Water Resources Management: Vulnerability of Coastal Aquifers to Climate Change & Human Effects.

Water Resources of The Bahamas
College of the Bahamas Lecture (Oct-2011)

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Water Resource Challenges: The Commonwealth of the Bahamas

- All freshwater is in the form of groundwater.
- Only three islands with significant water resources.
- Some small islands have no freshwater.
- Uneven and seasonal distribution of rainfall. North & North Central Rainfall: 50-60 in/yr (1,270-1,524 mm/yr), South Rainfall: 36 in/yr (914 mm/yr); Pronounced Wet Season: May to October.
- Most communities located away from the resources.
- Need for high cost water supply alternatives (Sea Water Reverse Osmosis – SWRO / Desalinization).
- Vulnerability of water resources; 90% of the freshwater lenses within 5-ft (1.5-m) of the surface.
Water Resources of The Bahamas

The groundwater resources of the Commonwealth comprise the fresh, brackish, saline and hypersaline waters found in the near and deep subsurface and in the lakes and ponds that intercept the surface. The freshwater resources occur as three-dimensional lens-shaped bodies, which overlies brackish and saline waters at depth.
Rainfall for The Bahamas

MEAN ANNUAL RAINFALL (1961-1990) FOR THE BAHAMAS

Approximate Scale 1:4,000,000

Tick marks show 15-minute intervals. Sixty minutes equals one degree.
Inverted Geothermal Gradient

A measurable scientific well condition, of the effectiveness of liquid waste dispersion in a deep well, is the temperature profile of the static well water. At depth throughout the Commonwealth of the Bahamas, due to the massive amounts of seawater that move in and out of the carbonate banks in response to tidal currents, the temperature of the water decreases with depth. This inverted geothermal gradient in the subsurface of the Bahamas, is indicative of a high degree of exchange with the surrounding ocean and responsible for very high hydraulic conductivities on a regional scale. This alone differentiates us to the continental areas (Cant, 2004). See Geophysical / Temperature Logs below, for typical 600-Ft zone in the Bahamas:
Environmental & Water Quality Concerns:

- Climate change as it relates to rising sea levels, and storm surges associated with tropical storms.
- Over-extraction of groundwater lenses, and distribution water losses due to the antiquated systems;
- Waste disposal in landfills and septic tanks, which are unlined;
- Industrial and commercial effluents, and their disposal;
- Agricultural and landscaping concerns with regards to the construction and irrigation of golf courses;
- Land & coastal development, excavation of Wetland Areas;
- Leaking underground storage tanks;
Water Resources of The Bahamas – Revised for Climate & Human Effects

Diagram of a Freshwater Lens in an Oceanic Island (Like The Bahamas) - SHOWING CLIMATIC / HUMAN EFFECTS
North Andros Water Resources
Per previous UN, and 2004 USACE Water Resources Assessments
Effects on the North Andros Water Resources, as a result of 2004 Storm Surge (Hurricane Frances!):

- The barging scheme wellfields are approximately 12,000-Acres (4,858-Hectares), with an available freshwater supply of 6,000,000-GPD (22,712-m³/Day). The area consists of the 'Old' and 'New' (Phases I & II) Wellfields.

- Storm surge across wetlands to the west of the wellfield area (distance of 0.9-miles or 1.5-km from wellfield), into the western trenches, and extending to the most eastern trenches of Phases I & II;

- Construction of the open, interconnected trench system facilitated the movement of sea-water throughout the wellfield;

- Trench Water Quality Compromised – Increase of composite salinities in 70% of the supply trenches from 330-mg/L (max) to a range of 1,300 to 15,000-mg/L. Chloride readings of 114-mg/L, down to minus eleven feet (3.35-meters) below ground level in the monitoring wells;

- Groundwater lenses not compromised, but the 4.5-MGD Shipments into the island of New Providence affected (Note: Andros = 2,300 Squ Miles or 5,956.97 Squ Km; Fresh Groundwater = 209.92-Mil Gal. Available, 0.38-Mil Gal. Demand);

- The overall effect on the water resources as a result of continued or repetitive sea-water inundation is a concern. No further occurrences' of storm surge since Oct-2004, but the resources continue to be monitored for the effects of the surge.

- Water Quality in Oct-2007: Trench Salinity Range between 1,000 to 3,000-mg/L.
NORTH ANDROS WELFIELDS
Evidence of Storm Surge (Hurricane Frances!)
The GRAPHIC Programme...

...to raise awareness of the importance of groundwater as a resource, and its vulnerability to climate change; to promote study areas around the world (“case studies”) that can provide key research with high transfer value.

