Under the Jungle - Geo Karst challenge - Sunday July 5

Nat says - Let's talk about FLOW! HOW LONG does it take for water to move from inland areas like Valladolid, or the center of the Peninsula to the coast? Is it possible we are diving in rain that hit the peninsula years ago? Decades ago? I would love to think that I am swimming in mastadon water 🙂 HOW FAR DOES THE WATER TRAVEL? Is water from Valladolid eventually coming out at Xel Ha or other places along our coast or does it end up somewhere else? I know there are a few outlets up north...

Wow – big questions this week. The following does eventually get around to answering them.

1. **How long does the water take to flow to the coast?**
    a. **Typical flow rates…**
        Once in the caves km or miles per **day**
        Water in the rocks – km or miles per **year**
    b. **"age" of the water**
        The water in the caves is a mix of younger and older water… and average age is likely 100-1000's of years old. Yes – you may be swimming in residual gomphothere pee…

2. **Where does the water flow / where does it come from?**

    a. **What do the drainage basins look like?**
        Short answer is …. We just don't know and we have sketchy overall water budget, and ideas on which way the water is flowing over most of the peninsula.

        I argue that yes, water form Valladolid does likely come out on the Caribbean coast – and crosses over some major features like the Holbox Fracture zone. It has to since so much water has been directly measured as coming out there.

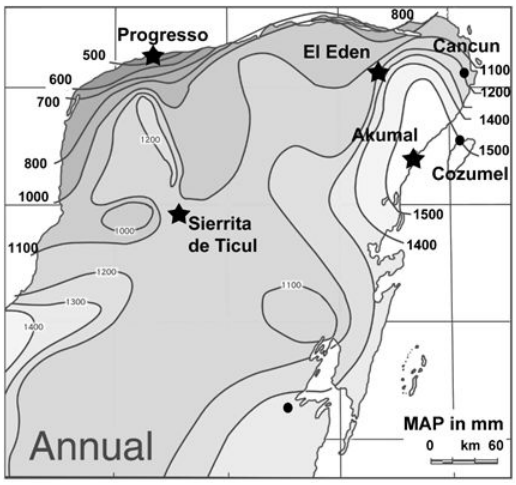
        While we definitely need exploration on the north and Gulf coast…. There does not look to be as much water coming out there – at least presently. We also need to look for shallow off-shore spring!

Background Information.

Last week we focused on how much water is in the fresh lens aquifer. Using a simple model based on representative halocline depths determined from instrumental profiles, and then combined with hydrogeo factors that include ~20% of the aquifer volume is water (compared to 80% is rock...) – we found that the fresh water lens is ~10 cubic km.

(See Nat's Facebook posting for all the chatter….. or you can go straight to the "long answer" summary here - https://docs.google.com/document/d/1REgEp2ro7TPWuIArd2miC14C1MUNh6SeXWmjbfQDadQ/edit)

If the aquifer were "empty" (and closed!) how long would it take to fill it up again with 100% rainwater?



Our model says that the average lens is 53.4 m thick, with it being thinner on the edges (~15 m) and thicker in the middle (70 m). The rainfall over the peninsula is ~1 m/year, with max of ~1.5 m rain around Playa del Carmen, and down to <500 mm in Progresso. Super dry there.

If we grossly pretend that nothing is coming out – no water to the coastlines and not a drop for the plants and animals…. then there MINIMUM flushing time for water in the system is ~50 years of water in the fresh water lens.

But there is water coming out – so how much? Ocean boundary…

If the caves were surface rivers, they would likely all have monitoring stations. Flooded cave monitoring – not so easy, and certainly not within the reach of most government agencies. We do not do this well in Florida either or any other coastal karst. A real challenge, and indeed that was a huge part of my PhD many years ago, and my motivation for developing new technologies (Cave Pearl Loggers) for monitoring cave slows in the last years.

Step 1 – get site access – and some assurance of having it for years!

Step 2 – get as much data as you can, for as long as you can, making sure you have good coverage of both rainy and dry sea season conditions, and then also a wide range of sea levels. Snapshot example data to the right...

