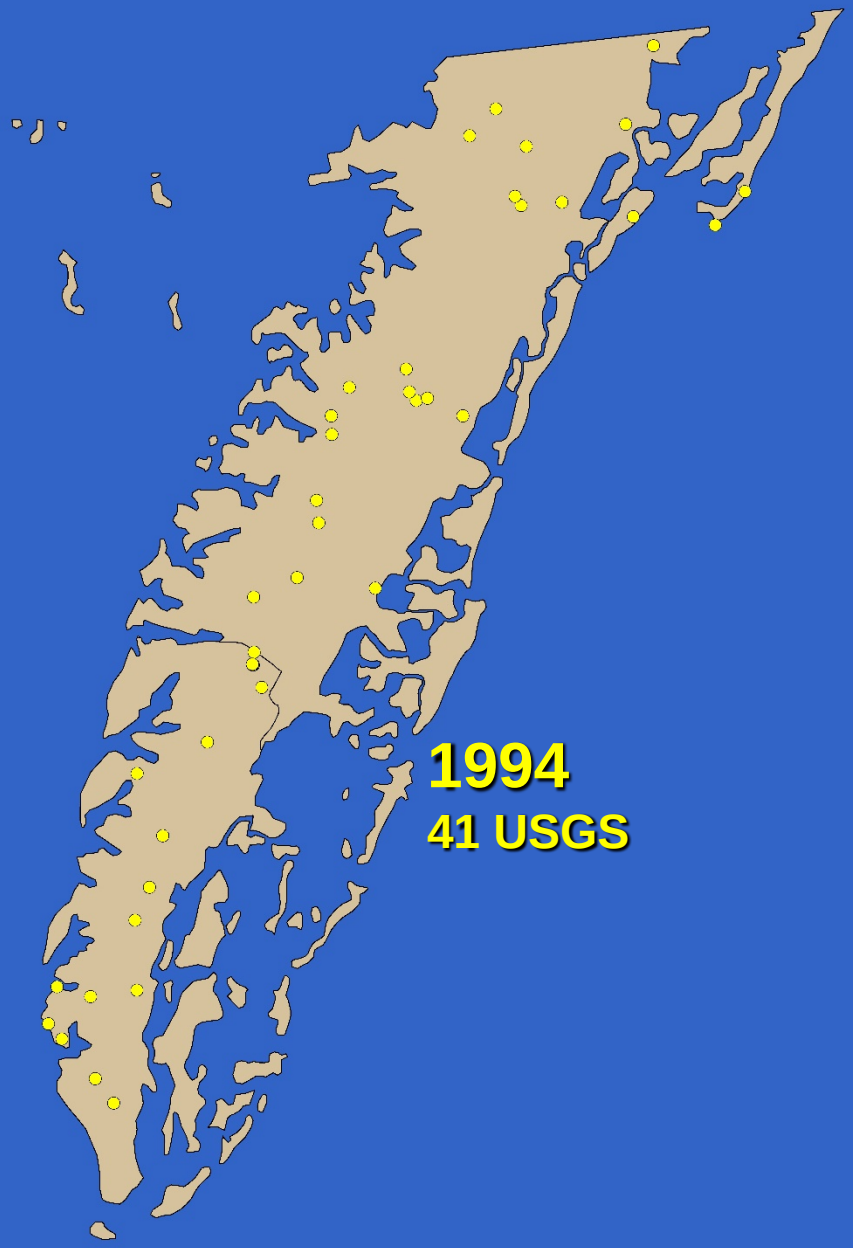
FY 2017 Eastern Shore Study

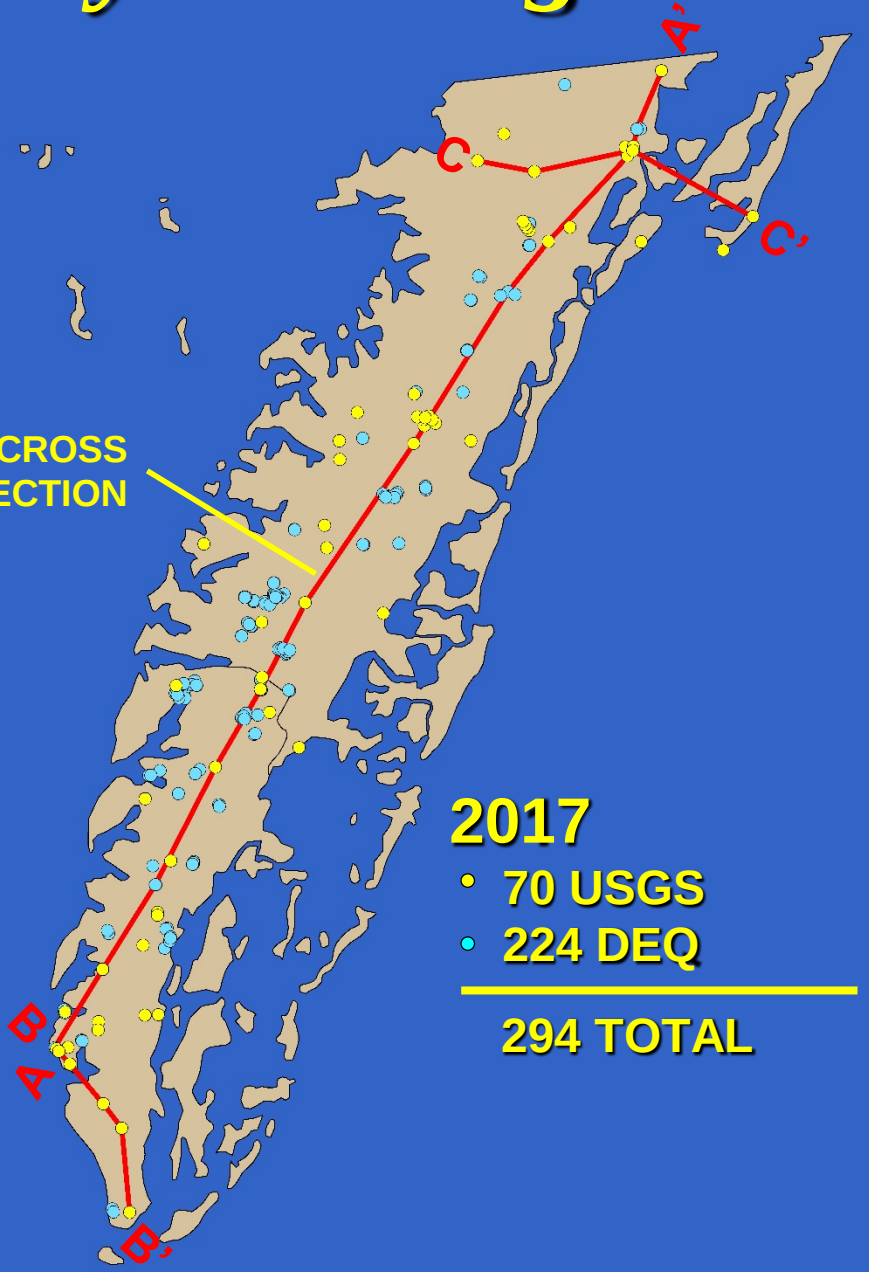
- *one year part time effort*
- *compile/summarize existing data*
- *technical-issue evaluation*
    1. *aquifer framework*
    2. *paleochannels*
    3. *chloride*
- *identify future needs*
    1. *research drilling*
    2. *water-quality sampling*

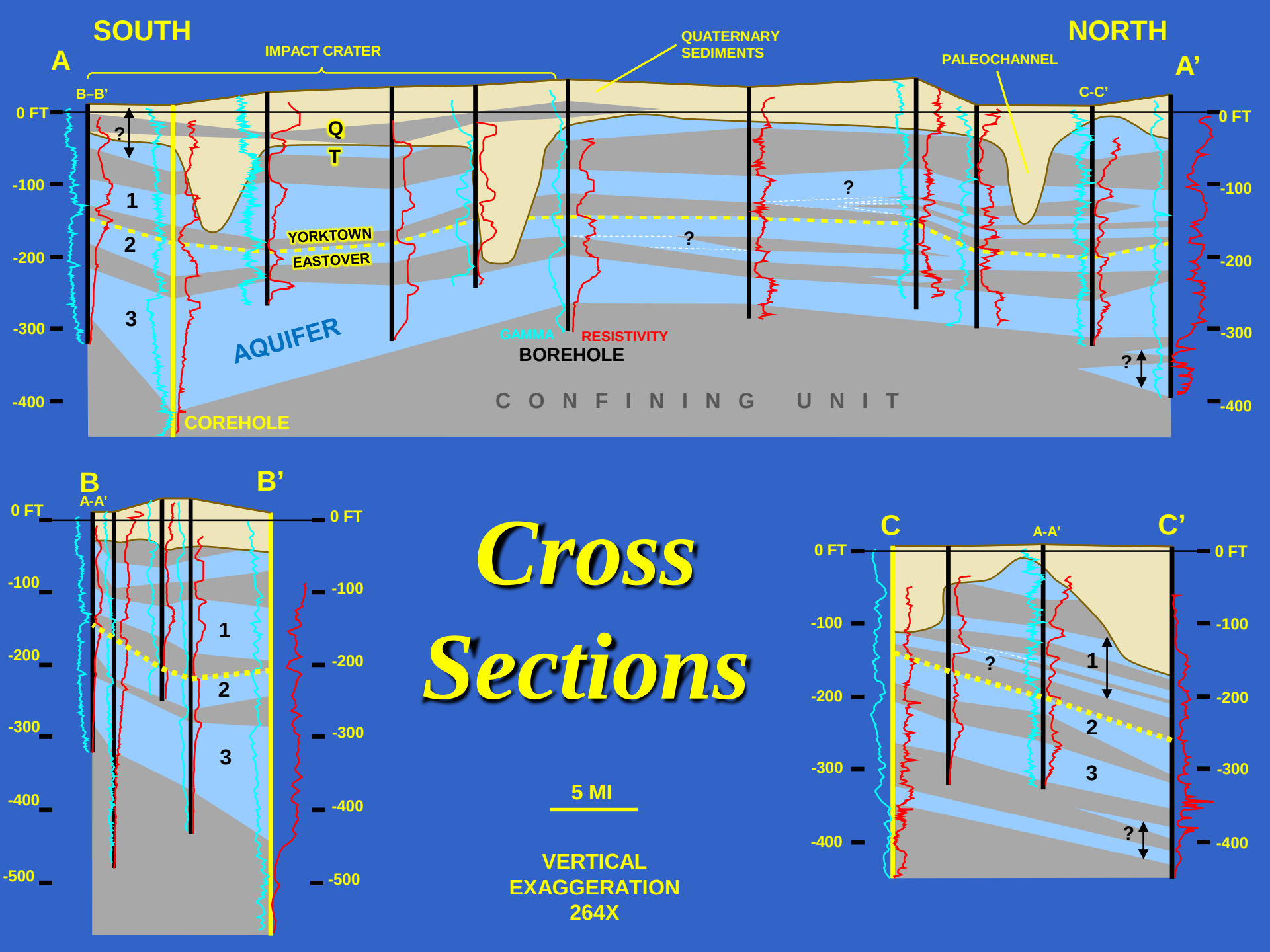
Interim (July) Results

- *aquifer framework*
- *paleochannels*
- *chloride*

Borehole Geophysical Logs





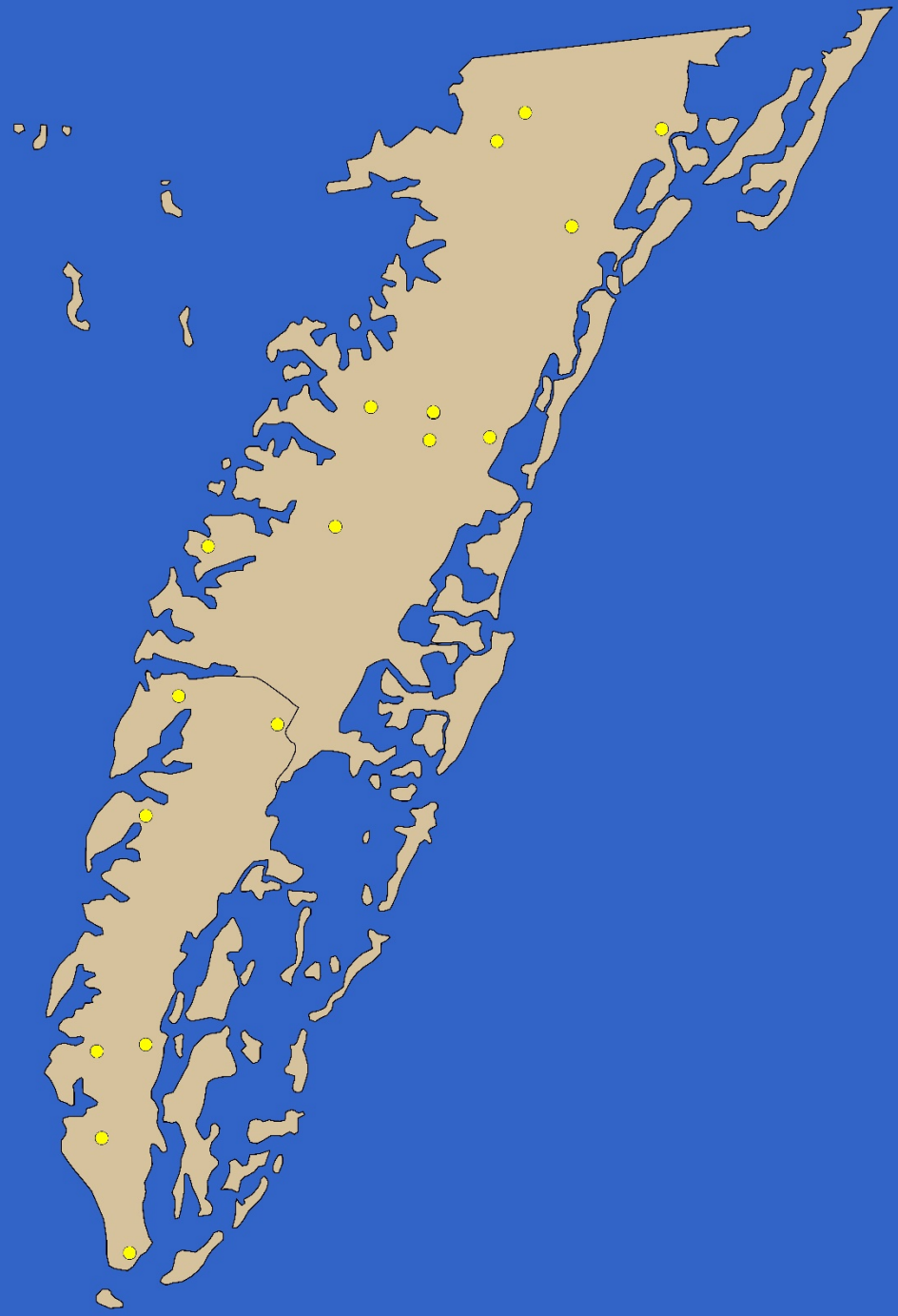

SOUTH
NORTH
A
A'
IMPACT CRATER
QUATERNARY SEDIMENTS
PALEOCHANNEL
B–B'
C-C'
0 FT
-100
-200
-300
-400
Q
T
1
2
3
YORKTOWN
EASTOVER
AQUIFER
GAMMA
RESISTIVITY
BOREHOLE
COREHOLE
C O N F I N I N G U N I T
?
B
B'
A-A'
-500
C
C'
Cross Sections
5 MI
VERTICAL EXAGGERATION 264X

Water-Level Analysis

- ***purpose**: assess vertical hydraulic connectivity across confining units*
- ***approach**: calculate vertical hydraulic gradients between collocated pairs of wells*
- ***additional factor**: vertical hydraulic stresses imposed by withdrawal*

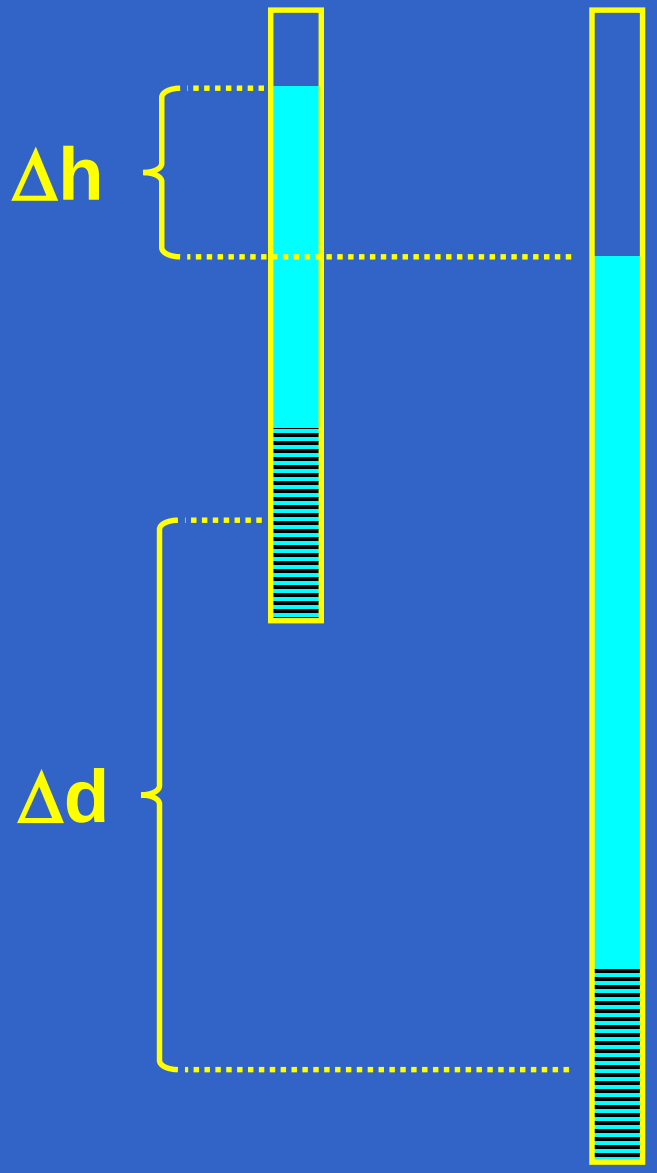
Vertical Hydraulic Gradients

- *17 locations*
- *39 pairs of wells*
- *10,022 paired water levels*
- *1977 – 2017*

