Using the correlation between ground-water levels and temperature to study the vulnerability of aquifers in Puerto Rico

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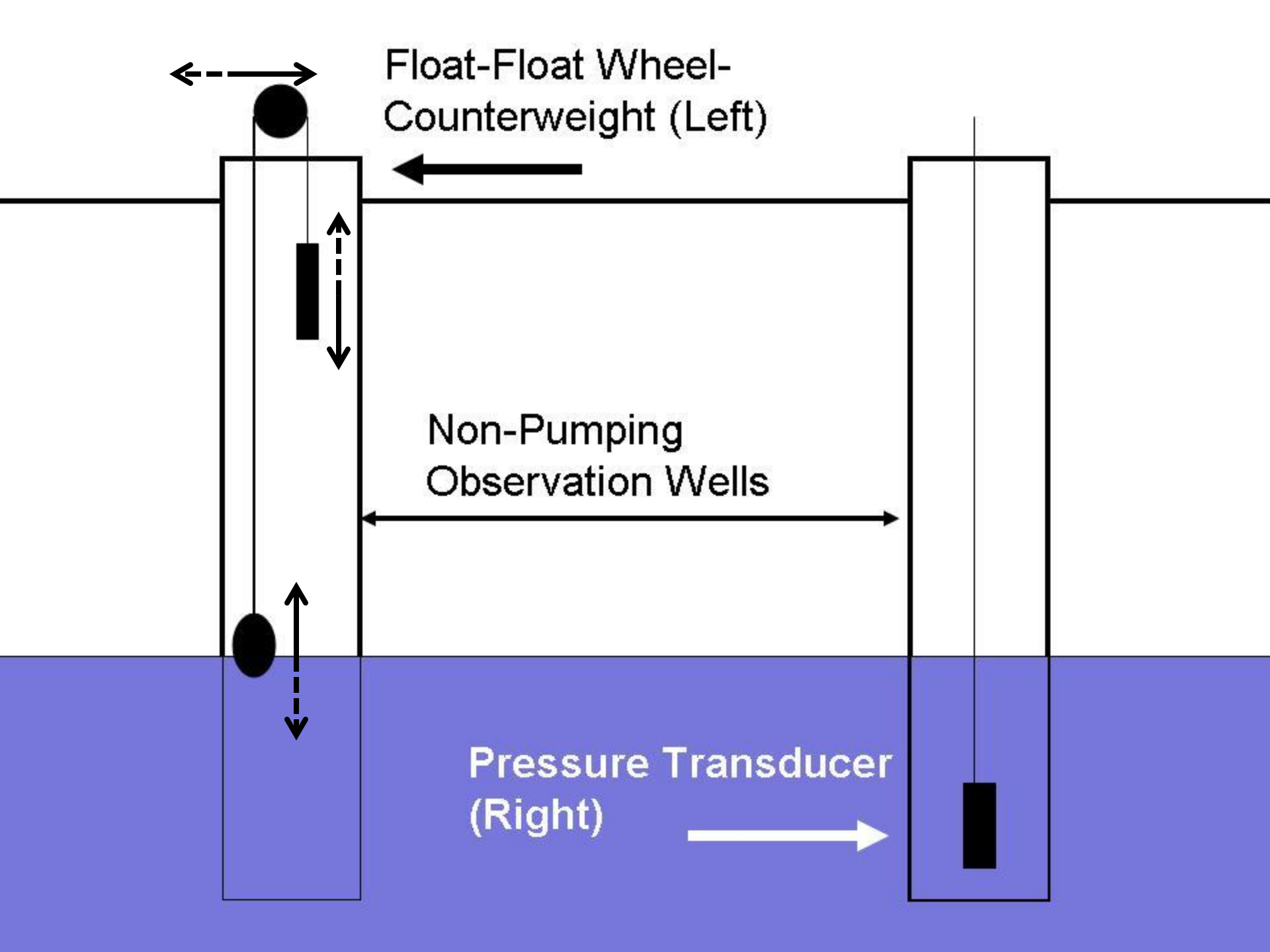
Disclaimer

- Data were collected by author when he was employee of the USGS.
- Author retired from USGS in 2008.
- Data are used with permission.
- This talk is not approved by the USGS.


Float-Float Wheel-
Counterweight (Left)
Non-Pumping
Observation Wells
Pressure Transducer
(Right)

Do Not Measure the Same Geophysical Variable!

- Float detects the density difference at the air-water interface.
- Float wheel converts elevation of float to a rotational position.
- Pressure transducer installed below record low water level.
- Pressure transducer measures pressure and temperature.
- Water level is calculated.

From Floats to Pressure Transducers

- Pressure transducers are more reliable.
- Pressure transducers cost less because less labor power is needed to install, maintain and remove the station and to process the data.
- Hourly water temperature data are the free unintended byproduct of this switch
- Nobody intended to use the water temperature data.
- Many hydrologic agencies are switching from floats to pressure transducers.

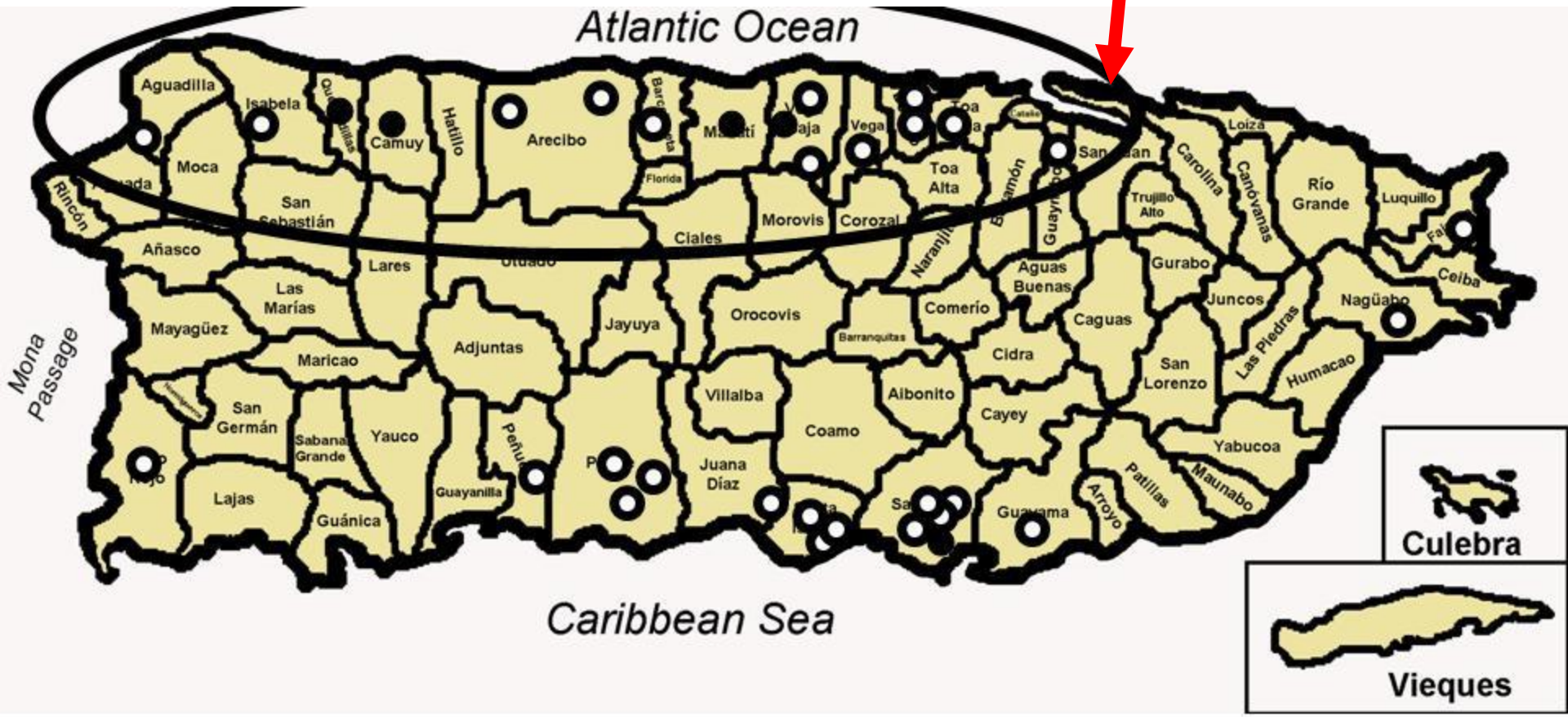
Correlation Between Ground-Water Levels and Temperature

- Hourly data for 12 to 18 months
- Most years have 8760 hours
- 33 observation wells
- Non-pumping
- Data from both karst and non-karst aquifers
- Study based on 800 000 data points
- If available used 2005 (rainy)