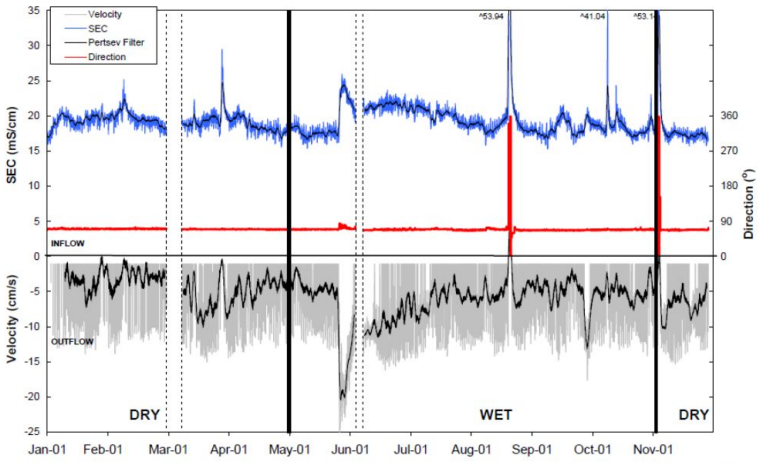


Figure 5.27 Casa Cenote RCM7 time series for velocity, direction to which water is flowing, and SEC from 1 January to 28 November 2001. Pertsev filter plotted for velocity and SEC.

Step 3 - Then the real work starts, which is calibrating the site – so that the instrument numbers can be read as actual discharge – which is volume of water over time – in m^3/s usually.

A team is needed since the velocity has to be measured at MANY points in cross section over the cave (see dots in the first panels below) – and has to be measured fast since the tide is shifting rapidly, with two tides a day in this area.

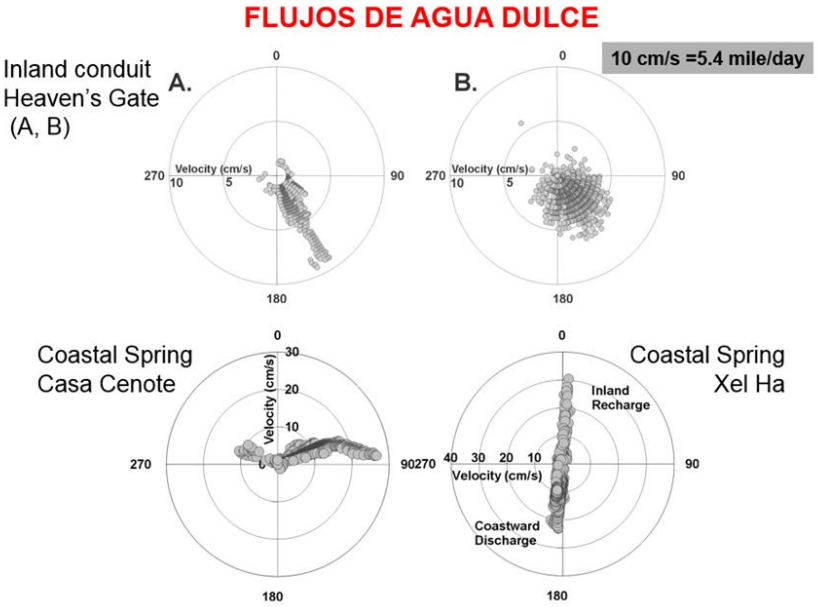
Once you get one pass across the cave done - pause – and do it again – and again! This can be grueling given the time in the water.

And horrors – the water flow direction can REVERSE – that you can see in the right hand side... with blue being out to the ocean, and red being inland with water coming in. You also have to measure the salinity of the water all the time so that you can then figure out how much of the water in the site is mixed/recirculated ocean water in this subterranean estuary.

Figure to right - Xel Ha - showing the flow reversals with inland in blue, and outflow in red.

Typical velocities in the caves where the water is flowing.... is km/day or miles/day.

Not all the water is flowing though - some caves can be stagnant even for months. Some caves are like oxbow lakes on surface rivers - just storage.