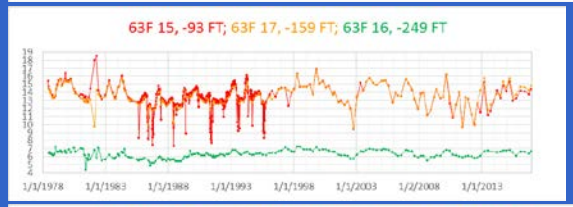


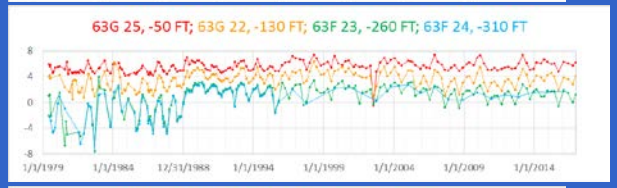
Vertical Gradient Calculation

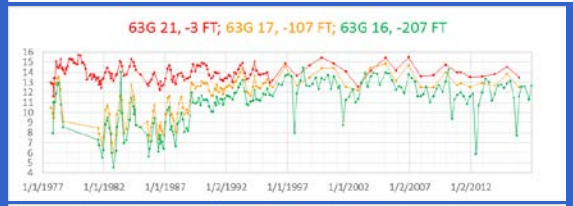
$$= \frac{\Delta h}{\Delta d}$$

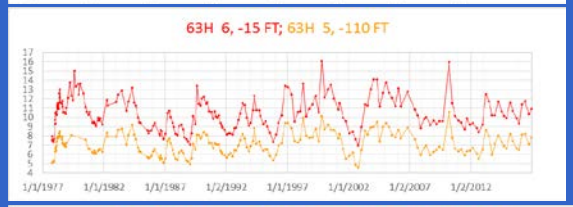


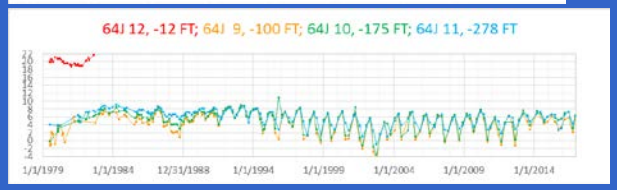
Groundwater Levels

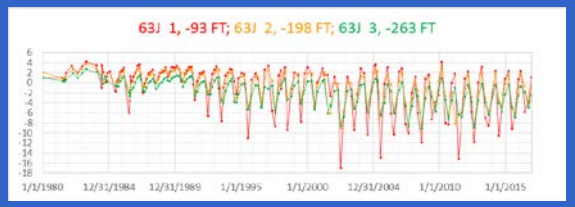


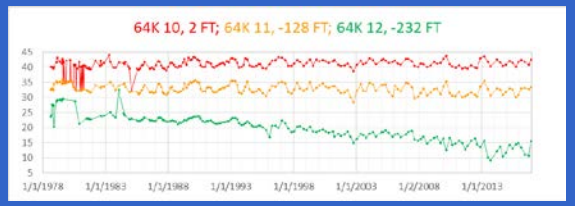


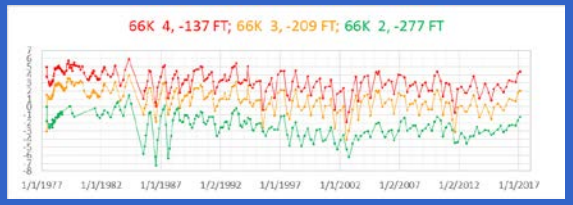


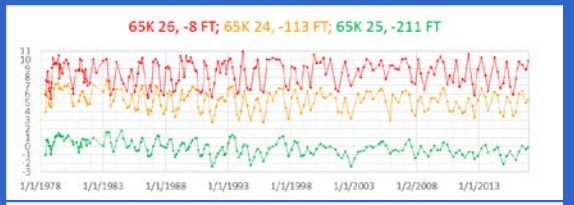


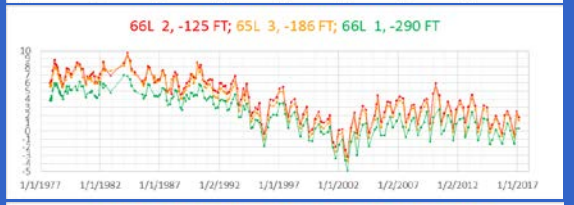


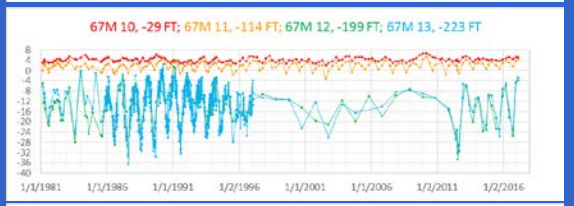


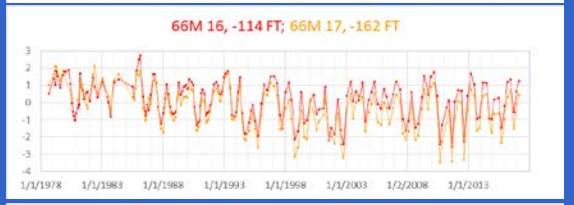


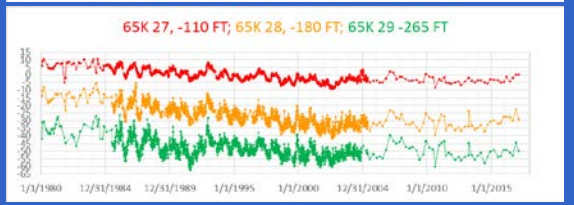


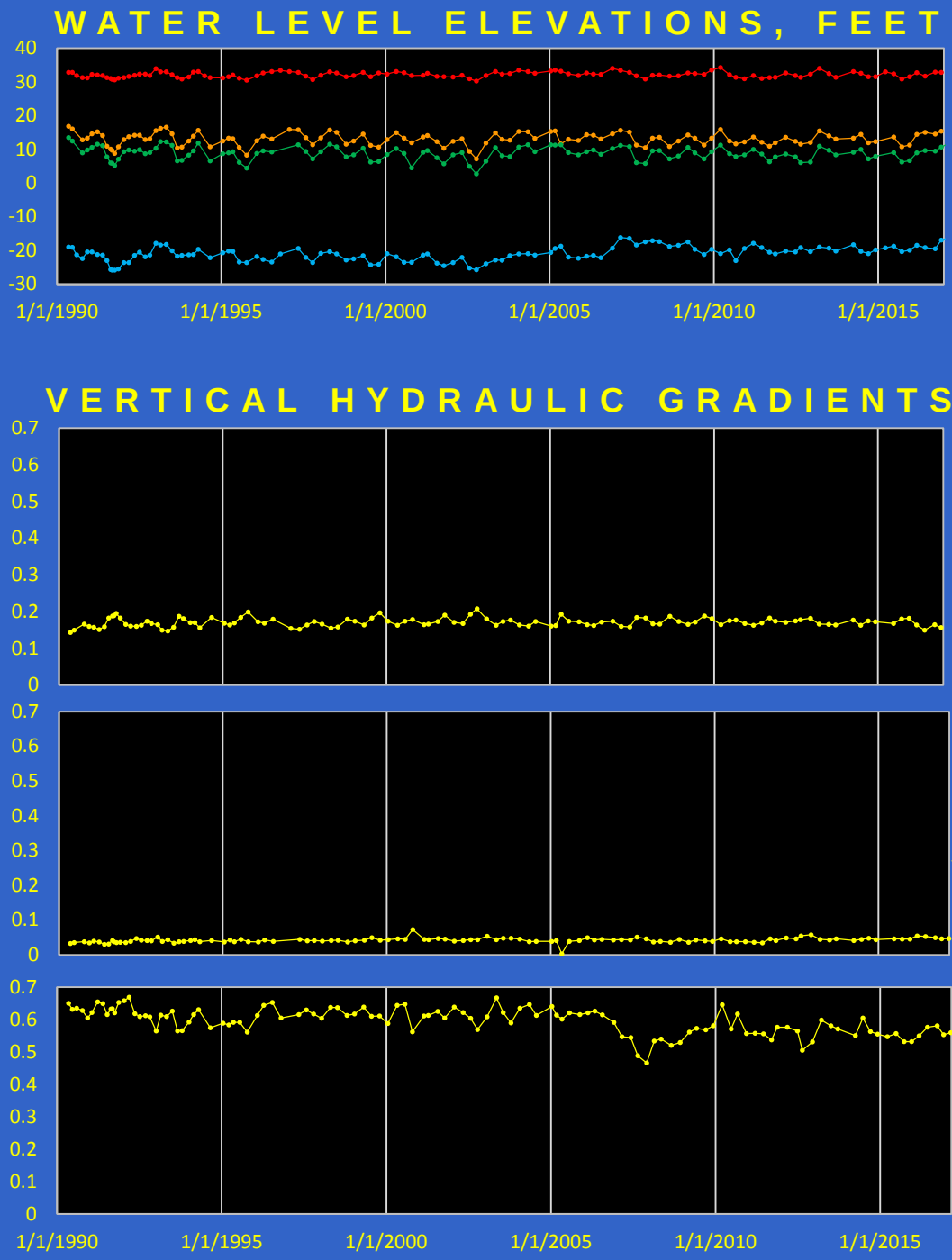


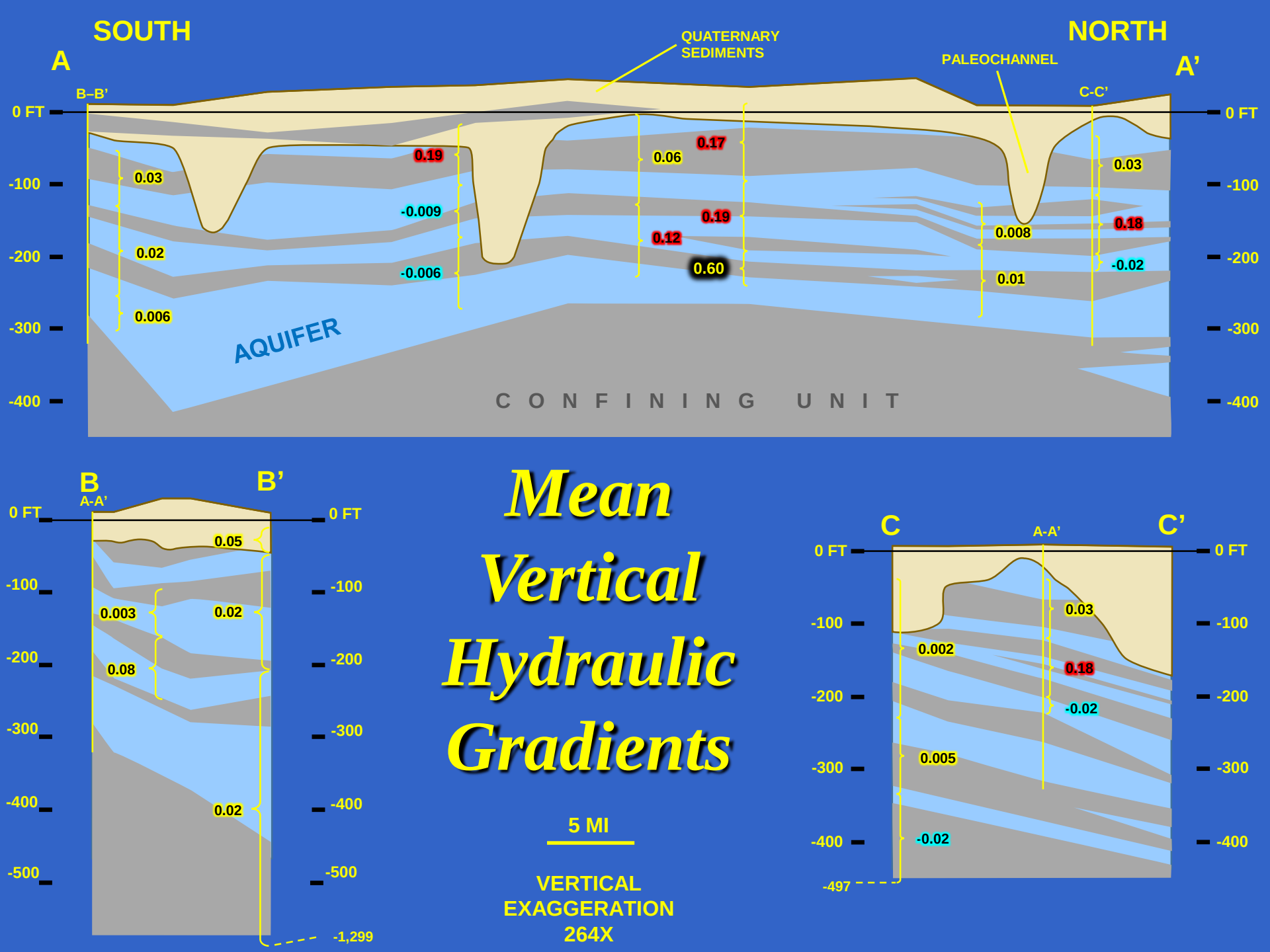




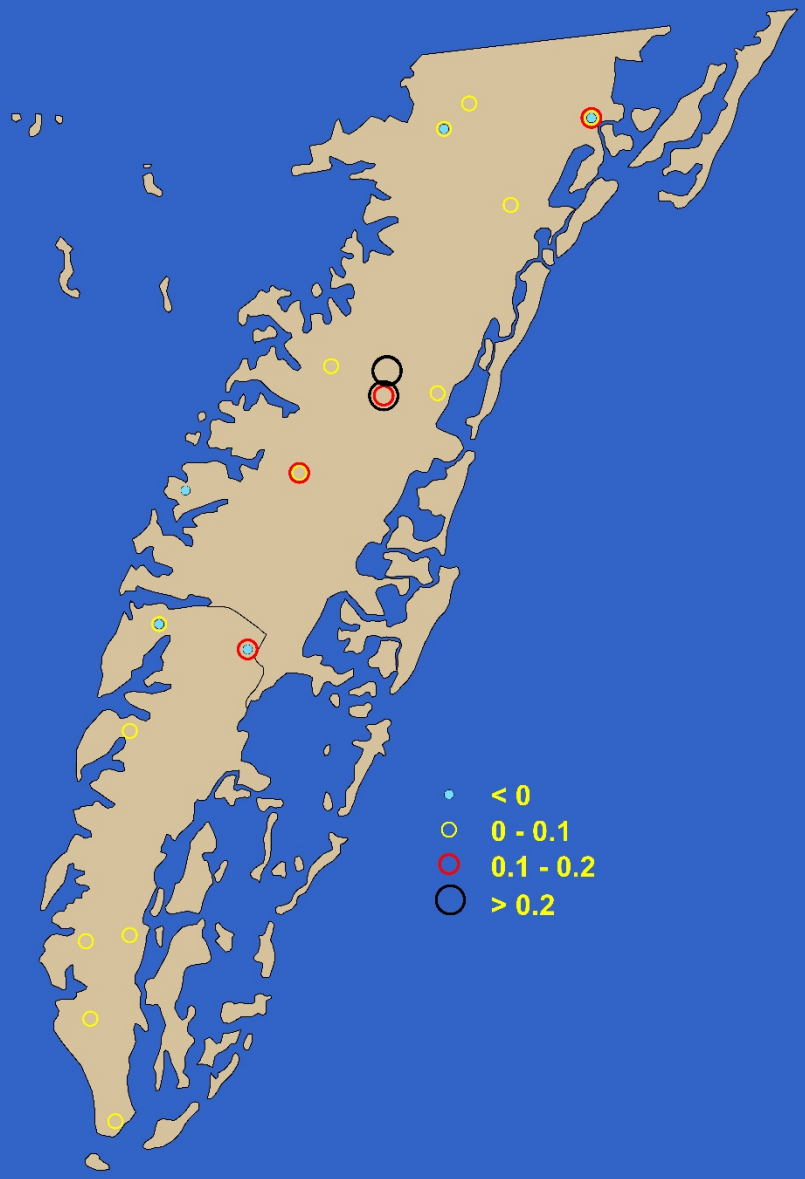




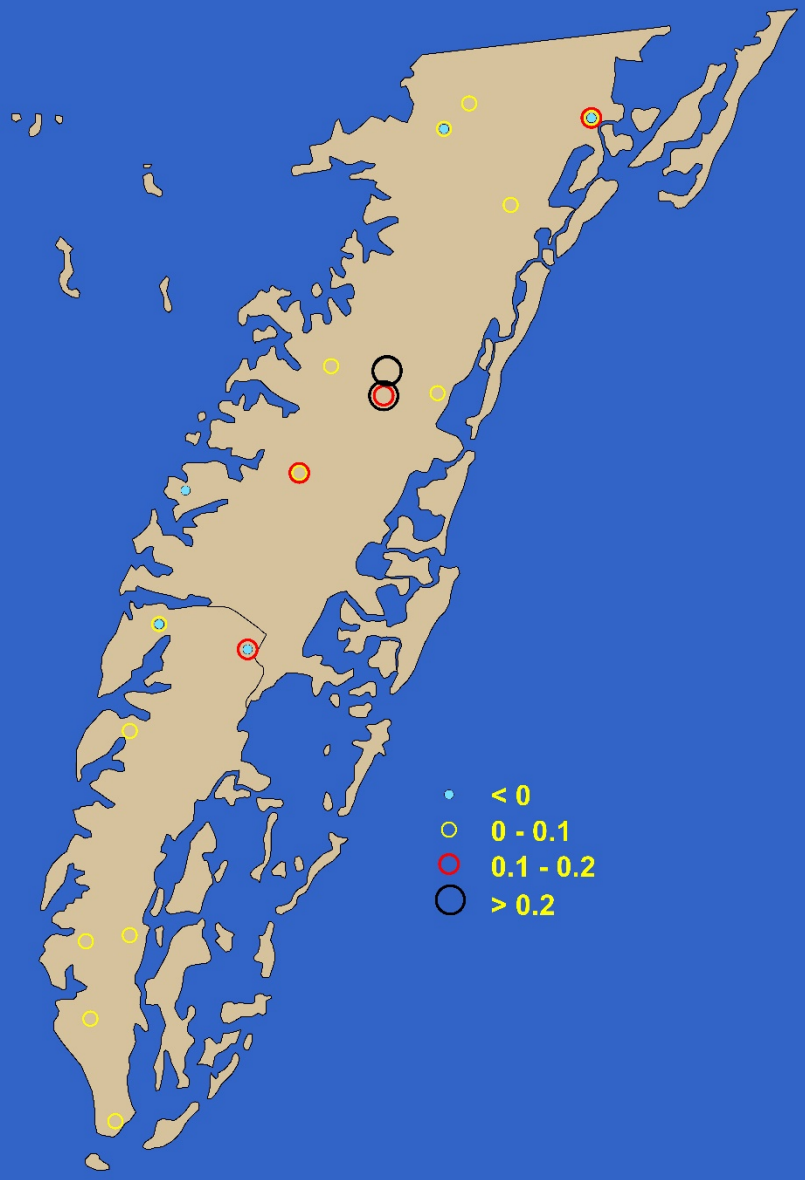

WATER LEVEL ELEVATIONS, FEET
40
30
20
10
0
-10
-20
-30
1/1/1990
1/1/1995
1/1/2000
1/1/2005
1/1/2010
1/1/2015
VERTICAL HYDRAULIC GRADIENTS
0.7
0.6
0.5
0.4
0.3
0.2
0.1
0
1/1/1990
1/1/1995
1/1/2000
1/1/2005
1/1/2010
1/1/2015
VERTICAL HYDRAULIC GRADIENT = Δh / Δd
65K 62
65K 61
65K 60
65K 59
+17 FT
0 FT
-100
-200
-94 FT
-195 FT
-245 FT
Δh
Δh
Δd
Δd
Δd


SOUTH
NORTH
A
A'
QUATERNARY SEDIMENTS
PALEOCHANNEL
B–B'
C-C'
0 FT
-100
-200
-300
-400
0.03
0.02
0.006
0.19
-0.009
-0.006
0.06
0.17
0.19
0.12
0.60
0.008
0.01
0.03
0.18
-0.02
AQUIFER
CONFINING UNIT
B
B'
A-A'
0.05
0.003
0.02
0.08
0.02
-500
-1,299
C
C'
0.002
0.03
0.18
-0.02
0.005
-0.02
-497
Mean Vertical Hydraulic Gradients
5 MI
VERTICAL EXAGGERATION 264X

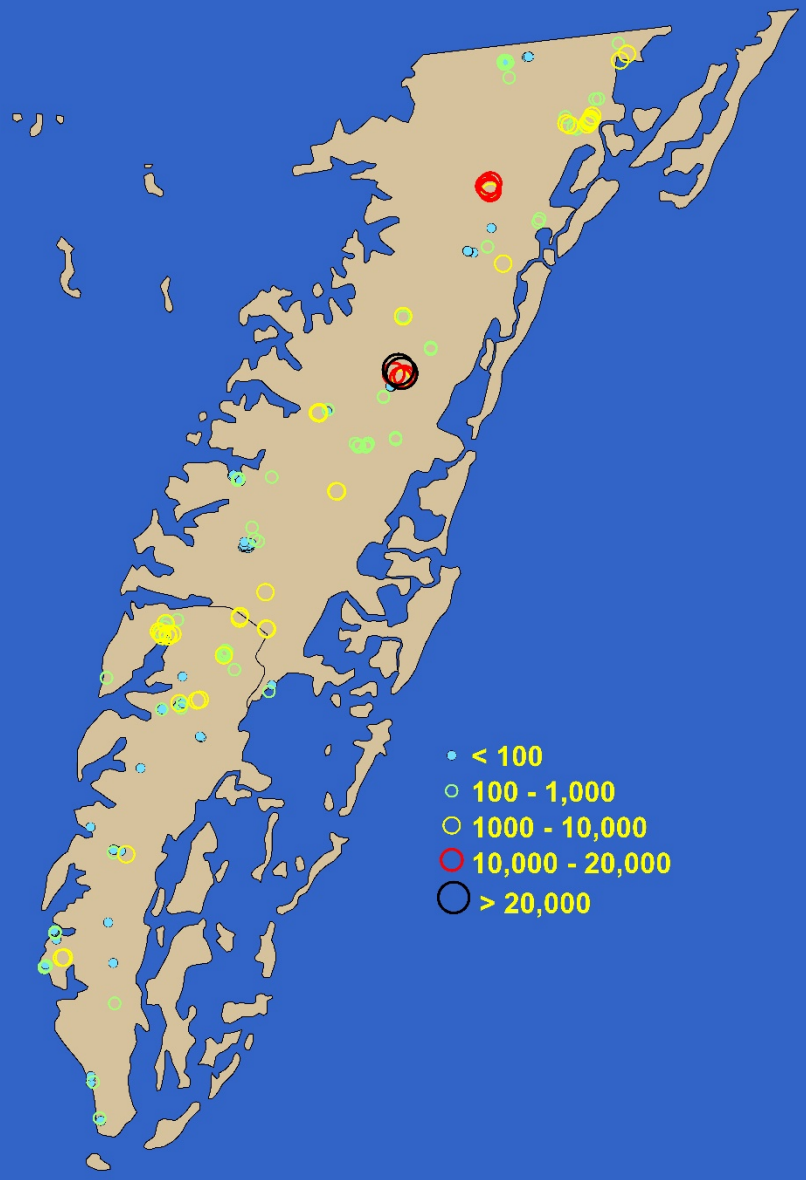
Mean Vertical Hydraulic Gradients



Mean Vertical Hydraulic Gradients

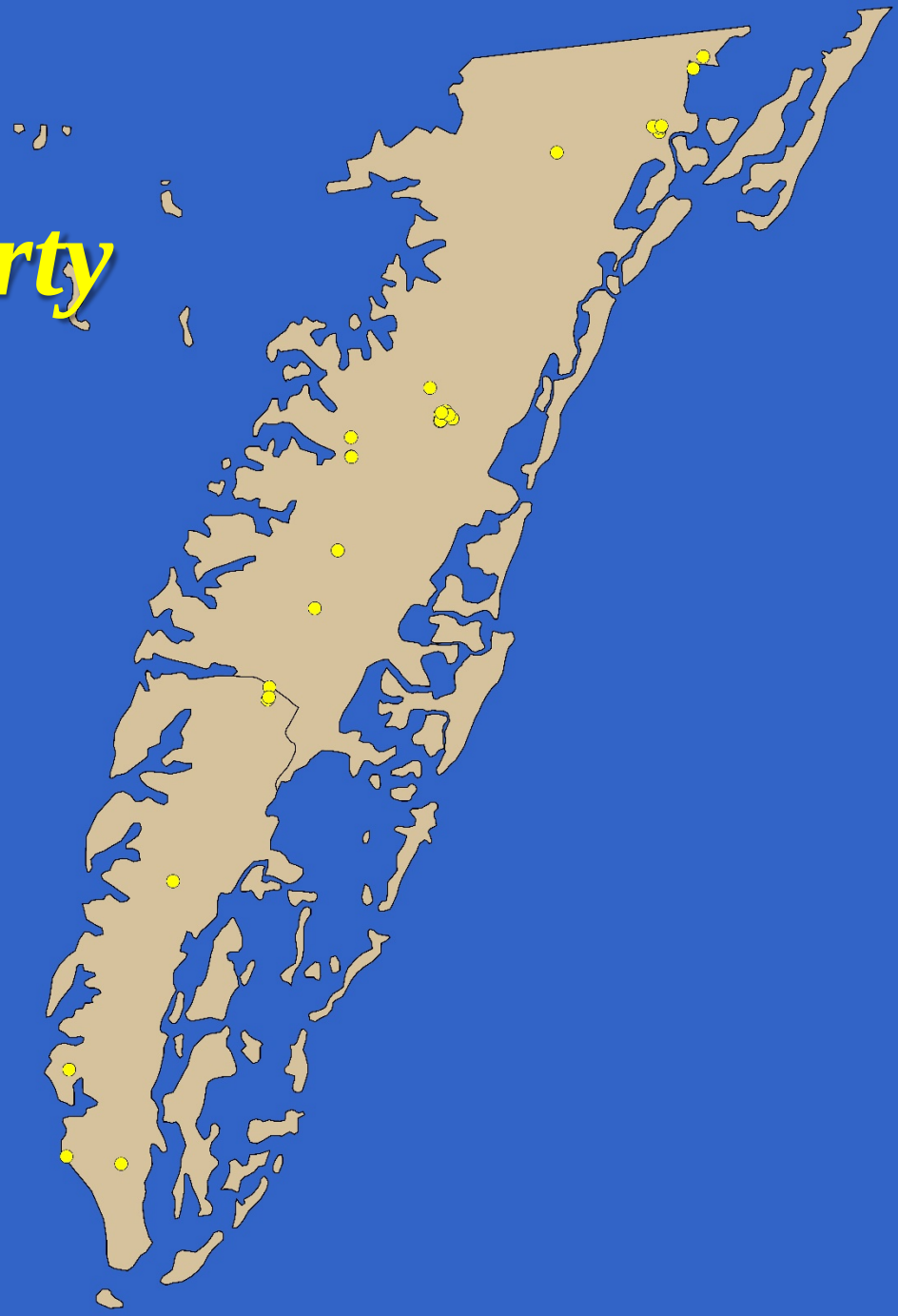


2003–2015 Total Withdrawal (Mgal)



Sediment Hydraulic-Property Data

- *USGS paper files*
- *29 wells*
- *mostly unanalyzed aquifer tests*
- *few permeameters*



Framework Results

- *number of boreholes increased more than sevenfold*
- *3 confined aquifers*
  - *Yorktown*
  - *upper Eastover*
  - *lower Eastover*

  } *associations with geologic formations*
- *localized interbedding*
- *partial confinement of Quaternary/upper Pliocene sediments*
- *large vertical hydraulic gradients possibly caused by withdrawals*

