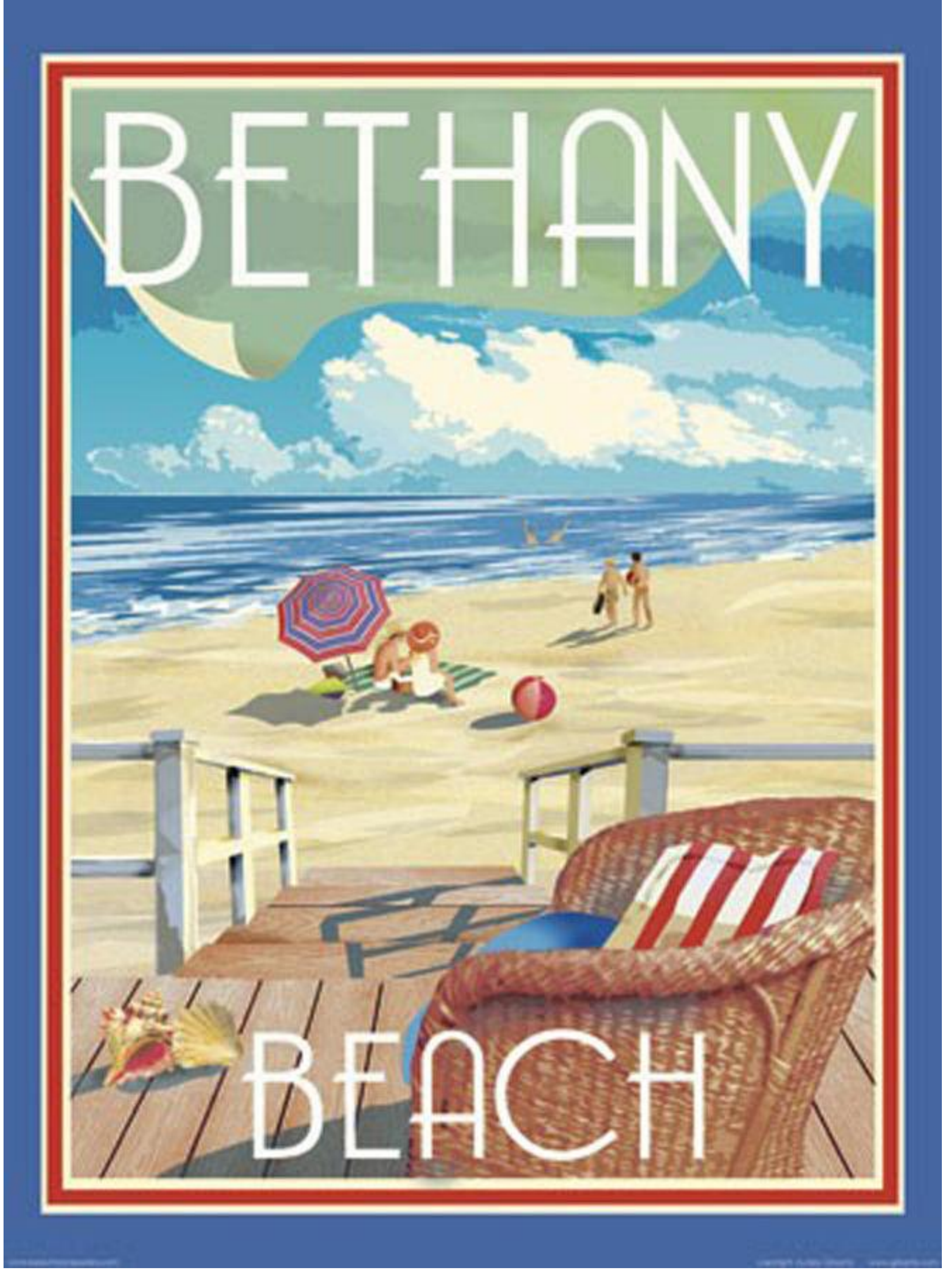

BETHANY
BEACH

Bethany Beach pre-1920

Bethany Beach pre-1920

Bethany Beach today

Bethany Beach today

	Elevation
My office in Middletown	64 ft.
The Circle in Georgetown	53 ft.
Millsboro	34 ft.
Frankford	32 ft.
Roxana	29-32 ft.
Dagsboro	24 ft.
Clarksville	8-17 ft.
Millville	10-14 ft.
Ocean View	5-12 ft.
South Bethany	3-15 ft.
Route 1	3 ft.

	Elevation
South Coastal Library	**9 ft.**
Bethany Town Hall	6 ft.
Intersection of Route 1 and 26	5-6 ft.
Atlantic Ave. at First St.	4 ft.
Gibson and Central Blvd.	2 ft.
Maryland Ave. at the Loop Canal	2 ft.
Second Street at the Loop Canal	2 ft.
Cul du Sac on Weigand Lane	1 ft.
Gibson Ave. at the Loop Canal	1 ft.
Ocean View Parkway at the Loop Canal	1 ft.
Pennsylvania Ave. at First St.	1 ft.
Pennsylvania Ave. at 4th St.	**0 ft.**

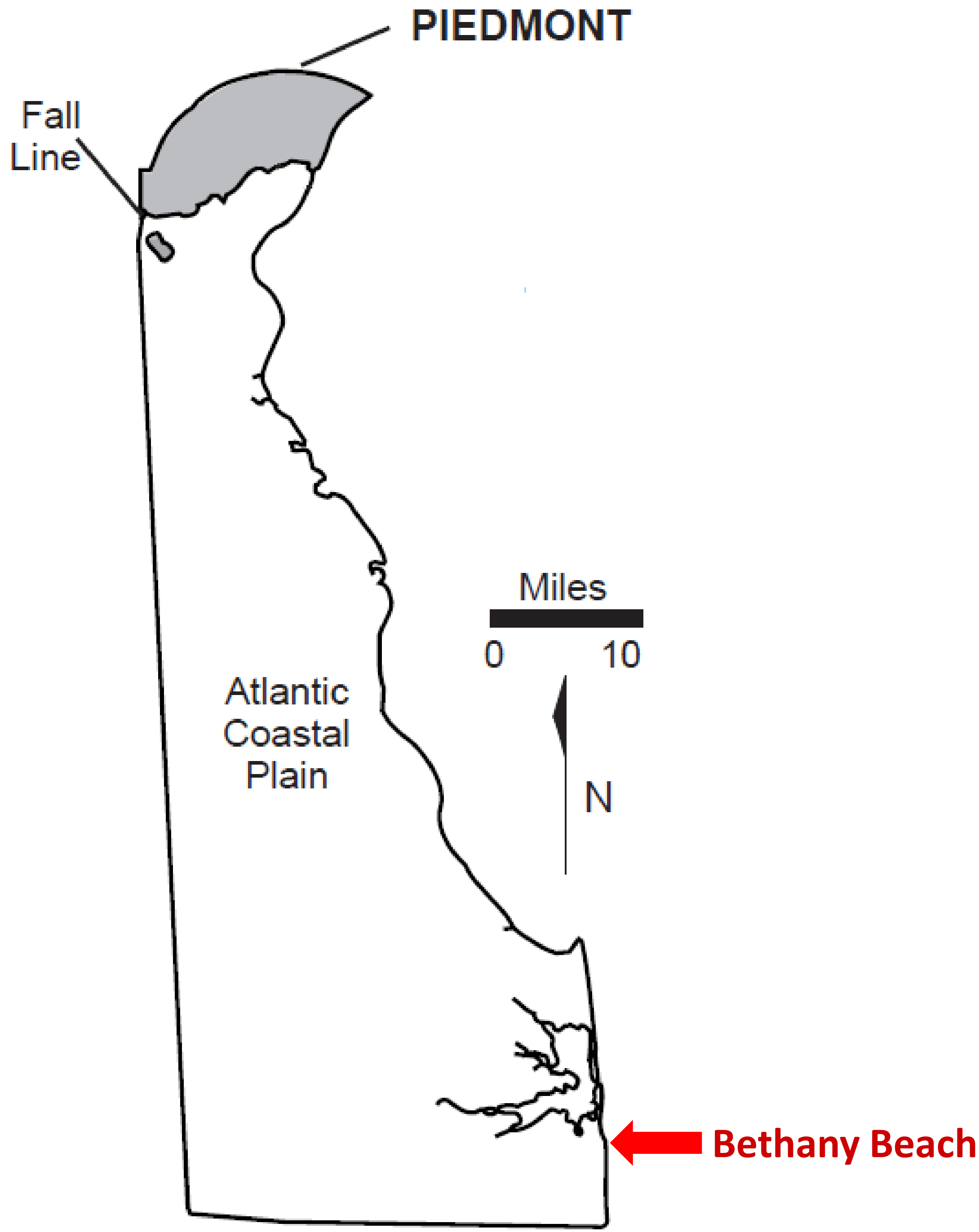

Pennsylvania Avenue
Looking South From North of 5th Street
Kayak Tours
Dolphin Watch
SPEED LIMIT
STOP
NEW
4-WAY
09/11/2009 08:28