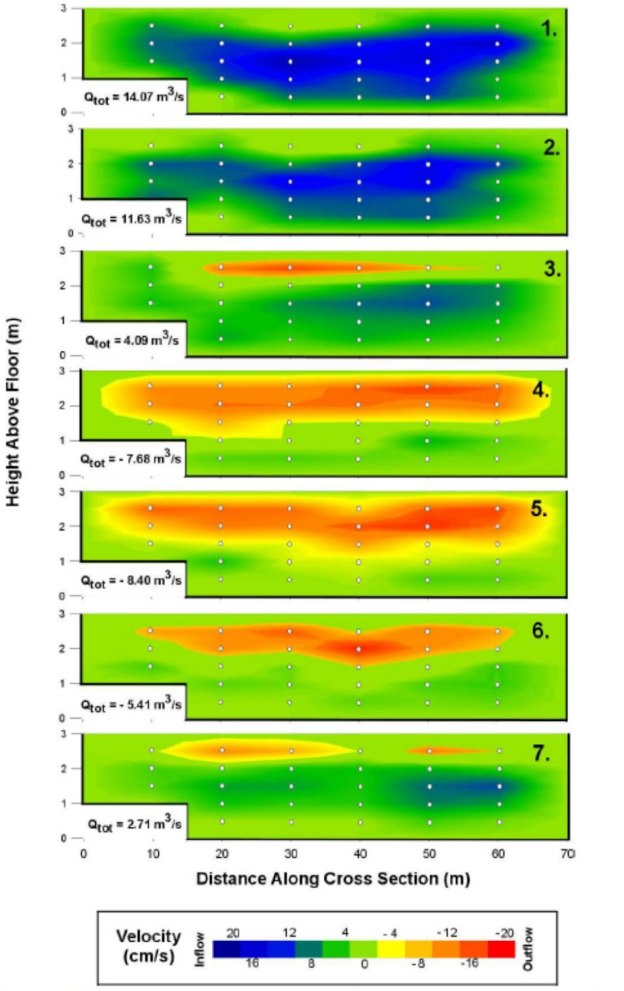


Figure 5.48 Xel Ha Estuary contoured velocity data for discharge calibration on 22 July 2001. Vertical exaggeration of 20.

So – HOW MUCH WATER coming out of the coasts?

Xel Ha for example 2.3+/-0.6 x 10^8 m3/year FRESH water, and also 6.8+/-10.6 x 10^7 m3/year SALINE

Casa Cenote 9.3+/-2.9 x 10^7 m3/year FRESH water, and also 4.6+/- 1.5 x 10^7 m3/year SALINE

[FYI - I now have more sites lined up for calibration (once COVID is behind us....) Expedition time!]

I am still impressed that Casa which is not nearly as large as Xel Ha is delivering nearly half the amount of fresh water to the coast that Xel Ha does. Xel Ha is huge! Turns out that because of so much water

back-flowing INTO Xel Ha – it is a real subterranean estuary. And - some of the smaller sites are discharging far more FRESH water then you can imagine.

As my overall data grows, I am finding that smaller sites that jet water can really discharge.

Furthermore, salinity is VERY important - even though a lot of water coming out.... It may be mostly salt water.

Back to - DRAINAGE BASINS? WHERE DOES THE WATER COME FROM?

We can start to figure out how much space / geography of the peninsula is needed to capture and give all the water measured leaving on the coastline.

We can build another small model – assuming that the geography is a rectangle, and that each of the coastal discharges has adjacent rectangles all the way up and down the coast.