Framework Needs

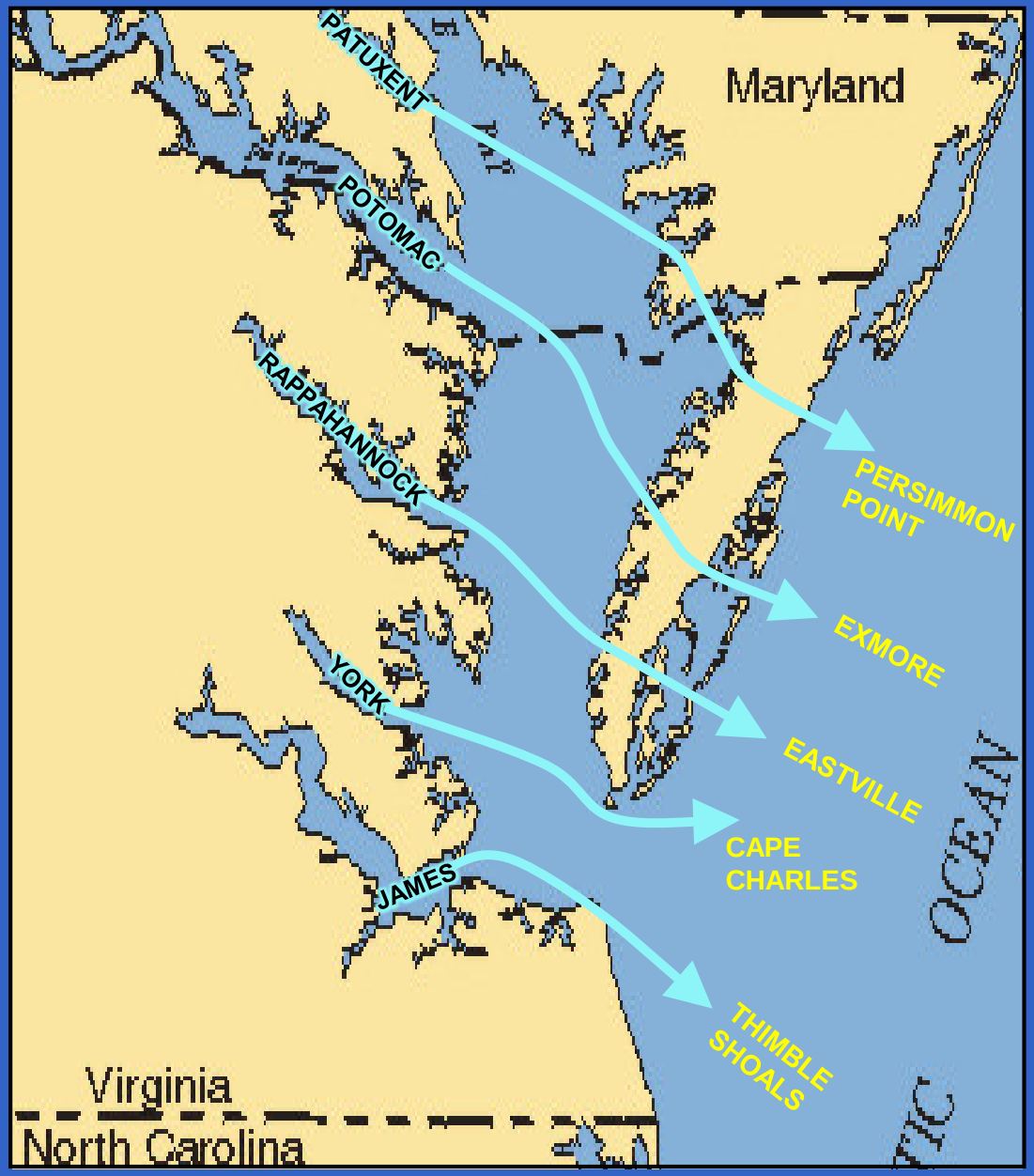
- *geophysical-log interpretation not complete*
- *aquifer surfaces not mapped*
- *aquifer tests not analyzed*
- *model refinement*
- *existing data*

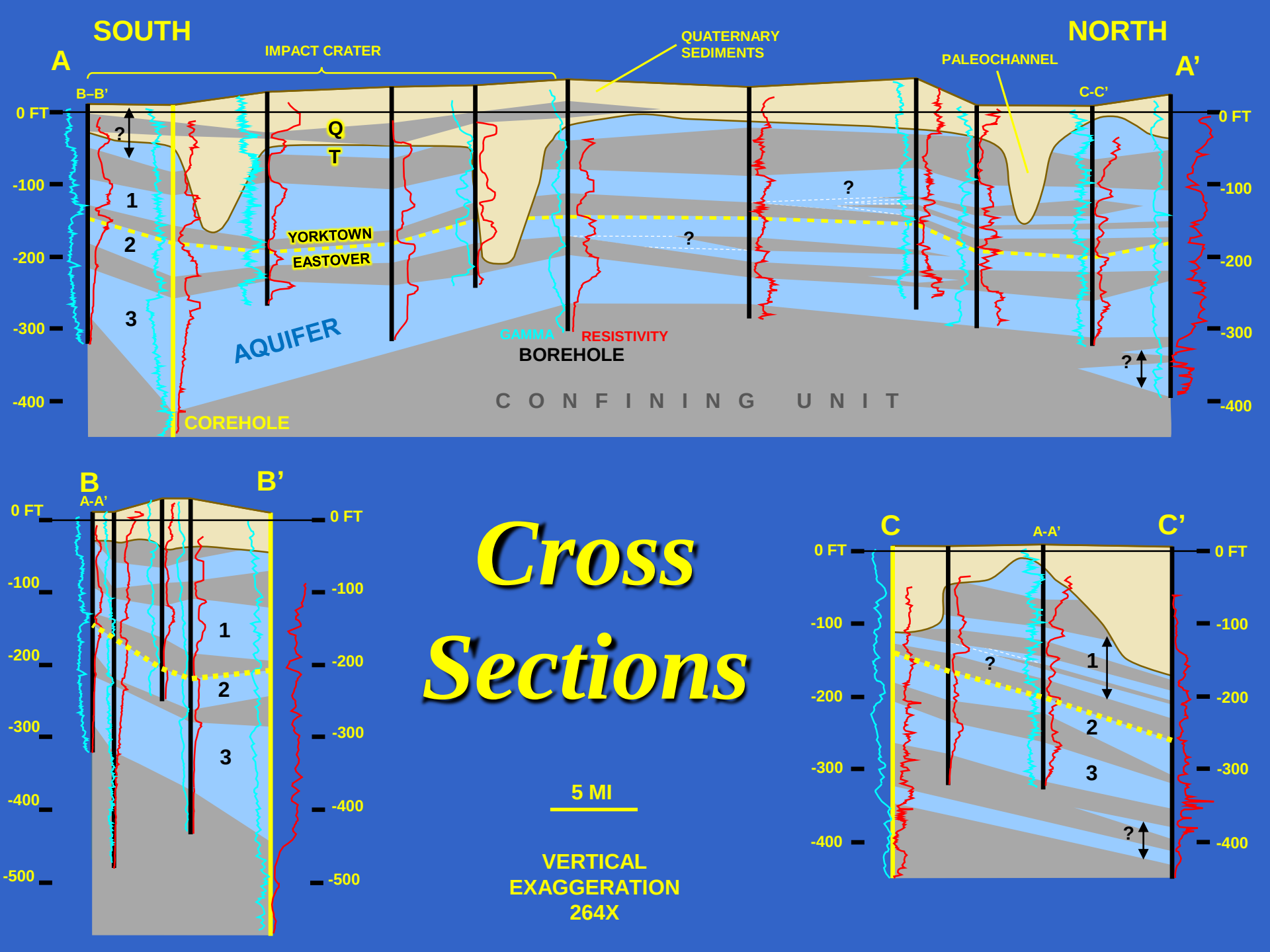
Results

- *aquifer framework*
- *paleochannels*
- *chloride*

Late Pliocene Lowstand Drainage

(Hobbs, 2004)




SOUTH
NORTH
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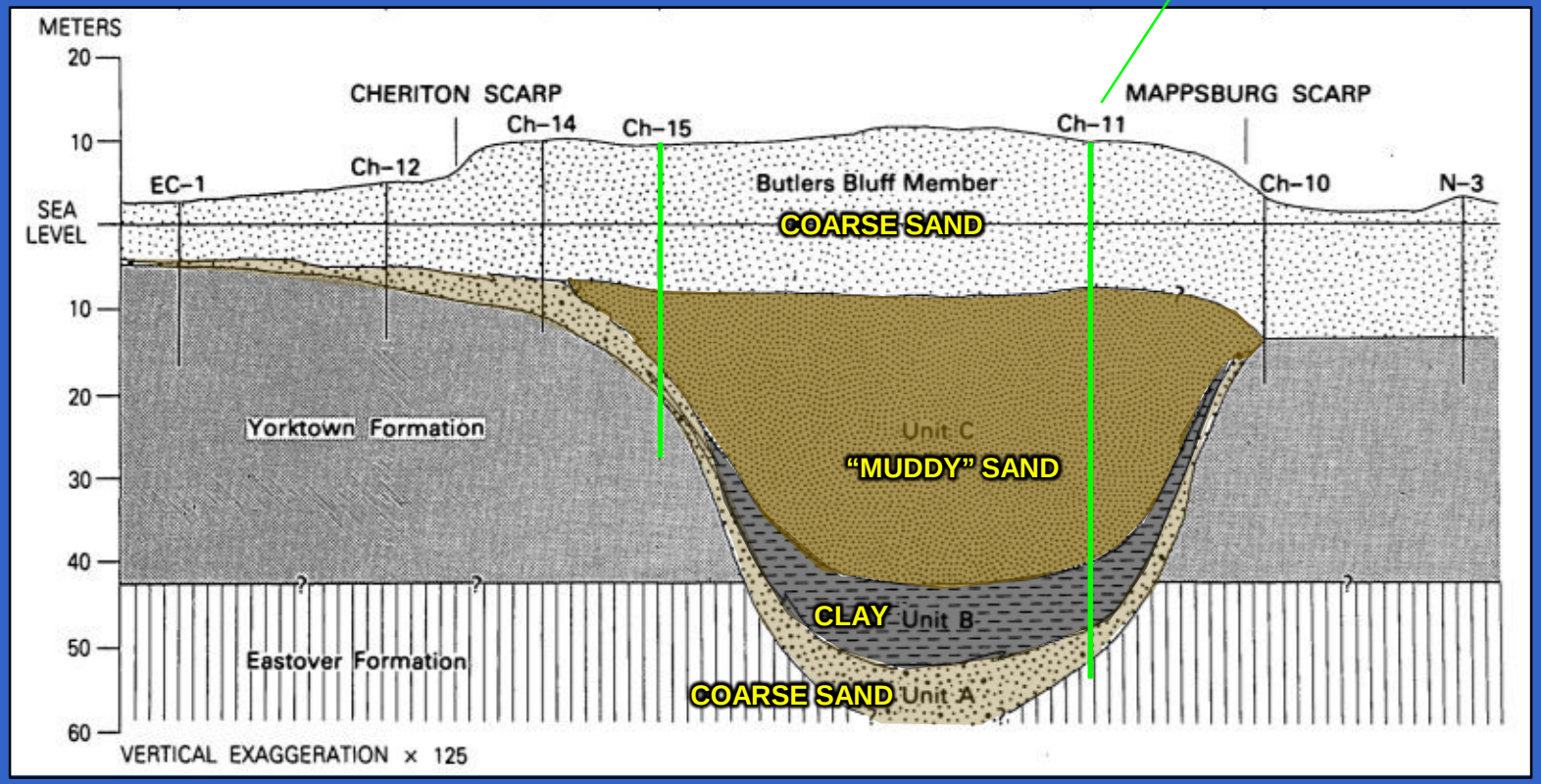
QUATERNARY SEDIMENTS
PALEOCHANNEL
B–B'
C-C'
0 FT
-100
-200
-300
-400
Q
T
1
2
3
YORKTOWN
EASTOVER
AQUIFER
GAMMA
RESISTIVITY
BOREHOLE
COREHOLE
C O N F I N I N G U N I T
?
B
B'
A-A'
-500
C
C'
Cross Sections
5 MI
VERTICAL EXAGGERATION 264X

Paleochannels

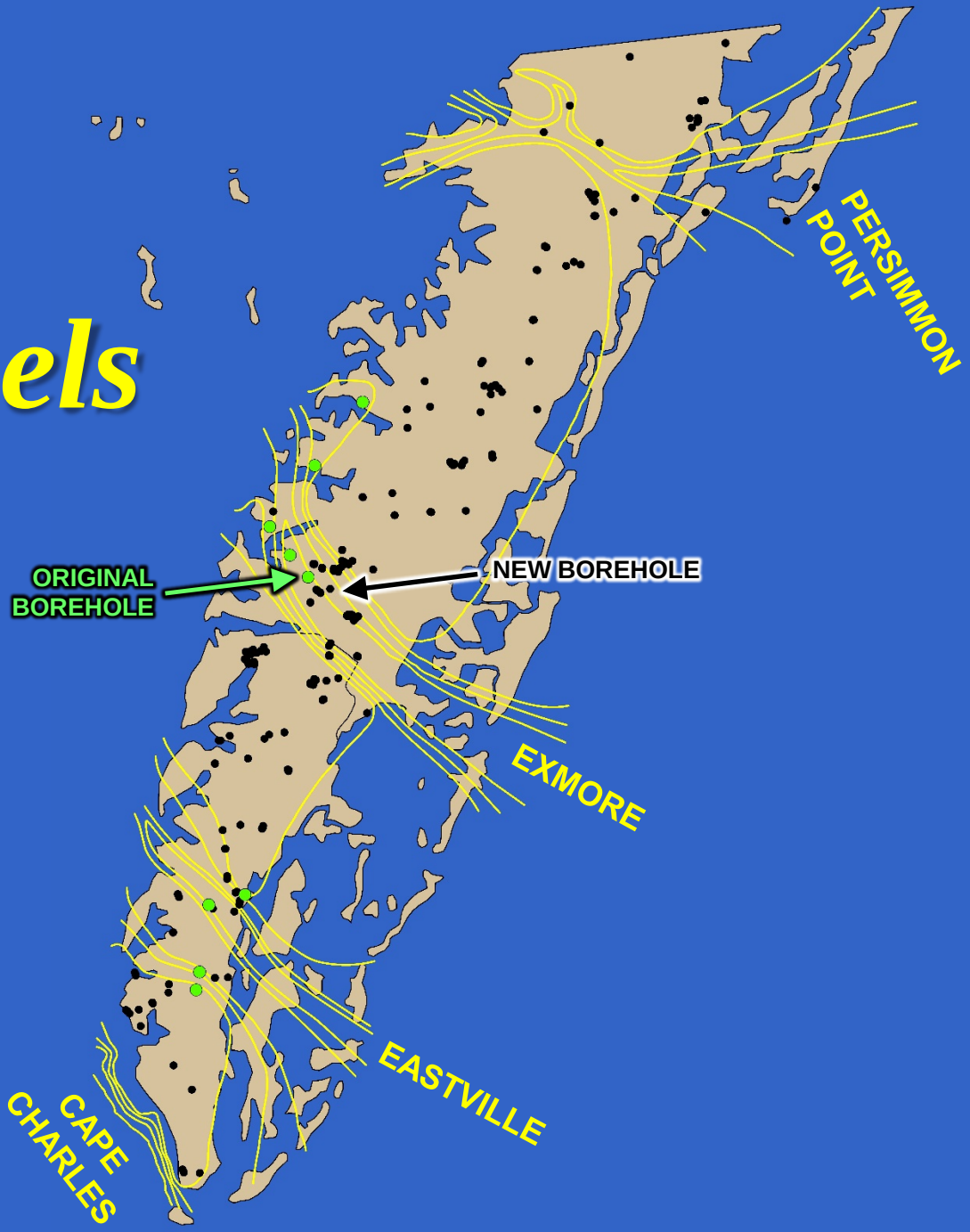
- *Mixon/Powars mapped base of Quaternary sediments*
- *original borehole data mostly unavailable*
- *positions of channels well known*
- *channel-fill sediments poorly known*

Documented Paleochannel Sediments

(Mixon, 1985)