Rain

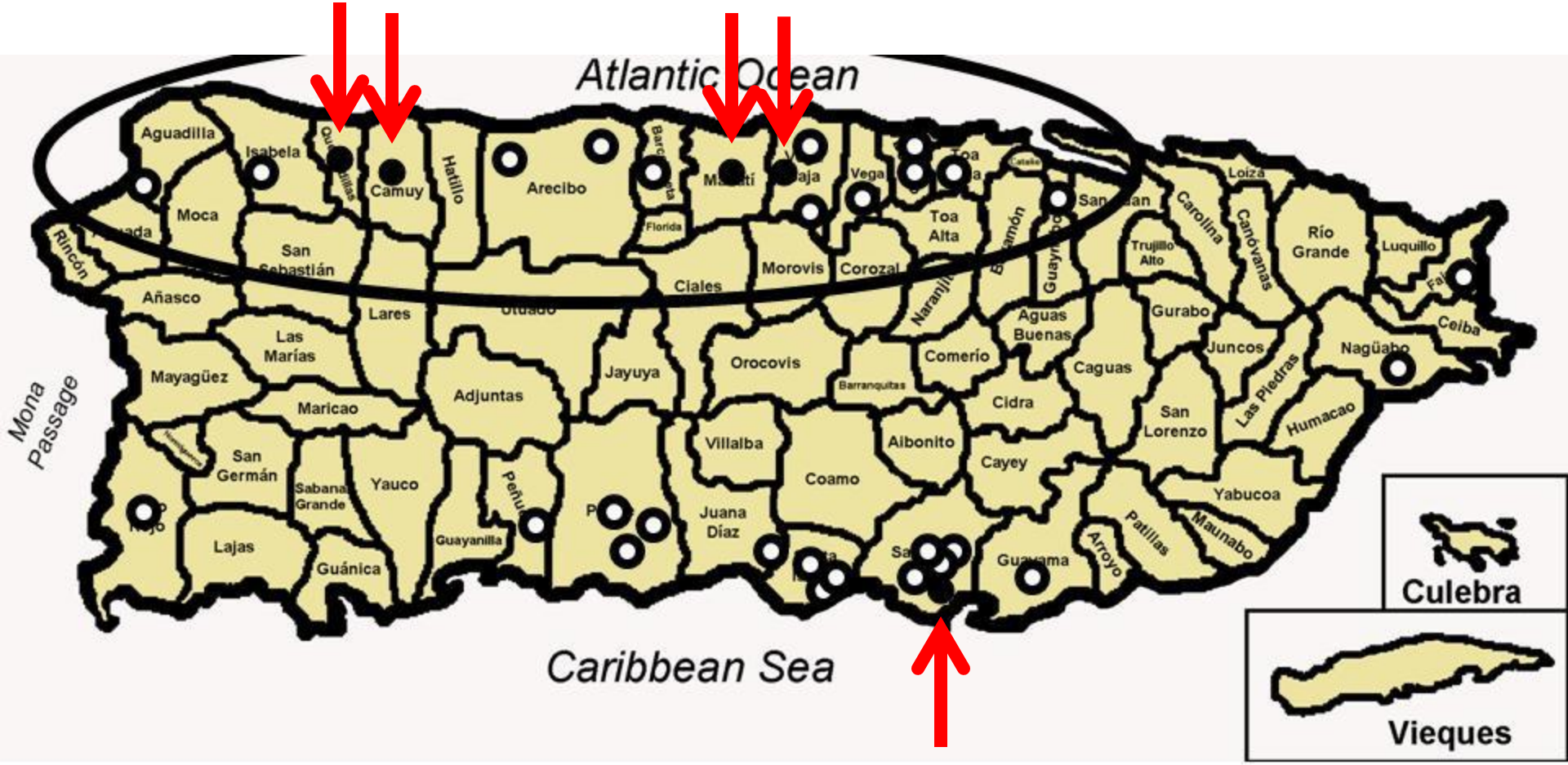
- Colder than ambient conditions in most geologic environments.
- If rain reaches the non-pumping well quickly than there will be a correlation between depth-to-water and temperature.
- If rain arrives at the observation well slowly then there will be no correlation between depth-to-water and temperature.

Anderson 2005

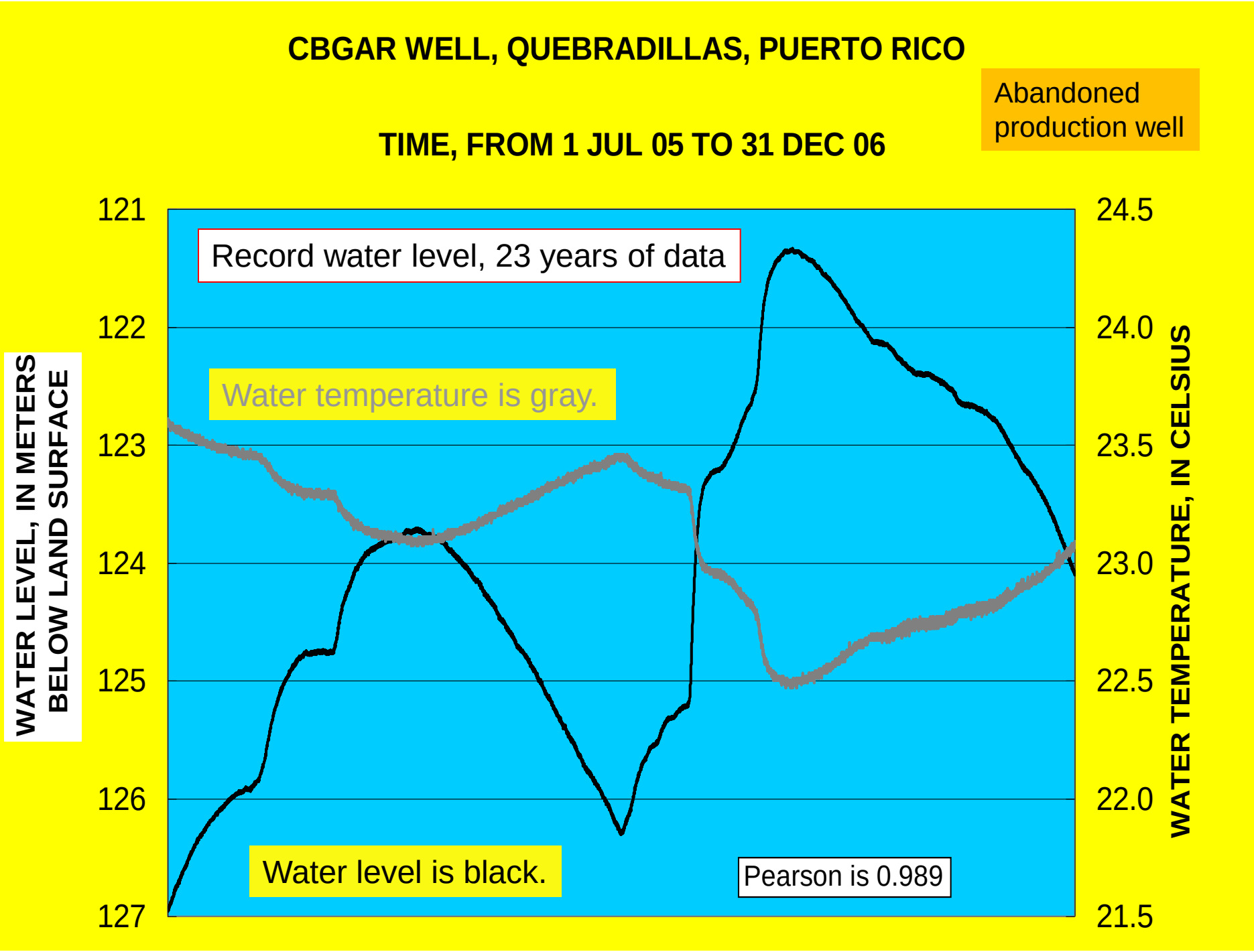

You are here/Usted está aqui
Atlantic Ocean
Caribbean Sea
Mona Passage
Aguadilla
Isabela
Camuy
Hatillo
Arecibo
Florida
Vega
Toa Alta
Morovis
Corozal
Ciales
Moca
San Sebastián
Añasco
Lares
Las Marías
Mayagüez
Maricao
Adjuntas
Jayuya
Orocovis
Barranquitas
Comerío
Aguas Buenas
Caguas
Cidra
Aibonito
Cayey
Villalba
Coamo
Juana Díaz
Yauco
Sabana Grande
San Germán
Lajas
Guánica
Guayanilla
Trujillo Alto
Carolina
Canovanas
Loíza
Río Grande
Luquillo
Gurabo
Juncos
Las Piedras
San Lorenzo
Humacao
Nagüabo
Ceiba
Yabucoa
Maunabo
Patillas
Arroyo
Guayama
Culebra
Vieques

Puerto Rico

North Coast Limestone Aquifer (elipse)



Map showing locations of non-pumping observation wells used in this study.

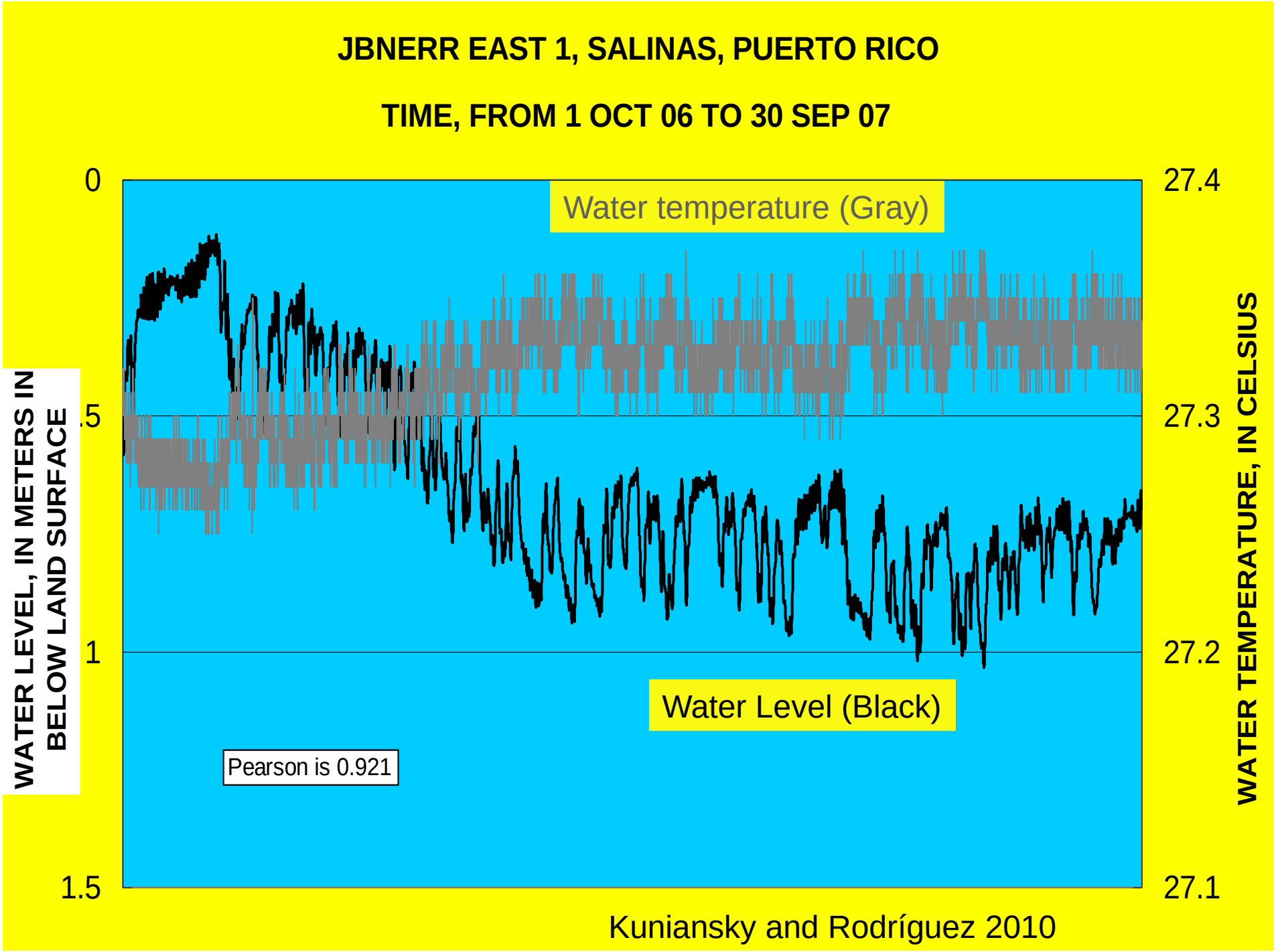

CBGAR WELL, QUEBRADILLAS, PUERTO RICO
TIME, FROM 1 JUL 05 TO 31 DEC 06
Abandoned production well
Record water level, 23 years of data
Water temperature is gray.
Water level is black.
Pearson is 0.989
WATER LEVEL, IN METERS BELOW LAND SURFACE
121
122
123
124
125
126
127
WATER TEMPERATURE, IN CELSIUS
24.5
24.0
23.5
23.0
22.5
22.0
21.5

