THE BAHAMAS USE OF DEEP WELLS FOR EFFLUENT DISPOSAL, AND AS A SOURCE OF SEAWATER USABLE FOR MULTI-PURPOSES.

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Abstract.

Using its unique geology the Bahamas is able to use deep wells to dilute and disperse treated wastewater to subsurface horizons that contain seawater but are distinct from the open marine environment. The best horizons for attenuation and advection occur between 400 and 600 ft and these relate to the sea level low stands of the glacial advances of the Pleistocene. The cavern systems at these horizons have been investigated in detail by means of geophysical logs, down-the-hole video, trace tests, cave divers, geologists, and the drill rig operators themselves. These horizons are used for the disposal of treated wastewater, desalination brines, used cooling water, and storm water runoff. This practice has been carried out successfully in some locations for more than 40 years. As much as 10 million gallons per day have been disposed of using just a single well uncased from 400 to 600 ft. Evidence and observations show that vast volumes of saline water move through the Bahamas Banks at these and some other shallower horizons, and this enables the wastes to be diluted to such an extent it achieves acceptable standards for open marine discharge.

Most if not all countries dilute their treated wastes in water bodies at the surface, like rivers and lakes, but the Bahamas does not have these, and since it will not dispose of such wastes directly into the sea, all it has left is the subsurface. It should be noted that most urban sewage collected by the WSC is too salty to be reused for irrigation, or similar practices, and so it is appropriate that it goes into a seawater environment. In a controlled collection system, like a private development, where the wastewater is fresh it can be reused. The WSC sets stringent requirements and specifications for all disposal wells, and presently there are hundreds in use around the various islands. Locations where Blue Holes occur need to be avoided.

Deep wells are also used as a source of clear cold seawater which is used for desalination, cooling purposes, and even mariculture. Specific horizons are reserved for certain practices which includes the protection of fresh and brackish groundwater.

Temperature logs indicate that the Bahama Banks have a reverse geothermal gradient caused by subsurface penetration of cold Atlantic seawater and this will enable deep wells to be used for Ocean Thermal Energy Conversion and Seawater District Cooling technologies.

Introduction.

What is unique about the geology of the Bahamas is that a carbonate/evaporite sequence of rocks extends down from the surface to just over 4 miles, and that these all comprise sediments that formed in shallow seas or evaporite basins. Oil exploration wells drilled down to depths of more than 20,000 ft provide hard data on this (Epstein and Clark, 2009), and geophysical investigations indicate that the igneous basement occurs at a depth of about 7 miles. Terrestrial-source sediments of Jurassic age appear around the 4 mile level in the central Bahamas, and these are believed to be underlain by Triassic red beds.

The Bahama Banks occur as partially exposed plateaux between the Atlantic Ocean, which is about 18,000 ft deep, and the North American Plate. At the ocean floor level the rocks forming these plateaux are about 100 million years old and at the surface modern day sediments are being deposited (Figure 1).

During the ice ages it is well established that sea level fluctuated as the ice sheets advanced and retreated. The lowest levels that sea level fell to range from 400 to 600 ft when the ice advances were at their maximum. This would have left a range of limestone plateaux in the Bahamas and Turks and Caicos areas, subject to atmospheric erosion. Karst solution systems would have developed, and these are now characterized by the Blue Hole sink systems and the many cavern solution systems that occur in the subsurface. These have been described and explored by many (Benjamin, 1970; Dill, 1977; Palmer 1985; Todhunter, 2010). With the present interglacial high they are all flooded, though they contain and preserve many fascinating relicts of the past (Steadman et al 2007).

Vertically orientated solution systems, like many Blue Holes, would reflect conditions generally typified in the vadose zone, whereas the horizontally aligned systems reflect those of the phreatic zone, including the halocline horizon (Smart et al 2006).

Where past sea levels remained for long periods, or where they occurred more frequently, the solution systems would have been better developed. These features would now dominate the hydraulic flow of water through the Bahama Banks particularly in response to tidal pressures.

Because of their significant impact on the subsurface hydrology of the islands (Cant, 1992) the cavern systems have been studied in as much detail as possible by means of geophysical logs, down-the-hole video records, trace tests, cave diving observations, geological studies, and of course by drill rig operators. Fairly good subsurface information is now available concerning these caverns, and as early as 1977 the Bahamas Land Resources Survey (BLRS) compiled a generalized geological cross section for the upper 100 ft for the central Bahamas area as shown in Figure 2(Little et al 1977).