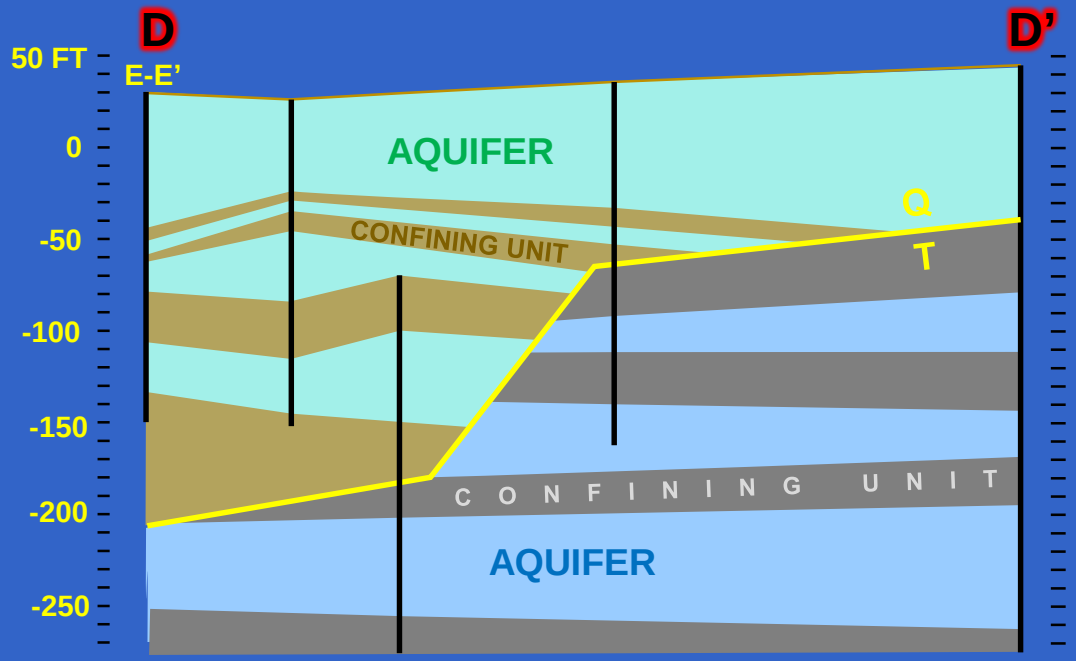


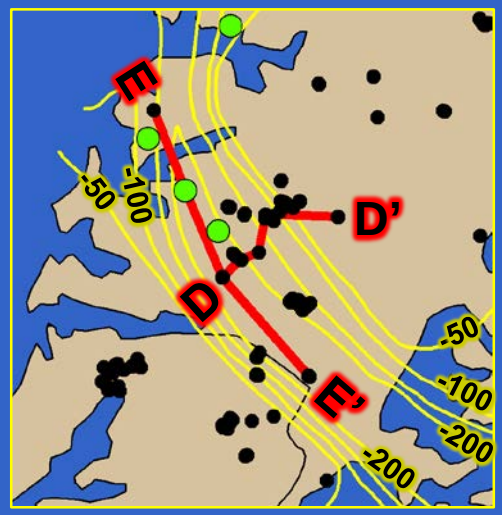
Paleochannels



Paleochannel Cross Sections

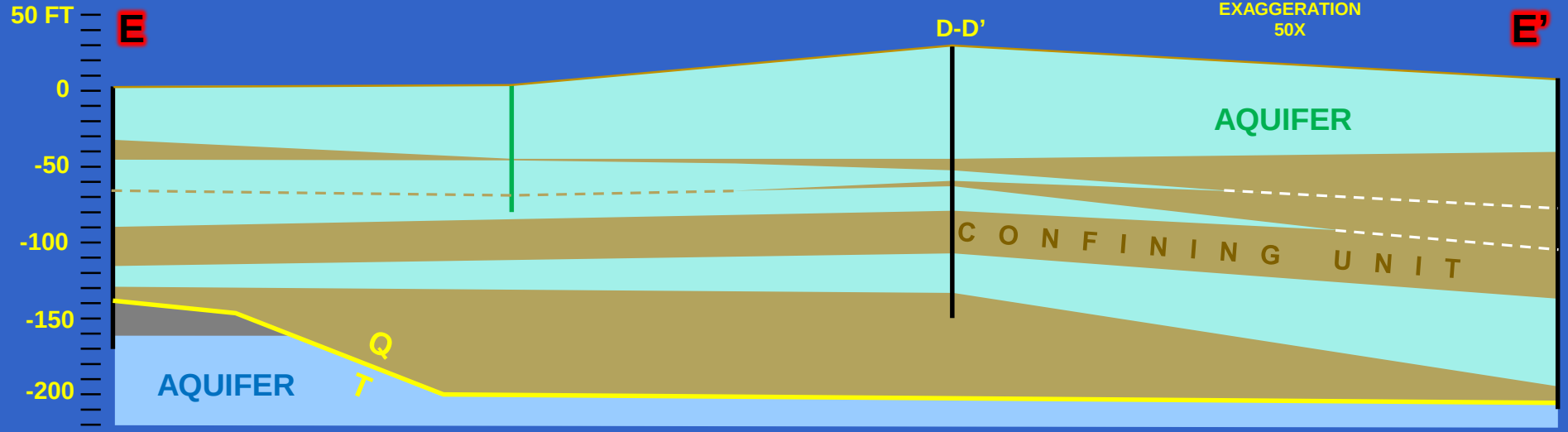
Exmore Paleochannel



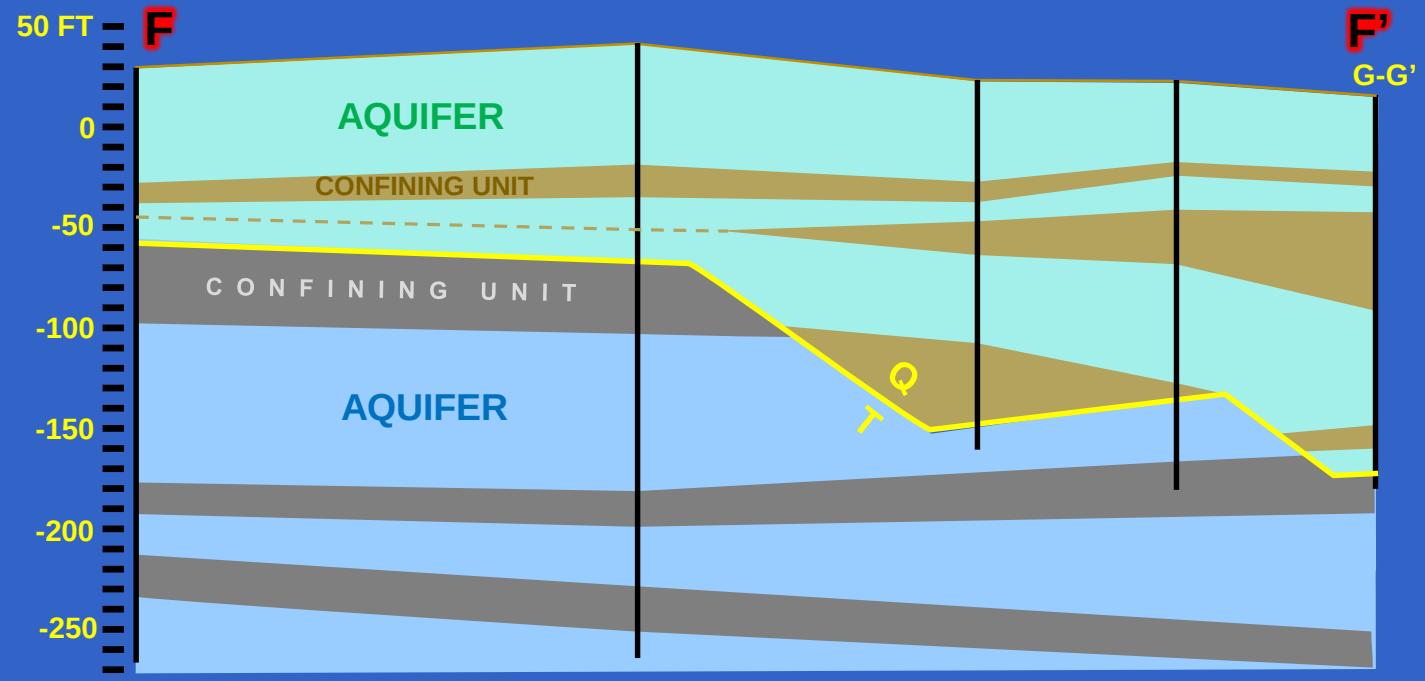


1 MILE

VERTICAL EXAGGERATION 50X

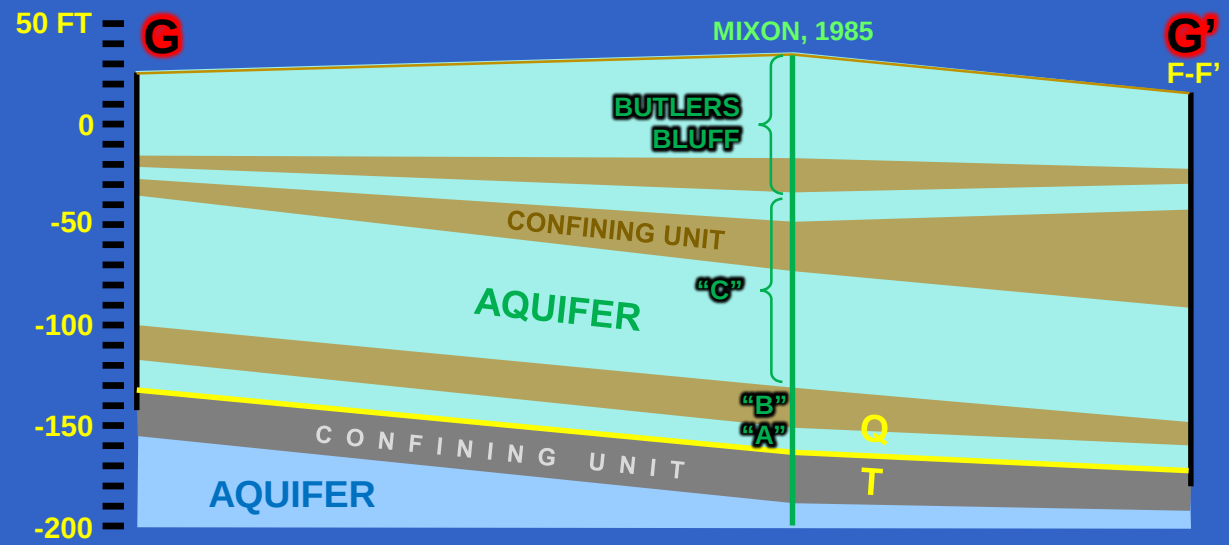


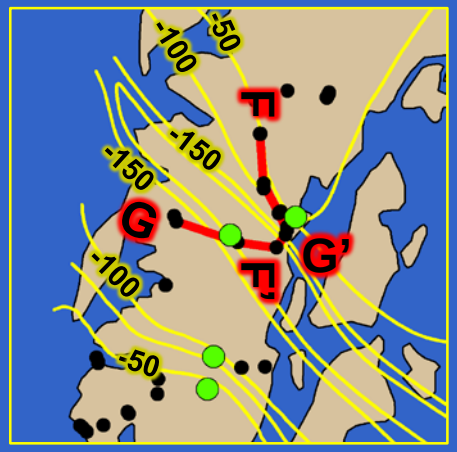
Eastville Paleochannel



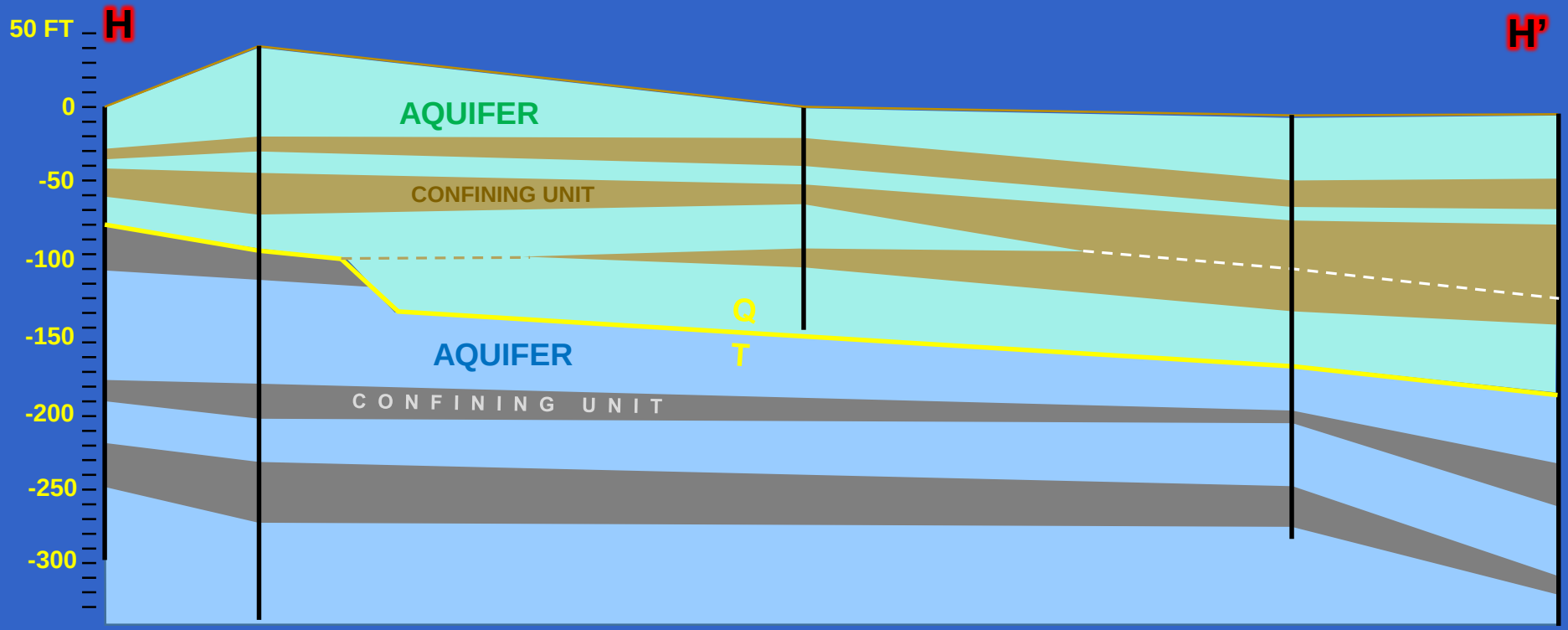
1 MILE

VERTICAL EXAGGERATION 30X



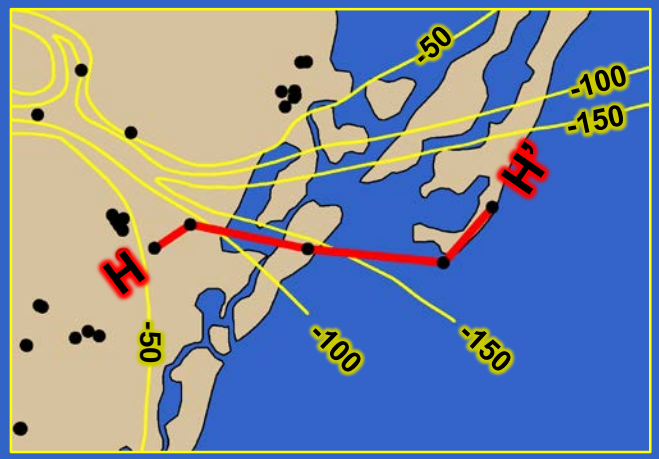


Persimmon Point Paleochannel



1 MILE

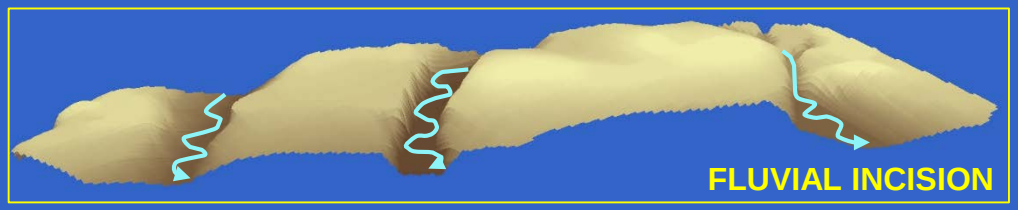
VERTICAL EXAGGERATION 70X



Paleochannel Inundation

NORTH →

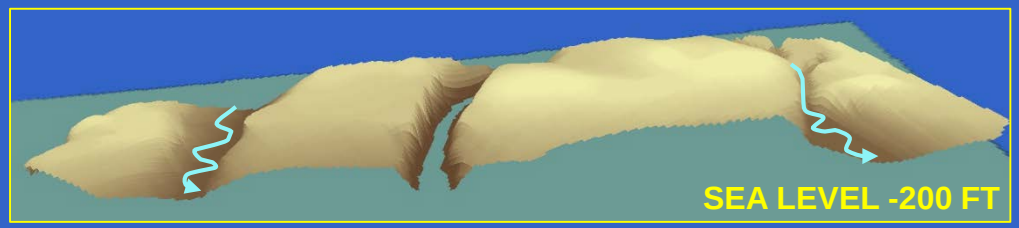
TIME 1



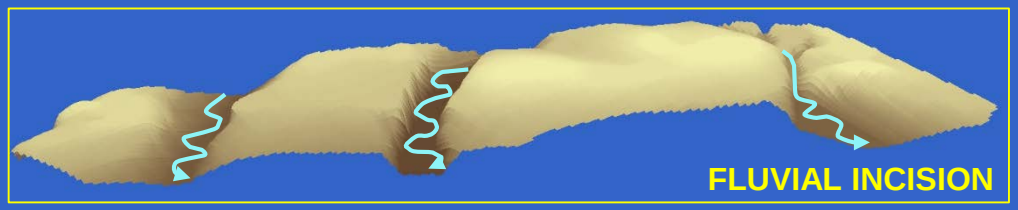
Paleochannel Inundation

NORTH →

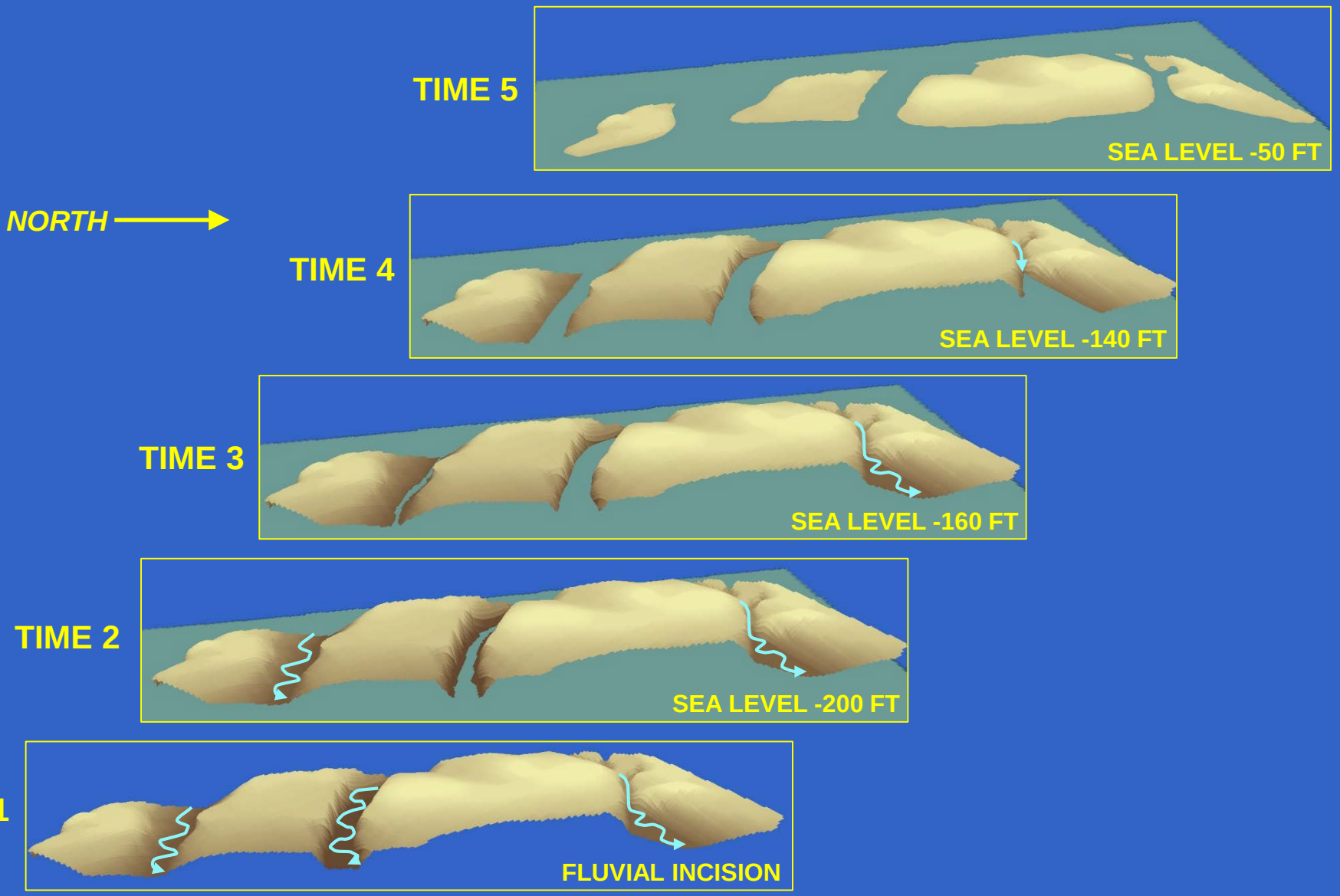
TIME 2



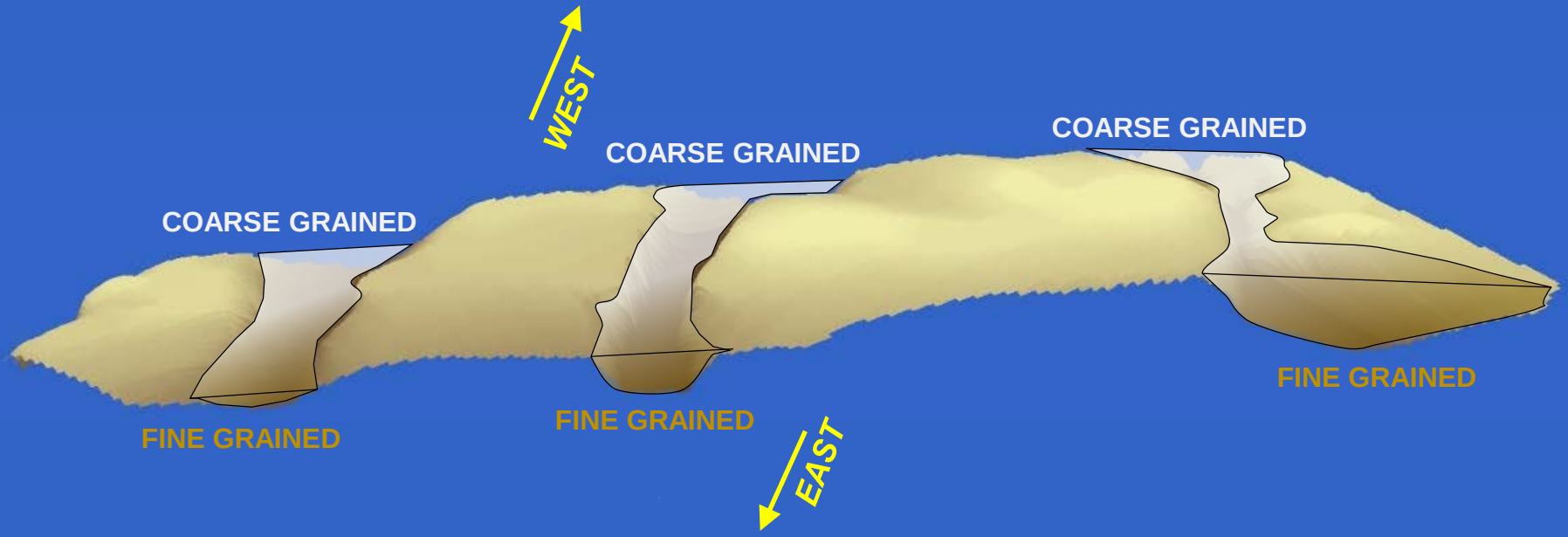
TIME 1



Paleochannel Inundation



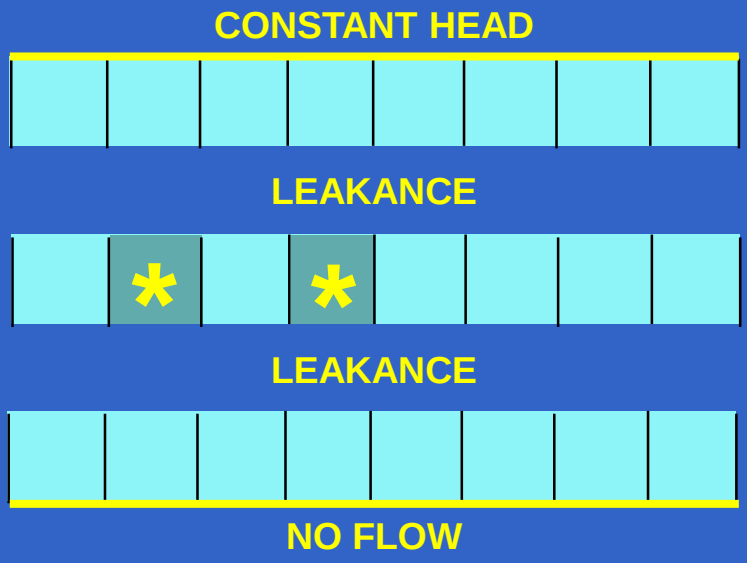
Paleochannel Backfill



Paleochannel Model Layering

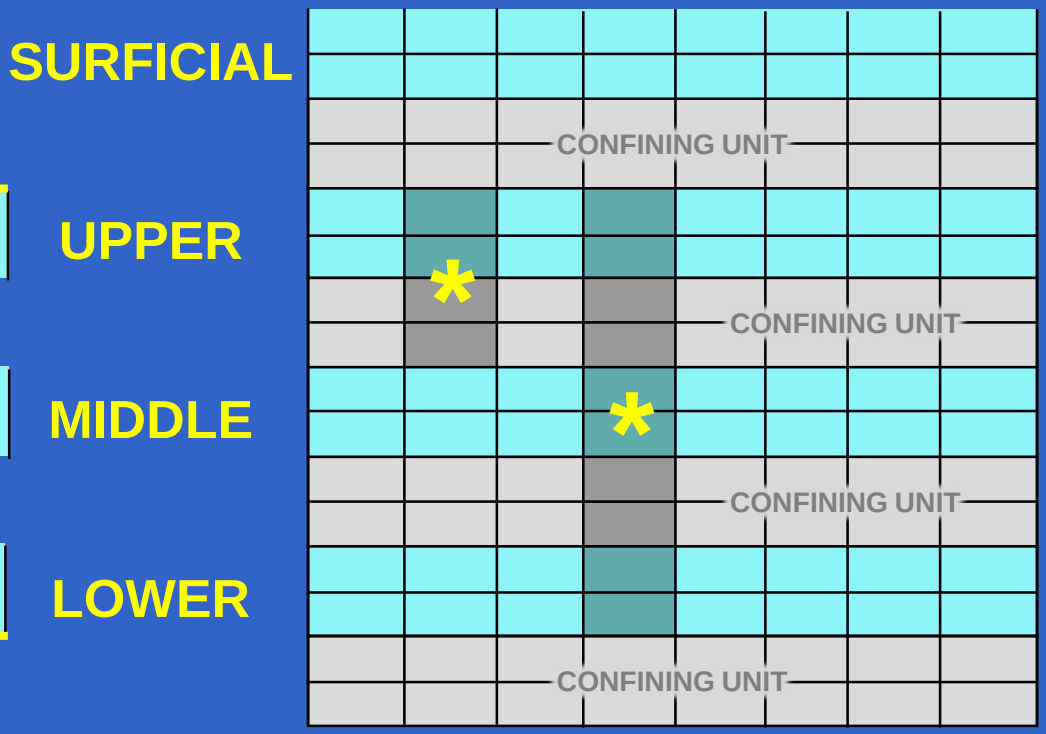
NORTH →

Richardson, 1994



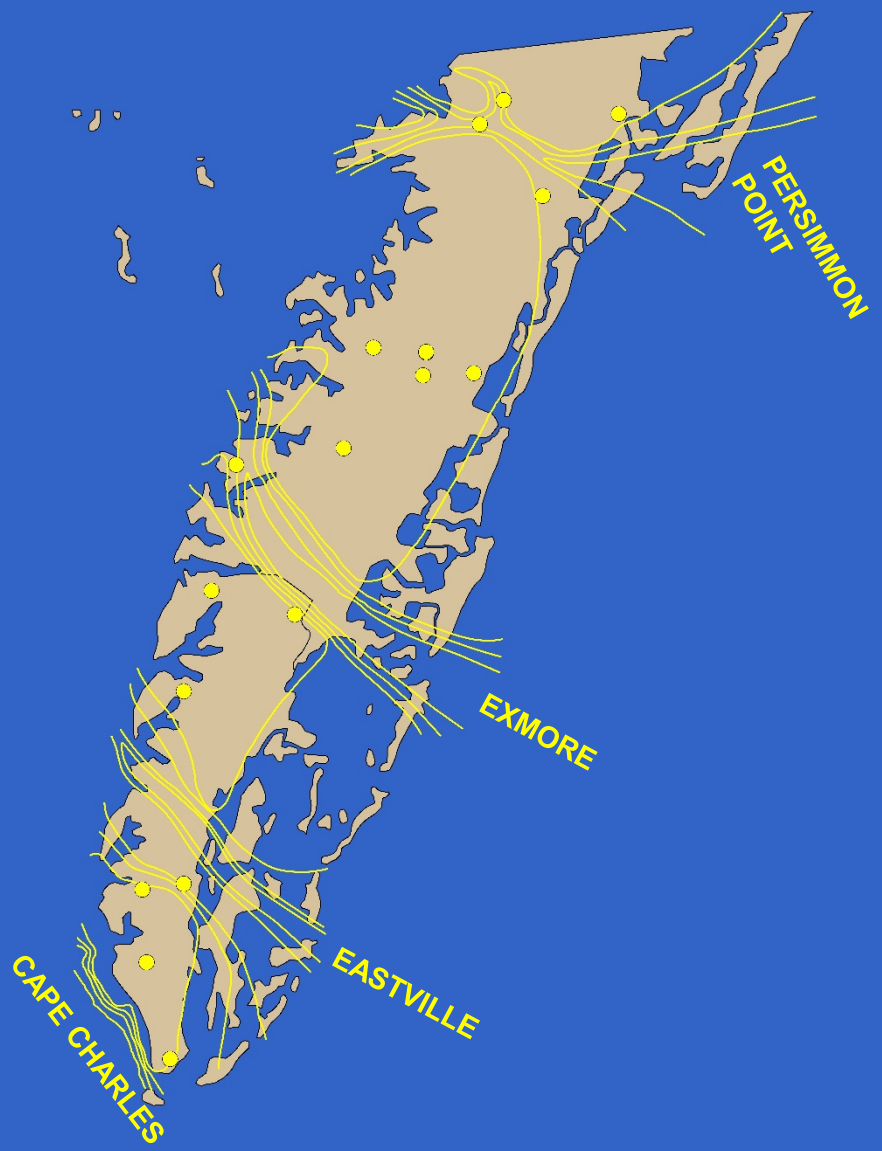
* EASTVILLE AND PALEOCHANNEL K = 1/10 CONFINED-AQUIFER K