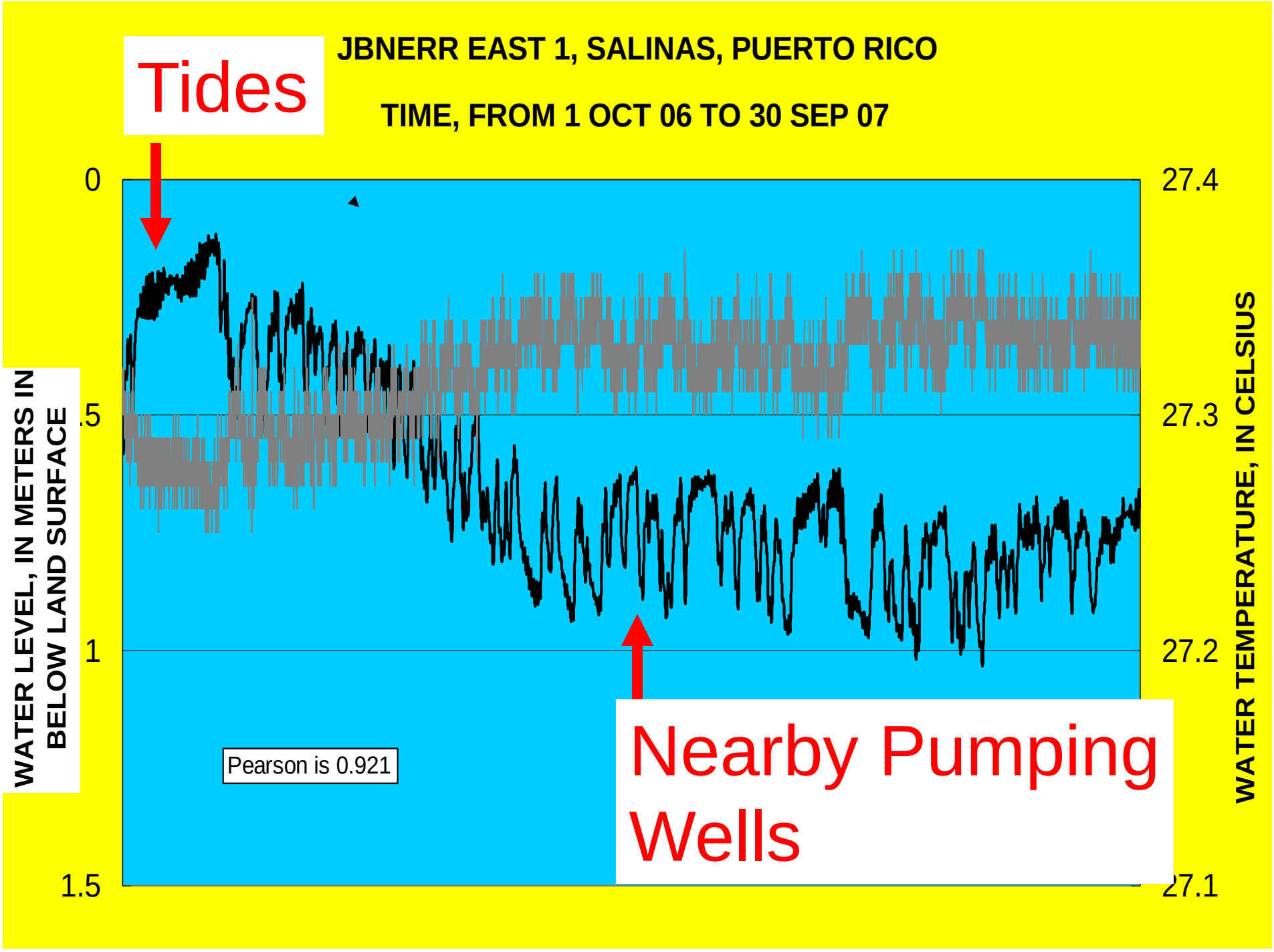
Hypothesis

- The karst North Coast Limestone aquifer will have a higher correlation between ground-water levels and temperature than non-karst aquifers
- If true then the karst is more at risk
- Will fail if intraaquifer variation is large
- Applies only to stations where the water level is not affected by tides or nearby pumping wells

Results

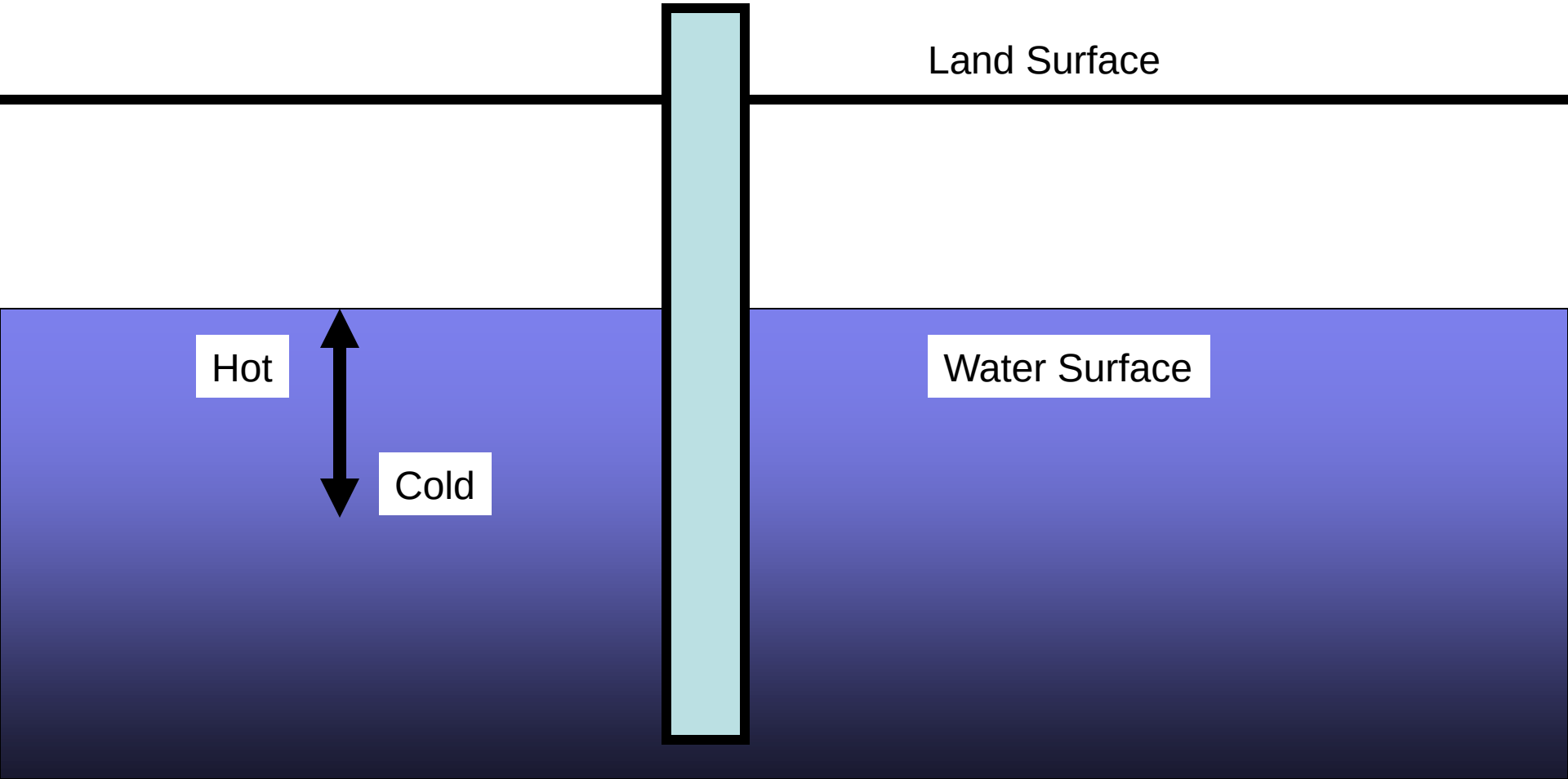
- NCL Pearson correlation coefficient
- r_{ak} = 0.241 and σ = 0.561
- SCP r_{an} = 0.023 and σ = 0.469
- P-Value = 0.24
- Differences between karst and non-karst aquifers are not statistically significant
- One station was removed because it is affected by tides and nearby pumping


JBNERR EAST 1, SALINAS, PUERTO RICO
TIME, FROM 1 OCT 06 TO 30 SEP 07
0
.5
1
1.5
WATER LEVEL, IN METERS IN BELOW LAND SURFACE
27.4
27.3
27.2
27.1
WATER TEMPERATURE, IN CELSIUS
Water temperature (Gray)
Water Level (Black)
Pearson is 0.921
Kuniansky and Rodríguez 2010


Tides
JBNERR EAST 1, SALINAS, PUERTO RICO
TIME, FROM 1 OCT 06 TO 30 SEP 07
0
.5
1
1.5
WATER LEVEL, IN METERS IN BELOW LAND SURFACE
27.4
27.3
27.2
27.1
WATER TEMPERATURE, IN CELSIUS
Pearson is 0.921
Nearby Pumping Wells