End of Weigand Lane September 30, 2016

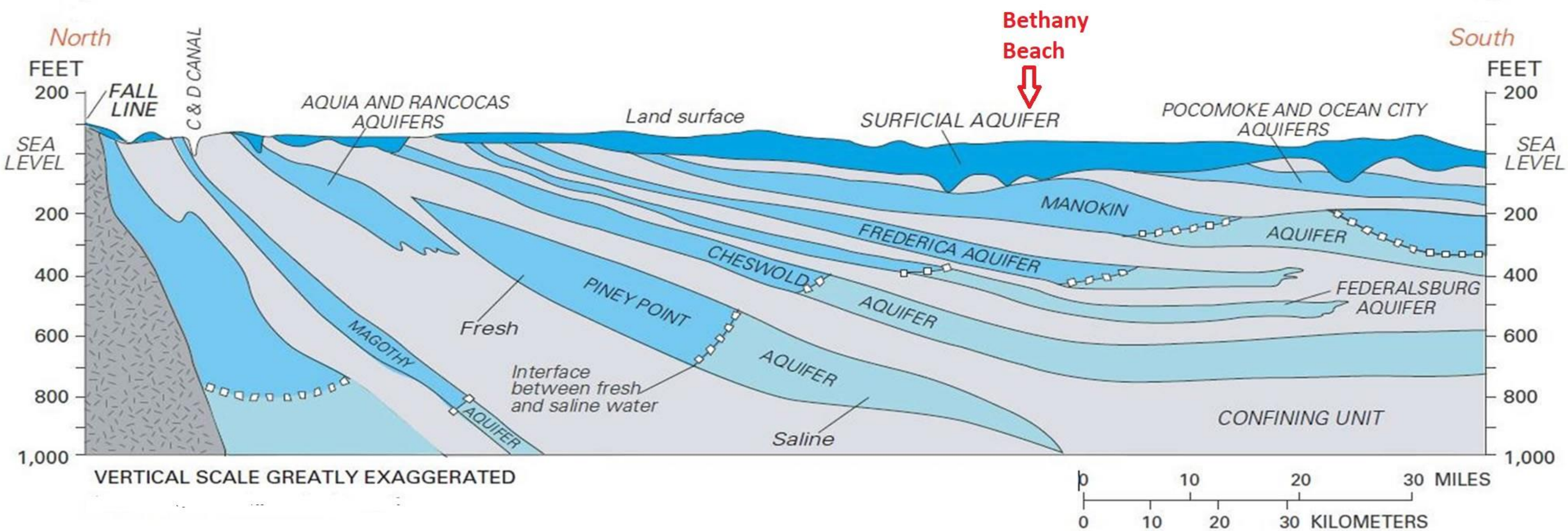
Delaware is in the Atlantic Coastal Plain

Figure 1. Location of the Atlantic Coastal Plain Province.

Delaware

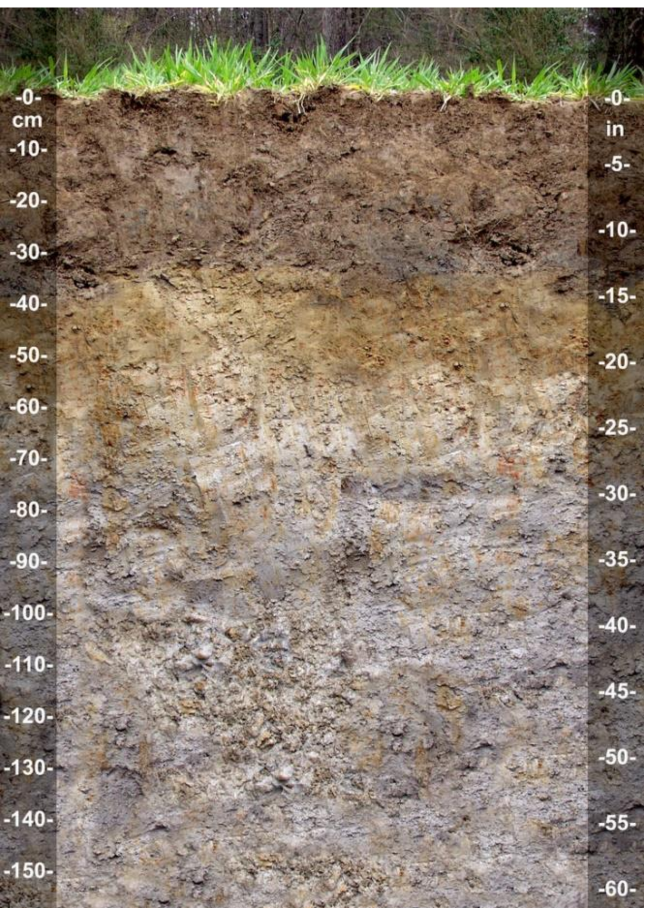

PIEDMONT
Fall Line
Atlantic Coastal Plain
Miles
0
10
N
Bethany Beach

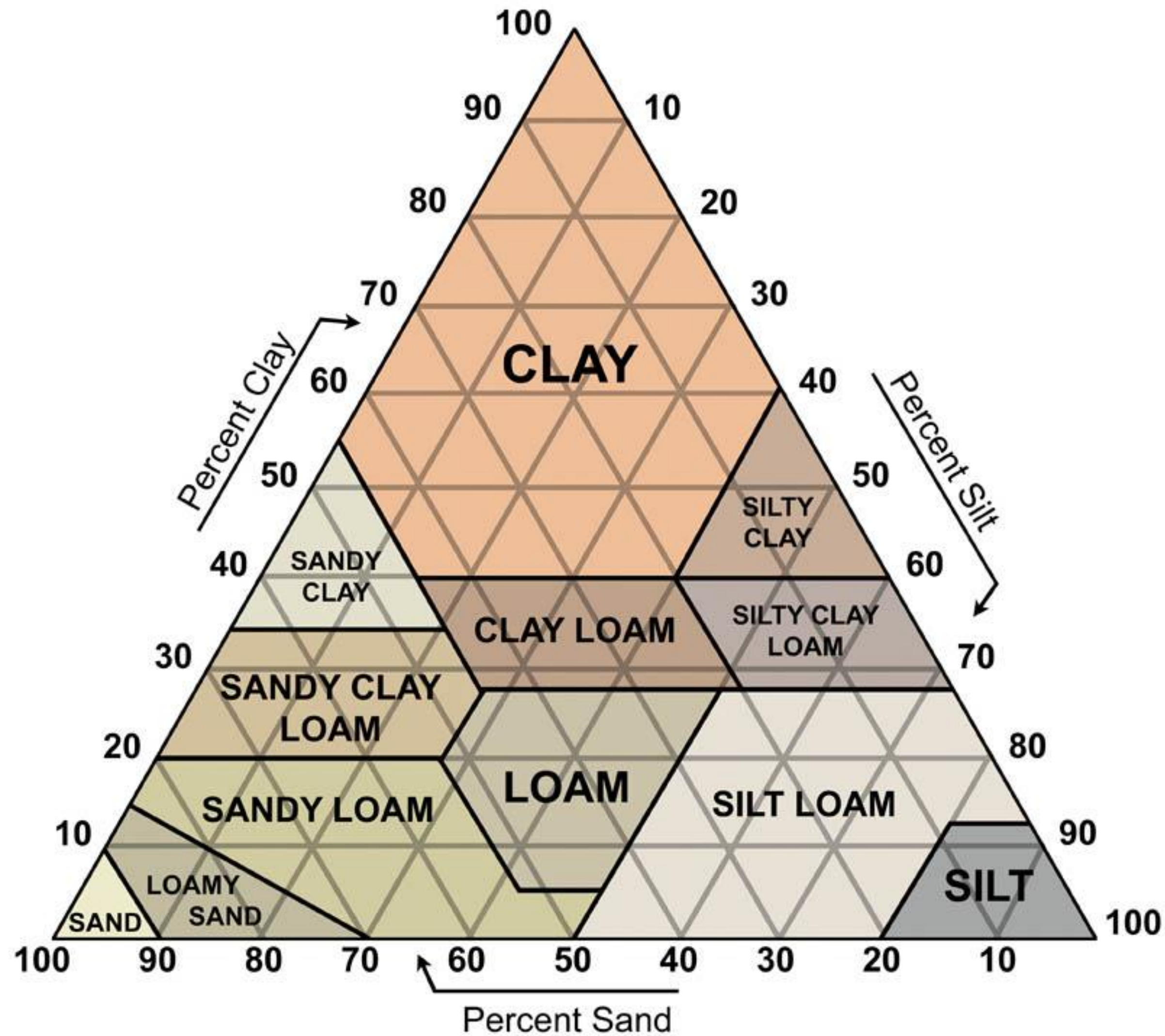
Atlantic Coastal Plain is composed of deep sedimentary materials from the weathering of the Piedmont and the Appalachian mountains.



