Under the Jungle - Geo Karst challenge - Sunday June 28

Nat says - These spaces underground are so incomprehensibly huge, they stretch across the Peninsula, and there's no way we have found all the caves. How much water is in the caves of the Yucatan Peninsula? [Send a message to Natalie and she will tag you for future Sunday Geo Science Discussions]

This is indeed a vast question, and to start to have some answers we will need to narrow it down a bit. This is going to be a constrained order of magnitude model estimate.

What is the "aquifer"? ~= fresh water lens

An aquifer is any ground formation that you can get water out of. Obviously the aquifers that are most of interest (human perspective - not ecosystem :-)), are the ones that you can get DRINKING water out of. In this case of the Yucatan Peninsula - we are therefore most interested in the fresh-water lens, which is formed by the accumulation of rainwater infiltrating down from the surface. The lens is the accumulation of rainwater that sits in the ground, literally as a puddle on top of the saline water that is underneath. It is thin near the costs and gets thicker as you move inland.

We are aiming to figure out to +/- cubic kilometer, the volume of the fresh water lens. Then we are going to figure out ~ how much of that is water and how much of that is rock.

#1 - how big is the Yucatan Peninsula aquifer?

Right now, there is only one fresh water lens that we know about with confidence (... more on that below) up to the coastline.

If we go too far south, then we hit the Maya Mountains, the geology changes, and .... arguably we are out of the lowland Yucatan Peninsula aquifer system. So let's stop around Chetumal and Campeche - which gives us an area really surprisingly close to 100 square km.

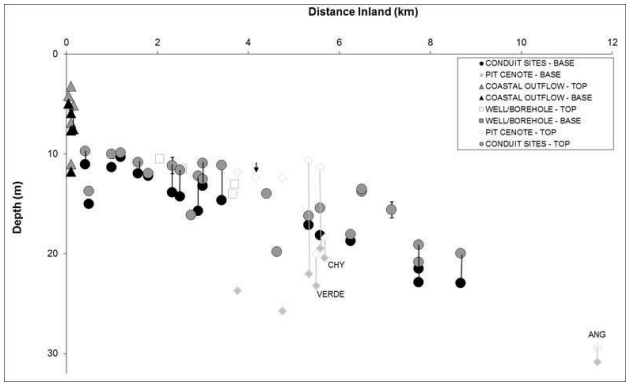
I am ignoring Cozumel island, but including most of the barrier islands. The treatment of the coastal features does not change the numbers much at all.

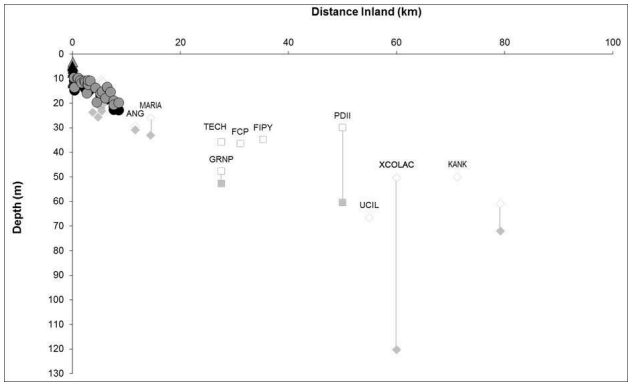
We have some data on the shape of the lens… which is our starting point but seriously guys we scientifically need more data from beyond the Caribbean coastline and I do mean middle of the Peninsula - from Coba and west (and north).

Here is the data I do have - showing that the base of the lens is ~10 m even right close to the coast, but overall it is ~ **15 m** for the first 10 km.

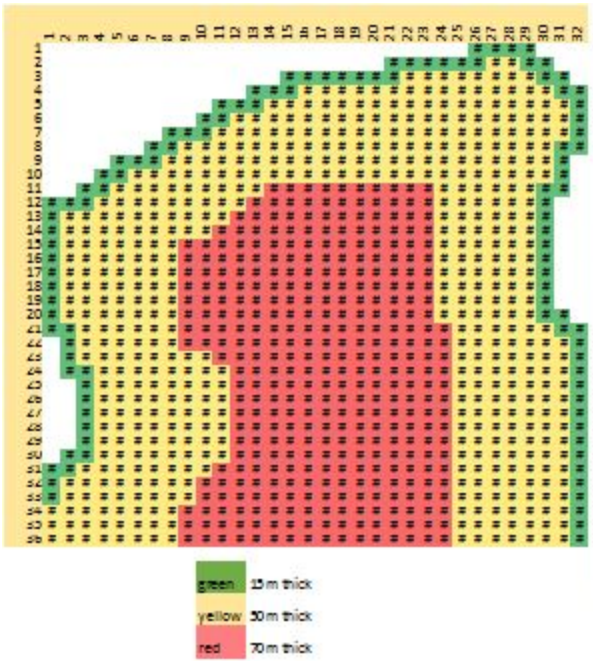
From 10 - 80 km - it is very approximately **50 m** to base of the lens (or top of the halocline).

Based on limited data, it does look to be deeper than **70 m** beyond 80 km. We will therefore use 70 m thick beyond 80 km from the coastline.





