it is certain that as result of the prolonged drought, the majority had, by May, become reliant on supplementary sources to make up the deficit. Actual unfulfilled demand was less than 714,000 Ig/day (because of the effect of those living off storage), but the figure is considered to realistically represent the worst case scenario potential shortfall (drier months than May 2009 do occur). As for non-residential customers, it is calculated that the average rate of supply of water to them, by mains and truckers, was 124,000 Ig/day lower in May 2009 compared to the average in 2008, despite the drought. This figure is too large to be dismissed as measurement error, and must be related to a decline in commercial activity, particularly

Figure 4. Residential water supply data for 2008 and May 2009



Residential water supply (Ig/day)		
Source	**2008**	**May 2009**
Rain	1,651,500	465,260
Trucked	259,320	491,120
Mains	307,840	548,030
Private well	264,220	264,220
TOTAL	**2,482,880**	**1,768,630**
Difference	714,250	

2008 average Residential sources of water	Supply per dwelling unit (Ig/day)				Supply per person (Ig/day)			
	No. Units	Rain	Supplementary	Total	No. persons	Rain	Supplementary	Total
Rain and trucked*	19,560	54	13	**67**	41,076	26	6	**32**
Rain and mains	5,650	54	54	**108**	11,870	26	26	**52**
Rain and private well	5,890	54	45	**99**	12,370	26	21	**47**
Rain, mains and private well	- 560				- 1,180			
TOTAL/weighted average	30,540	54	27	**81**	64,000	26	13	**39**

May 2009 Residential sources of water	Supply per dwelling unit (Ig/day)				Supply per person (Ig/day)			
	No. Units	Rain	Supplementary	Total	No. persons	Rain	Supplementary	Total
Rain and trucked*	19,560	15	25	**40**	41,076	7	12	**19**
Rain and mains	5,650	15	97	**112**	11,870	7	46	**53**
Rain and private well	5,890	15	45	**60**	12,370	7	21	**30**
Rain, mains and private well	- 560				- 1,180			
TOTAL/weighted average	30,540	15	43	**58**	64,000	7	21	**28**

* Includes residences which have no well or mains connection and never purchase supplementary water.
These data assume that all dwelling units are the same with a national average of 2.1 occupants. (Average dwelling units per house and condominium are respectively 1.7 and 20)

in the tourism sector, over the period. This is consistent with dwindling sales to non-residential customers reported by Alan Rance of Bermuda Waterworks. What it means is that projections of any shortfall in national production capacity, in the near-term, need only consider factors associated with residential demand. Commercial and institutional demand can be considered as stable and as effectively unaffected by rainfall. This is consistent with observations made in Part I, Section 6.iv that regardless of rainfall, non-residential customers are either self-sufficient at all times, or rely heavily on supplementary water at all times.

The peak potential demand for supplementary water in a serious drought can, thus, be calculated by adding the worst case scenario shortfall in supply/distribution (as experienced by residential customers in May 2009) of 714,000 Ig/day to 1,697,000 Ig/day, which was the total rate of supplementary water supply to all customers (delivered by mains and truckers) in that month. The total of 2,411,000 Ig/day compares to an existing combined potential capacity* to produce supplementary water of 3,004,000 Igpd (Figures 5 and 6) or, after allowing for reasonable losses of about 15%, compares to a current potential ability to supply water at a rate of 2,550,000 Ig/day.

Therefore, even assuming that no special conservation measures are taken by householders and even allowing for normal mechanical failures and leaks in water production and distribution systems, a surplus capacity would still exist in a serious drought. The existence of this surplus may seem inconsistent with un-fulfilled demand in May 2009. The discrepancy is, however, attributable to: 1). the aforementioned serious deficiencies in the reach and capacity of the distribution system; 2). abnormal water losses; and 3). neglected ground water production capacity.