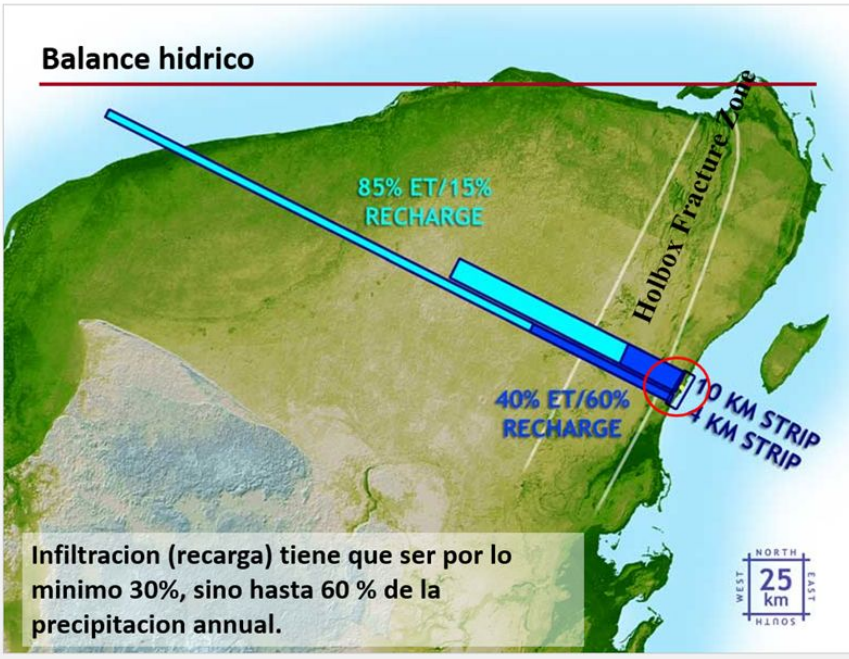
Ground rule – the rectangles can not overlap – since that would mean the same water is going to two places at the same time and that breaks a certain rule about conservation of matter that our universe depends on.

Given how tightly packed the *known* and suspected discharges are north of Tulum – lets start with 4 km wide drainage basin - and then also consider an extreme of 10 km for Xel Ha even though that is stealing water from adjacent sites.

One more step – The vegetation, animals and sky needs some water....How much water goes "up"?

The standard publications which*all* say that 85% of the rainfall is lost to evapotranspiration. That means that ONLY 15% of the rainfall is actually going into the aquifer.... I absolutely do not accept this since the water infiltrates so easily through the porous/permeable rocks. It was also based on a back of the envelope calculation using only mean annual temperature by Lesser in 1976 – and he actually came up 10% but given the high infiltration he added 5% fudge factor.... It is therefore not strong science...

If we use the "accepted" water budget of 85% evapotranspiration/15% infiltration-recharge then the drainage basin for Xel Ha reaches all the way across the peninsula and includes some of the Gulf of Mexico. Obviously – that is ridiculous.



If we consider that all of the water for the also ridiculous 10 km of the coastline goes to Xel ha - since that is stealing water from adjacent sites - then we reach to Valladolid.

Lets question Lesser 1976 and double his number to 30% infiltration (see dark blue bars on figure) – we still get areas that are too large but getting somewhat reasonable.

Personally I think the 4 km strip is much more correct – and scientifically defensible – and

that 30% infiltration/recharge might perhaps be enough - which means that water is flowing from Valladolid and out to the Caribbean coast – which means going across the Holbox Fracture Zone.

The other part of this equation that we also need to question is how much rainfall there is... and as some of you know I have also been putting in climate stations. ...