Subsurface hydraulics, and the use of deep wells.

Studies on water level fluctuations in boreholes drilled in the islands by the BLRS and other researchers, reveal that major impacts can occur that effect these where cavern systems came into play. Tidal effects are greater in boreholes penetrating cavern horizons, and the time lag for highs and lows are also greatly reduced. The specific capacities and transmissivities of the formations with these features are significantly higher than those where they are not present. Based on the evidence provided from these factors it can be assumed that the hydraulic connection to the sea therefore increases with connection to these systems. This demonstrates that the tidal pressure wave penetrates through the subsurface of the banks, and in turn so does the ocean, which duplicates the situation described in South East Florida (Kohout 1967). This hydraulic relationship explains situations where Blue Holes and similar features demonstrate "water fountains" or "whirlpools" in many wetland environments (Little et al 1977).

It has been documented (Whitaker and Smart, 1990; Whitaker 1992) by hydrological monitoring that the volumes of saline water moving through the subsurface caverns are significant, though such movement has not been quantified for any specific horizon at this time.

By drilling a borehole from the surface down to a specific cavern horizon it is possible to link the surface environment with a zone which can have a far greater hydraulic connection to the sea. Stormwater drainage wells exploit this situation by using whatever head the ponded water might have above that of the natural water table to drain water down to the subsurface.

Treated wastewater and other effluents like reject brines can all similarly be "drained" or pumped down into the subsurface into a seawater environment which is itself distinct from the open marine environment. The hydraulic characteristics of the major cavern horizons, like those described from the 400 to 600 ft level, mean that the waste effluent is quickly diluted (attenuated) in the receiving zone, and then dispersed by advection resulting from the dynamics of the groundwater flow in that location. This process enables effluent wastes to be diluted to such an extent that it can achieve standards for open marine discharge.

In an ideal situation the cavernous receiving zone would be overlain by an impermeable aquiclude, which would provide a barrier to the migration of the wastes up to the surface. Unfortunately no such formations have been discovered at the depths presently used for waste disposal, though some horizons do comprise dense limestones and dolomites and these have proven to be relatively impermeable. The Blue Holes which are common features in some areas can provide an obvious connection between the disposal zone and the surface and so areas where these occur have to be avoided.

Trace tests and other investigations carried out, to date, have all failed to reveal the build up of "waste plumes" at the 400 to 600 ft depth horizon. In the Malcolm's Park location where a steel casing was used to inject raw sewage in the early 1970s, the casing failed at a shallow depth as a result of corrosion, and monitor wells installed in close proximity did reveal widespread evidence of subsurface pollution in the area (Cant, 1975).

Disposing of treated wastewater in the Bahamas.

Most if not all countries dilute their treated wastes in water bodies at the surface, like rivers and lakes, and some use sea outfalls. The water in certain rivers, particularly in Europe, is reused for potable purposes time after time. The Bahamas has no rivers or suitable lake bodies, and because of the results of sea outfall tests carried out in the early 1970s (Howard Humphreys and Sons, 1972) there is a Government policy in place that prevents the use of sea outfalls.

This means that effluent wastes can only be reused or disposed of into the subsurface. Significantly most of the urban sewage collected by the Bahamas Water and Sewerage Corporation is brackish or saline, mainly because of the use of private wells and infiltration, and this means that it is unsuitable for reuse for irrigation purposes. It is therefore appropriate that the treated effluent be returned to a seawater environment, and just such an environment is conveniently located in the subsurface throughout the Bahamas. In a controlled collection system, like a private development, where the wastewater is fresh it can be reused, and this is the recommended procedure.

The Water and Sewerage Corporation sets stringent requirements and specifications for all disposal wells. Generally these are based on the composition and volume of the treated effluents, the local hydrology and geology, casing and grout requirements, and the results of pumping tests. In the Bahamas fresh groundwater only occurs in the Lucayan Limestone (Cant and Weech, 1986), and this horizon, which extends down to about 110 ft in the Central Bahamas, is a protected zone. Below this the next 150 ft in the subsurface is reserved for seawater abstraction, and the reject zone extends from below 400 ft to whatever depth might be necessary. Geophysical logs and pumping tests usually reveal where adequate receiving zones occur.

It should be noted that in those areas where sea outfalls are used that the deepest in existence, in Macuto, Venezuela, discharges untreated wastewater at a depth of 180 ft. This is significantly shallower than the reject zone presently used in the Bahamas' subsurface.