* production capacity (post-treatment) based on licensed abstraction potential (sea water and ground water)

ii. Trends in per capita supply and demand

Many Bermuda households live comfortably on 30 Ig/day per person. In fact, measurements and surveys suggest that true consumption at traditional Bermuda homes, which do have direct access to supplementary water, falls in the range of 25 to 30 Ig/day per person. The increase from 20 Ig/day per person in the 1950s (Macky, 1957) can, largely, be attributed to the introduction of high capacity clothes washing machines and dishwashers. It can safely be assumed that this trend has plateaued and with the introduction of increasingly efficient water saving appliances and toilets. Average water consumption today is the same as that estimated 12 years ago (Saunders, 1998) and there is no reason to project an increase above 30 Ig/day per person over the next few decades, other than with a change in attitude, perhaps prompted by more readily available water (See section 5.iii, below).

Population growth (including non-Bermudians) as projected by the Bermuda Government (Department of Statistics, 2006) decreases from plus one tenth of one percent in 2015, to negative growth by 2030. The majority of the growth subsequent to 2000 (population 62,131) was projected to have occurred by 2008, when the population was estimated to stand at 64,209 as compared to only 65,447 by 2030. This information was compiled prior to the economic downturn of 2008, which undoubtedly has temporarily reversed population growth in the non-Bermudian sector.

Figure 5. Bermuda's potential water production capacity (Imperial gallons/day)

Source	Total Potential Capacity (except for irrigation)	Capacity dedicated to supplementary public supply (via mains and truckers)
Sea water treatment		
MW&E (Tynes Bay)	500,000	500,000
MW&E (Container)	108,000	108,000
MW&E (St.G. Golf Club)	25,000	25,000
Bermuda Waterworks	800,000	800,000
WEDCO	83,000	
BLDC (Southside)	50,000	
TOTAL	**1,566,000**	**1,433,000**
Ground water*		
"Fresh" (80% recovery)	1,336,000	1,336,000
Brackish (50% recovery)	235,000	235,000
TOTAL	**1,571,000**	**1,571,000**
Private wells		
Commercial (includes Corporation of St.George's)	235,000	
Domestic	180,000	
TOTAL	**415,000**	
Rain water		
Residential roofs	1,708,000	
Commercial roofs	914,000	
Ground level catchments	62,000	
TOTAL	**2,684,000**	
Private RO plants		
TOTAL	**508,000**	
GRAND TOTAL	6,744,000	3,004,000

* Based on ground water resources which are licensed for abstraction.

Housing construction and sub-divisions have, meanwhile, outstripped population growth causing a steady decline in occupancy per dwelling unit from 3.5 in 1960 to 2.6 in 1990 to 2.1 in 2009. (These figures do not account for unoccupied units and so actual occupancy is slightly higher). Construction of new housing creates new roof area, which translates into greater volumes of harvested rainfall. Even though the new housing is predominantly high density with low roof areas per unit, this is offset by the reduction in average occupancy across all housing. Factors behind this trend are the increasing numbers of single-parent families and the disaggregation, into separate dwellings, of extended families, who by necessity previously lived under one roof.

iii. Trends attributable to mains network expansion and private well construction

The data reveal that residences with a mains supply tend to consume more water than others. As mentioned earlier, this can partly be explained by the fact that mains connections are optional. Residences which opt for connections are most likely those which have a history of water shortages attributable to small roof areas relative to occupancy. Once connected, there is no question that consumption is encouraged by the ready availability of water and, sometimes, by the terms of the mains supply contract.