We are going to now discretize the aquifer…. Which means conceiving of it in squares and assigning values. The green are the squares adjacent to the coast with ~15 m thick fresh water, yellow 50 m, and red inland at 70 m. I have made a shape ~approximately that of the peninsula - slightly rotated to make this easier.



1000 squares ~=100 km^2 - or 10x10

36 squares north to south - from Chetumal to Holbox ~= 360 km

~32 squares - or 320 km across from Tulum to Clestun

53448 sum - m thickness.

53.4 average thickness in m

0.053 km thick (ie /1000 m / km)

53.4 cubic km

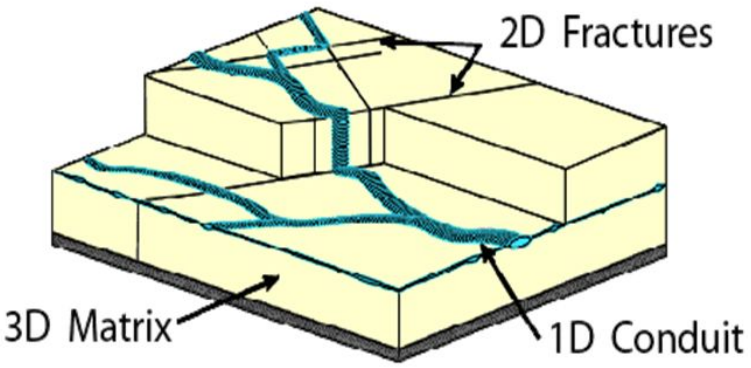
17.6 % porosity - combined rock matrix + fractures/bedding + conduits

9.4 cubic km of "fresh" water.

But we are not done - since that is the total volume of the fresh water lens….. And most of that is rock!

Removing the rock from the aquifer….. So that we have just.

You might have been with us when we talked about porosity, fractures, and conduits. Of course the conduits are the most important for the permeability - and in all karst the great majority of all the water flow is in the conduits. That is a key feature defining karst - that dissolution conduits exist and that they dominate the flow. However - I want to underline that a conduit is anything with turbulent water flow - so about the size of pencil! As cave divers we just like our conduits to be much bigger and diveable...



FLUJOS HIDROLOGICOS ESTAN CONCENTRADAS EN LOS SISTEMAS INTERCONECTADAS, TIPICO DE CARST

When we up the open spaces in the rock matrix + fractures + conduits (e.g. caves - including the tiny ones).... We get **17.6%** using hydrogeo data from the area of Nohoch Nah Chich. This is also consistent with direct measurement of the rock porosity near Merida where a very nice study was done on hundreds of samples. [FYI - porosity is more like ~20 around Merida- data below.]

		Matrix	Fracture	Conduit
Porosity	Mammoth Cave, KY	2.4 %	0.03 %	0.06 %
	Nohoch Nah Chich, QR	17 %	0.1 %	0.5 %
Proportion of Storage	Mammoth Cave, KY	96.4 %	1.2 %	2.4 %
	Nohoch Nah Chich, QR	96.6 %	0.6 %	2.8 %
Proportion of Flow	Mammoth Cave, KY	0.00 %	0.3 %	99.7 %
	Nohoch Nah Chich, QR	0.02 %	0.2 %	99.7 %

(Worthington, Ford & Beddows 2000)

Total volume = ~53 km^3, but only 17.6% of that is water, so that leaves .... 9.4 km^3 of water.

Sadly - this is NOT a "fuck-ton" of water, to use Lexi's technical hydrogeo term….

If we compare that to the great lakes (per US-EPA www.epa.gov) …. Then we see that it is disappointing really.

You can appreciate this if you ever try and draw the fresh water lens to scale - at 0.07 km thick to 320 km across, you would be challenged to draw that to scale with a pencil on a normal sheet of paper.

Lake	Volume in Cubic Kilometers
Superior	12,100
Michigan	4,918
Huron	3,543
Ontario	1,640
Erie	480
Total	22,681

If these numbers are not quite right - then how wrong could they be?

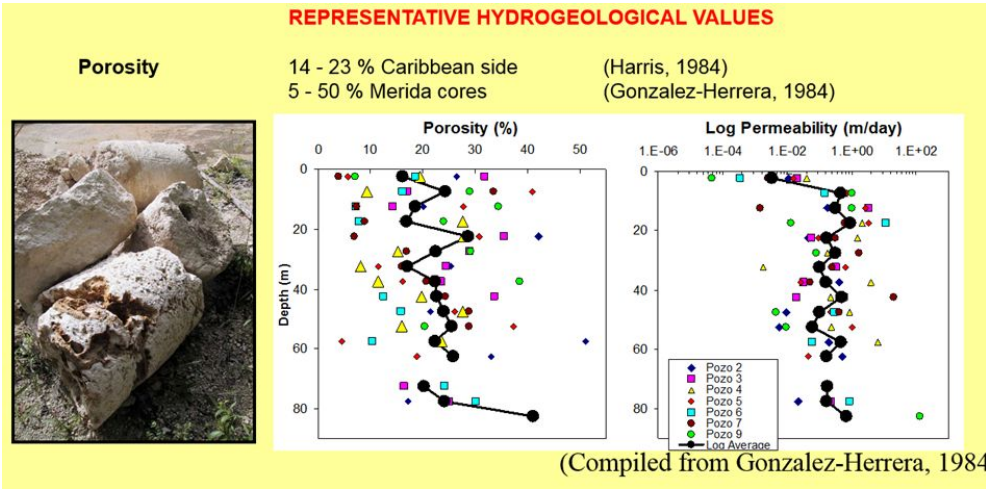
Let me know if you find a calculation error - that would certainly not be the first …..