Sanford and others, 2009

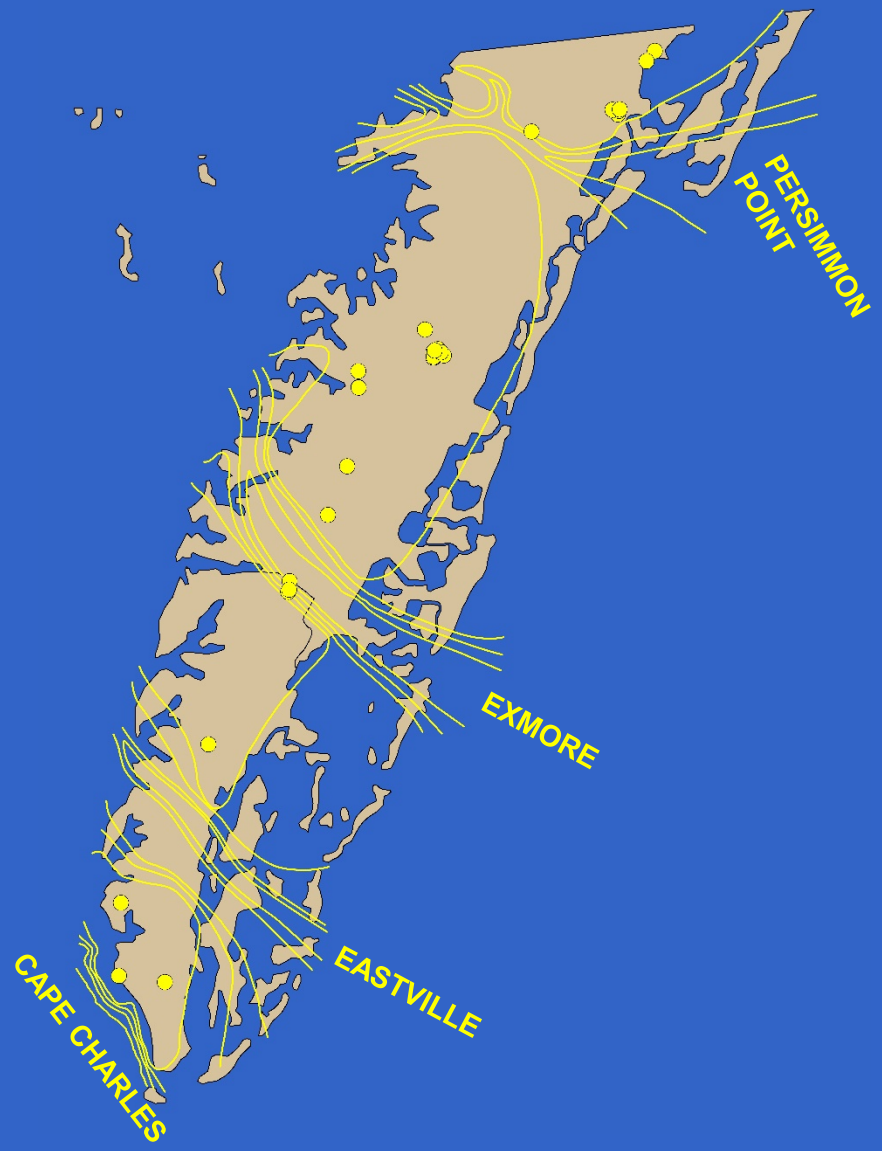


* PALEOCHANNEL K
5 FT/D EASTVILLE
100 FT/D EXMORE

Vertical Hydraulic Gradients



Sediment Hydraulic-Property Data



Paleochannel Results

- *stratification within paleochannels*
  - *localized confinement*
  - *fine-grained sediments increase eastward*
- *aquifers and confining units truncated across channel sides*
- *shallow aquifers and confining units extend beyond paleochannels*

Paleochannel Needs

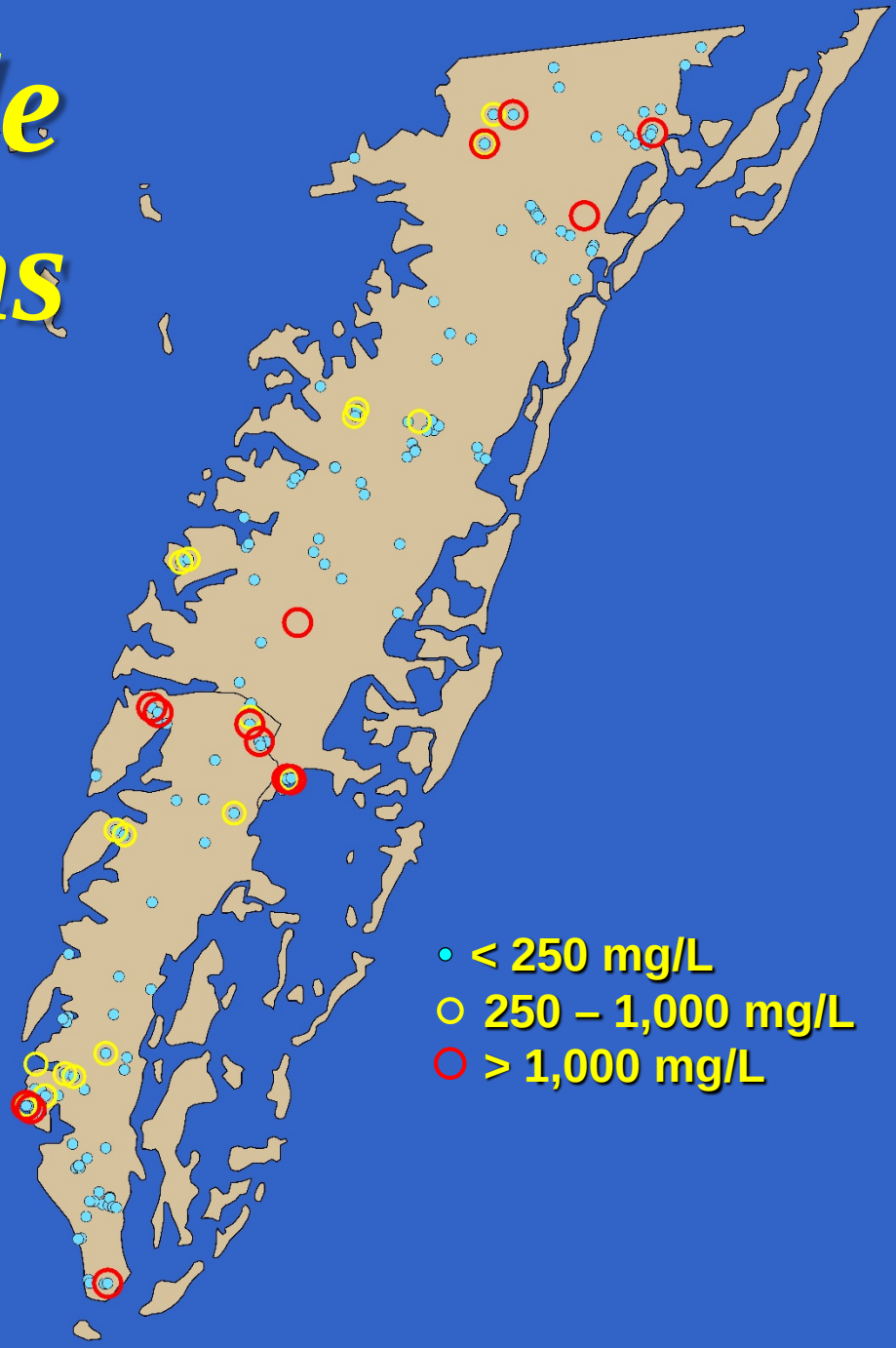
- *geophysical-log interpretation not complete*
  - *within paleochannels*
  - *between paleochannels*
- *additional boreholes and cross sections*
  - *Eastville*
  - *Persimmon Point*
- *additional observation wells*
  - *vertical hydraulic gradients*
  - *sediment hydraulic properties*
- *model refinement*

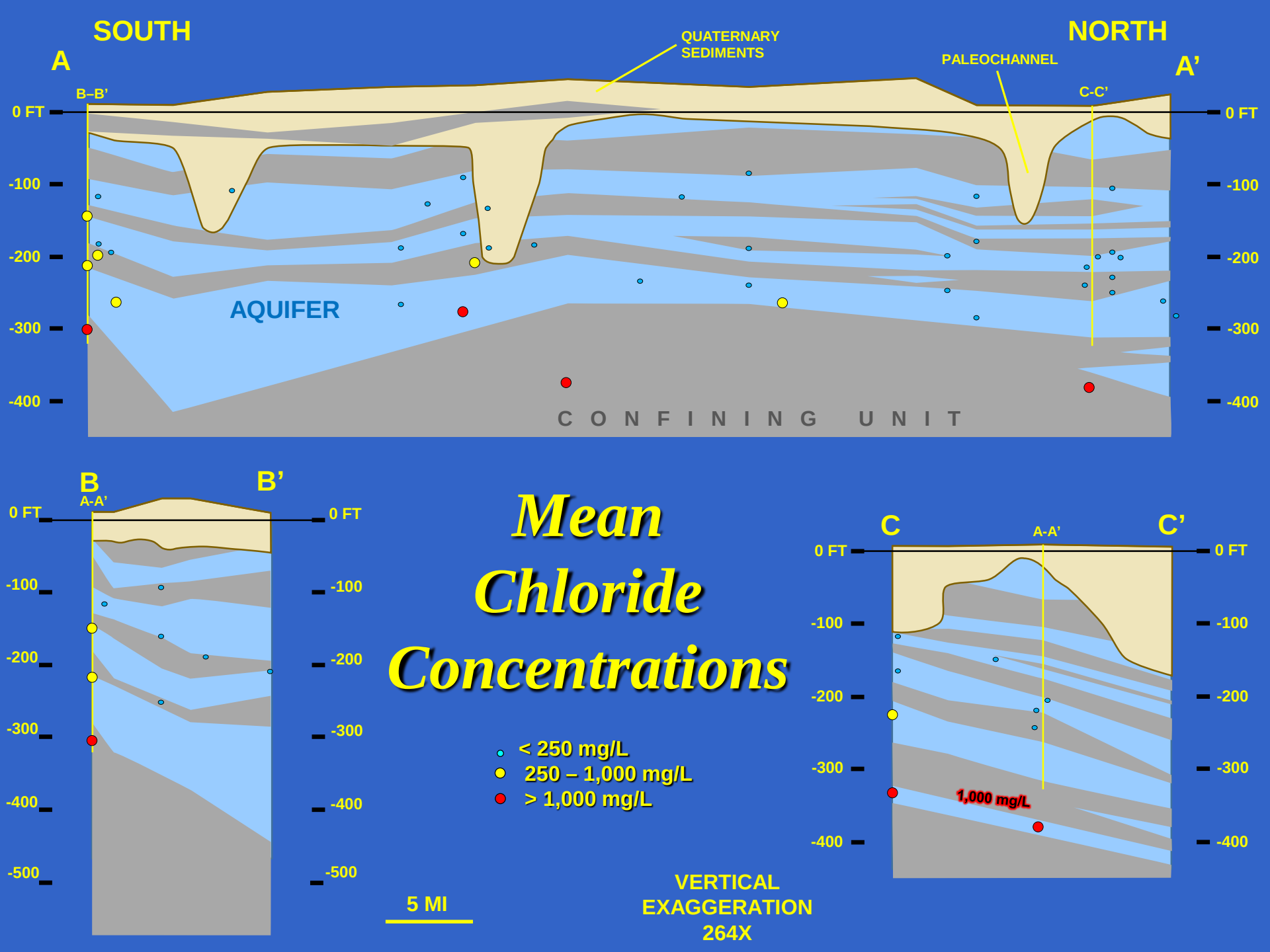
Results

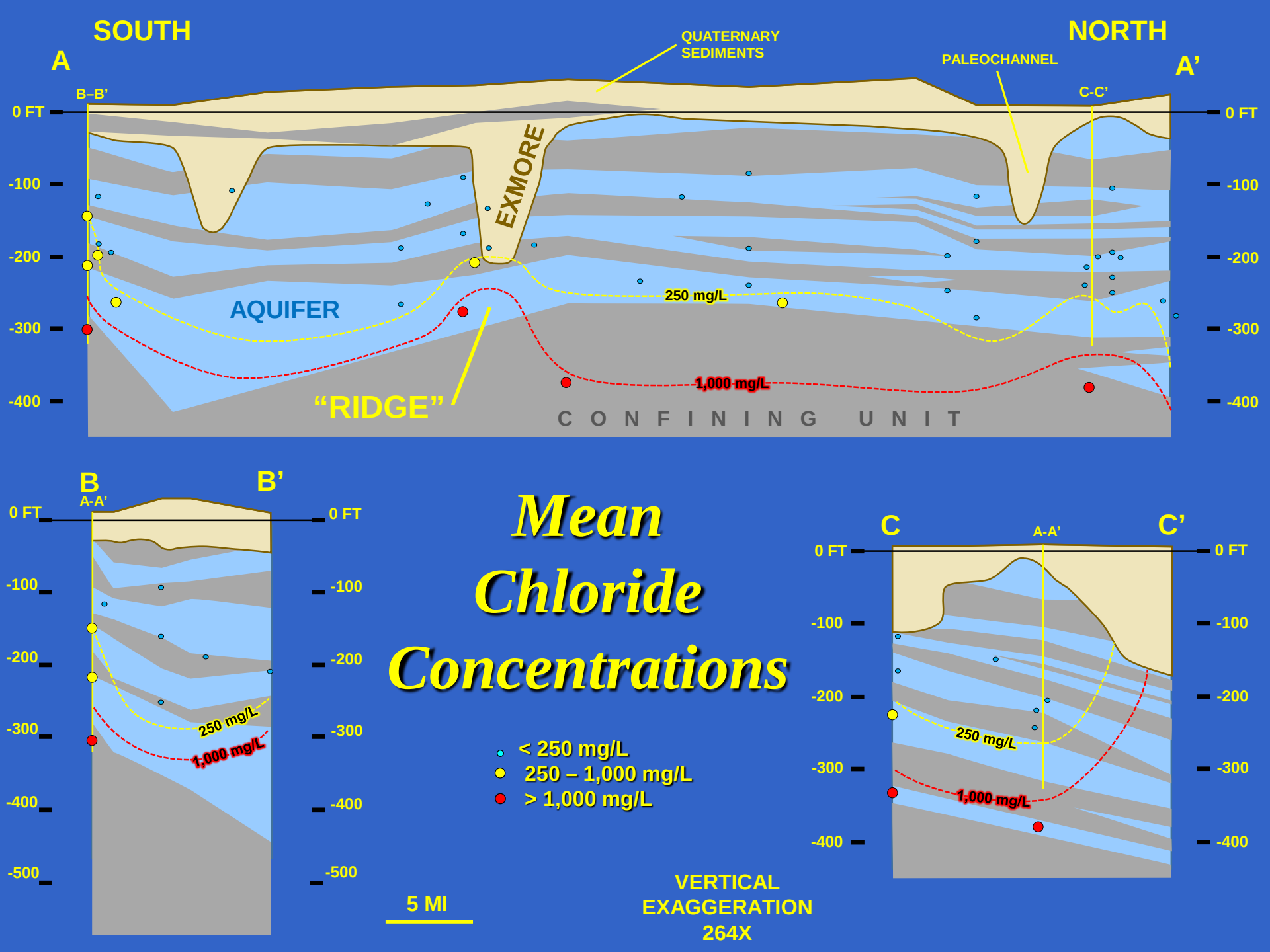
- *aquifer framework*
- *paleochannels*
- *chloride*

Mean Chloride Concentrations

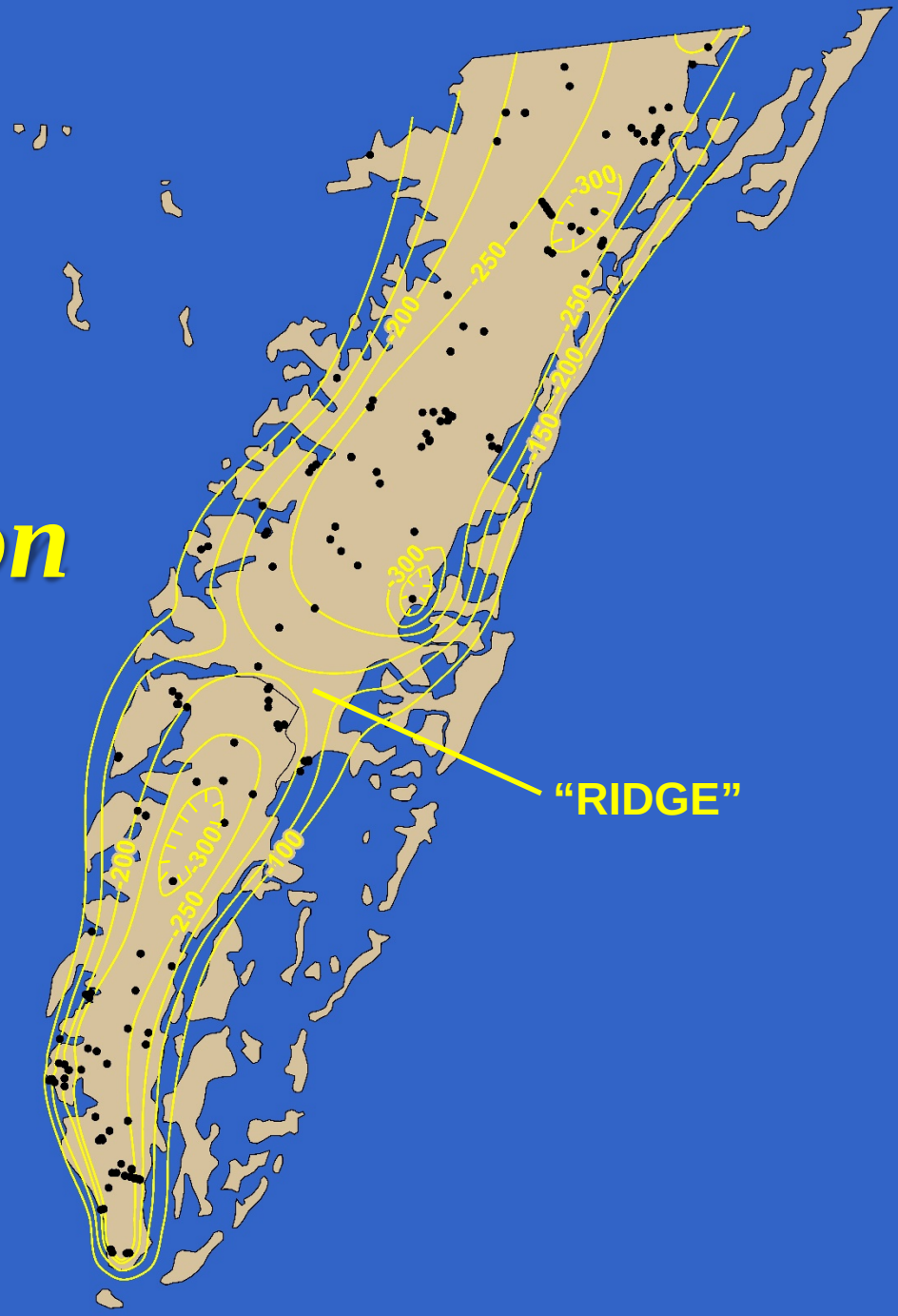
- *291 wells*
  - *190 USGS*
  - *48 DEQ*
  - *53 SWCB Bulletin 332*
- *1,992 samples*
  - *341 USGS*
  - *1,547 DEQ*
  - *104 SWCB Bulletin 332*
- *1906 - 2016*




SOUTH
NORTH
A
A'
B–B'
C-C'
QUATERNARY SEDIMENTS
PALEOCHANNEL
0 FT
-100
-200
-300
-400
AQUIFER
C O N F I N I N G U N I T
B
B'
A-A'
-500
C
C'
Mean Chloride Concentrations
< 250 mg/L
250 – 1,000 mg/L
> 1,000 mg/L
1,000 mg/L
5 MI
VERTICAL EXAGGERATION 264X

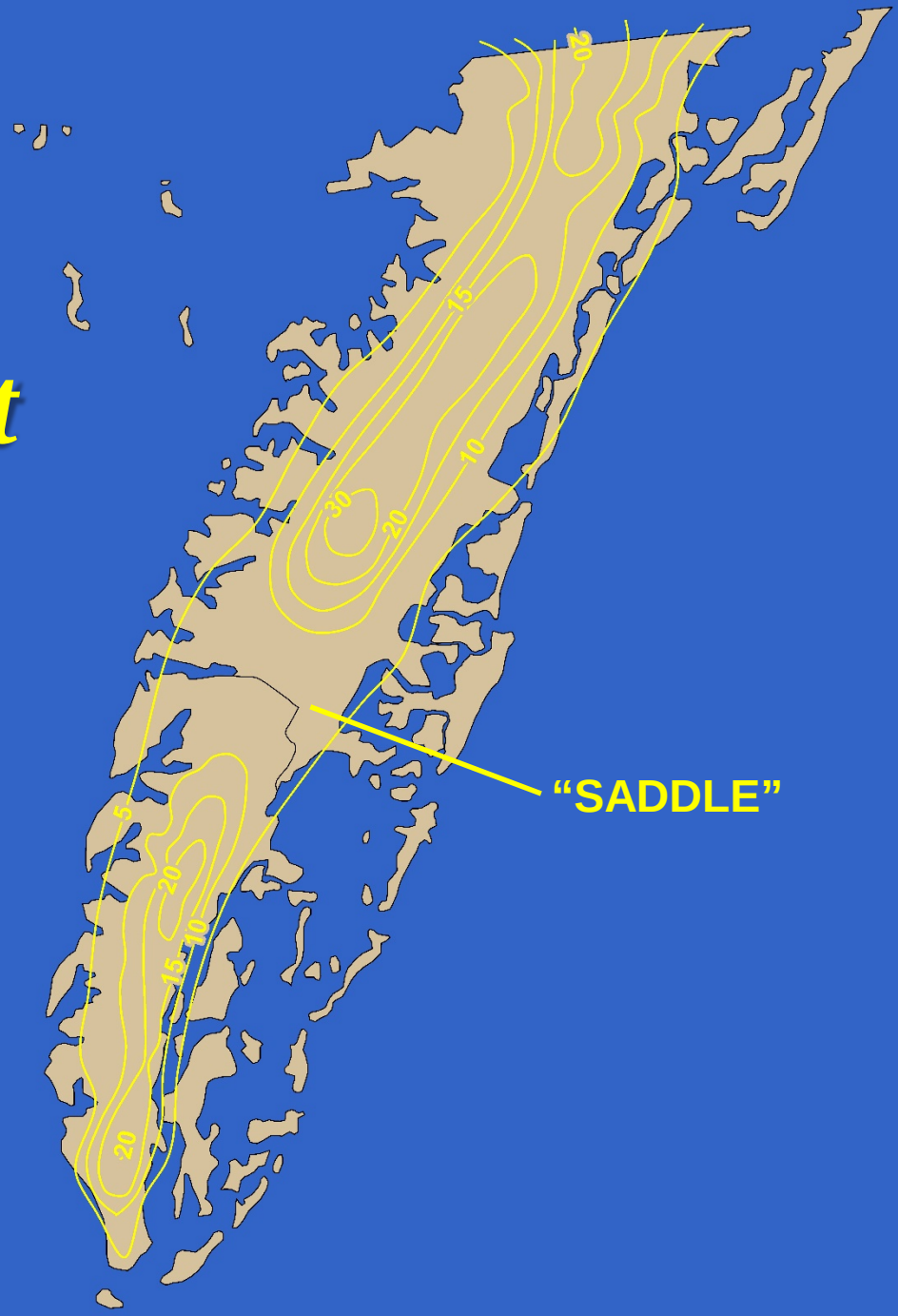

SOUTH
NORTH
A
A'
B–B'
C-C'
QUATERNARY SEDIMENTS
PALEOCHANNEL
EXMORE
0 FT
-100
-200
-300
-400
AQUIFER
250 mg/L
1,000 mg/L
"RIDGE"
C O N F I N I N G U N I T
B
B'
A-A'
-500
C
C'
Mean Chloride Concentrations
< 250 mg/L
250 – 1,000 mg/L
> 1,000 mg/L
5 MI
VERTICAL EXAGGERATION 264X