There are presently hundreds of disposal wells in use around the islands. Individual wells have been used to take as much as 10 million gallons per day, but usually much less than this. Some wells have been in use for 40 years. The practice has generally been successful. Failures have resulted from blockages because of inadequate screening and the lack of appropriate treatment, the use of the wrong casing material, and the improper installation of casings and grout. The Corporation will normally have competent technicians on site to observe critical phases of well installation and testing.

Deep disposal wells are used for treated effluent wastes, desalination brines, used cooling water, and storm water disposal. In a properly managed development the wells may be used for the disposal of effluents collected from several sources.

Other uses for deep wells.

As mentioned in the previous section the 110 to 260 ft zone is used to abstract seawater. This water is used for desalination, various cooling purposes, and mariculture projects. Other uses have been proposed (Hall, 2003), but not yet implemented.

Deep wells provide an excellent source of water for reverse osmosis because there is usually no organic content. In certain situations the presence of hydrogen sulphide has been a problem and the possibility of buried paleosols can introduce unwanted elements like iron. Generally the water is good and those planning to use it will test it to ensure it meets their requirements.

Because the ocean water surrounding the banks penetrates into the subsurface, colder water is found at greater depth. The Bahamas has proven to have a reverse geothermal gradient and to date all temperature logs taken from deep boreholes have shown the temperature falling in a similar fashion to that of the surrounding sea. Cold water from depths below 400 ft has been used for air conditioning with chillers in many developments. At about 600 ft the water is approximately 71 F degrees (21.5 degrees C). If this temperature trend continues down to greater depths then water cold enough to be used for air conditioning could be obtained without the need for chillers. This will make Seawater District Cooling (SDC) using just boreholes a viable option, and therefore a good economic proposition.

Continuing to extrapolate it is possible that at a depth of about 3,000 to 3,500 ft the water should have a temperature of about 43 degrees Fahrenheit (6 degrees C) which would make it suitable for Ocean Thermal Energy Conversion (OTEC). Boreholes would be considerably cheaper to install than the ocean pipelines usually used for this purpose, and there would be a justifiable project to drill test wells to this depth to prove the contention and to carry out the tests needed to show the adequate volumes of water could be obtained from this depth. A proposal for such a study has been prepared (Cant, 2011). If boreholes can provide the water required then this source of water will enable OTEC projects to be used more frequently on a smaller scale than presently envisaged.

The application of deep well use elsewhere.

Making use of deep wells for disposal purposes can be applied in any geological environment where subsurface cavern systems occur at the appropriate depths, however there needs to be a dynamic hydraulic system in place to ensure dilution and dispersal of effluent wastes will occur. In south east Florida the “Boulder Zone” has long been used for this purpose (Meyer, 1989). The “Boulder Zone” occurs in the Upper Oldsmar Formation, at a depth of 2,750 to 3,250 ft in the Dade County area, and in 2002 approximately 340 million gallons per day of liquid wastes were injected into it by means of 126 active injection wells in South Florida (Maliva, Guo, and Missimer, 2007). Vertical confinement of injected wastes in the “Boulder Zone” provide effective transit times for natural attenuation of wastewater constituents according to Malina et al (2007). The exception occurs where vertical hydraulic conductivity caused by fracturing allows upward migration of wastes. The fracturing is thought to have occurred at the time of a deformation event in the Late Miocene or Early Pliocene. There is no evidence to date that such fractures occur in the subsurface of New Providence, however on-going research that might reveal new information on this subject is followed with interest.

Atolls and other small limestone islands provide some potential for the technology, but in nearly all cases these are caps overlying a volcanic seamount, and so there is a depth limitation to the practice, and there will be little scope in exploiting a reverse geothermal situation. Test wells, geophysical logs, and pumping tests will indicate what potential there is for the use of deep wells in any given location.

The Bahamas is a signatory to the Cartagena Convention and its Protocols. The Protocol concerning pollution from Land-Based Sources (LBS) is the one that relates to effluent disposal in the marine environment. It is important to note that in the nineteen (19) Articles, and four (4)

Annexes that comprise the LBS Protocol there is no mention made to the practice of deep well disposal as used in the Bahamas. Minor amendments would need to be made to the existing Articles and Annexes, and the Bahamas has prepared a modified draft for consideration should it be deemed necessary.

Conclusion.

Based on the recent results of using deep wells for effluent waste disposal in the Bahamas, it can be concluded that this is an acceptable method of disposing of treated liquid wastes. It has also proven to be a satisfactory method of disposing of other effluents like desalination brines, flood water, and used cooling water.