Groundwater Resources Assessment under the Pressures of Humanity and Climate Change

GRAPHIC

A framework document
GRAPHIC Series N°2

GRAPHIC provides a platform for exchange of information through case studies, thematic working groups, scientific research, and communication.

GRAPHIC serves the global community through providing scientifically-based and policy-relevant recommendations. GRAPHIC uses regional and global networks to improve the capacity to manage groundwater resources.
The Bahamas...

- Low lying carbonate “platform” islands with little topographic relief

- Lack of topography means little surface-water runoff, heavy reliance on fresh groundwater floating on deeper salt water (augmented by desalination)
Andros Island

- At 2,300 square miles (5,956.97 Sq Km); Andros is the largest island in the Bahamas and the fifth-largest island in the Caribbean
- 80% of Andros is less than 5-ft above sea level
- Extremely vulnerable to sea-level rise and topical storm surge
Fresh Groundwater Lens: A Key Drinking-Water Resource

Precipitation needed to continuously replenish freshwater lens.

Pumping well

Sea level

Freshwater drains into ocean.

Freshwater/Saltwater interface

Lower density causes freshwater to ‘float’ on top of saltwater.

Tidal fluctuations mix freshwater and saltwater at base of lens.
Storm Surge Vulnerability...

- Sept 2-4, 2004: Hurricane Frances (Category 4) passes directly over the Bahamas and eastern US.
- Nearly complete destruction of the Bahamas agricultural economy, several homes destroyed, at least 3 deaths.
- The associated storm surge on Andros Island pushed several feet of ocean water onto the north end of the island inundating the freshwater collection trench network. This part of the collection system is being pumped but remains contaminated by salt.
[1.] The North Andros Barging Scheme Wellfields were recently utilized to supply 50% of the present demand to the island of New Providence. Exploitation of this aquifer is considered to be medium to high.

[2.] In excess of 10-years of simultaneous data exists for the area: Measurements of quantified extraction, as well as water quality (temp, level, conductivity) are available. Rainfall is available and limited piezometric level data is on file.

[3.] Previous detail studies are available that characterize the topography, geology, hydrogeology, and its hydrologic behavior.

[4.] Four immediate individuals available, with water resources experience: Dr. Richard Cant (Hydrogeology), Mr. Philip Weech (Hydrology/Environment), Mr. Michael Swann (Hydrologist-Water Quality), and Mr. John Bowleg (Engineering/Hydrology). A total of four technicians/servicemen are available to assist (between Nassau and Andros).

[5.] Given the 2004 inundation of seawater into the wellfield area, and the displacement of all the freshwater contained in Phases I, & II; both the Bahamas Government and WSC remain favorable to additional hydrological studies of the area.

(Note) Previous ‘MoRSCA PDF-B’ Submission - Management of Risks to the Sustainability & Integrity of Coastal Aquifer Systems in SIDS.
Key Resource Management Questions...

- How is the dynamic stability of the fresh groundwater lens related to weather events?
- How will the groundwater lens respond to changes in the frequency and intensity of tropical storms or incremental sea-level rise?
- Are there specific areas of the groundwater resource that should be protected for future development as a drinking-water supply?
- How long before sea-level rise removes this as a viable water supply; what is the planning horizon for developing alternatives?
Long-Term Plan of Study...

- Install wells; refine extent of the lens; and monitor event driven, seasonal, and pumping effects on the freshwater lens.
- Improve the data archive and data management system for the study area.
- Develop a conceptual model and understanding of the water budget for the freshwater lens.
- Numerically model the system to permit simulation and forecasting of the impacts of management decisions and climate change.
- Use of Deep Wells (reverse geothermal conditions in the Bahamas): For Ocean Thermal Energy Conversion (OTEC) Research, & continued use for Treated Effluent Disposal?
Refine extent of, and monitor seasonal and pumping effects on, the freshwater lens.

- Inventory existing well network and verify location, depth, and integrity.
- Install approximately 20 additional wells at critical locations and depths, weekly monitor water levels.
- Instrument selected wells with water-level pressure transducers and conductivity monitors.
- Erect and telemeter a data collection tower for evapotranspiration, energy budget, and meteorological data.
- Evaluate effects of pumping trench-network collection system on freshwater lens.
- Train staff in the monitoring and maintenance of the field data network.
ADDITIONAL DATA:

Water Resources – The Bahamas
What is different about the Water Resources in The Bahamas?

- **Hydro-geology**
  - Freshwater lenses float on seawater at depth.

- **Land Elevations**
  - 80% of the land within 5-ft (1.5-m) of mean sea level.