Chloride 250 mg/L Iso-Concentration Surface

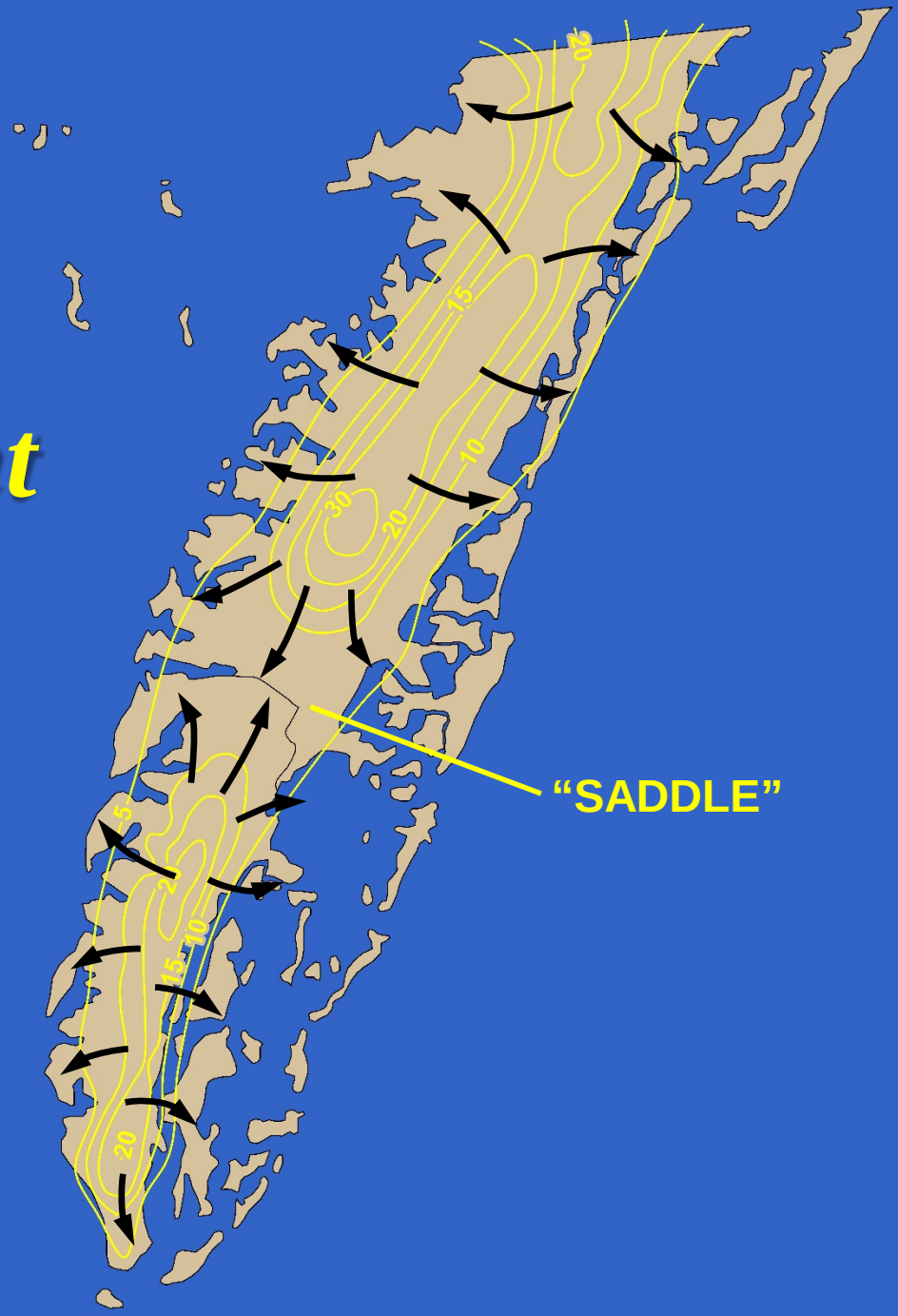


Simulated Predevelopment Potentiometric Surface

(Sanford and others, 2009)

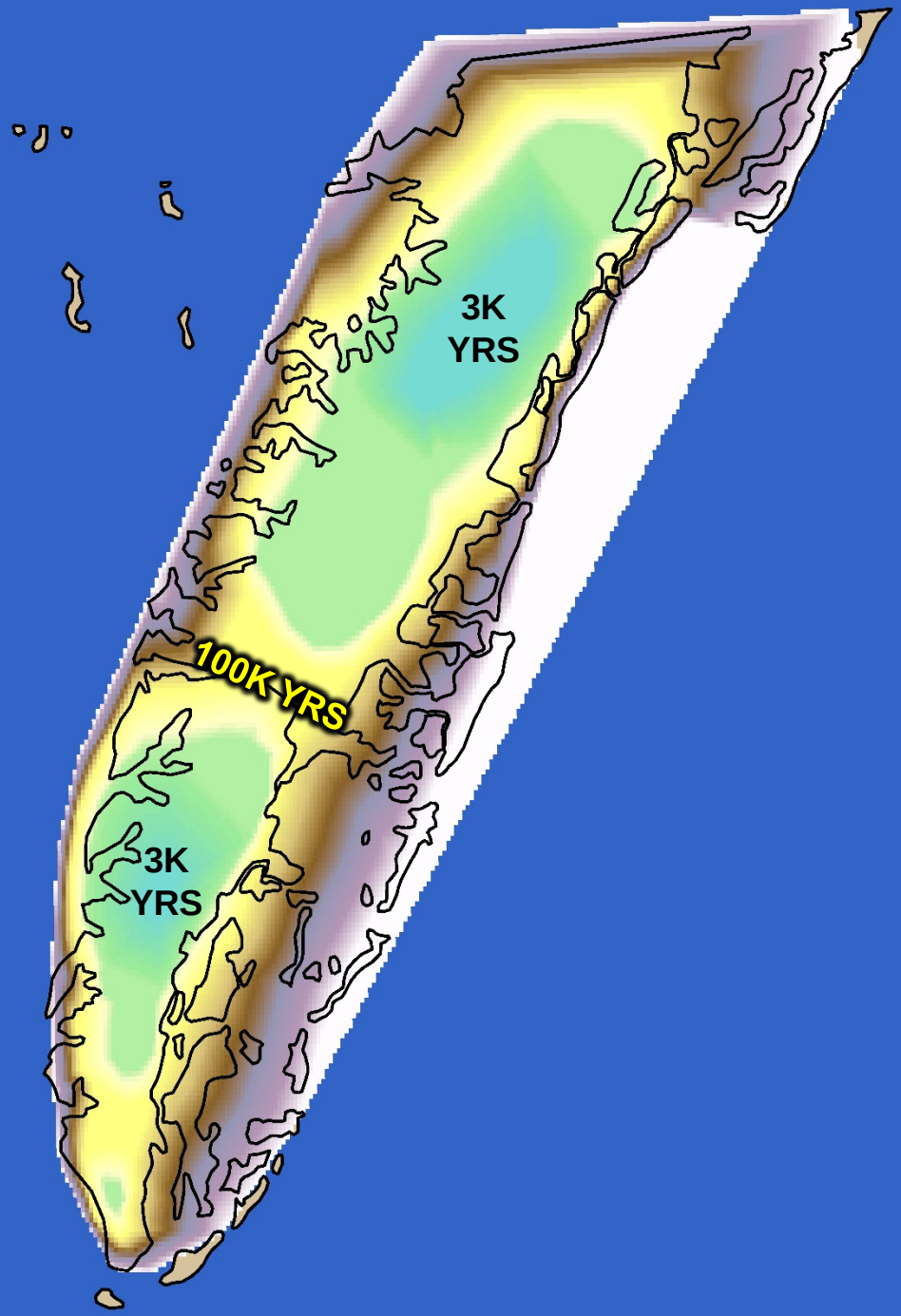


Predevelopment Flow

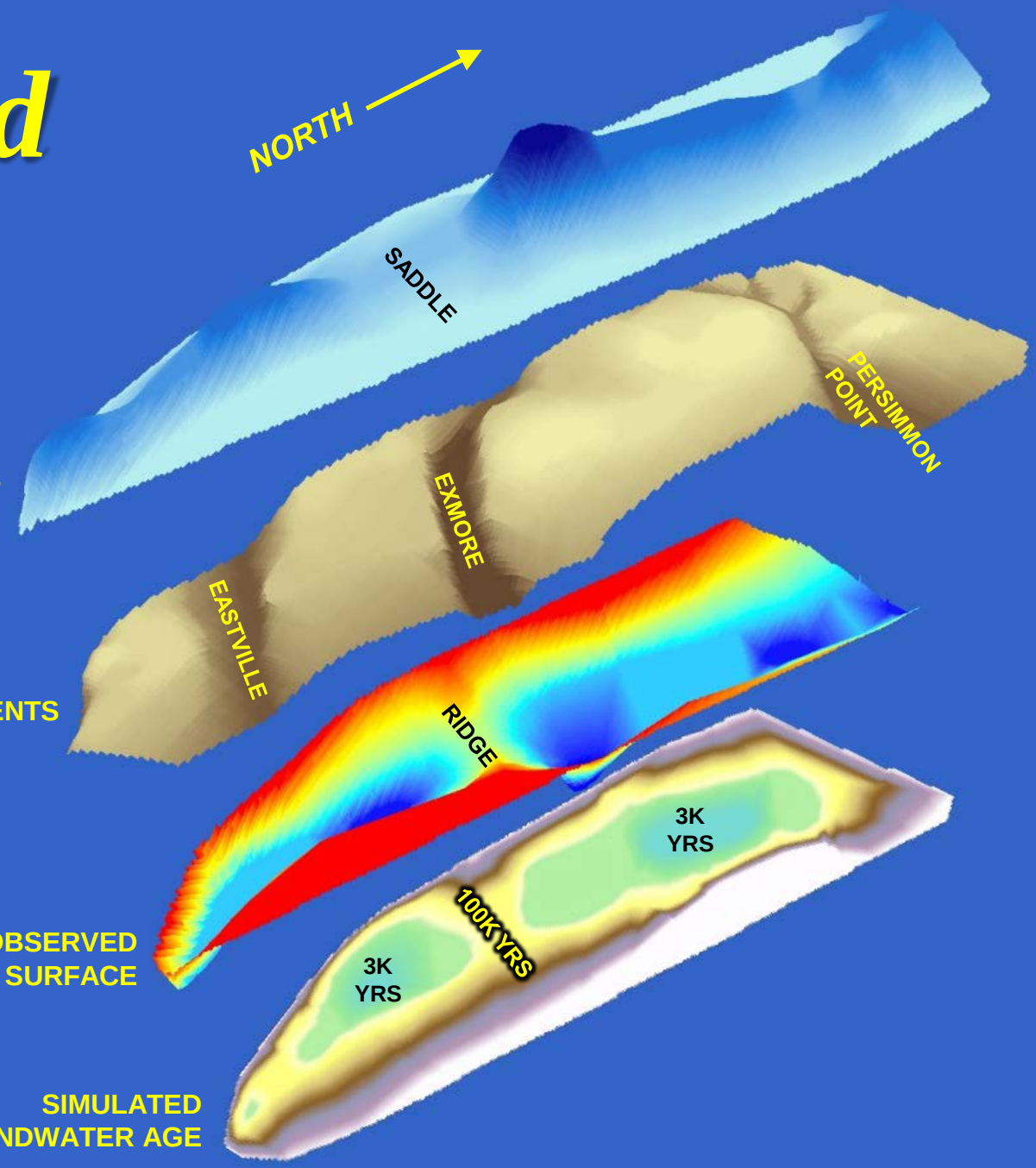


Simulated Groundwater Age

(Sanford and others, 2009)



Exploded View

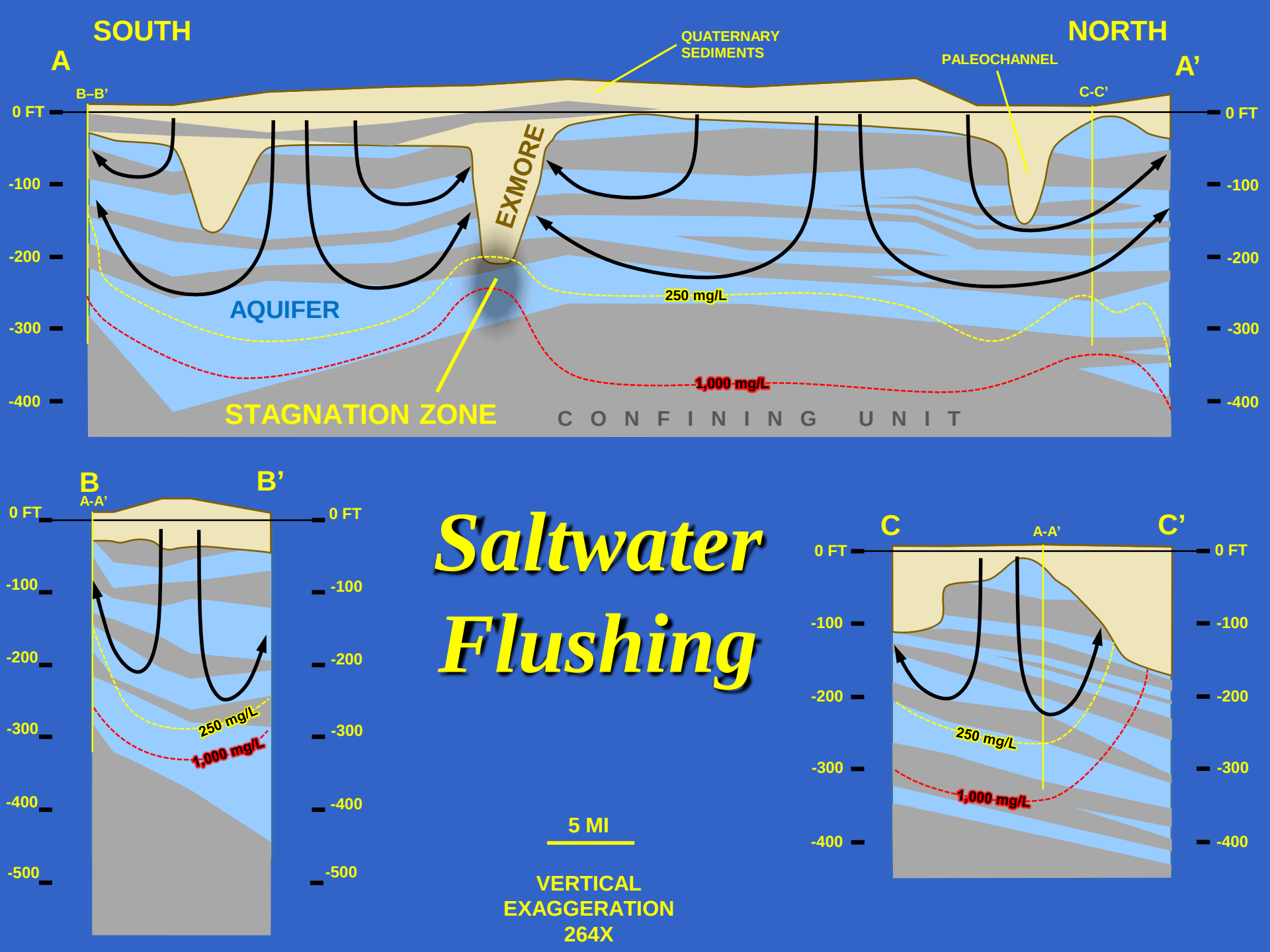


SIMULATED PREDEVELOPMENT POTENTIOMETRIC SURFACE

BASE OF QUATERNARY SEDIMENTS

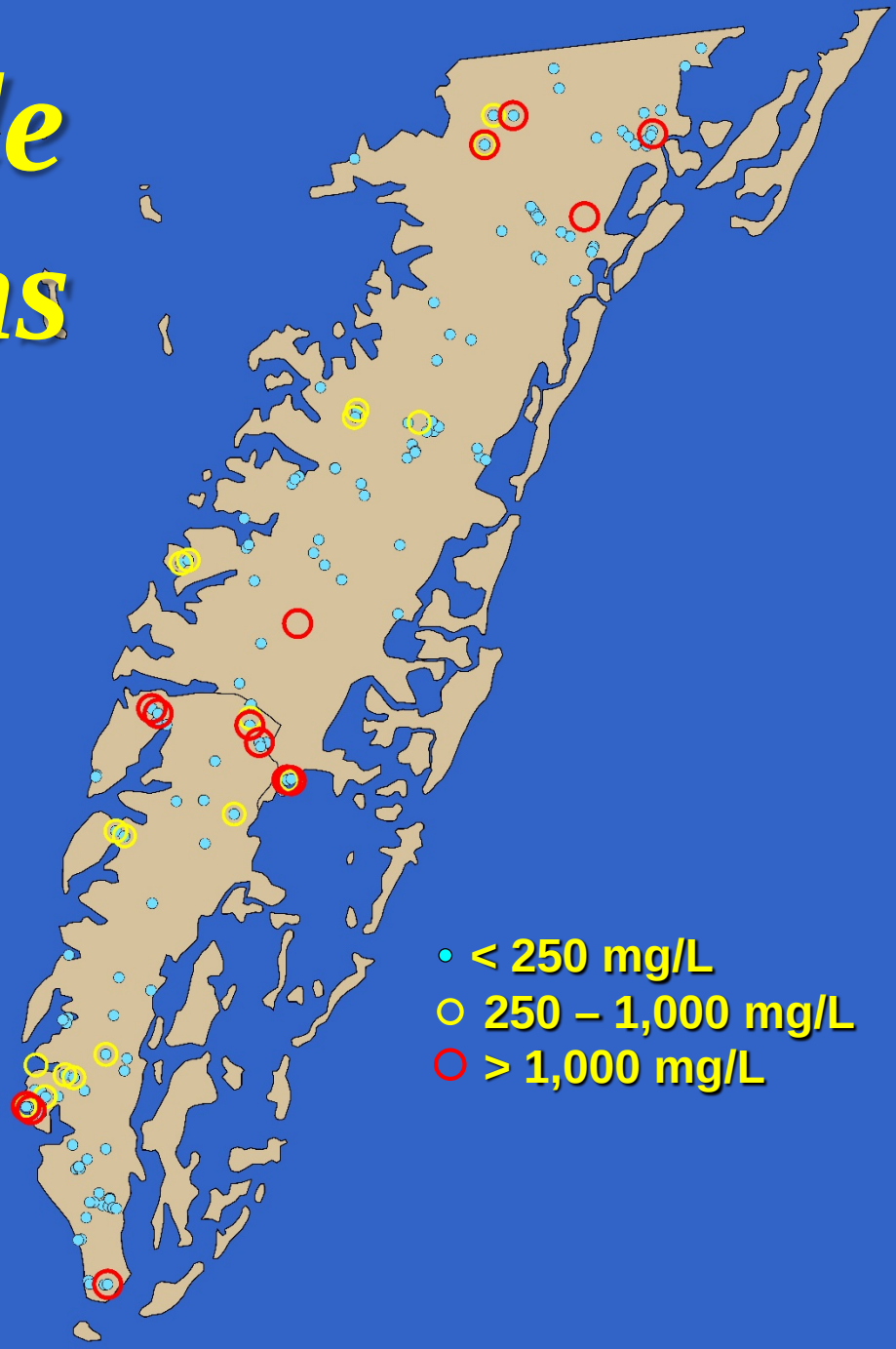
OBSERVED CHLORIDE 250 mg/L SURFACE

SIMULATED GROUNDWATER AGE

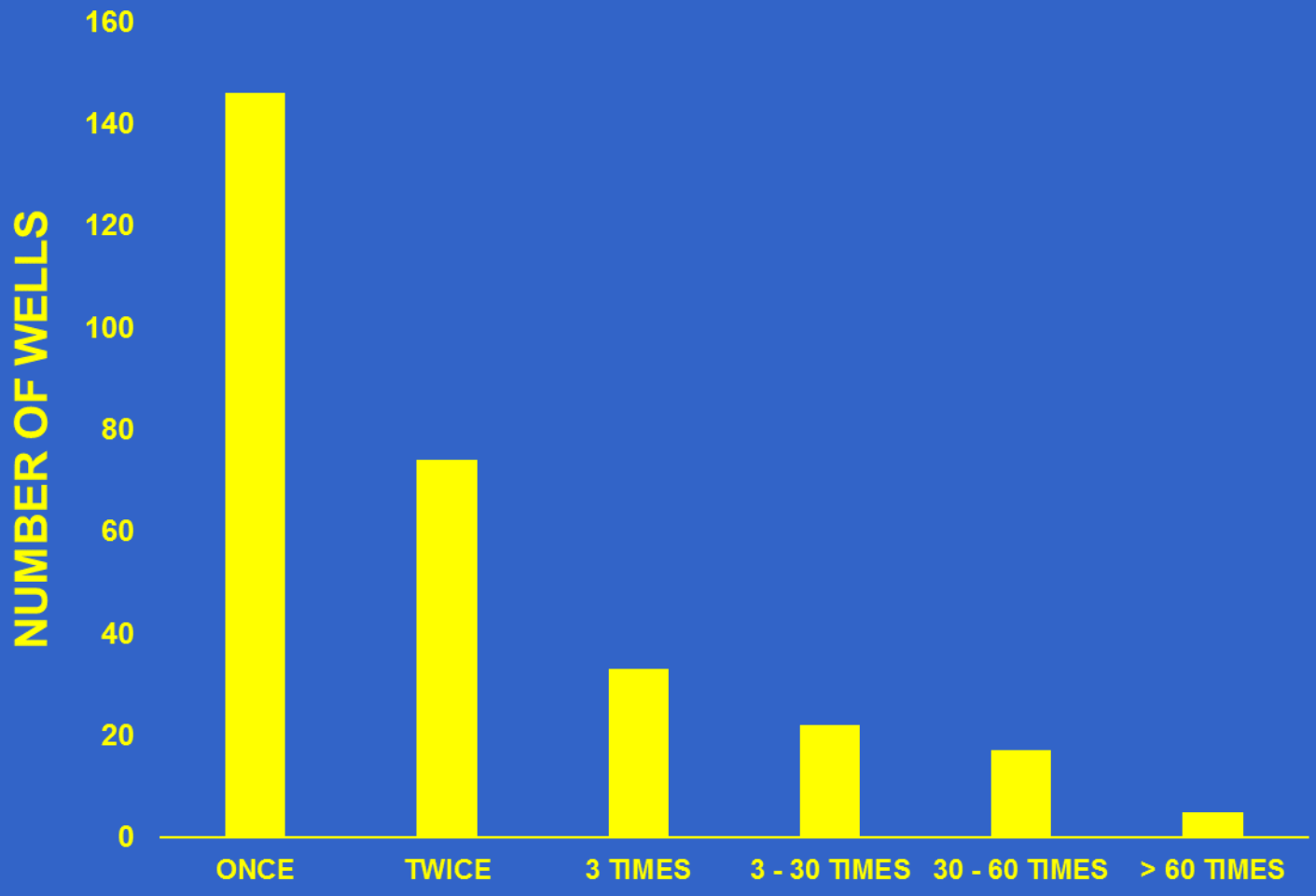

SOUTH
NORTH
A
A'
B–B'
C-C'
QUATERNARY SEDIMENTS
PALEOCHANNEL
EXMORE
0 FT
-100
-200
-300
-400
AQUIFER
250 mg/L
1,000 mg/L
STAGNATION ZONE
C O N F I N I N G U N I T
B
B'
A-A'
-500
C
C'
Saltwater Flushing
5 MI
VERTICAL EXAGGERATION 264X