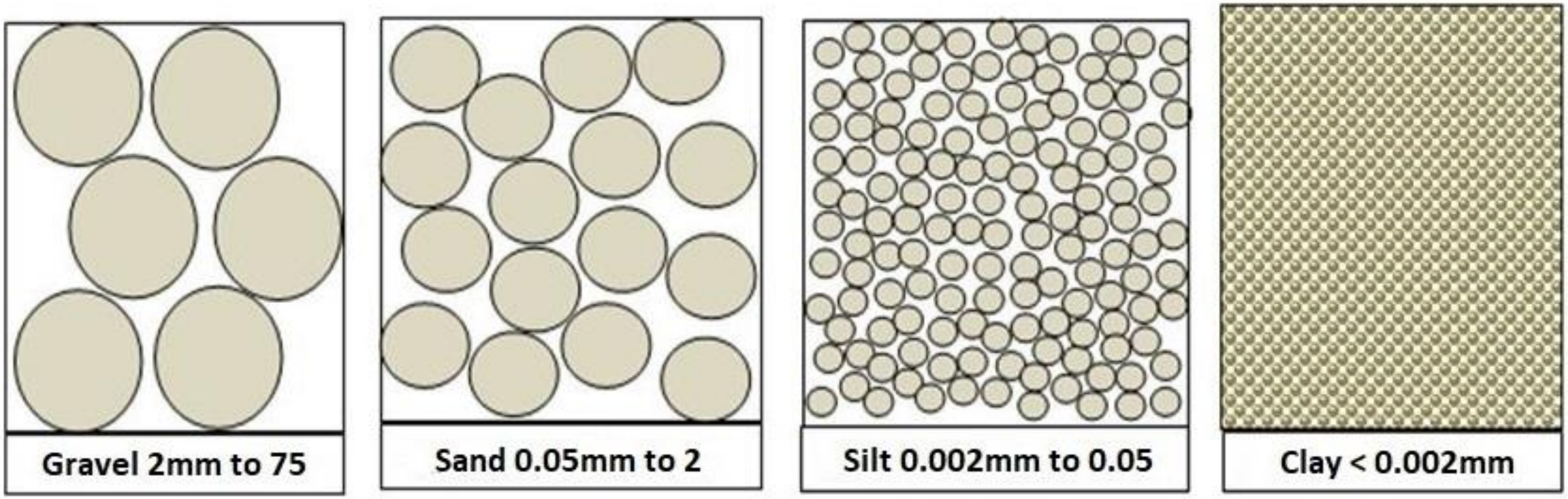
Soils and Sediment

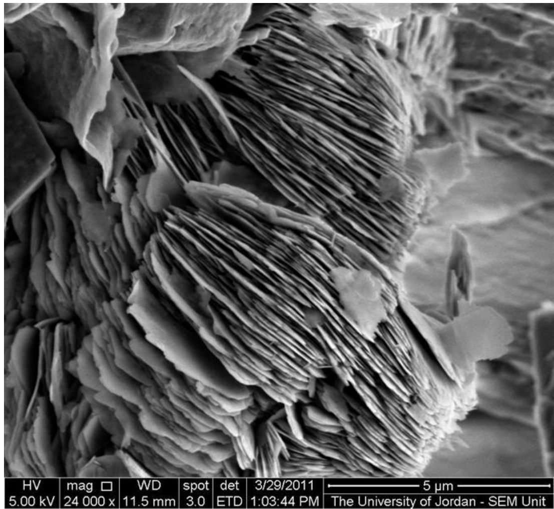
Soils are composed of Sand, Silt and Clay particles.
Characteristics of soil
change with depth.





The spaces between the soil particles is called Porocity





Porocity or Pore Space that we use every day

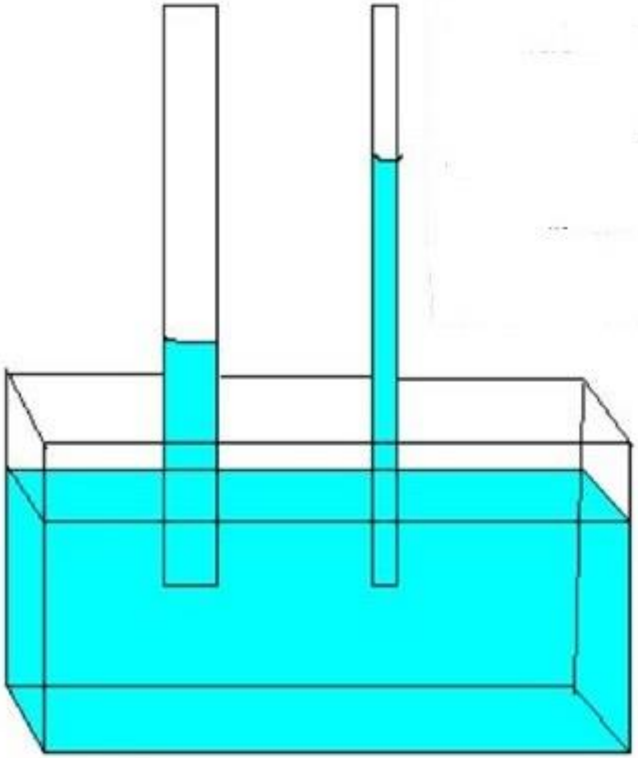
Pore Space is the area available for air or water.
Bulk Density is the solid material.

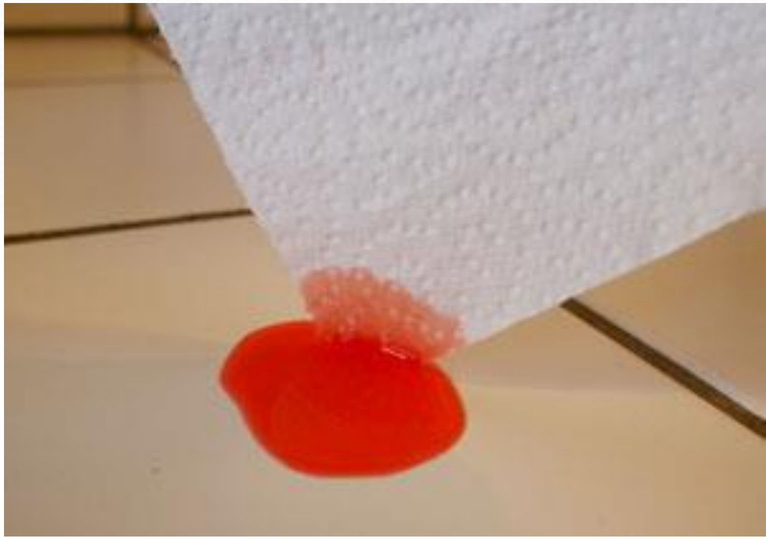
Brick = high bulk density,
low pore space

Sponge = low bulk density,
high pore space

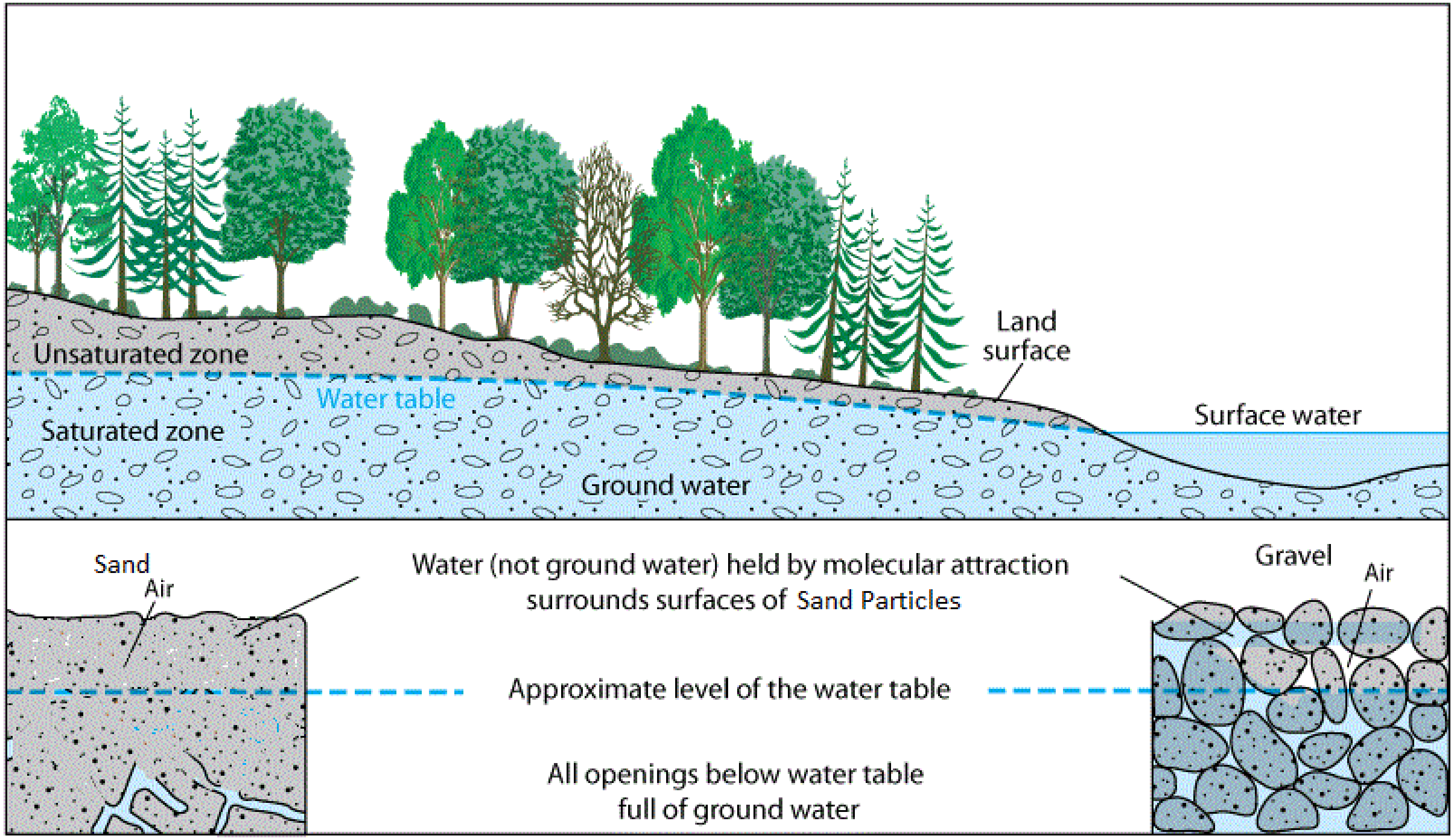
Capillary Action

- Capillary action is the tendency of a liquid to rise in narrow tubes or to be drawn into small openings.
  - For example, water will be drawn into small tubes and rise against the force of gravity
  - Water will move into the areas between grains of sand or soil
  - A dry paper towel absorbs water because of the spaces between the fibers of the towel
- The smaller the opening, the stronger the capillary action