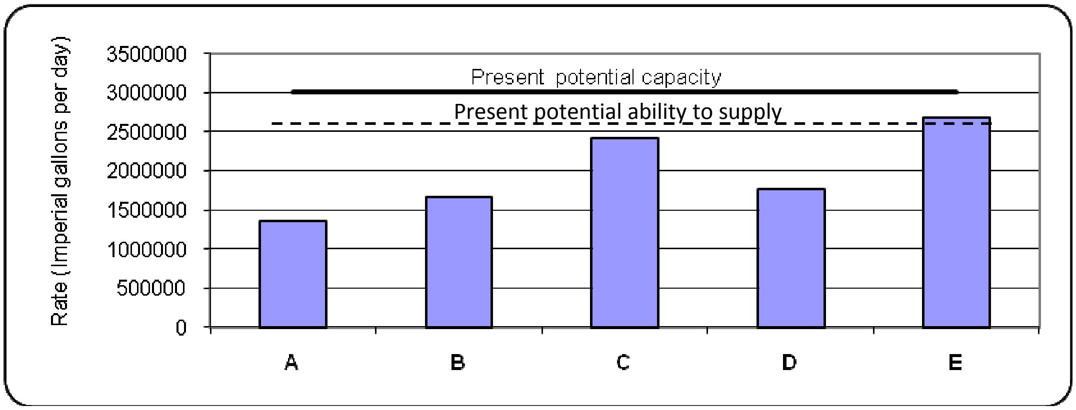
According to Alan Rance of Bermuda Waterworks, an average of 60% of households accept an offer of a connection. This suggests that 40% are confident in their self sufficiency, supported perhaps by an occasional delivery of trucked water or by supply from a private well.

5650 dwelling units (2510 houses and 71 condominiums and apartments) are served by mains supply and purchase water at an average rate of 54 Ig/day per unit. Given that 60%, of those offered, opt for mains connections, 9420 of the total of approximately 30,540 dwelling units must have already had the opportunity to connect. Should 60% of the remaining 21,120 units sign up for connections if offered, then there remains the potential to connect 12,760 more units, making a total of approximately 18,400* connected units. If this were to happen there would be an increase in demand commensurate with the average high demand for mains water (54 Ig/day per unit) relative to trucked water (13 Ig /day per unit).

What is not taken into account, above, is the ongoing construction of private wells, which currently are approximately equal in number to mains connections. Since most residences do not require both a private well and a mains connection, the ongoing construction of private wells will reduce the pool of residences, which might otherwise have opted for a mains connection. It is calculated that new well construction will reduce the total number of units which potentially could be connected in the future, by approximately 1900 from the 18,400 to 16,510* (Figure 6). This is based on the following assumptions: that the mains connection network will be completed in 30 years; that approximately 40 new private wells will continue to be drilled each year; and, that each well serves a residence divided into 1.6 units.

The “best” customers of the water trucking industry would, most likely, be lost in the process of offering mains connections to all residences. However, a significant number of present trucker clients may consider it less costly to buy an occasional load of trucked

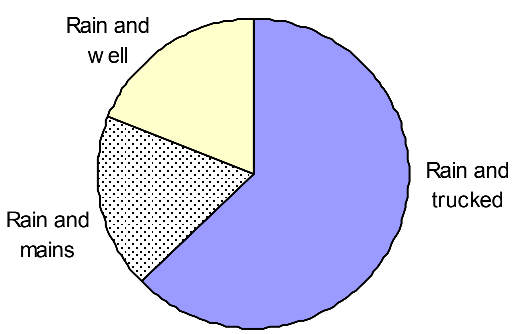
Figure 6. Projected national demand for supplementary water delivered by mains and truckers.



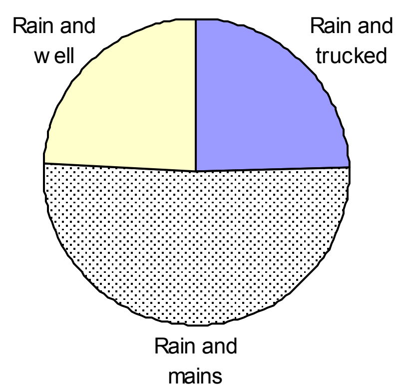
A - Average supply 2008 **B** - Supply in May 2009 (demand not met)
C - Projected present demand in drought conditions (e.g. May 2009)
D - Projected future demand with an island wide mains network – 2040 (?)
E - Projected future demand, as with D, but in drought conditions.
Present potential capacity – post-treatment production capacity based on licensed abstraction potential for sea water and ground water.
Present potential to supply – potential capacity less 15% losses from leakage etc.

All figures are for total supplementary supply delivered by mains or truckers from the water producers (Government and private) to residential and non-residential customers.

Sources of residential water 2008



Sources of residential water 2040 (?)