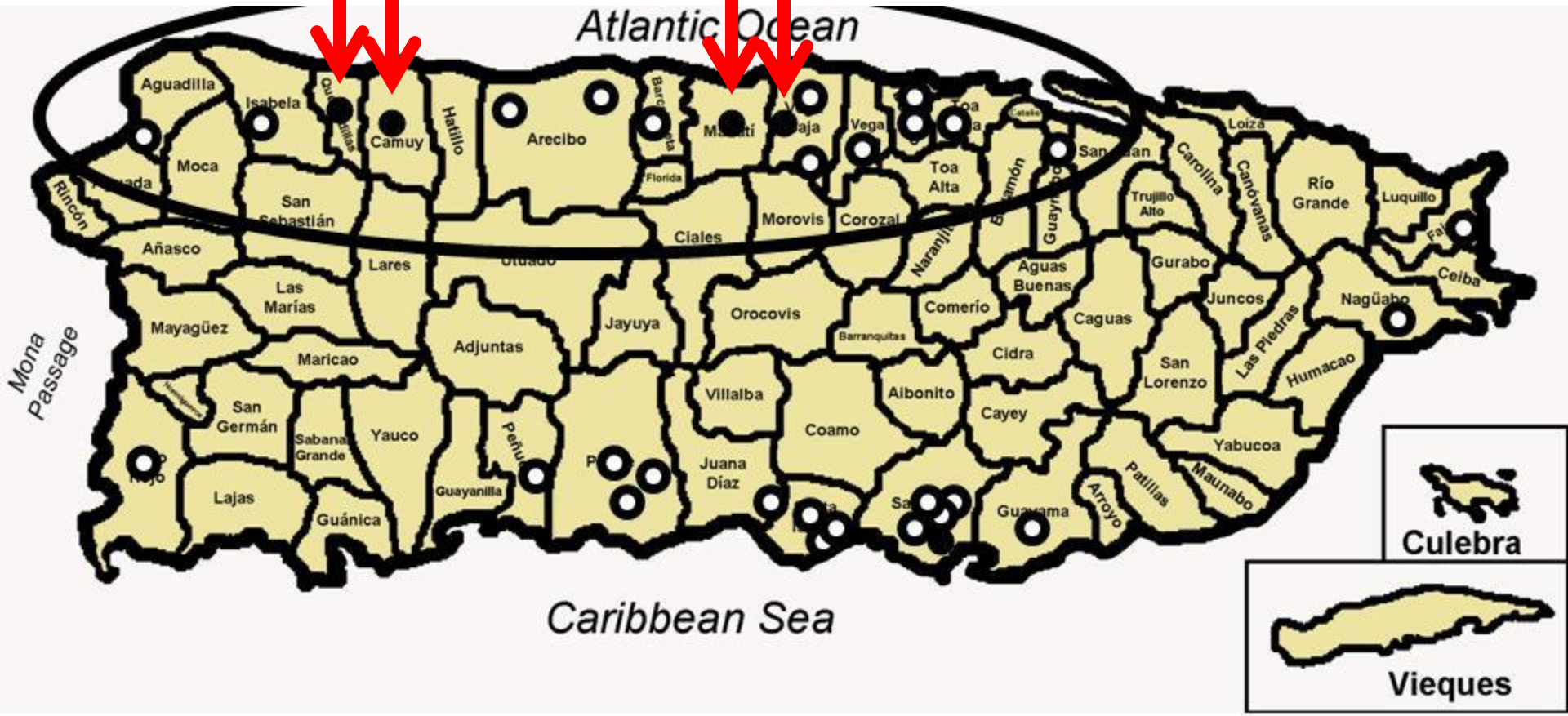
JBNERR EAST 1 SALINAS, PUERTO RICO

If the water in the aquifer is thermally stratified with warmer water on top then this would explain the high correlation between water levels and temperatures.