Deep wells have also proven to be an ideal source of water used for a variety of purposes like reverse osmosis, cooling buildings and machinery, and mariculture. With further refinement it would appear deep wells could also be used for major Seawater District Cooling projects, and possibly Ocean Thermal Energy Conversion undertakings.

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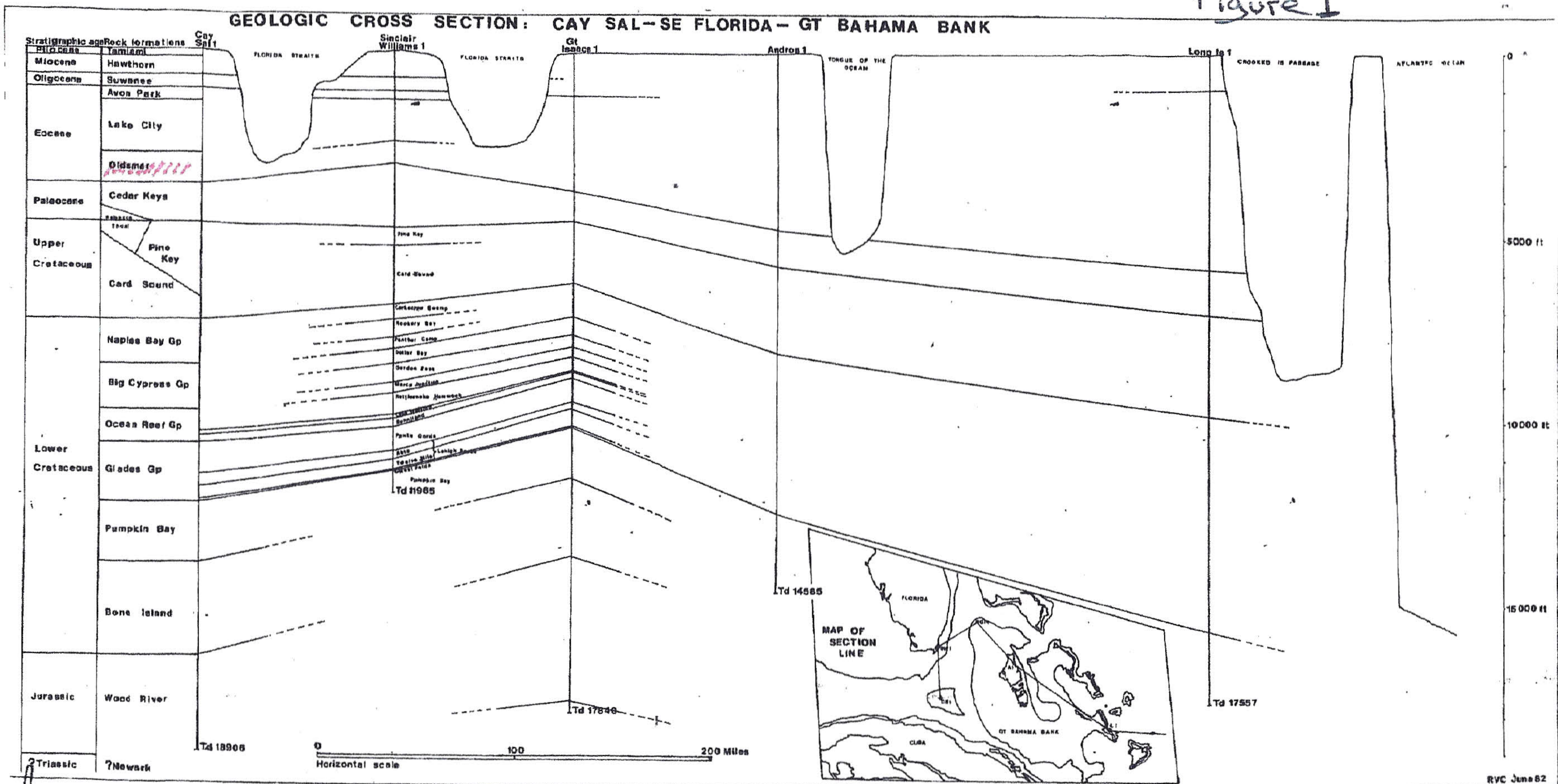
Figure 1



Based on stratigraphic correlation of Winston (1982)

//////// Lower Floridan Aquifer: Boulder zone.

Figure 2 Generalised geological section through Bahamas Bank marine sequence