	2008		2040 (?)*	
	No. Units	%	No.Units	%
Rain and trucked[1]	19,560	64	7,900	26
Rain and mains	5,650	19	16,500	54
Rain and private well	5,890	19	7,790	26
Rain, mains and private well	- 560	- 2	- 1,650	- 5
TOTAL	30,540		30,540**	

* This is the date by which a mains connection is available to every residence. 2040 was chosen arbitrarily.
** The total number of units will have increased, but the population is projected to be stable. Water capacity calculations are based on occupation per unit and so are not affected by the number units alone.

water, currently at 9 cents per Ig (Imperial gallon) vs a minimum compulsory annual purchase of 12,000 Ig at 2.3 cents per Ig.

Survival of a scaled-back water trucking industry is probably assured regardless of the degree of penetration of the mains network. Truckers will be needed to serve remaining unconnected units that will occasionally require supplementary water. Based on the May 2009 deficit in rainfall of approximately 40 Ig/day per unit, the estimated potential demand in a worst case drought from "holdout" units would be 320,000 Ig/day which at 14 loads per day can be met by 25 truckers. However, under normal circumstances there would not likely be full time work for more than 15 truckers.

If, hypothetically, 30 years hence, an additional 10,860 dwelling units were to be served by the mains and an additional 1900 served by wells, then in the former case, consumption of trucked water of 150,000 Ig/day (13 Ig/day per unit) would potentially be replaced by a consumption of mains water of 586,400 Ig/day (54 Ig/day per unit). As for the 1900 units which installed wells, it is assumed that no supplementary water would be required, resulting in a reduction of demand of 24,700 Ig/day. The new net consumption of supplementary water by units which previously had neither a well nor a mains connection would be 561,700 Ig/day. This represents an increase of 411,700 Ig/day over present consumption of 150,000 Ig/day of trucked water. This would increase total demand (residential and non-residential) for supplementary water delivered by truckers and mains, from 1,348,900 Ig/day (2008 average) to an outside maximum of 1,760,600 Ig/day.

1,760,600 Ig/day is the projected demand for supplementary water (delivered by mains and truckers) under normal rainfall conditions. In the event of prolonged drought, based on a deficit of rainfall of approximately 40 Ig/day per unit as experienced in May 2009, an additional 910,000 Ig/day** would be required for residences (assuming storage had been exhausted in all tanks), making for a projected worst case peak demand of approximately 2,670,600. This is compared to existing potential capacity to produce supplementary water of 3,004,000 Ig/day or, after allowing for reasonable losses of about 15%, only just exceeds the existing ability to supply water (Figure 6).

In summary, after factoring in maximum penetration of mains supply throughout Bermuda and the associated increase in demand, combined with the effects of very serious drought conditions, demand would still not exceed the capacity to produce supplementary water and, after accounting for losses, would only just exceed the capacity to supply water, based on current licensed abstraction potential (sea water and ground water).

** Note that there is a difference between the number of connections and the number of dwelling units served by connections, because each metered connection supplies a residence and each residence comprises on average of 1.7 dwelling units. Also note that projections of water consumption assume no increase in population (see Section* 5.ii*). The number of dwelling units will increase but this will be offset by decreased occupancy. ** 40 Ig/day unit X (30,540 units – 7790 units with wells) = 910,000 Ig/day*

iv. Commercial demand

Much of the data presented in this report were from 2008. Since that time a downturn in the economy has resulted in flat or declining non-residential water sales. This is on the back of a long-term trend of hotel closures and impending challenges for International companies based in Bermuda. New hotels and offices may well continue to be built, but this has no bearing on water consumption unless there is a commensurate growth in the numbers of visitors and expatriate workers. Also pertinent is the fact that large commercial, hotel or institutional developments occasionally choose to provide for themselves with respect to water supply. This possibility creates great uncertainty in projections of national water production capacity requirements, even in the event of steady economic growth.

v. Climate change

Climate change is expected to have some impact on rainfall at Bermuda. A trend towards lower rainfall and/or towards a more seasonal pattern of rainfall would increase the required capacity for production of supplementary water. There is, however, nothing particularly anomalous in recent patterns of rainfall to indicate that any such trends are evolving. Total rainfall over the 2007 – 2009 study period, which was selected for tank storage level modelling, was almost exactly average. The "May 2009 drought", in the context of it being a once in 20 year event, was not abnormal in its intensity or character.