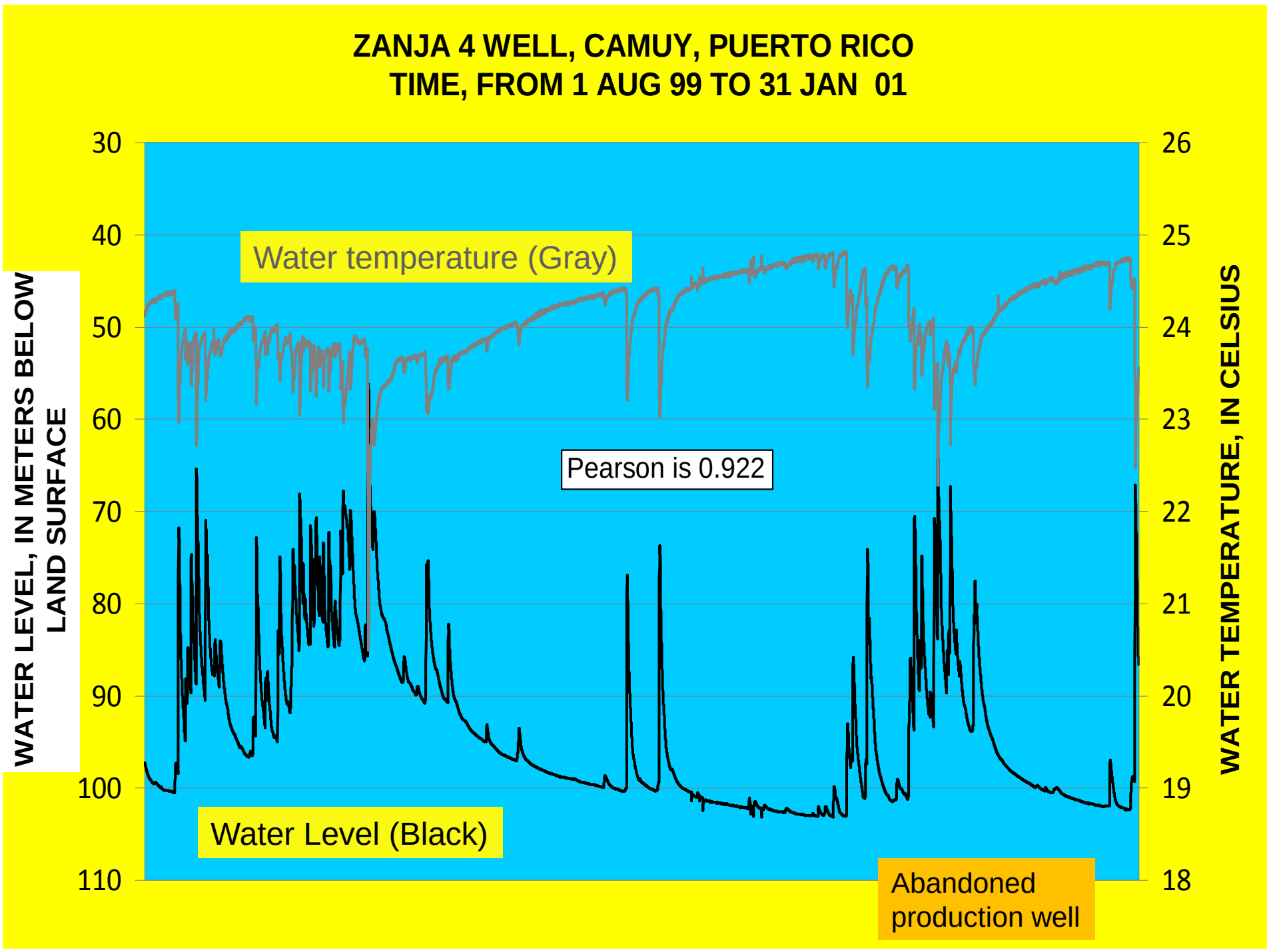


Quebradillas/Camuy

Manatí/Vega Baja

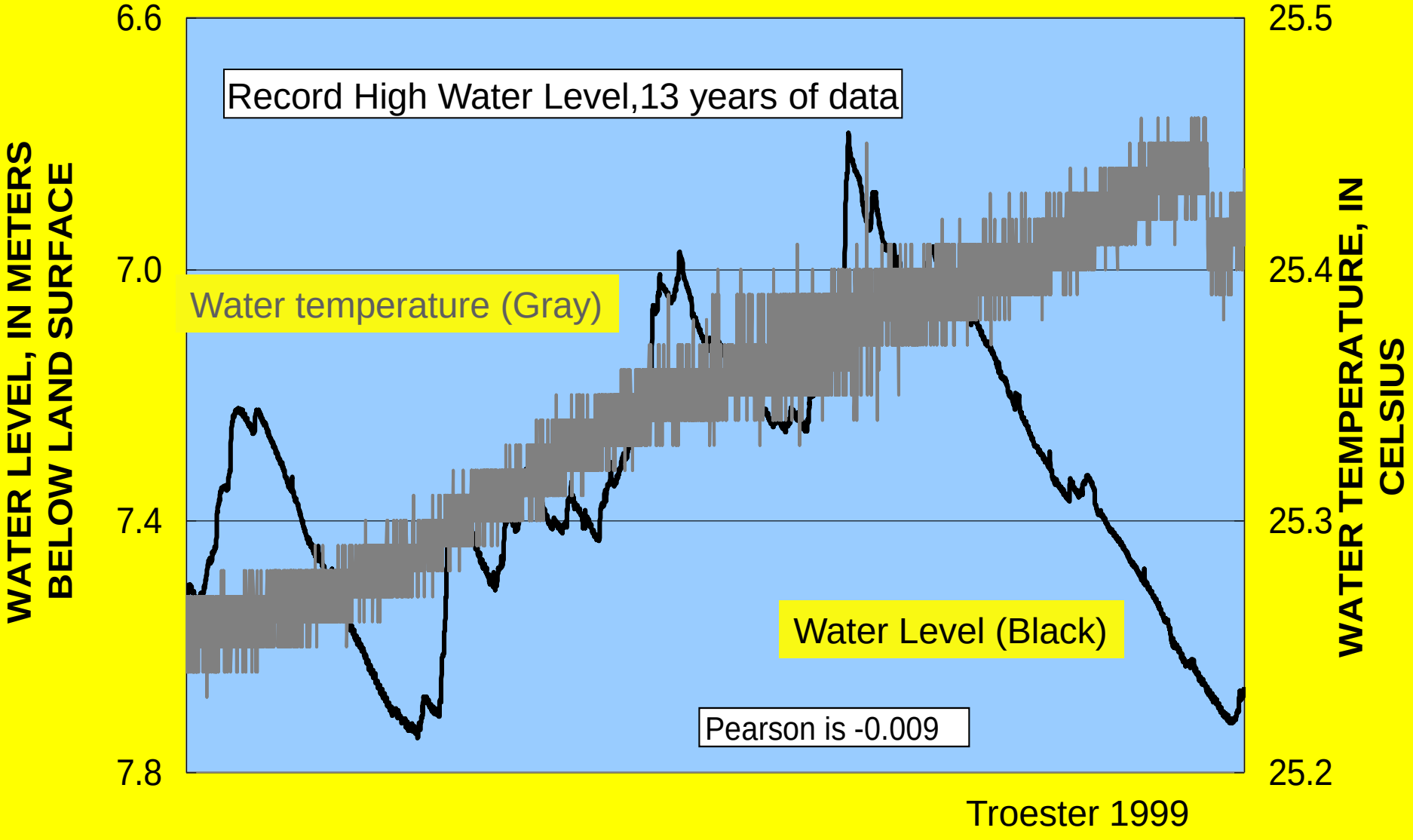


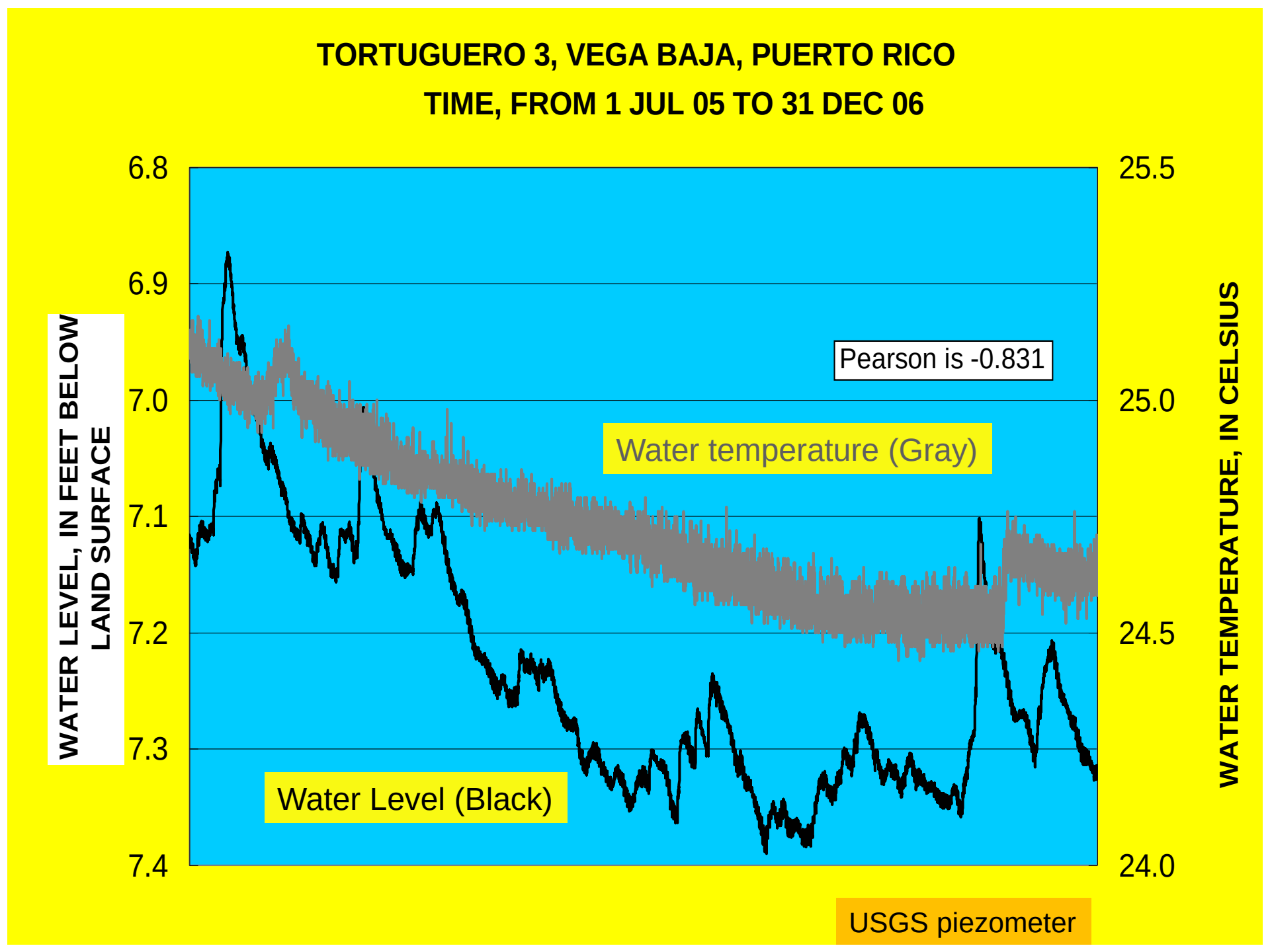
The two areas at highest risk from surficial contaminants are in Quebradillas-Camuy and Manatí-Vega Baja.

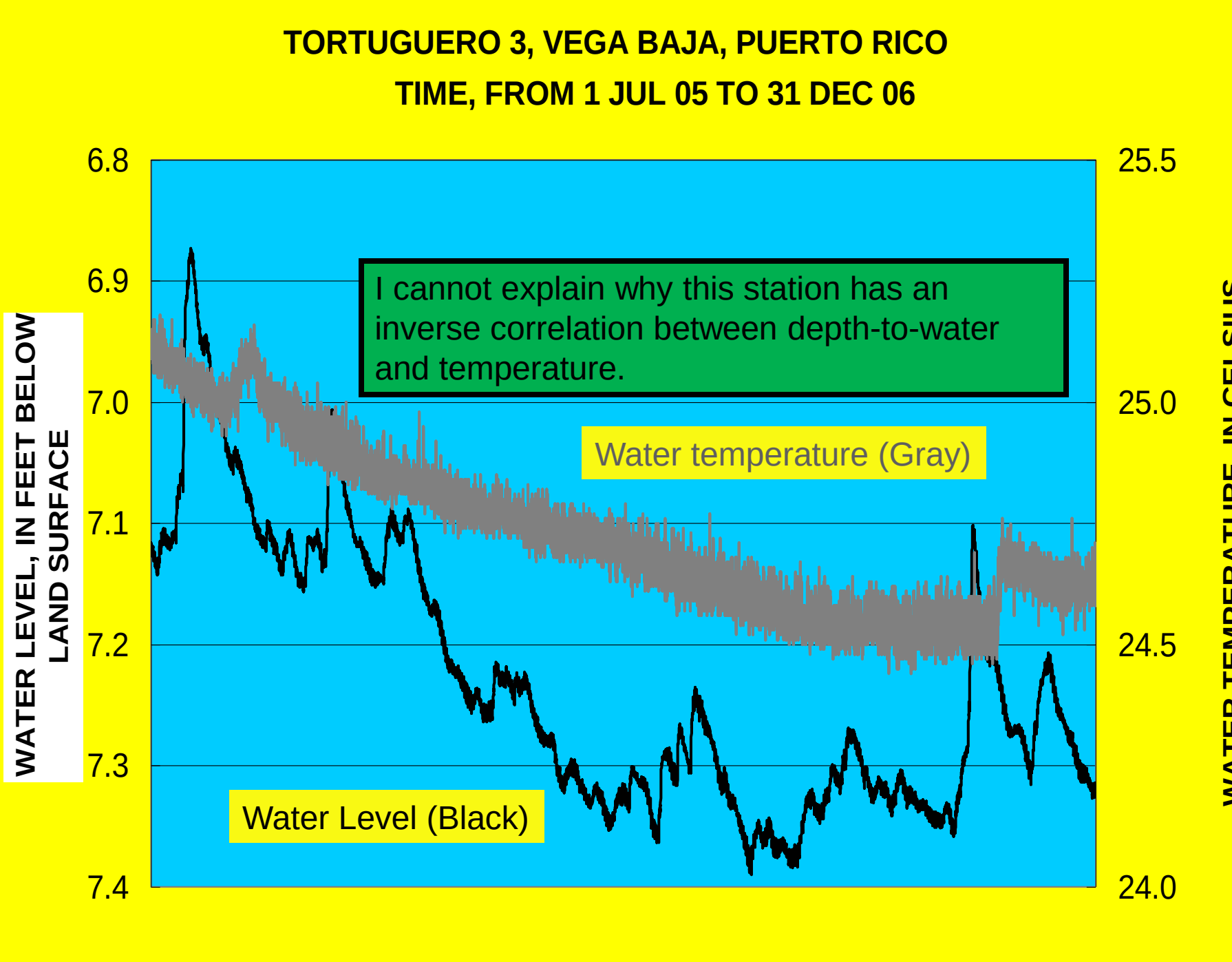

ZANJA 4 WELL, CAMUY, PUERTO RICO
TIME, FROM 1 AUG 99 TO 31 JAN 01
WATER LEVEL, IN METERS BELOW LAND SURFACE
30
40
50
60
70
80
90
100
110
WATER TEMPERATURE, IN CELSIUS
26
25
24
23
22
21
20
19
18
Water temperature (Gray)
Pearson is 0.922
Water Level (Black)
Abandoned production well