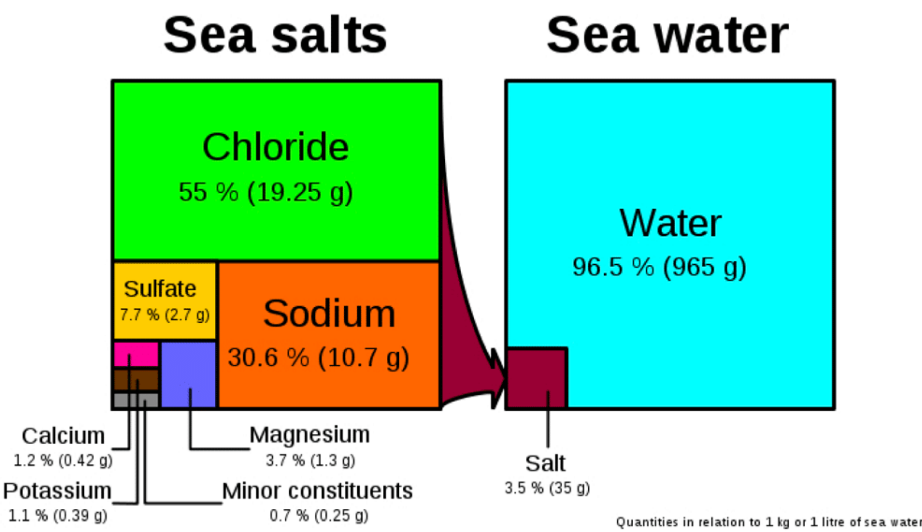


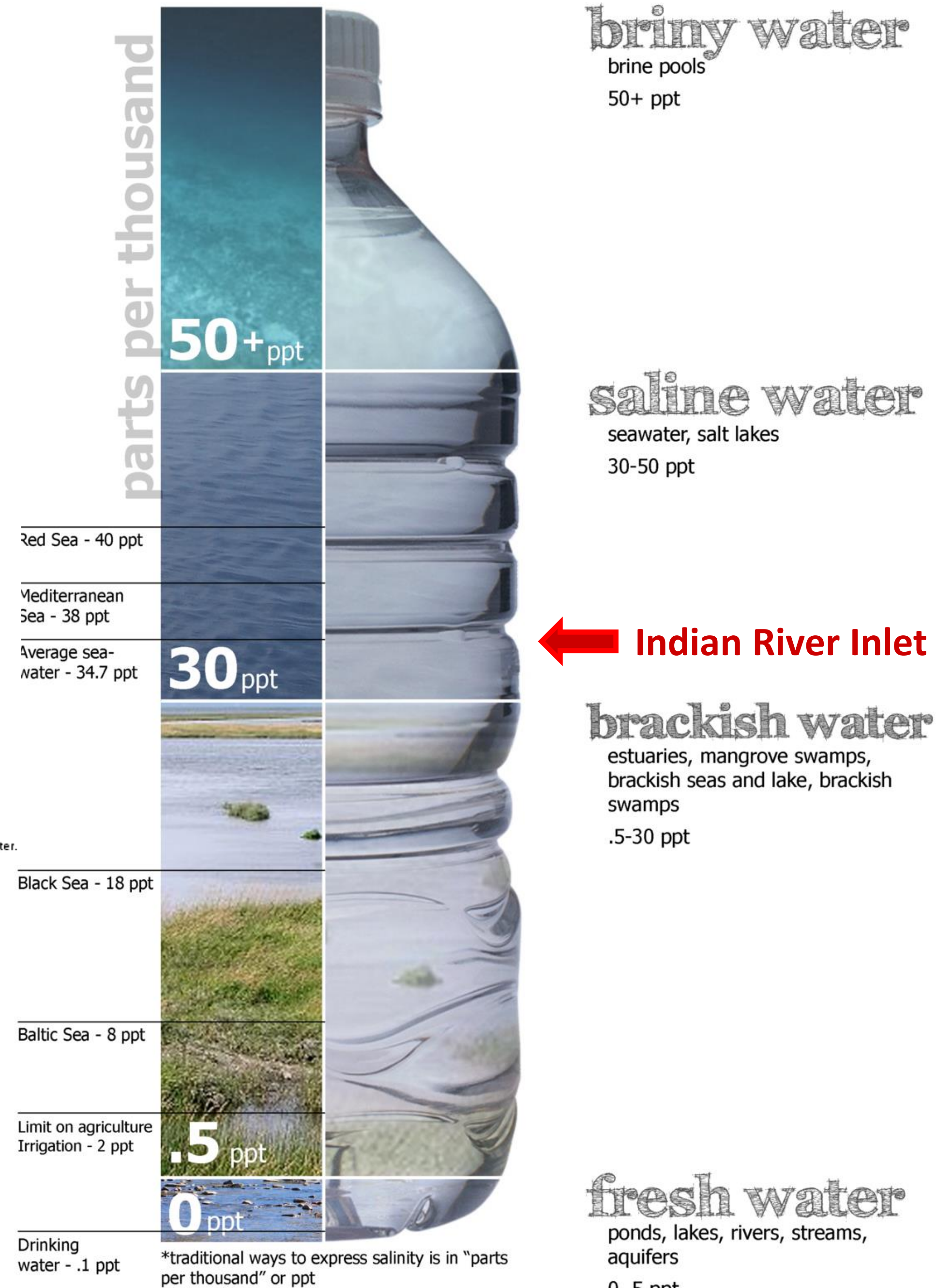


Groundwater Hydrology

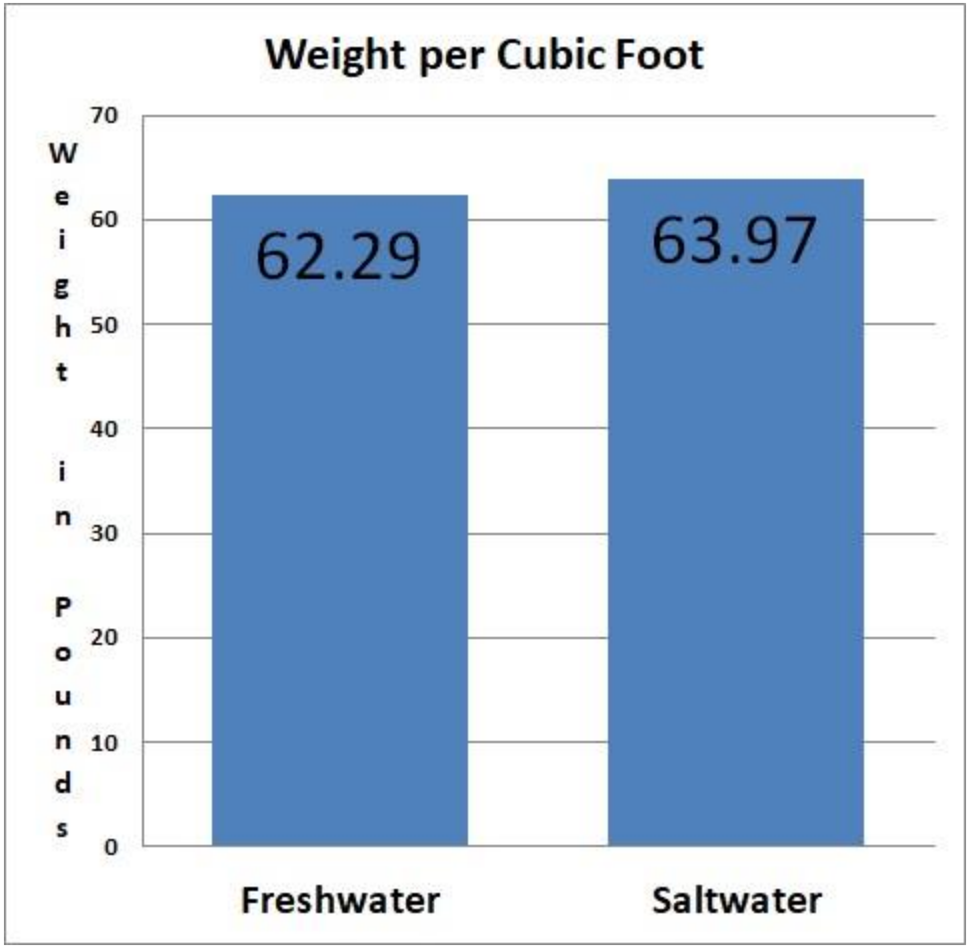


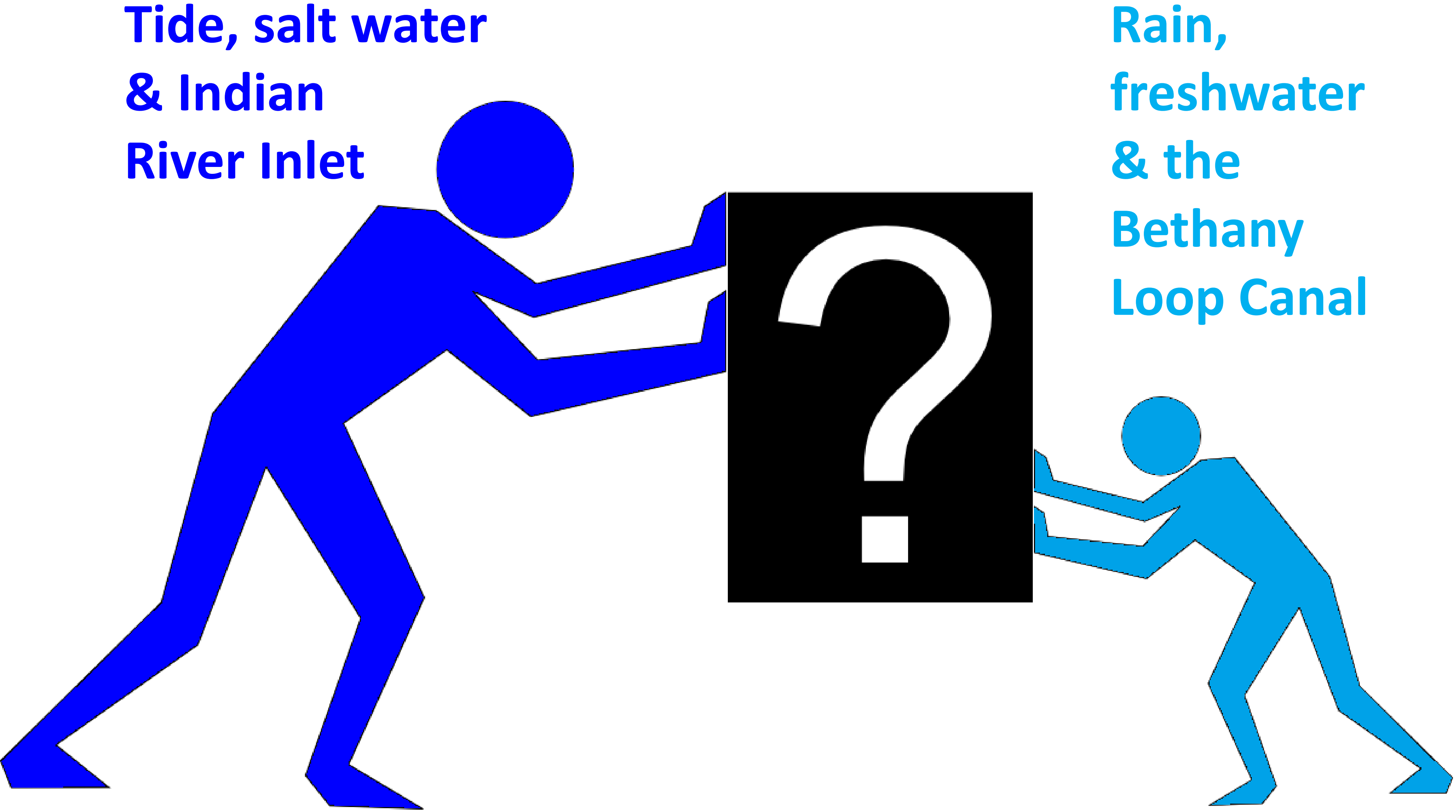
Freshwater and Salt water



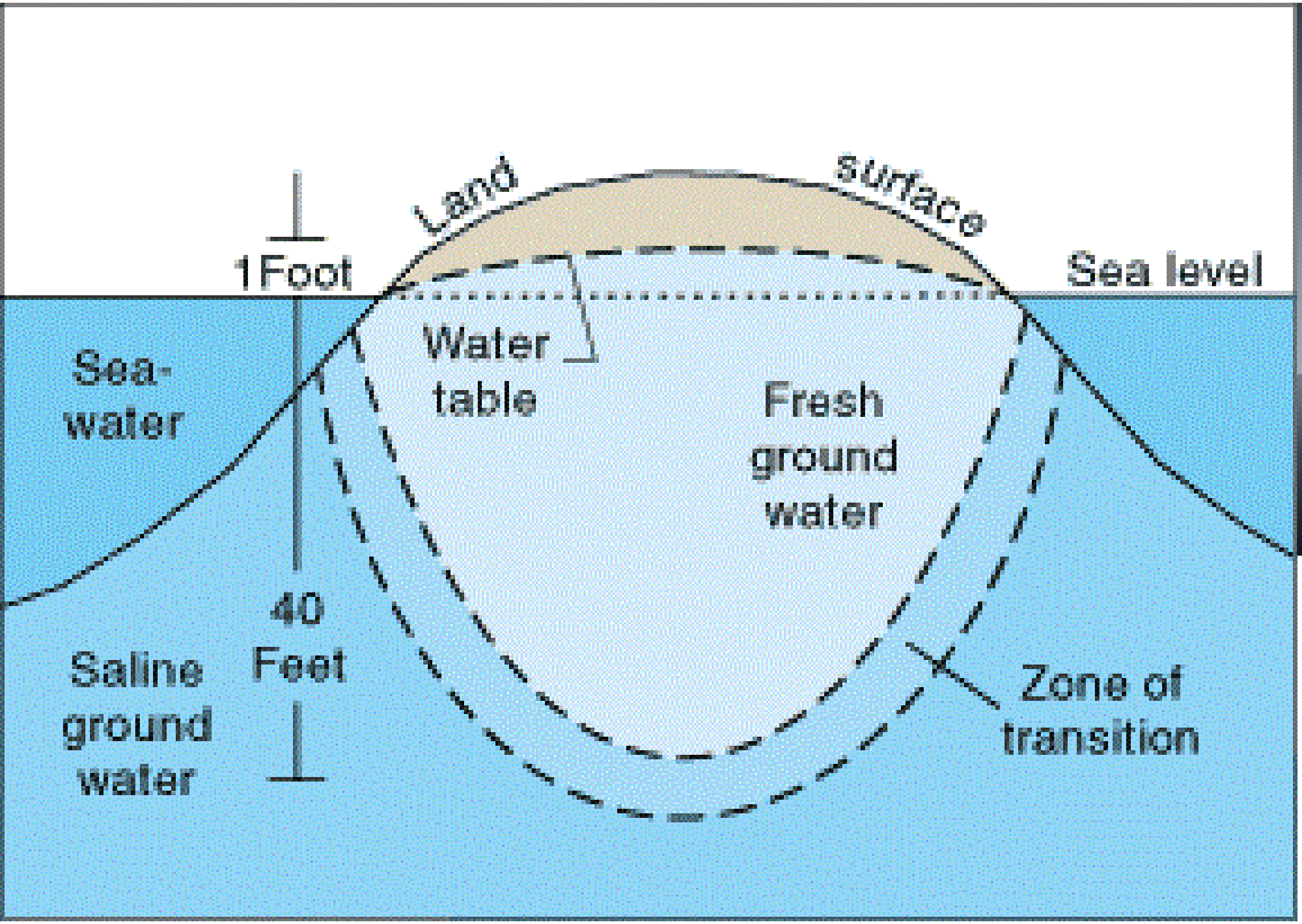