Dr Anne Glasspool (2008) summarized the projected potential impact of climate change on Bermuda's rainfall as causing a 7% rise in annual precipitation and increased variability with "more intense rainstorms interspersed with longer periods of drought". She cautioned, however, that such projections assume that Bermuda's climate will respond similarly to that of continental USA (north east) which "might seem unreasonable". If, nonetheless, we accept these projections as a scenario which Bermuda could possibly face, it is not one that is likely to affect future water production capacity requirements. The increase in the length of droughts would probably be offset by the higher total rainfall. This could be confirmed by spreadsheet modelling of water tank storage levels.

Global warming has caused a sea level rise, in recent decades, averaging between 2 and 3 millimeters per year at Bermuda. This is attributable to thermal expansion of the oceans and, to a lesser extent, addition of water from melting glaciers and ice caps. According to Dr Glasspool (2008) a projected increase of 0.6 meters in the 21st Century would result in inundation of approximately 3% of Bermuda's land mass by the sea. This is a small proportion, compared to many other island-nations which are not blessed with such a steep shoreline and hilly topography. It follows that if Bermuda's land area is not significantly depleted, then the lateral extent of the fresh ground water resources, which exist in the form of "lenses", will be largely preserved. They will maintain their volume and simply float upwards with rising sea level.

vi. Re-cycling

In making projections a decade or more into the future to account for the likes of mains expansion and climate change, another potential development which must be considered is re-cycling of water. While reduced water consumption offered by re-cycling might prove attractive to those planning to construct new buildings, the benefit versus cost of retrofitting existing buildings is thought to be sufficiently unfavourable to discourage its adoption on a significant scale.

On another level, there is the re-cycling of waste water produced by large developments (such as hotels) and by municipalities such as Hamilton and St George's. It is most probable that within the next decade "water reclamation", as has been implemented at the West End Development Corporation (WEDCo), will be more widely undertaken. Treatment and re-use of effluent will replace discharge into outfalls and boreholes. As a consequence, large quantities of reclaimed water will potentially become available, either directly for toilet flushing and irrigation or indirectly through artificial recharge of ground water aquifers. Under these circumstances, the demand on potable water production capacity could be significantly reduced. This counterbalances any unforeseen increases in water consumption (for example associated with a surge in tourism activity) or will, simply, grow Bermuda's water production capacity surplus.

vii. Summary

It has been established that post-treatment water production capacity from existing licensed sea water and ground water wells and the ability to supply water (after accounting for losses) exceeds total demand for supplementary water (delivered by trucks and pipelines. However, centralised massing of production facilities coupled with inadequacies in the water delivery system, mean that even "projected present demand in drought conditions" as shown in Figure 6 cannot yet be satisfied. Production capacity, in consequence, is very much a secondary issue.

Expansion of the mains network is a slow process which is currently being undertaken only by Bermuda Waterworks. Over a decade, or so, this will noticeably improve delivery of water, but will also increase demand at the residences served. Ongoing construction of private wells will partially offset this trend of increasing demand for supplementary water.

It is not anticipated that increased production capacity, over present licensed levels, will be required within the next decade. The challenge, which Bermuda faces, is to fully develop and strategically distribute existing water production and delivery resources, as opposed to arbitrarily increasing centralised capacity.

6. Conclusions and Recommendations

i. Main Conclusions

In 2008, a year of normal rainfall, the equivalent of 26 Ig/day per person (Imperial gallons per day) of water was harvested at residences and an average of 13 Ig/day per person of supplementary water was purchased for domestic consumption. The total of 39 Ig/day includes overflow from tanks at some residences and so exceeds actual average consumption (at home), which is estimated at 30 Ig/day per person. Currently, there are 382 sq.ft (square feet) of residential roof catchment area per person, compared to the requisite 450 sq.ft to supply 30 Ig/day, based on average annual rainfall. However, with the construction of housing outstripping population growth and declining levels of occupancy per dwelling unit, this deficit is, if anything, being reduced.