- **Subsurface - Inverted Geotherm**
  - Indicative of a high degree of exchange with the surrounding ocean.
### Table: Freshwater Resources – The Bahamas

<table>
<thead>
<tr>
<th>Island</th>
<th>Maximum Volume Available Daily (million imperial gallons)</th>
<th>Water Available Daily per Person (imperial gallons) 2000 Census</th>
<th>Calculated Water Demand** (million gallons†)</th>
<th>Total Population 2000 Census</th>
</tr>
</thead>
<tbody>
<tr>
<td>Abaco</td>
<td>79.1</td>
<td>6,004</td>
<td>0.66</td>
<td>13,174</td>
</tr>
<tr>
<td>Acklins</td>
<td>4.36</td>
<td>10,307</td>
<td>0.02</td>
<td>423</td>
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<tr>
<td>Andros</td>
<td>209.92</td>
<td>27,567</td>
<td>0.38</td>
<td>7,615</td>
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<tr>
<td>Bimini and The Berry Island</td>
<td>0.17</td>
<td>74</td>
<td>0.12</td>
<td>2,308</td>
</tr>
<tr>
<td>Cat Island</td>
<td>6.8</td>
<td>4,393</td>
<td>0.08</td>
<td>1,548</td>
</tr>
<tr>
<td>Crooked Island</td>
<td>1.74</td>
<td>5,103</td>
<td>0.02</td>
<td>341</td>
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<tr>
<td>Eleuthera, Harbour Island &amp; Spanish Wells</td>
<td>8.13</td>
<td>721</td>
<td>0.56</td>
<td>11,269</td>
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<tr>
<td>Exuma &amp;Cays</td>
<td>2.9</td>
<td>811</td>
<td>0.18</td>
<td>3,575</td>
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<tr>
<td>Grand Bahama</td>
<td>93.17</td>
<td>1,984</td>
<td>2.35</td>
<td>46,954</td>
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<tr>
<td>Great Inagua</td>
<td>0.86</td>
<td>822</td>
<td>0.05</td>
<td>***1,046</td>
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<tr>
<td>Long Island</td>
<td>2.88</td>
<td>978</td>
<td>0.15</td>
<td>2,945</td>
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<td>Mayaguana</td>
<td>0.65</td>
<td>2,481</td>
<td>0.01</td>
<td>262</td>
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<td>New Providence</td>
<td>9.63</td>
<td>45</td>
<td>10.62</td>
<td>212,432</td>
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<tr>
<td>Ragged Island</td>
<td>0.01</td>
<td>145</td>
<td>0.00</td>
<td>69</td>
</tr>
<tr>
<td>San Salvador, &amp; Rum Cay</td>
<td>0.1</td>
<td>97</td>
<td>0.05</td>
<td>1,028</td>
</tr>
<tr>
<td><strong>All Bahamas</strong></td>
<td><strong>420</strong></td>
<td></td>
<td></td>
<td><strong>304,989</strong></td>
</tr>
</tbody>
</table>


Notes:
- † Assume imperial gallons, although source document states 'million gallons' as stated here.
- * Freshwater resources occur as concave lens-shaped bodies that overlie brackish or saline waters at depths (ground water).
- ** Based on standard water usage of 50 gallons per person per day.
- *** Population figure differs slightly from Table 1 due to reference used.
Available Water Resources - New Providence
New Providence (Nassau) Water Sources
Approximate Production Cost, per thousand imperial gallons (TIG):

Based on 2003/04 Production Figures.

<table>
<thead>
<tr>
<th>SOURCE</th>
<th>VOLUME (Million Gallons / Day – MGD)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Desalinization / Reverse Osmosis (RO)</td>
<td>2.0-MGD @ $5.61 / TIG (Est. 6.5-MGD, 2006) = 65%; ^ 90% (2012)</td>
</tr>
<tr>
<td>Andros Wellfields (Shipped)</td>
<td>4.5-MGD @ $5.50 / TIG (Est. 2.0-MGD, 2006) = 20%; 0% (2012)</td>
</tr>
<tr>
<td>New Providence (NP) Wellfields</td>
<td>3.5-MGD @ $3 to $4 / TIG (Est. 1.5-MGD, 2006) = 15%; 10% (2012)</td>
</tr>
</tbody>
</table>

NOTE: WSC NP Storage Reserves (Total) = 45-MIL. All information is subject to change, based on additional SWRO Sources & increased Storage Reserves.
Water Resources Assessment of The Bahamas

MOST RECENT UPDATE

Produced By:- U.S. Army Corp’s of Engineers (2004)

Compiled Using Existing Data and Reports. Data approved by the Bahamas Government.