Freshwater vs Salt Water

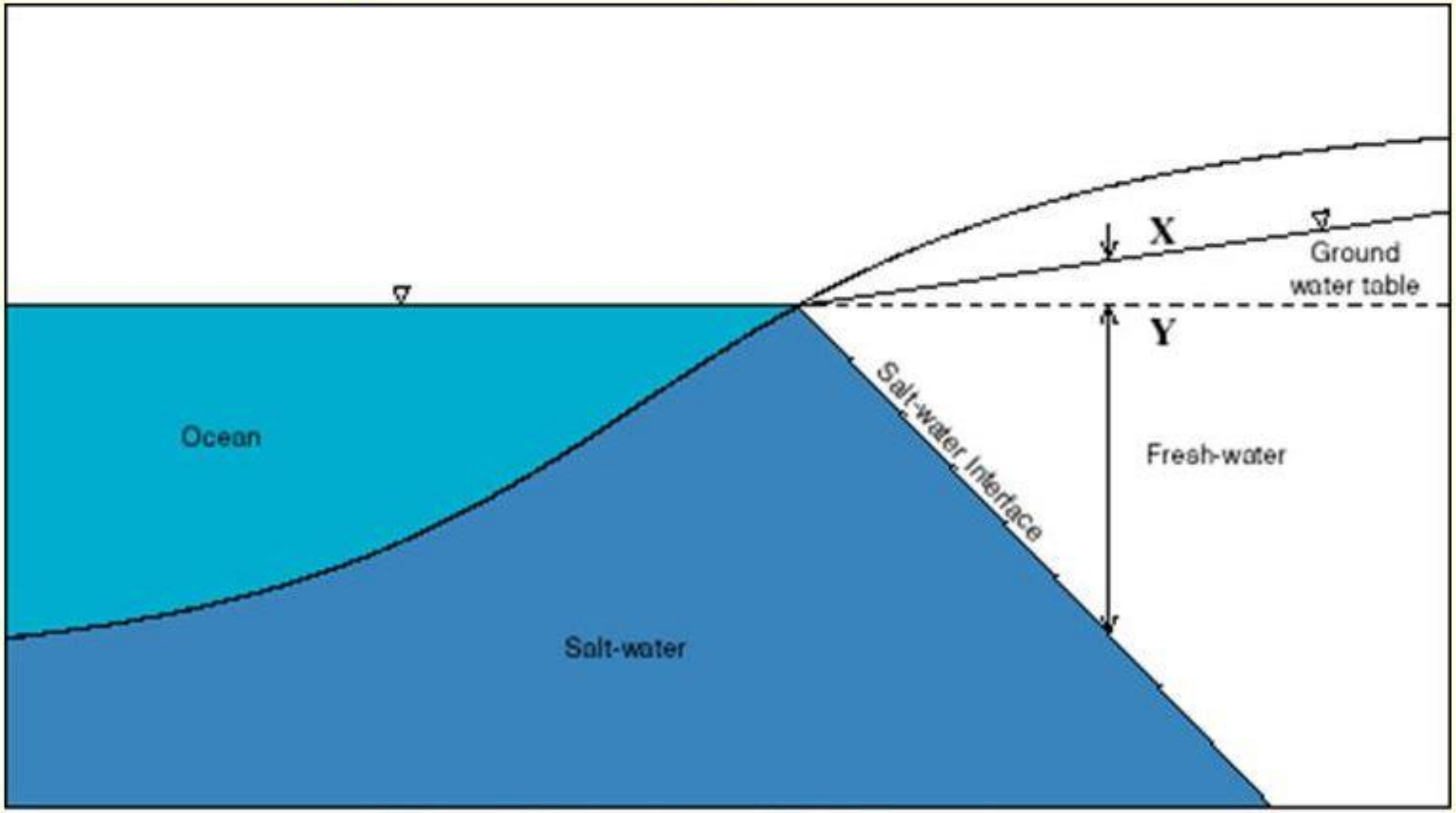



Tide, salt water & Indian River Inlet
Rain, freshwater & the Bethany Loop Canal

The interaction of Saltwater and Freshwater Is described by the Dupuit-Ghyben-Herzberg Lens