There are approximately 30,540 dwelling units in Bermuda. 64% have no on-site source of supplementary water, such as a private well or water mains connection. 19% are served by a mains connection and another 19% are served by a private well (2% have both). Those with no direct access to a supplementary water source purchased trucked water at an average rate of 13 Ig/day per unit in 2008. Those with a mains connection purchased water at an average rate of 54 Ig/day per unit; while those with a private well are estimated to have consumed 45 Ig/day of well water per unit. While residences which have opted for mains connections are more likely to be those with higher than average occupancies, the data doubtless, also, reflect significantly higher per capita consumption of water as a consequence of the convenience offered by a mains supply.

Nine months of accumulating rainfall deficit culminated with a very dry month in May 2009. This intensity of drought, which recurs approximately once in twenty years, provided an ideal opportunity to estimate maximum demand for supplementary water and to assess the ability of Bermuda's water producers (Government and private) to cope. Total water delivered to residences in May 2009 from all sources, including rain water, was approximately 714,000 Ig/day less than the average delivered in 2008. This deficit was accounted for by the shortfall in harvested rainfall at residences with no well or mains connection. In other words, it was attributable to the failure of trucked water deliveries to satisfy demand. Unlike previous droughts where total water production capacity proved inadequate, in 2009 it was the diminishing number of suitably located supply points (outlets) available to truckers, as the drought progressed, coupled with insufficient carrying capacity that led to a backlog of orders and forced a reduction in consumption. Knowing the maximum shortfall in supply in May 2009, the potential demand for supplementary water (residential and non-residential) in the event of a serious drought was calculated at 2,421,500 Ig/day. This is comfortably exceeded by an existing potential capacity for production of supplementary water of 3,004,000 Ig/day; and it can be concluded (after allowing for reasonable losses from leakages etc of 15%) that assuming efficient distribution, the ability to supply water from existing licensed resources exceeds demand in the worst case scenario.

Factors which affect demand for supplementary water over the long-term, in Bermuda, such as rainfall, catchment area per capita, water consumption per capita, and commercial activity are either stable or too unpredictable to realistically account for. The only verifiable trends, which are expected to affect demand for supplementary water, are the expanding mains network and construction of private wells. The former tends to increase demand for supplementary while the latter decreases it. The net outcome of both of these developments if taken to their conclusion, say 30 years hence, is that average demand (residential and non-residential) could increase to 1,760,600 Ig/day, and demand in a drought could increase to 2,670,600 Ig/day. Even the latter figure only just exceeds the current ability to supply water after allowing for reasonable post-production losses of 15%.

The fact that Bermuda now has a buffer of surplus water production capacity and yet, at times, demand fails to be met, can be attributed to centralised massing of production facilities coupled deficiencies in the reach and capacity of the water distribution system. At the eastern and western extremities of the island, neither truckers nor residences have access to central production capacity via pipelines. The limited water production resources in these areas are, therefore, invariably overwhelmed by demand in the event of a serious drought, as occurred in May 2009. Truckers who normally operate in these outlying areas are increasingly forced to queue for water at central locations as a drought progresses. The Bermuda Government commissioned a 500,000 Ig/day sea water reverse osmosis treatment plant at the beginning of 2009, which operates at near-capacity under contractual obligation. This created a source of readily available water, which contributed to the relief of acute shortages in the first half of that year. However, the inability to efficiently distribute this water resulted in surplus production and necessitated cut backs of abstraction from ground water resources which were already under-exploited. At the conclusion of the drought, even further reductions in ground water abstraction have had to be made to counterbalance continued, near-capacity production of treated sea water.

The ground water abstraction system did not respond well to such throttling, and significant water losses were incurred, and continue to be incurred. Government's approach to management of its dual water source is contrary to that of Bermuda Waterworks, which fully exploits its available ground water resources to meet base load, while adjusting its production of treated sea water, as necessary, to match fluctuating demand.