Mean Chloride Concentrations

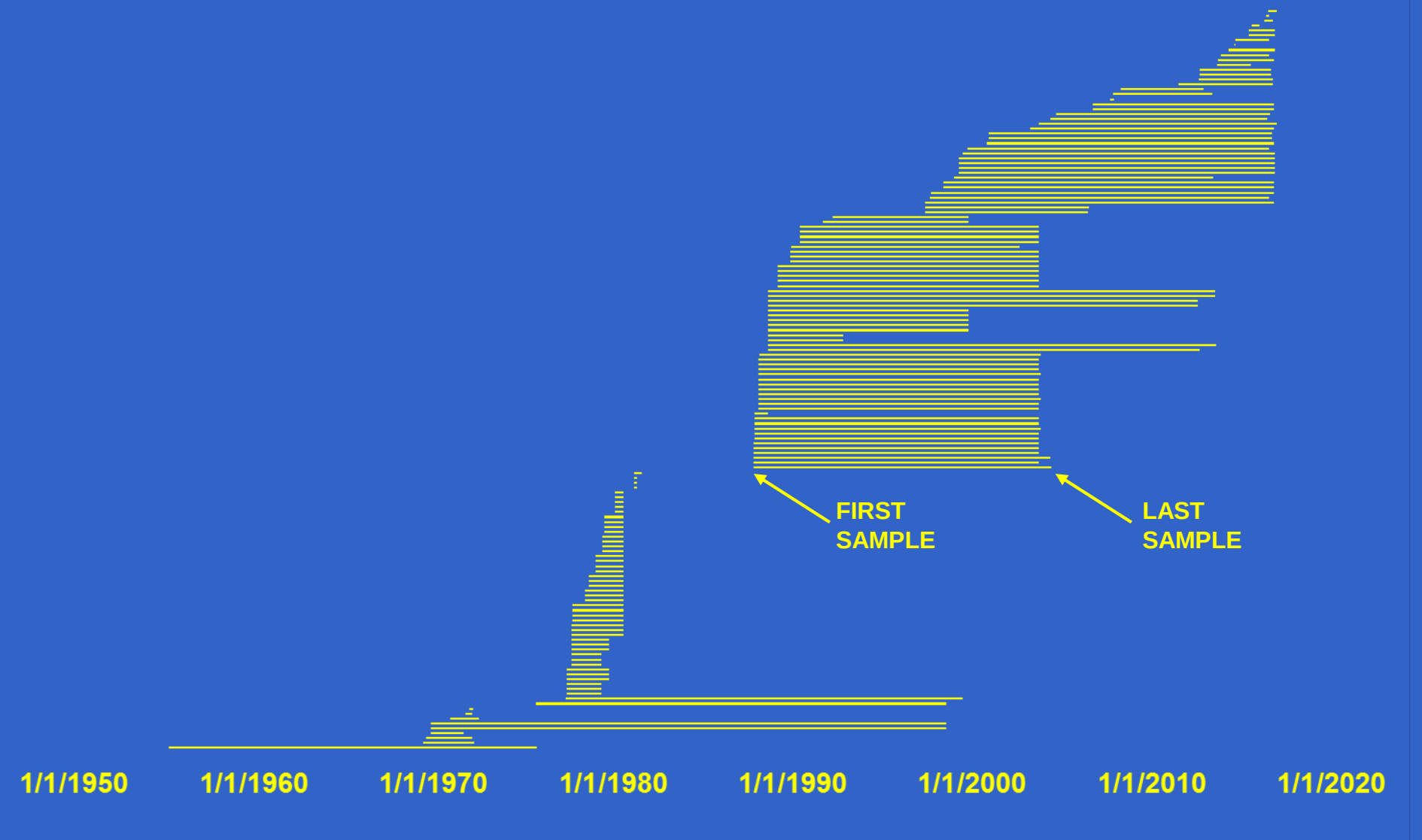
- *291 wells*
  - *190 USGS*
  - *48 DEQ*
  - *53 SWCB Bulletin 332*
- *1,992 samples*
  - *341 USGS*
  - *1,547 DEQ*
  - *104 SWCB Bulletin 332*
- *1906 - 2016*



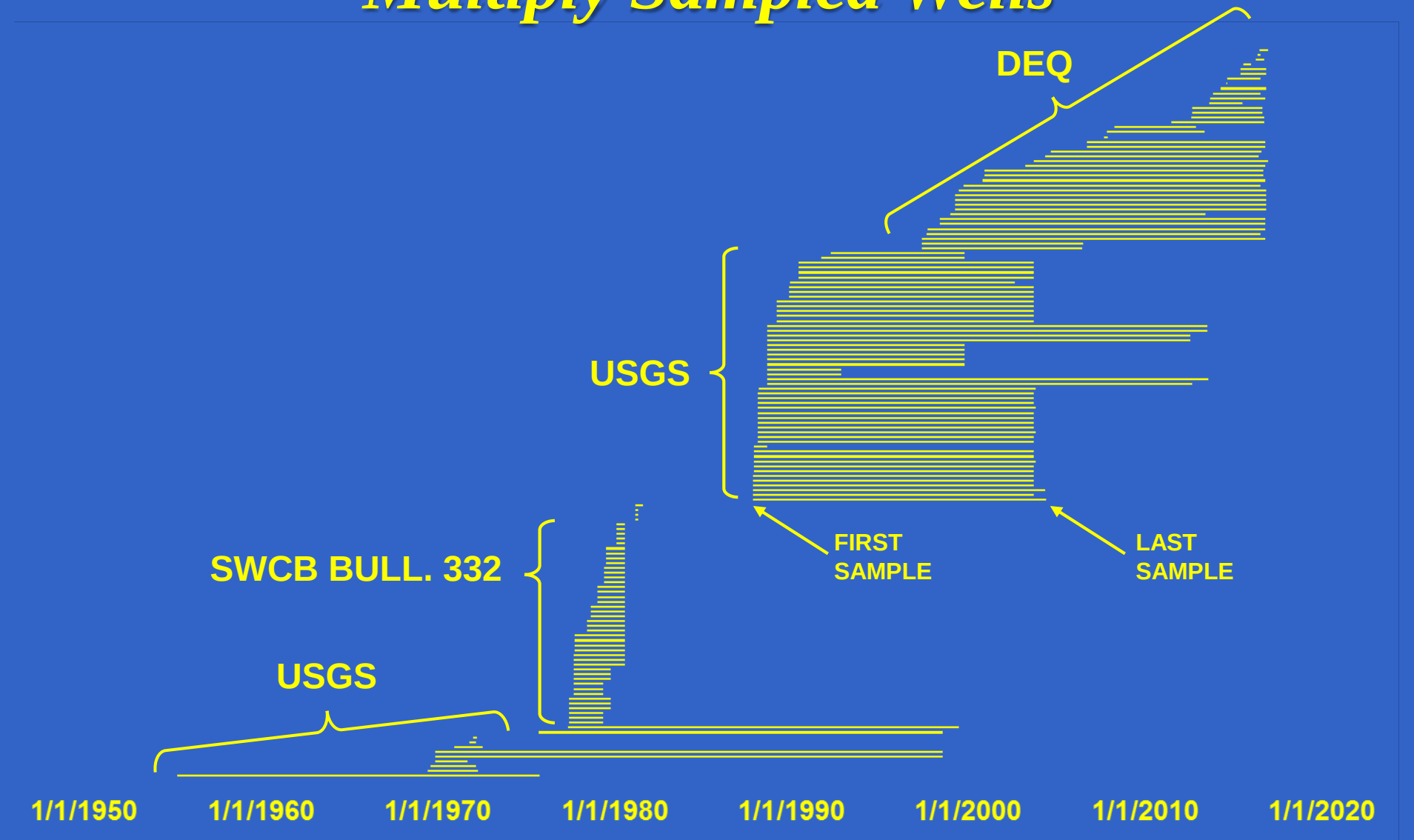
Sampling Frequency



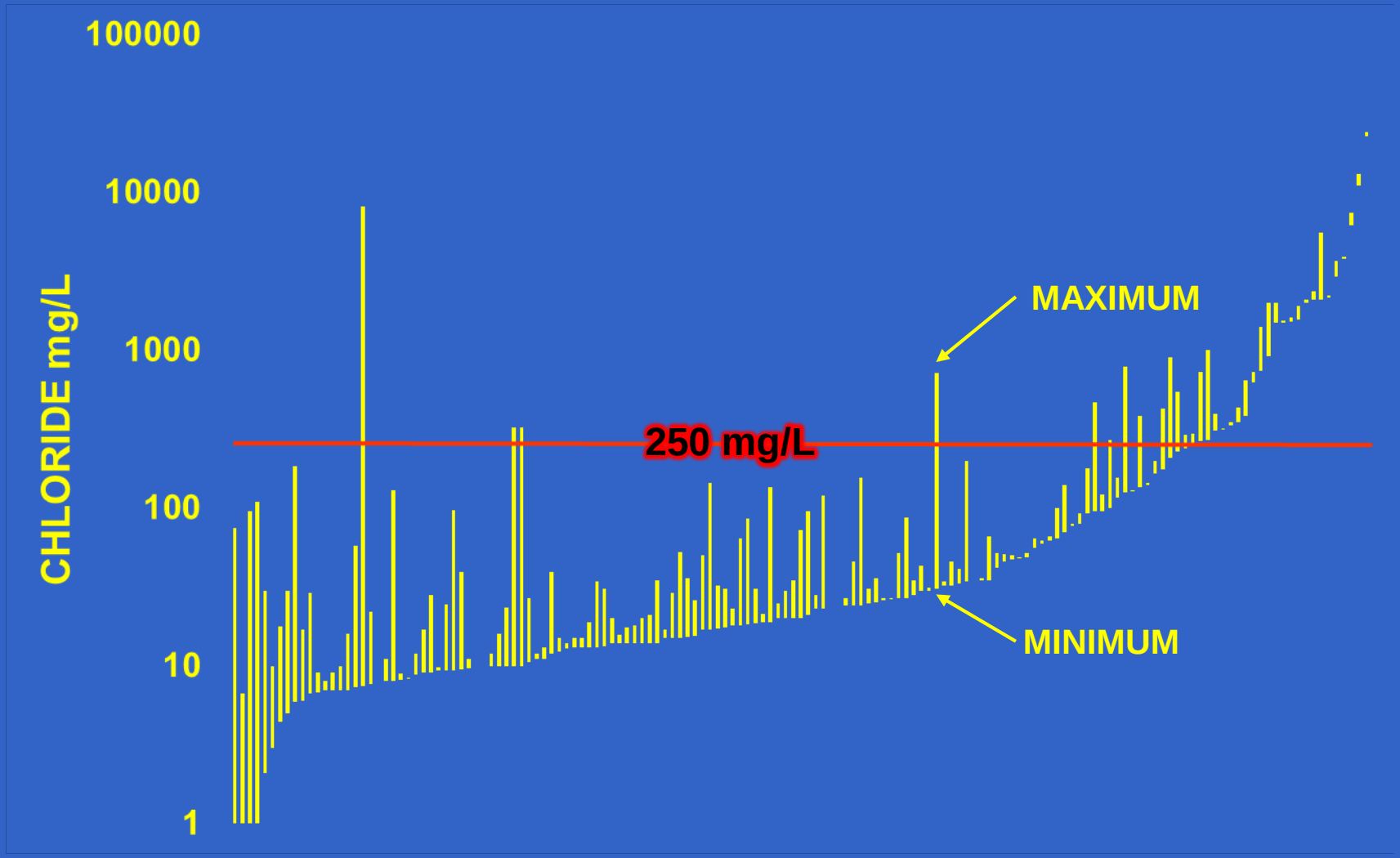
Periods of Record Among Multiply Sampled Wells



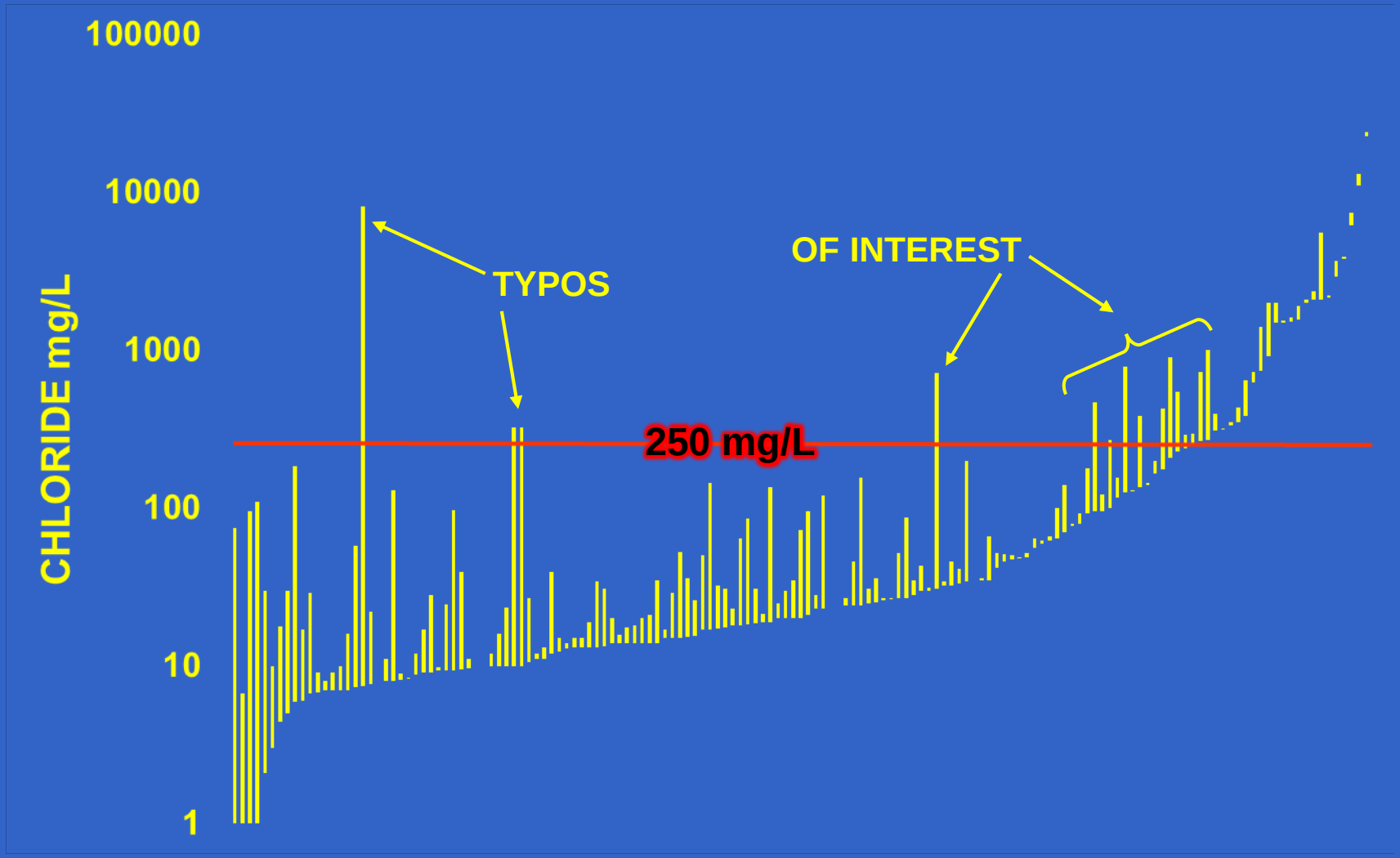
Periods of Record Among Multiply Sampled Wells



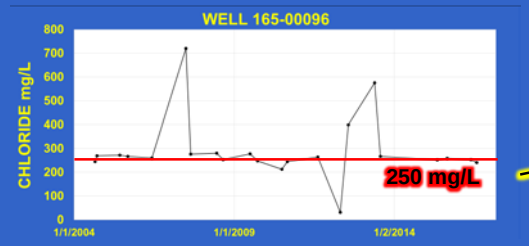
Concentration Ranges Among Multiply Sampled Wells

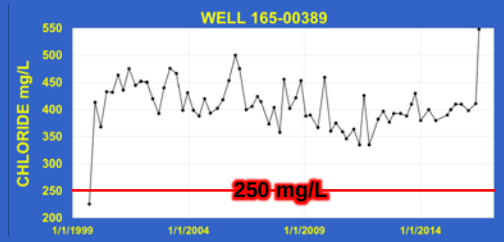


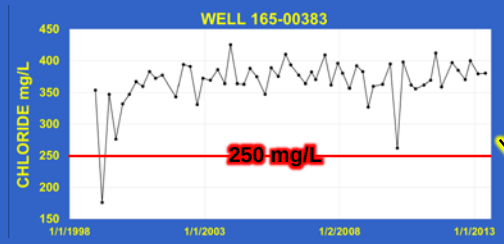
Concentration Ranges Among Multiply Sampled Wells

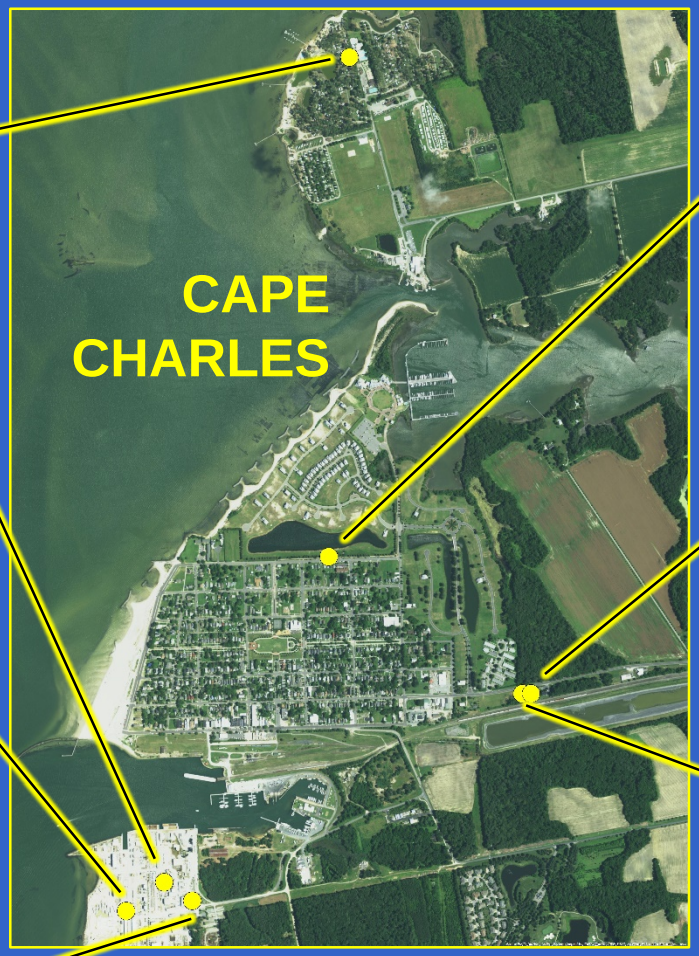


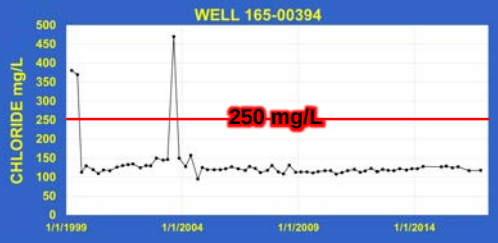
Chloride Concentration Ranges Spanning 250 mg/L