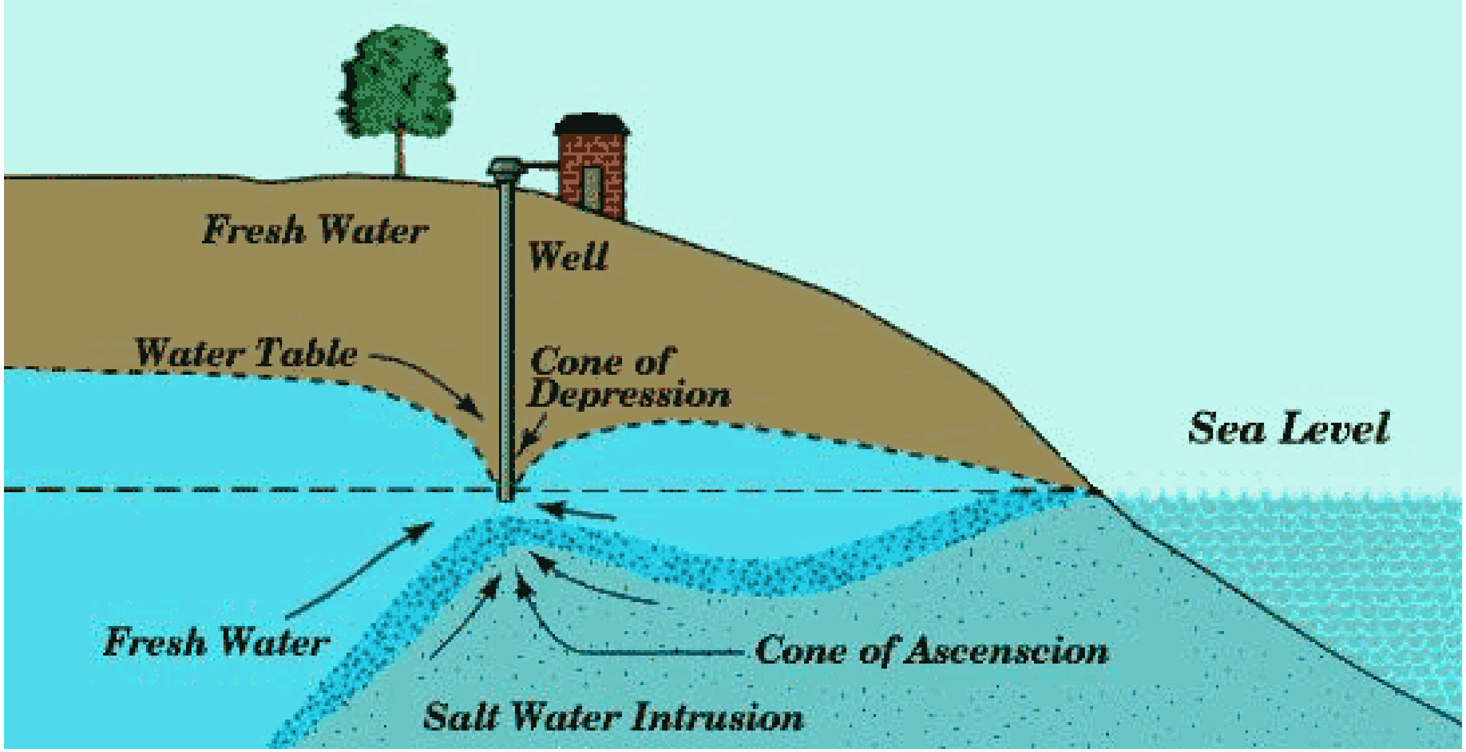


Ghyben-Herzberg relation

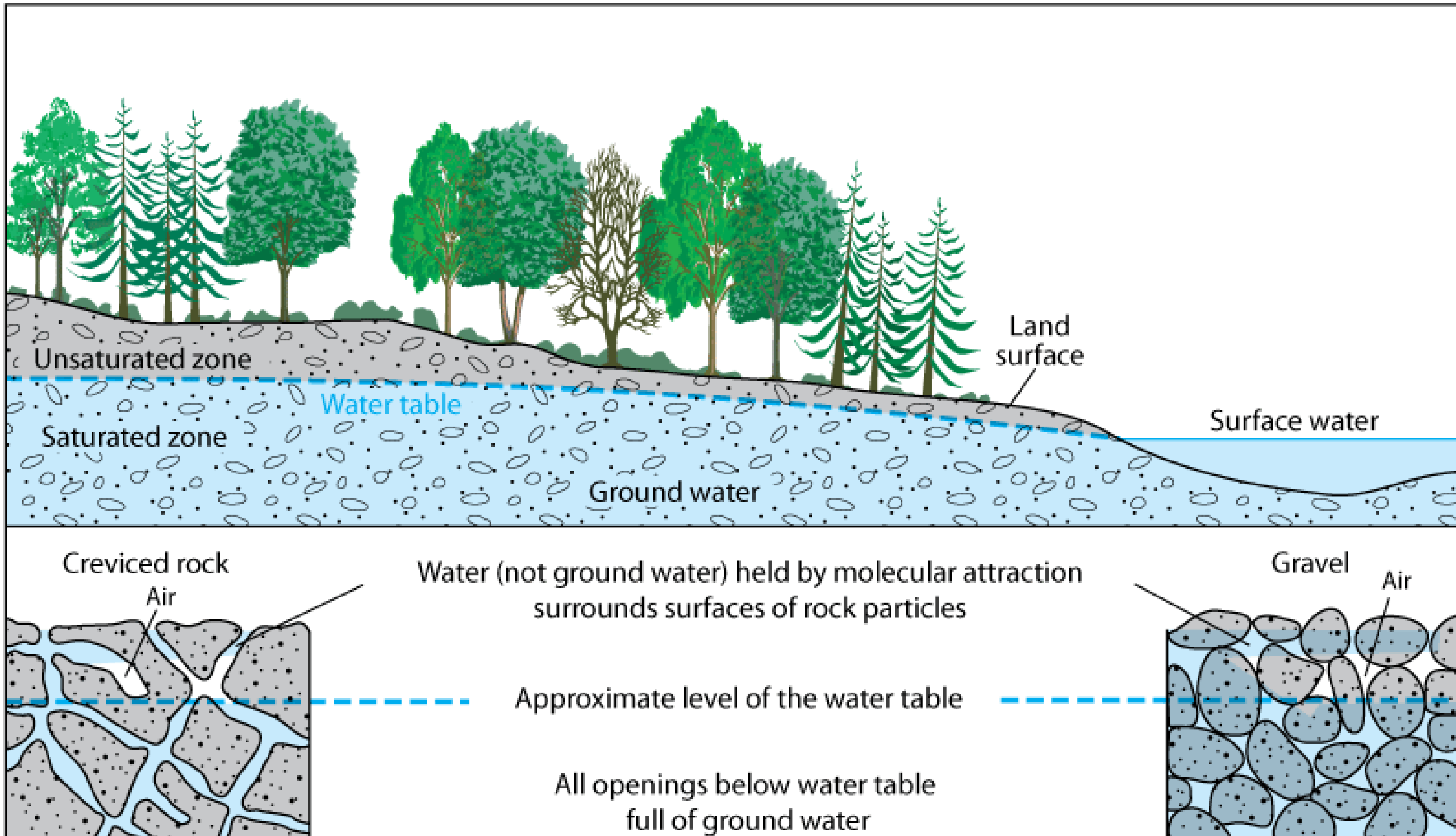


Salt-water interface in an unconfined coastal aquifer according to the Ghyben-Herzberg relation.

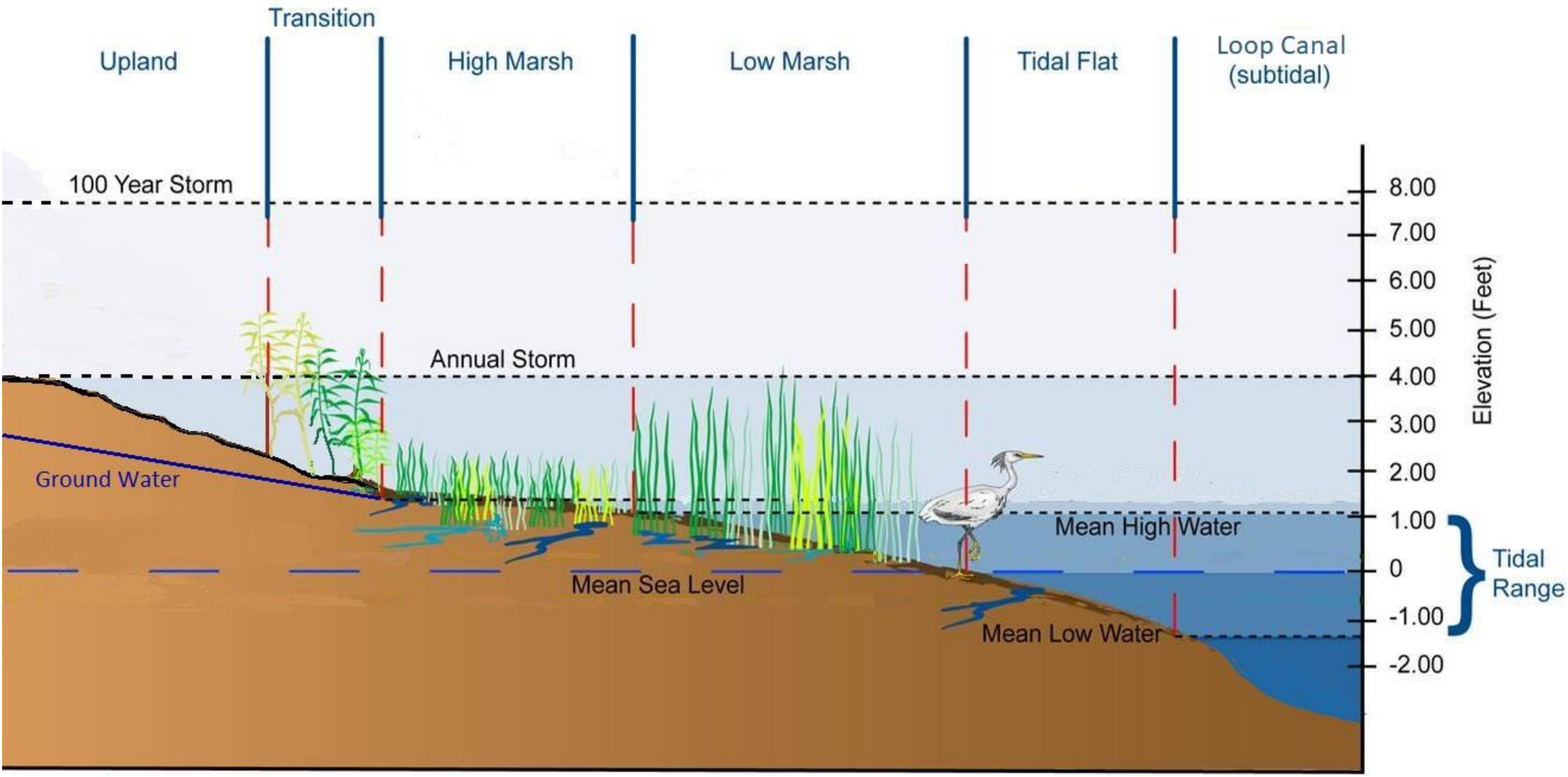
Coastal Water Wells and Salt water intrusion