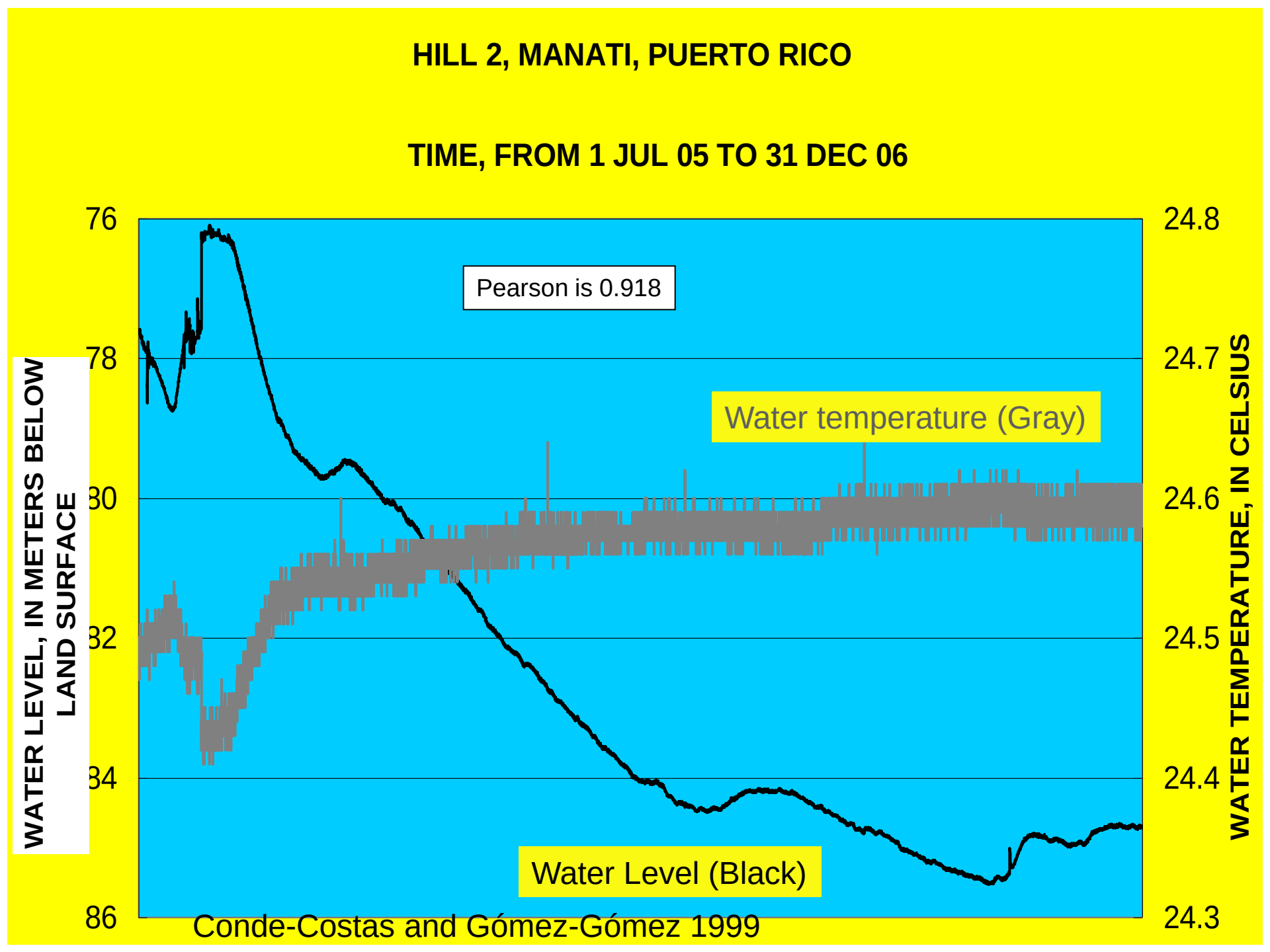
MAGUAYO 2, DORADO, PUERTO RICO

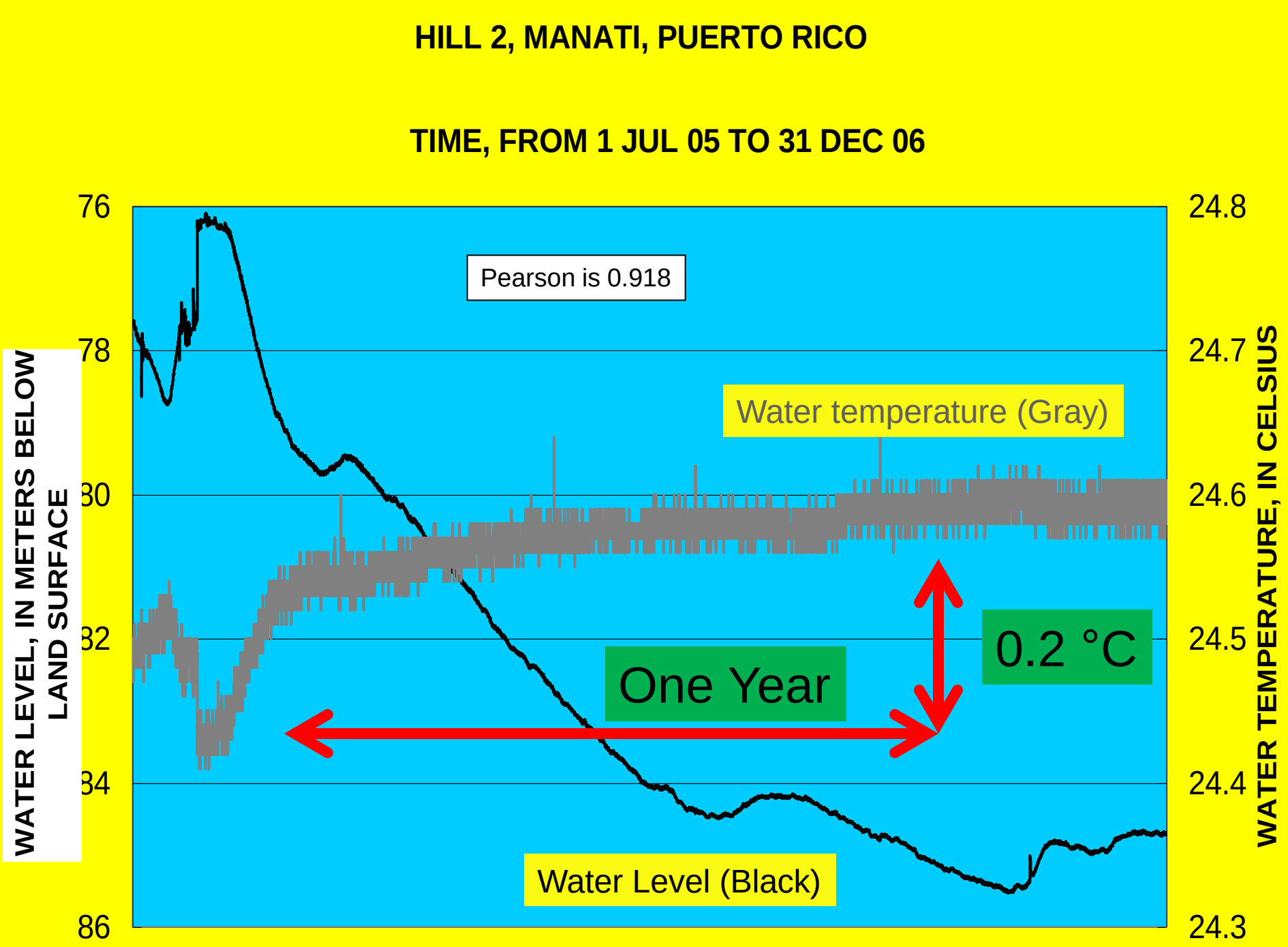
TIME, FROM 1 JAN 05 TO 31 MAR 06

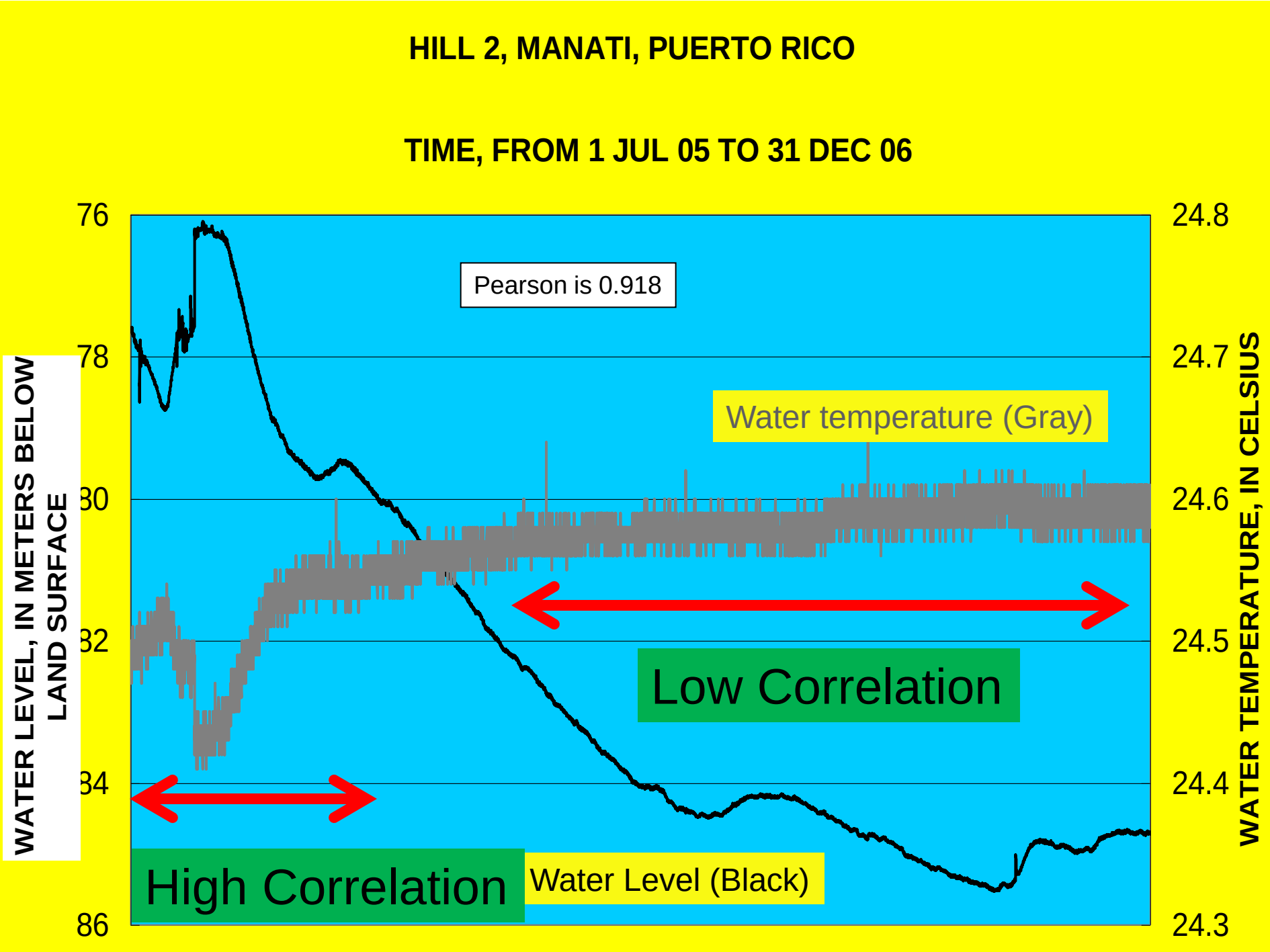


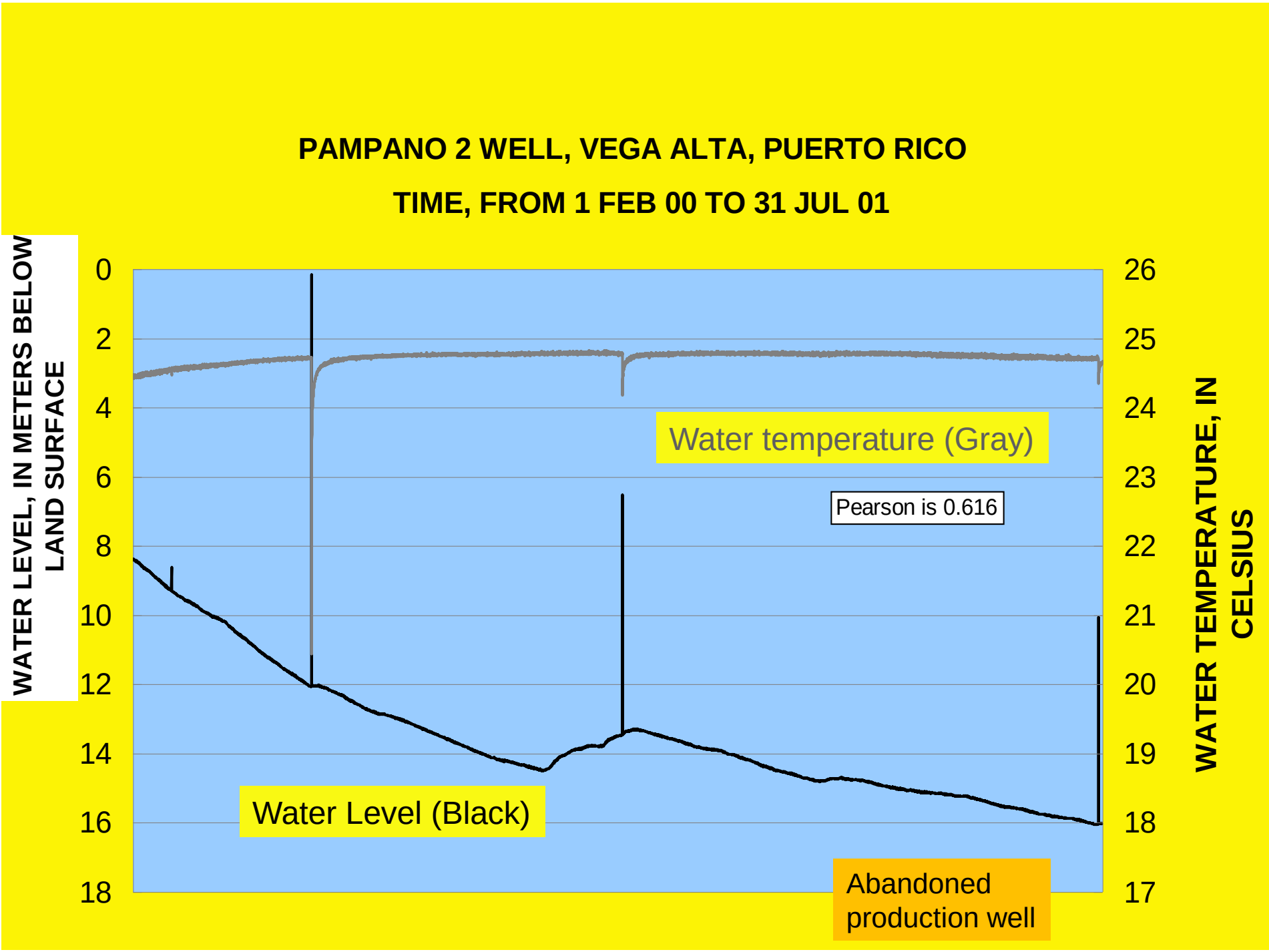

TORTUGUERO 3, VEGA BAJA, PUERTO RICO
TIME, FROM 1 JUL 05 TO 31 DEC 06
WATER LEVEL, IN FEET BELOW LAND SURFACE
6.8
6.9
7.0
7.1
7.2
7.3
7.4
25.5
25.0
24.5
24.0
WATER TEMPERATURE, IN CELSIUS
Pearson is -0.831
Water temperature (Gray)
Water Level (Black)
USGS piezometer


TORTUGUERO 3, VEGA BAJA, PUERTO RICO
TIME, FROM 1 JUL 05 TO 31 DEC 06
WATER LEVEL, IN FEET BELOW LAND SURFACE
6.8
6.9
7.0
7.1
7.2
7.3
7.4
25.5
25.0
24.5
24.0
WATER TEMPERATURE, IN CELSIUS
I cannot explain why this station has an inverse correlation between depth-to-water and temperature.
Water temperature (Gray)
Water Level (Black)


HILL 2, MANATI, PUERTO RICO
TIME, FROM 1 JUL 05 TO 31 DEC 06
Pearson is 0.918
Water temperature (Gray)
Water Level (Black)
WATER LEVEL, IN METERS BELOW LAND SURFACE