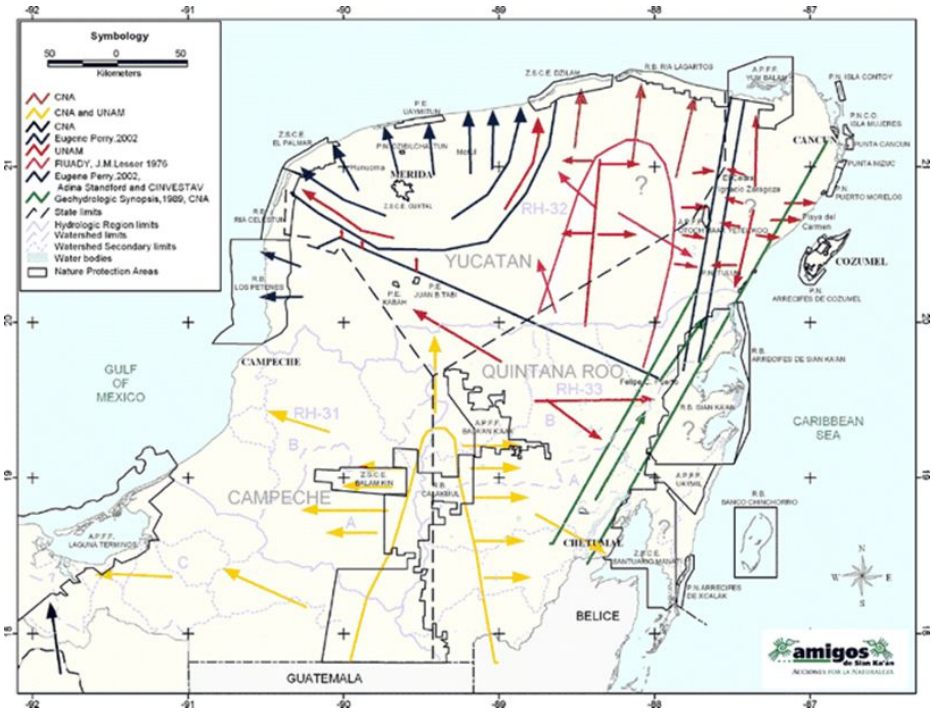
Wait – the Government maps and other sources say the Holbox shunts water to the north coast!

Yeah – that is also a problem. If the water is flowing into the Holbox Fracture and sending it north….then:

It is super hard to find, after 6+ years working on the north coast looking for the missing water. There are numerous springs and boils, but all of them are unimpressive and often very salty! Not that much fresh water going that way – and nothing compared to what is coming out of the Caribbean coast.

Also – if water is flowing TO the Holbox Fracture – then some water from near the coast (ie the area behind Playa, Akumal, and Tulum) is going inland to it, which further pushes the problem of how much recharge there is, so maybe we need to multiply the accepted number by 4!!! To 60% infiltration/recharge …. Just to get more water in the aquifer to account for all these flows. Yeah - I can easily see 60% recharge...

Based on what I think I know – yes I think there is a lot of water flowing into the Holbox Fracture, flowing north and south along it, but then the water gets into the headwaters of the coastal caves systems that lead to the Caribbean. Yes – Holbox Fracture may be highly hydro geo active and important - but it does not mean that the water is getting to the north coast. I do not accept that water from Tulum is shunted all the way to the north coast. *** if you have evidence of a "Xel Ha" on the north coast – please point me to it…. But really there needs to be dozens of big sites like Xel Ha in order to even start to think that water from Tulum is going to the north coast. ***



The "concensus" does not make sense, and more work is needed…. Incidentally - this map was drawn by having several people draw their own versions, and then they were overlaid. The exercise by ASK was in part to show that we need more science, but unfortunately it has been taken out of context by many, including decision makers.

<u>BUT HOW FAST IS THE WATER FLOWING – HOW LONG DOES IT TAKE?</u>

Once the water is in the caves….. it is typically going at km/day (miles per day). So – VERY VERY fast for groundwater.

The water in the rocks and fractures is moving at km/year, or miles/year. Still fast for groundwater globally, but way slower.

The cave water is continuously refilled by the seepage of much older water coming out of the rocks and fractures all along the length of the caves.

The typical age of the cave water would be 100's to 1000's of years old.... From mixing some modern with much older water. So yes - you may be swimming in gomphothere pee.

A final word - The concept of drainage basins does not work well (and sometimes not at all) in karst

It is increasingly obvious that we have one massive unified aquifer system. If you ever see solid lines on a map in any way suggesting that there is a "divide"where water on one side always flows one way..... Then ask that person what is the field data (not calculated model) that it is based on.

I am very concerned at some seeing recent efforts to try and draw drainage basins of the Yucatan Peninsula., using topography and standard mathematics in information system software packages.

Topography often means nothing for which way water flows in karst. One of the biggest drainage divides of the planet is the CONTINENTAL DIVIDE through the Rocky Mountains, and where there is karst the water goes in one side of the mountain and comes out on the other side - breaking the continental divide. We have similar examples in Europe where mountains are irrelevant to karst flow patterns. Apparently the water is not reading the tourist signs declaring the continental divides. I can assure you that topography means even less in the Yucatan Peninsula.