Stormwater storage capacity is in the space above surface water and the pore space in the soil above the Water Table.



Wetlands also provide Stormwater storage capacity in the pore space above the water table which is close to the surface.

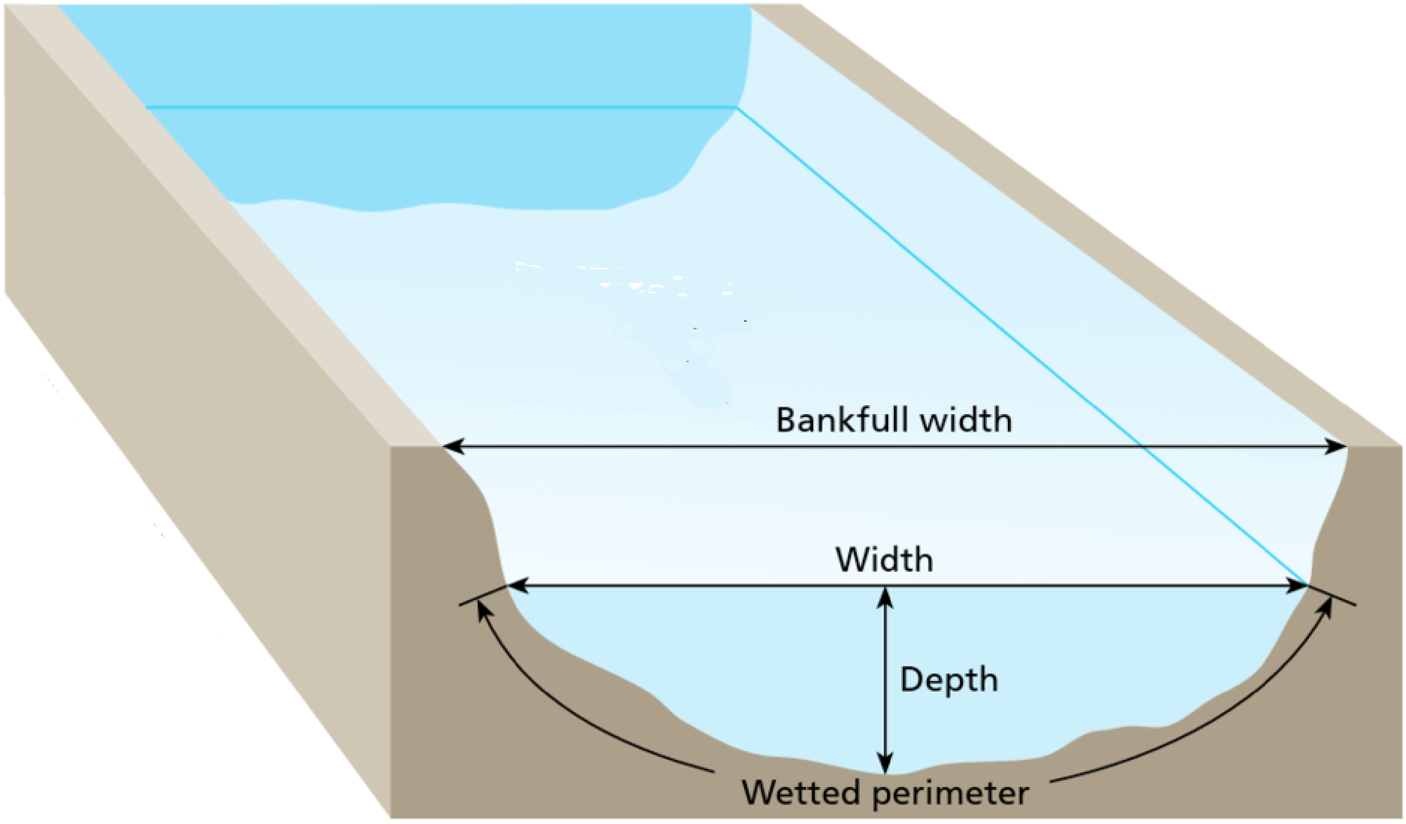


Bethany Loop Canal September 30, 2016

www.townofbethanybeach.com/492/Loop-Canal-Tides

Dredged Channels

A deeper channel does not mean more Stormwater Storage.
Deeper channels can move more water to or away from a site.



Sources of Freshwater Flow into the Inland Bays

- Inland Bays Watershed (**190,488** Acres)
- Love Creek
- Herring Creek
- Guinea Creek
- Indian River
- Pepper Creek
- White Creek
- Bethany Beach Watershed

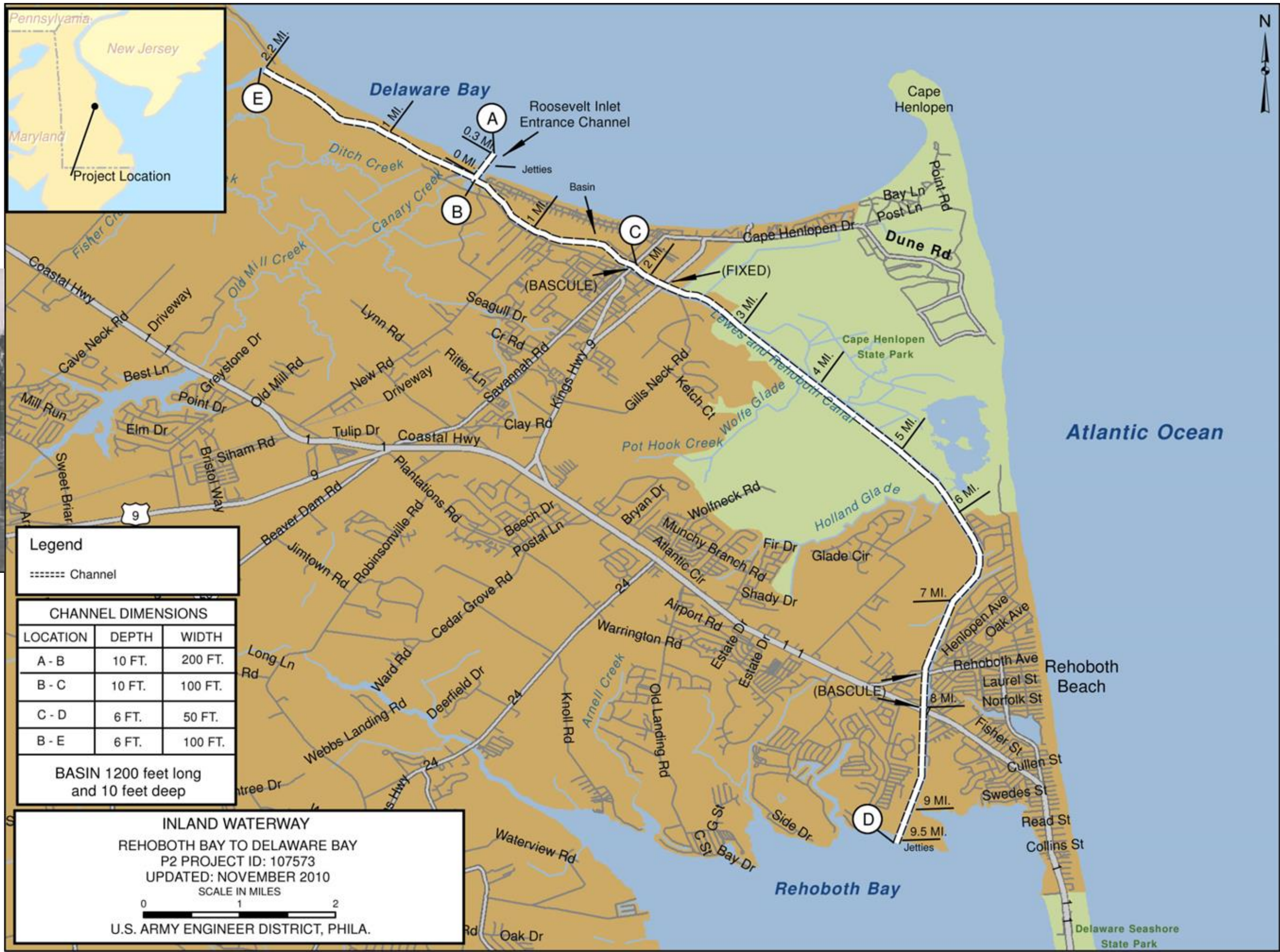
Sources of Tidal Flow into the Inland Bays

- Roosevelt Inlet through the Lewes Rehoboth Canal
- Indian River Inlet through Indian River Bay
- The channel through Fresh Pond
- Assawoman Canal
- Bethany Loop Canal

Lewes Rehoboth Canal

Originally proposed in 1803, the canal was finally constructed by the Army Corps of Engineers from 1913 to **1916**. Despite its intended use as **a freight shipment route**, it saw little use for that purpose due to the development of more efficient roads and railways; instead, the canal has primarily been used for leisure boating for the majority of its history.