WATER TEMPERATURE, IN CELSIUS
76
78
80
82
84
86
24.8
24.7
24.6
24.5
24.4
24.3
Conde-Costas and Gómez-Gómez 1999


HILL 2, MANATI, PUERTO RICO
TIME, FROM 1 JUL 05 TO 31 DEC 06
WATER LEVEL, IN METERS BELOW LAND SURFACE
WATER TEMPERATURE, IN CELSIUS
76
78
80
82
84
86
24.8
24.7
24.6
24.5
24.4
24.3
Pearson is 0.918
Water temperature (Gray)
0.2 °C
One Year
Water Level (Black)


HILL 2, MANATI, PUERTO RICO
TIME, FROM 1 JUL 05 TO 31 DEC 06
WATER LEVEL, IN METERS BELOW LAND SURFACE
WATER TEMPERATURE, IN CELSIUS
76
78
80
82
84
86
24.8
24.7
24.6
24.5
24.4
24.3
Pearson is 0.918
Water temperature (Gray)
Low Correlation
High Correlation
Water Level (Black)

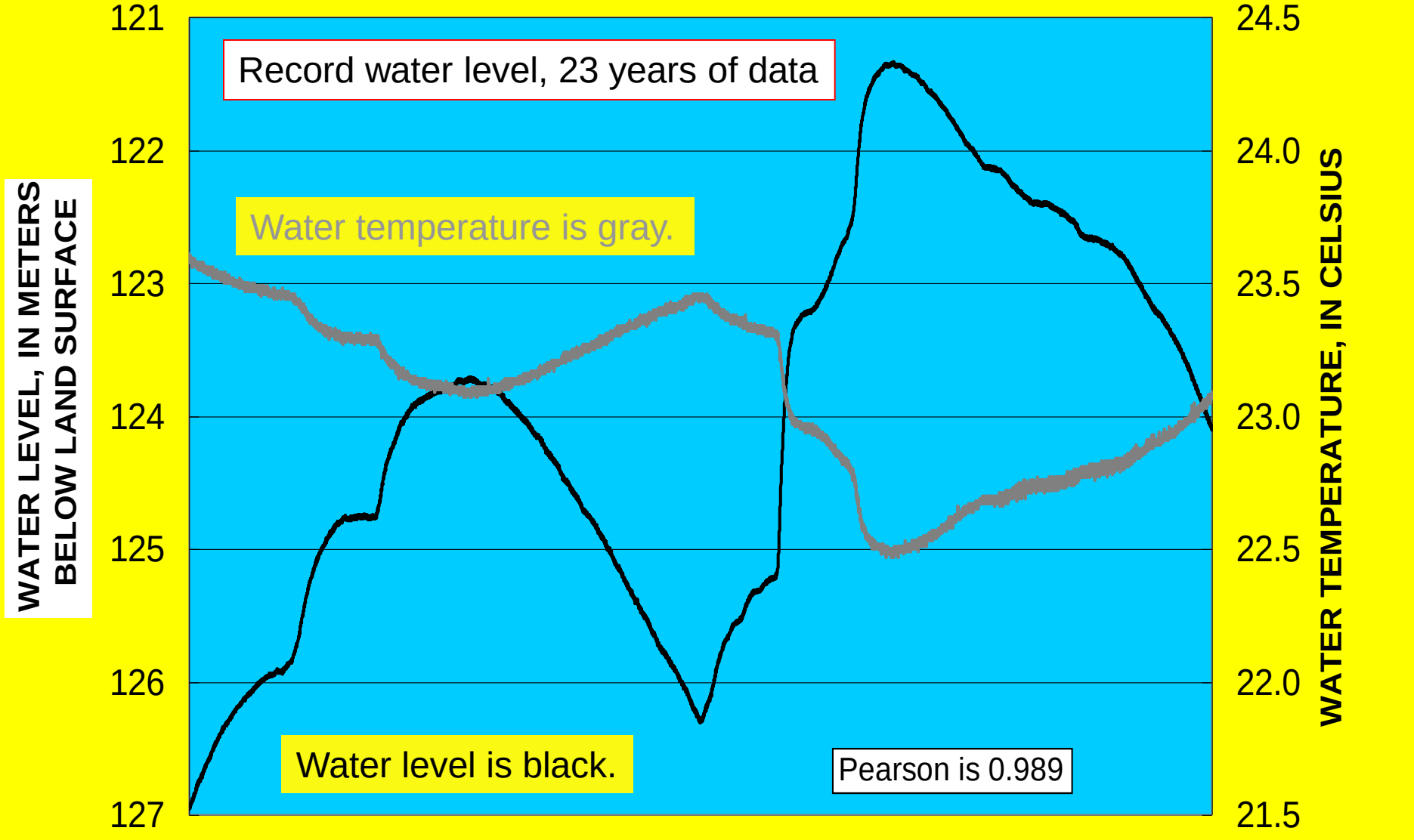

PAMPANO 2 WELL, VEGA ALTA, PUERTO RICO
TIME, FROM 1 FEB 00 TO 31 JUL 01
WATER LEVEL, IN METERS BELOW LAND SURFACE
0
2
4
6
8
10
12
14
16
18
26
25
24
23
22
21
20
19
18
17
WATER TEMPERATURE, IN CELSIUS
Water temperature (Gray)
Pearson is 0.616
Water Level (Black)
Abandoned production well