Sea water treatment, in the case of the Bermuda Government, appears to have gained favour, perhaps, on the basis of organizational considerations. Purchase of treated sea water under contract for resale to the public eliminates many challenges associated with public sector operations. Despite the fact that Bermuda's fresh ground water bodies represents a true sustainable natural resource, which would be the envy of many other small islands, the cost advantages of its development have been eroded by long-standing inefficiencies in the operation of well fields and by water losses. These, in turn, have had a demonstrable negative impact on the quality of ground water being abstracted, with a knock-on detrimental effect on the reputation this valuable resource.

Under-resourcing of programmes related to the maintenance of ground water abstraction and treatment facilities will impact the ability of ground water to meet the crucial role which seems to have been imposed on it: of meeting peak demand in a drought. The gains made by adding sea water treatment capacity could be negated by losses associated with an inability to access ground water resources, particularly at short notice.

ii. Recommendations

Mains network expansion and, more particularly, the installation of private wells to serve individual residences should be encouraged to combat the distribution crisis which arises in a drought. The need for water truckers will slowly decrease, but will never be totally eliminated. Natural attrition by retirement should ensure that none of the truckers presently in business will suffer redundancy. A cap on the number of licences, at less than the present 41, should be considered in the future.

Current ground water and treated sea water resources are centrally massed as a consequence of an emphasis on capacity development, without sufficient regard to distribution. Consideration should be given to the extension of "trunk" pipelines to the extremities of the island. Alternatively, or additionally, all means of maximizing the development of neglected outlying resources and re-distribution of existing water production facilities should be pursued. Construction of small water production facilities in areas where there is localised high demand and poor service from water truckers was a recommendation made in Ian Saunder's report (1998), which never came to fruition.

Detailed data, as gathered for this report, must be the basis for informed decisions concerning the development of water production capacity in Bermuda. The necessity for more capacity and the form and location of that capacity must be analysed. Unlike Bermuda Waterworks, the Bermuda Government has eschewed full exploitation of available ground water resources, which according to Rowe (2005) are of perfectly adequate quality as sources of water for public supply. These circumstances must be openly examined both from the point of view of organizational challenges associated with public sector operations and from that of potential inefficiencies in the technology and approach to management of the Government well-fields. Thorough capital and operational cost comparisons must be made between production of water from a seawater source and efficient production from ground water sources. (In such an assessment it should be kept in mind that the exploitation of waste heat from the Tynes Bay Incinerator can benefit both sea water and ground water treatment, not just the former).

Underperformance of the Bermuda Government's ground water abstraction and treatment facilities manifested in high losses, high salinities and low output, contributed to the decision to develop sea water treatment capacity. Now that a buffer of surplus capacity exists, it is recommended that the opportunity be taken to objectively review a variety options for the re-development of neglected licensed ground water production capacity. The practice, as appears to have been adopted by the Bermuda Government, of using ground water for peaking purposes as opposed to base load should also be reviewed in light of the challenges entailed in adjusting ground water production at short notice. The inability to react rapidly to accelerating demand, associated with a drought, remains to be effectively addressed.

The Environmental Authority is empowered to "determine or diminish" water rights which have not been "made beneficial use of" (the Water Resources Act, 1975). Depending on the outcome of reviews, recommended in the previous two paragraphs, consideration might have to be given to surrendering the Government's unexploited ground water abstraction licences (water rights) to other developers.

An absence of a body explicitly charged with responsibility for coordinating national water supply in Bermuda has resulted in decisions being made in isolation, unsupported by comprehensive consultation and investigation. Certain aspects of the "big picture" are being ignored such as the important contribution that might be made by private wells. More private wells translate into more low cost water being supplied directly to the point of demand. It is not, however, within any one organization's purview to investigate the relative merits of disparate water sources and promote the development of one over another. It is recommended that ambiguities and shortcomings in Bermuda's national system of water supply should be identified and reviewed with the objective of determining what organisational gaps allowed them to develop and how, or if, a coordinating body would rectify the situation.

Mark P. Rowe, May 2010.

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