First I would mention that you can spend mucho time figuring out details, drawing better coastlines, creating better boxes, etc… and your answers will only change in the decimal places.

That being said - yeah lets see how sensitive our calculations are to the numbers we did use…..

Thickness is too small? Lets say the fresh water is 100 m thick in the middle part (instead of 70), and is 70 m thick in the 10-80 km band. That still only gives 75 cubic km for the whole lens - and 13.2 km^3 of water. Still unimpressive.

There is more cave/porosity? Let's use a more generic 25% porosity for young tropical limestones…. And indeed a good set of data from Merida comes in at ~20%. With 25%, we still only get 13.4 km^3 of water.



What if both the thickness and porosity are higher? If we go with 25% porosity, and the 15+70+100 m thicknesses for our three zones… we have 18.7 km^3.

Still - even with putting much greater porosity (25%), and much thicker lens (100 m over middle) - the overall answer does not change, with ~20 km^3 of water (instead of ~10 km^3) - remains quite small compared to Lake Eries the smallest of the great lakes.

What are the known-unknowns.

- Top of my list, is we need to get much better quality and distribution of halocline top-to-bottom going right across the peninsula. Is the lens 70 or 100 m in the middle - that makes some big differences for management, policy, contaminant flows, etc.
- More geological sections and analysis of samples of - especially to find cavernous beds and consider porosity/permeability - again going across the peninsula. This is also needed - An extreme permeability beds need to found. That is not where you want to inject waste waters.
- If we can't have the cores, then we can do hydrogeo pump tests on wells, and get permeability parameters from that.... Even though we won't know much about the caves except that they exist and when forced under the pressure the water flows. Anyone got a compressor and a pump? .... Also need the boreholes....

What are the unknown-unknowns.

It is a very real possibility - that there is a second deeper freshwater lens that has not yet been scientifically measured.

This is the one that gets HYPER-VENTILATING.... And really I put this in the known-unknown bucket these day. It increasingly can be argued that there is a DEEPER fresh water lens - under the top one - and under some saline water intruding from the margins.

We know there is deep cave at 100 + meters - and that it may not be human-enterable. Nonetheless it does have turbulent flow, therefore = cave. The British Geological Survey video taped fish at 120+ m depth in a borehole in Merida decades ago. [This was in the early 90's and the report exists, but the tape was lost.]

I now have several measurements of lower salinity in the bottom of very deep wells - which at first I always thought was an error of some kind (ie the drill "mud" used to make the boreholes is lower salinity and also sinks), but now they look like they may be real.

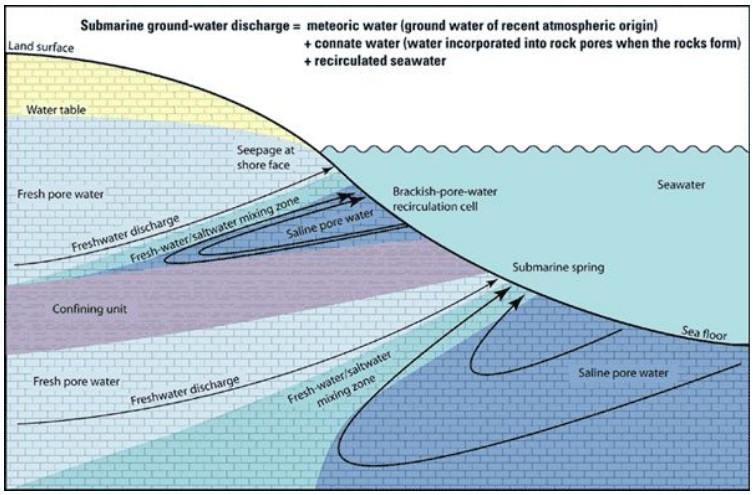
All the well drillers say there is more fresh water - under the salt water!!! I put great weight on local knowledge....

And - we have historical (80's :-)) reports of deep discharges off the coast - the first ones coming from people profoundly narked. But Steve Bogarts has found them diving correct mixes (ie non-narked).

Most recently I have been working with Luis Leal who has brought back initial water samples that are dilute from marine water for offshore sites.

And the geology would support this. We know we have caliche layers which even in the shallow aquifer are aquitards over 10-100's of m easily in places. There could easily be a massive caliche further down, that traps fresh water underneath.

Globally - these 'burried" fresh water aquifers do occur in other carbonate platforms.



From USGS - florida technical doc