Construction Defects

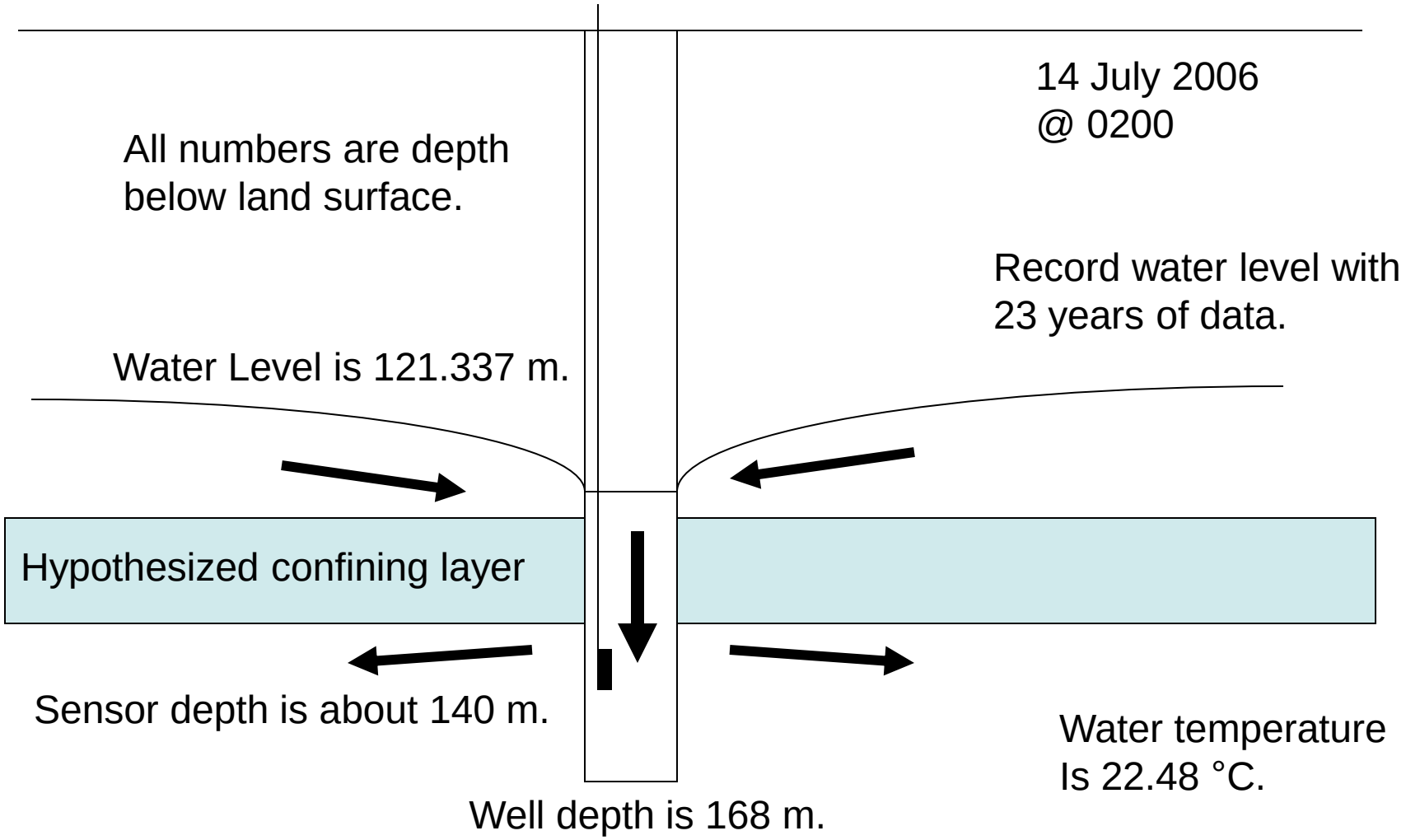
- Leaking in the annual spacing
- Injection well during heavy rains
- 15 percent in study have this pattern
- Abandoned wells are a potential entry point for contaminants

CBGAR WELL, QUEBRADILLAS, PUERTO RICO

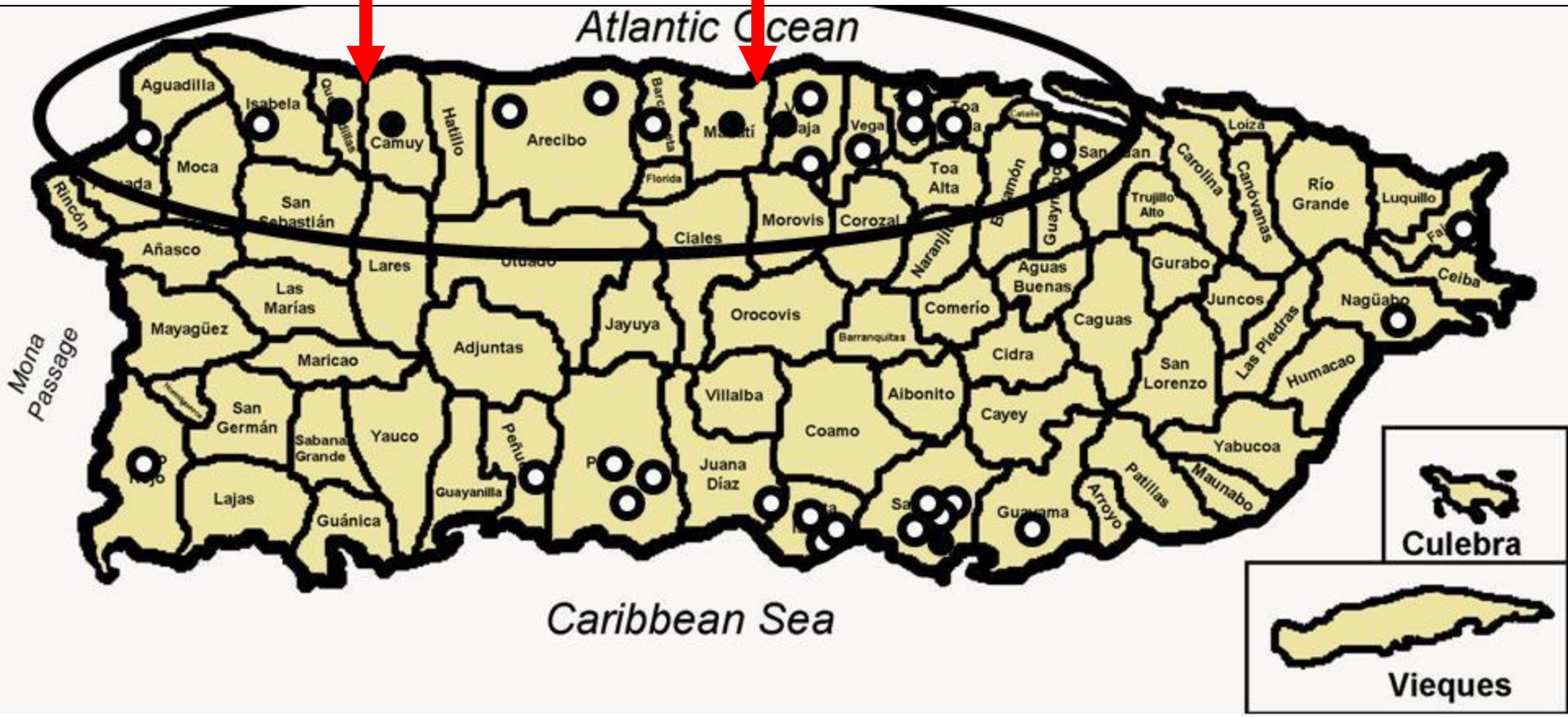
TIME, FROM 1 JUL 05 TO 31 DEC 06



CBGAR, Quebradillas, Puerto Rico



Quebradillas/Camuy **Manatí/Vega Baja**



Two areas with the highest risk of surficial contamination!

Conclusions

- Karst aquifers are not at significantly higher risk than non-karts aquifers.
- Within the karst North Coast Limestone aquifer Quebradilla/Camuy and Manatí/Vega Baja are at highest risk.
- Abandoned wells may be points of entry for contaminants.

The journal *Earth Science and Engineering* has expressed interest in publishing a paper on this topic.

Thankyou!

¡Muchas Gracias!

Literature

- **Anderson MP**. 2005. Heat as a Ground Water Tracer. Ground Water. 43(6): 951-968. Doi:10.1111/j.1745-6584.2005.00052.x.
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- **Kuniansky EL, and Rodríguez JM**, 2010, Effects of changes in irrigation practices and aquifer development on groundwater discharge to the Jobos Bay National Estuarine Research Reserve near Salinas, Puerto Rico: U.S. Geological Survey Scientific Investigations Report 2010-5022, 106 p., available at http://pubs.usgs.gov/sir/2010/5022/
- **Troester, JW**, 1999, Geochemistry and hydrogeologic framework of the saline-freshwater interface and the calculation of net recharge in the Dorado area, north-central Puerto Rico, U.S. Geological Survey Water-Resources Investigations Report 98-4030, 36 p.

Using the correlation between ground-water levels and temperature to study the vulnerability of aquifers in Puerto Rico

Ronald T. Richards
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20 March 2013

Abstract

Hourly data for 12 to 18 months from 33 non-pumping observation wells were used to study the correlation between depth-to-water and temperature in Puerto Rico. The data were collected by the author when he was an employee of the United States Geological Survey Caribbean Water Science Center. The author retired in 2008 and the data are used with permission. In many hydrogeologic environments rain is colder than ambient conditions. If the rain reaches the observation well quickly then there will be a correlation between depth-to-water and temperature. If the water reaches the observation well slowly then it will have warmed to ambient conditions and the water level will rise independently of the temperature. Areas with a high correlation between ground-water level and temperature are areas where the recharge from rain can quickly reach the aquifer and are more vulnerable to contamination from the surface than areas where there they are not correlated. The hypothesis is that in Puerto Rico, the karst North Coast Limestone aquifer will on average have a higher Pearson correlation coefficient between depth-to-water and temperature than non-karst aquifers. The hypothesis is not proven. In the karst North Coast Limestone aquifer, the average Pearson correlation coefficient between depth-to-water and temperature is larger than in non-karst aquifers but the intraaquifer variability is large enough to prevent the results from being statistically significant. The two areas in the karst North Coast Limestone aquifer that have the highest correlation between water level and temperature and thus the highest risk of surficial contamination are in the adjoining municipios of Quebradillas-Camuy and Manatí-Vega Baja. Fifteen percent of the observation wells in this study are mixed and have periods of high correlation between temperature and depth-to-water and periods of no correlation. This pattern could be caused by construction defects that allow the rainwater to flow down the annular spacing and into the aquifer. The author recommends that the government of Puerto Rico initiate a program to identify and plug thousands of unused water wells on the island.

Presented at Geological Society of America Southeastern Regional Conference in San Juan, Puerto Rico on 20 March 2013.