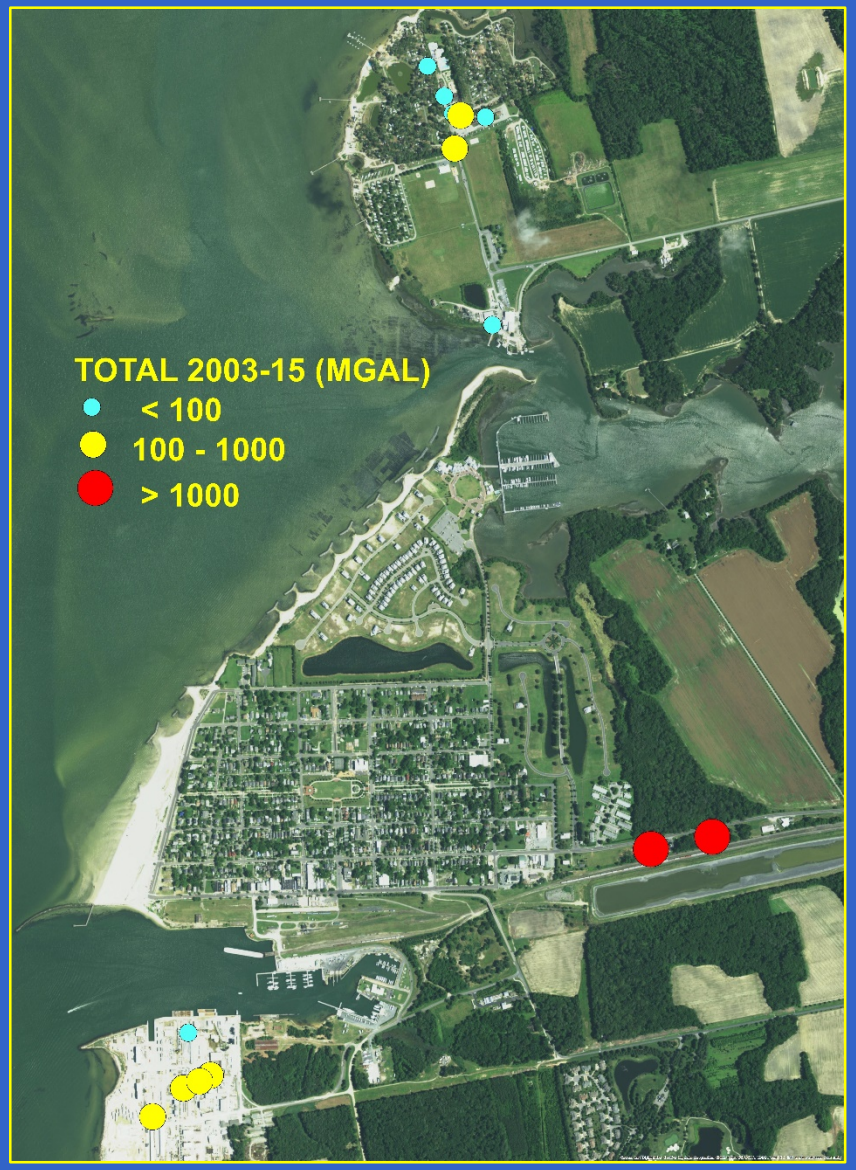
Cape Charles

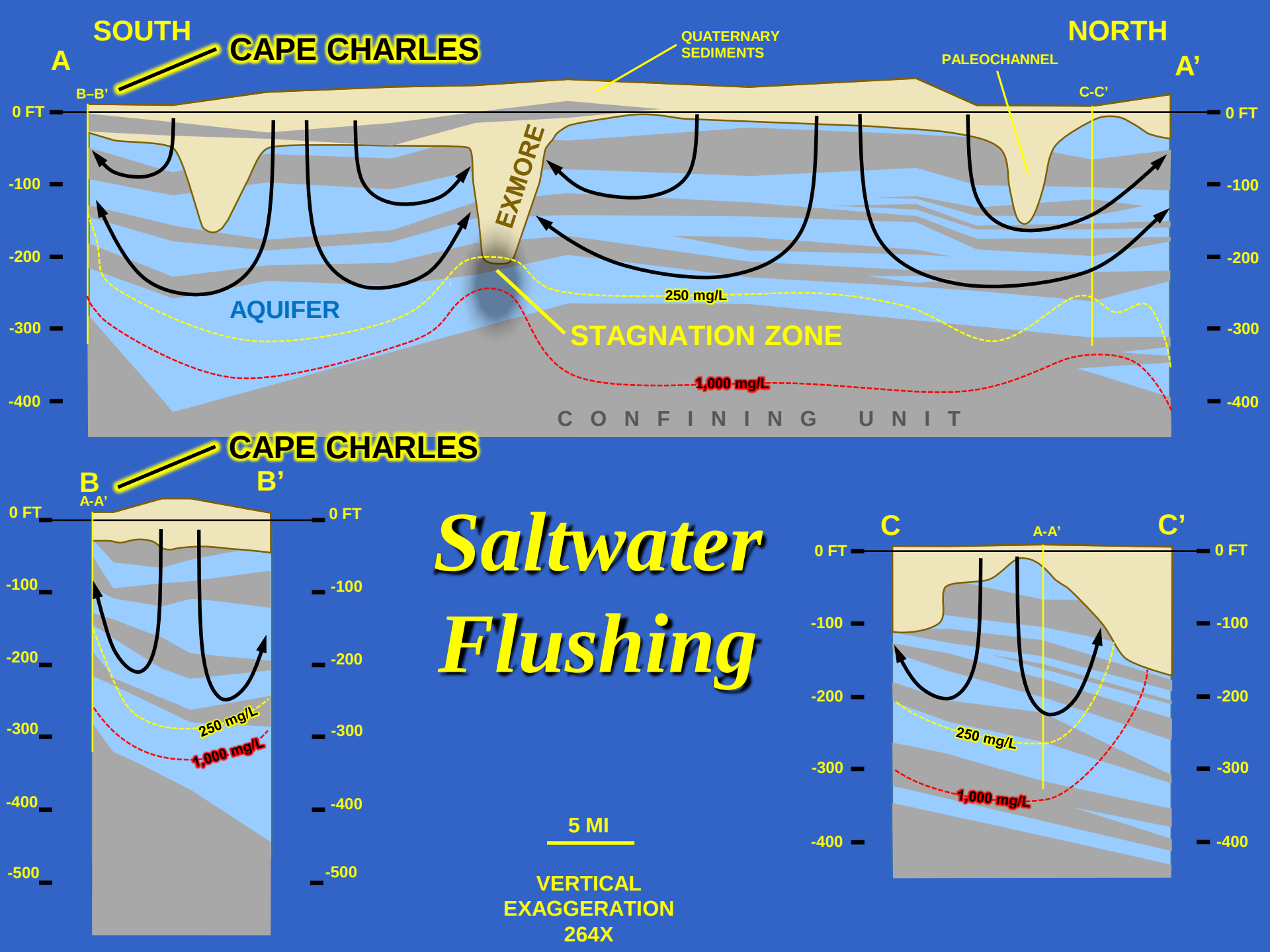
Cape Charles

CHLORIDE SAMPLES

1000 FT

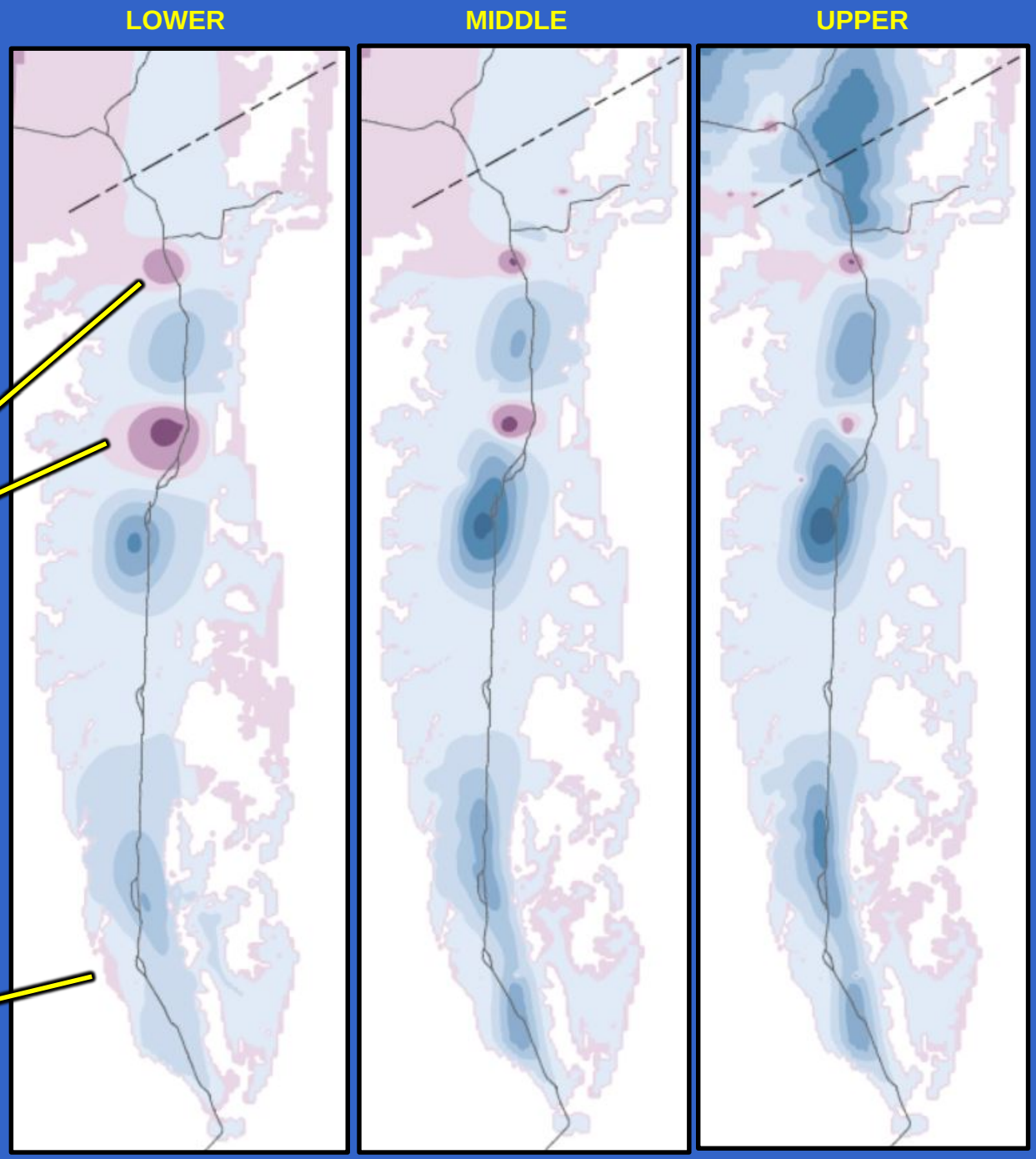
GROUNDWATER WITHDRAWALS



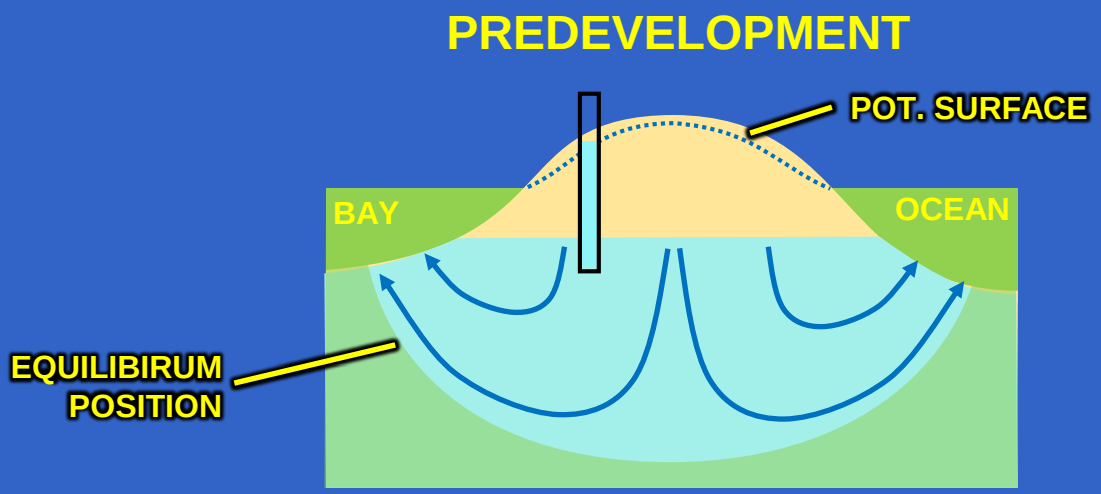

SOUTH
CAPE CHARLES
A
B–B’
QUATERNARY SEDIMENTS
NORTH
PALEOCHANNEL
C-C’
A’
0 FT
-100
-200
-300
-400
EXMORE
AQUIFER
250 mg/L
STAGNATION ZONE
1,000 mg/L
C O N F I N I N G U N I T
CAPE CHARLES
B
B’
A-A’
-500
Saltwater Flushing
C
C’
5 MI
VERTICAL EXAGGERATION 264X

Simulated 2000 Potentiometric Surfaces

(Sanford and others, 2009)

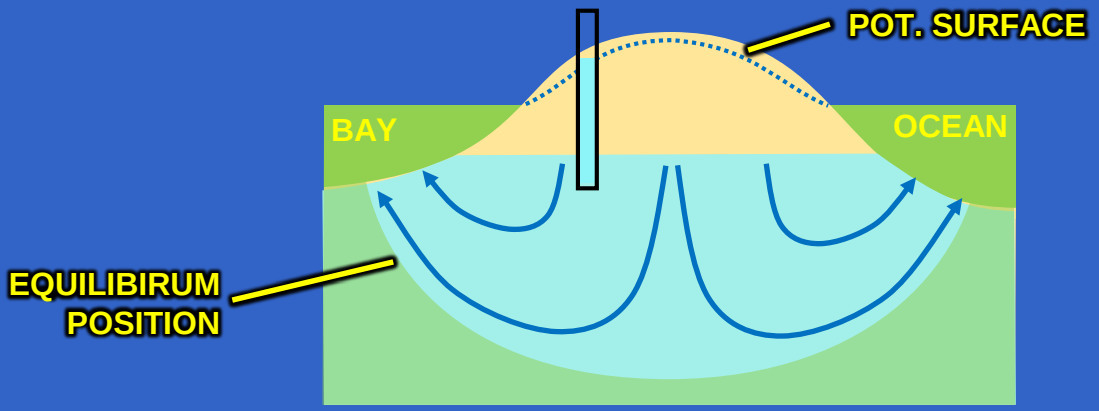


Saltwater Position

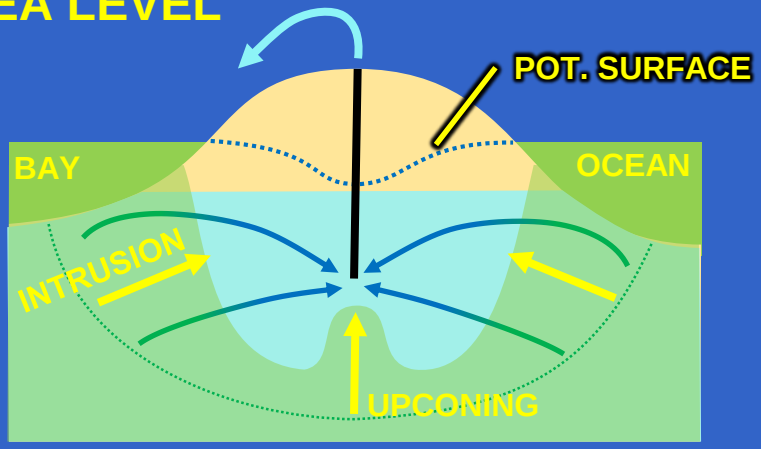


Saltwater Position

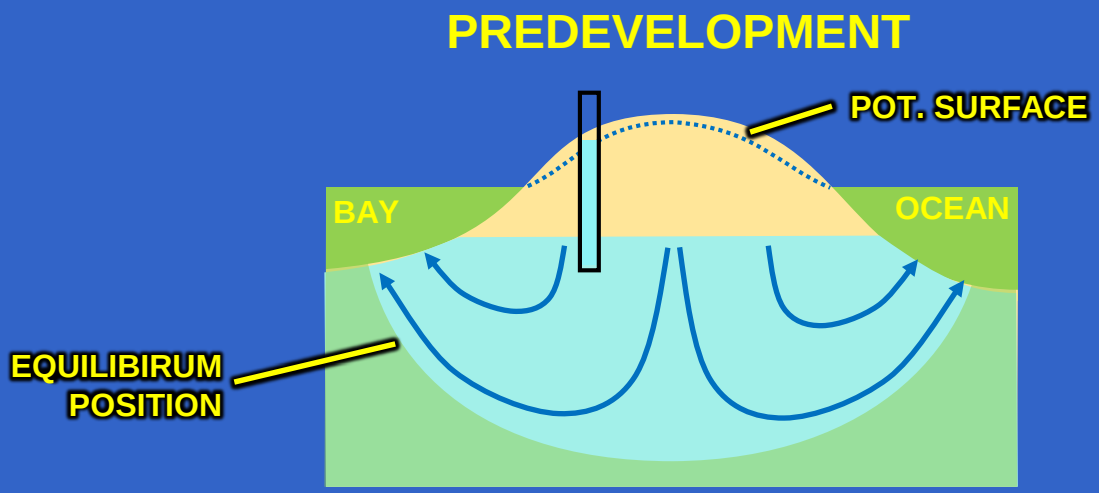
PREDEVELOPMENT

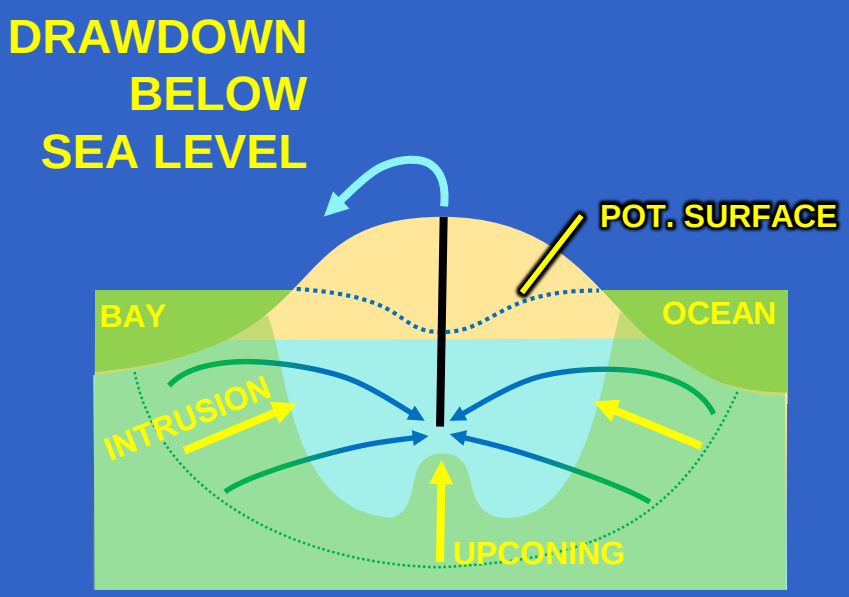


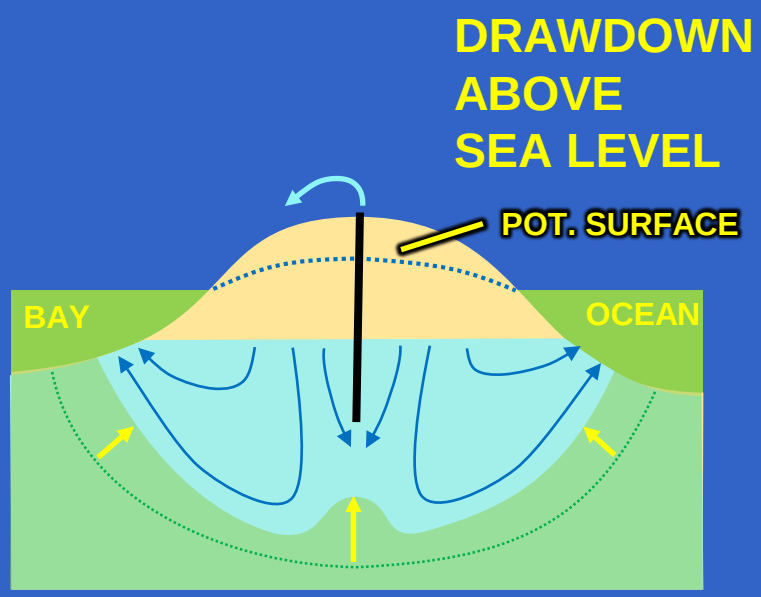
DRAWDOWN
BELOW
SEA LEVEL



Saltwater Position

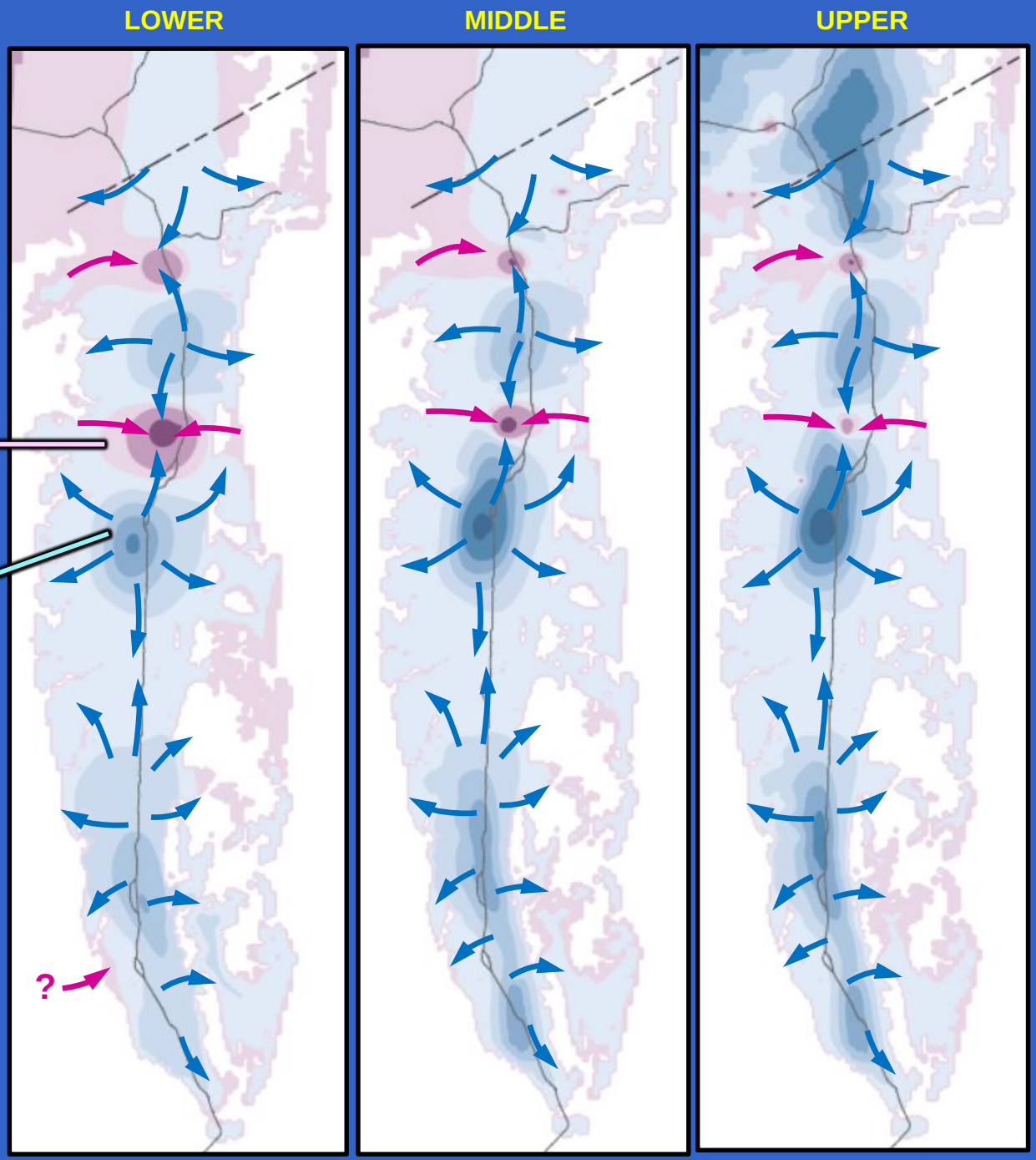




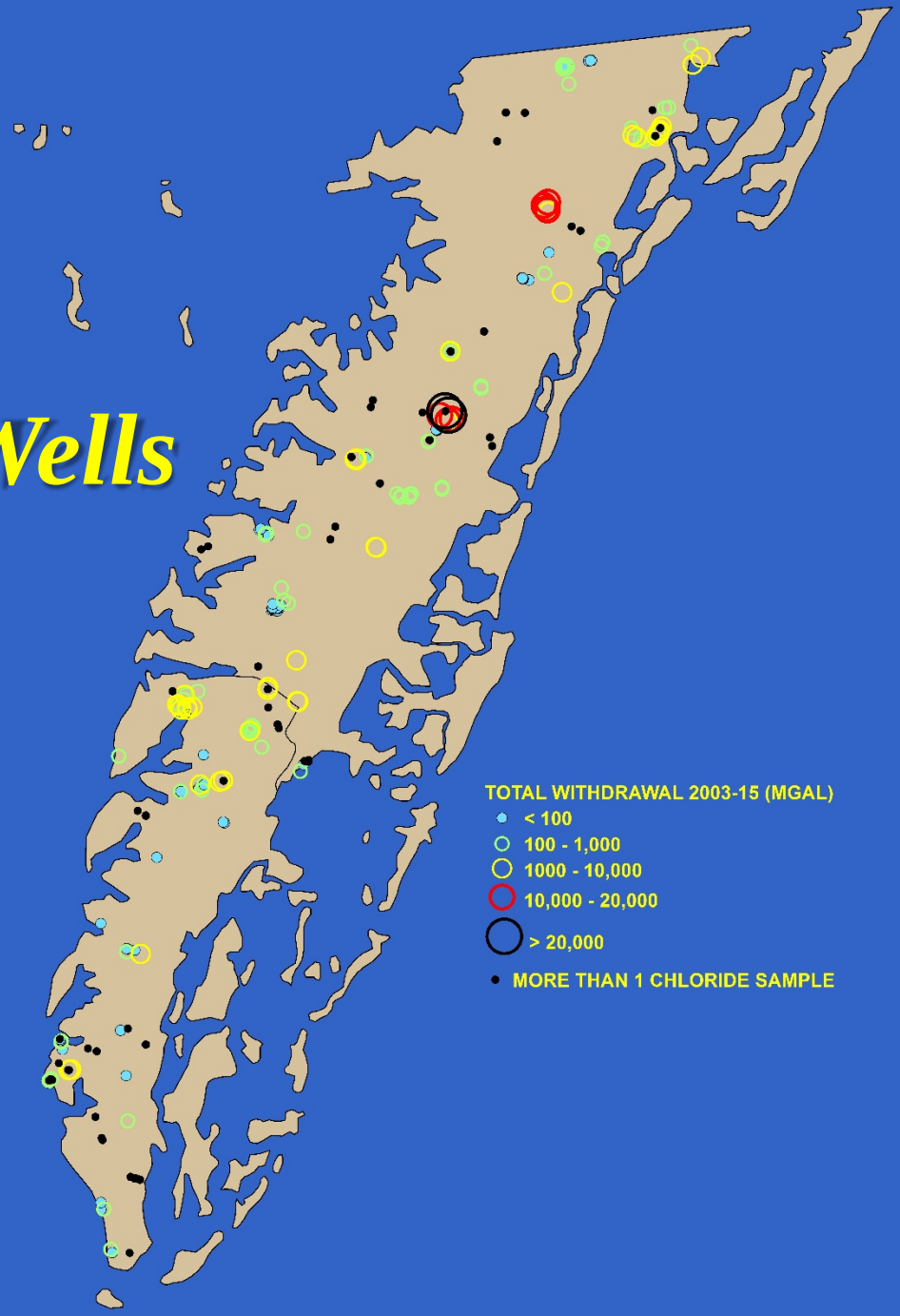


Simulated 2000 Potentiometric Surfaces

(Sanford and others, 2009)



Overlap of Multiply Sampled Wells and Groundwater Withdrawal



Chloride Results

- *saltwater "ridge" beneath Exmore paleochannel*
  - *flow converges on paleochannel*
  - *stagnation zone beneath paleochannel*
- *few existing samples greater than 250 mg/L*
- *few wells sampled over long periods*
- *significant chloride changes in Cape Charles*
  - *shallowest part of 250 mg/L surface*
  - *local coincidence with withdrawals*
  - *upconing predominant*

Chloride Needs

- ***monitoring***
  - ***colocation of sampling and withdrawal***
  - ***lateral-intrusion monitoring where water levels below sea level***
  - ***multiple sampling over long periods***

Chloride Needs

- ***monitoring***
  - ***colocation of sampling and withdrawal***
  - ***lateral-intrusion monitoring where water levels below sea level***
  - ***multiple sampling over long periods***
- ***model refinement***
  - ***prehistoric "flushing" simulation***
  - ***used to develop mainland model by reconstructing configuration of saltwater interface***
  - ***emplacement of fresh groundwater in aquifer sediments upon lowering of sea level***
  - ***test and refine Eastern Shore model by simulating position of the 250 mg/L chloride iso-concentration surface***

Needs Summary

- *framework*
  - *geophysical-log interpretation*
  - *aquifer top-surface mapping*
  - *aquifer-test analysis*
- *paleochannels*
  - *geophysical-log interpretation*
  - *additional boreholes and cross sections*
  - *additional observation wells*
- *chloride*
  - *sampling locations and periods*
  - *prehistoric “flushing” simulation*