The Helen Marie II ran From Rehoboth to Bethany in 1912.



Indian River Inlet

Until **1928**, the Indian River Inlet was a natural connection to the ocean that shifted up and down a two-mile (3.2 km) stretch of the coast from Rehoboth to Bethany Beach. The inlets opened with storms and closed through longshore movement of sand.

About **1920** former Governor John Gillis Townsend had a dredge remove sand and used 2000 or more pounds of Hurcules black powder to open a 6 foot deep, 60 foot wide channel which lasted only a short while.

Dredging kept the inlet open **for navigation** in its current location from **1928** to **1937**.

In **1938** the United States Army Corps of Engineers built jetties that now hold it in place.

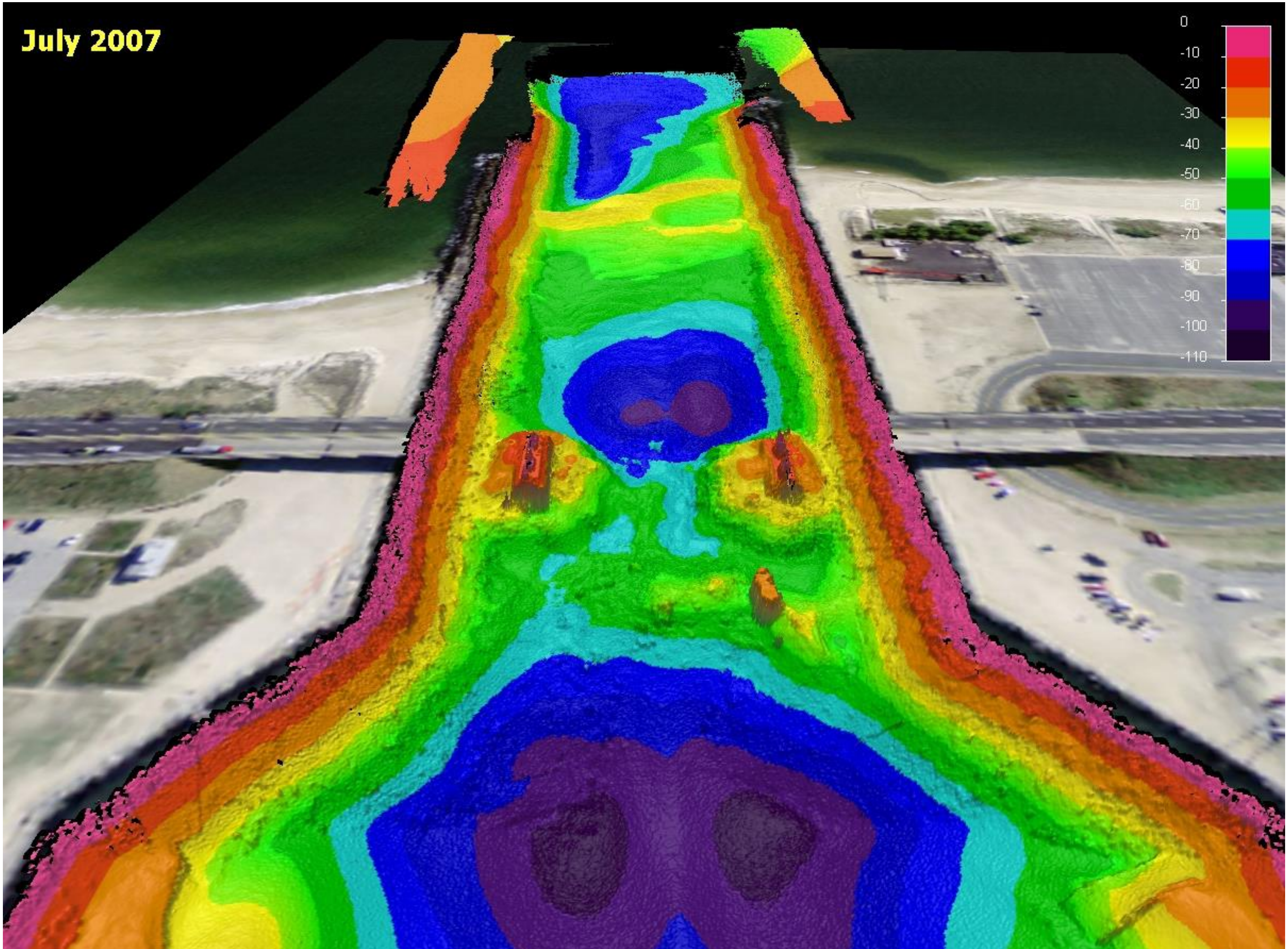
Indian River Inlet, 1931

Indian River Inlet

The bridge piers from the third Indian River Inlet Bridge took up space and provided turbulence which slowed the flow past.

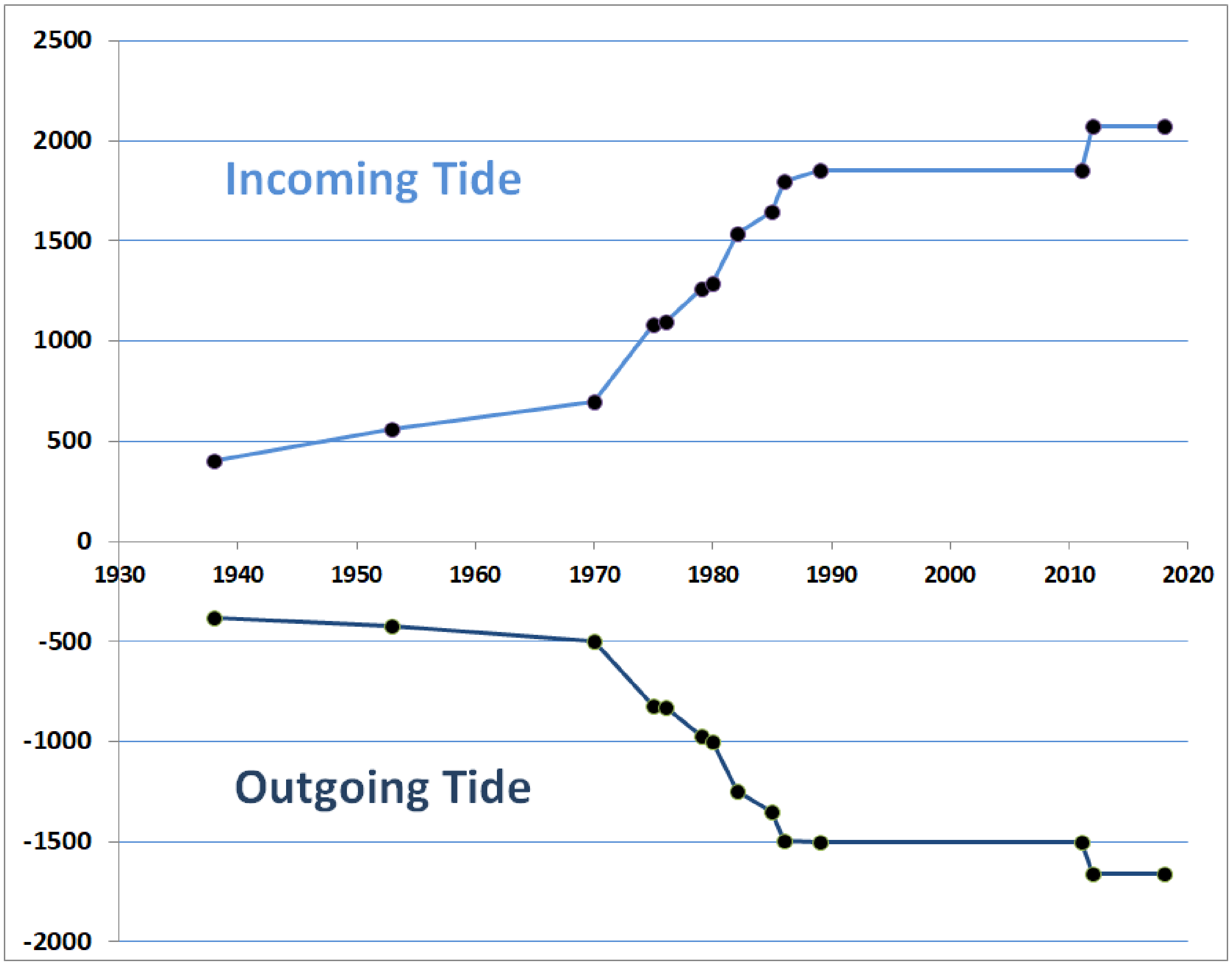
North Shore Fishing Pier in the 1960s

The old North Shore Fishing Pier was part of the second bridge across Indian River Inlet.


July 2007
0
-10
-20
-30
-40
-50
-60
-70
-80
-90
-100
-110

Indian River Flushing

2012 open area increase of 10.57% (1938-1989 from Bason, 2011)



Assawoman Canal

The Assawoman Canal was initially dug by hand in the **1890**s by immigrant labor **for navigation** to transport agricultural products to market.

The canal was not dredged from the **1950**s until **2006**.

By the early **2000**s, it was no longer deep enough to handle the boat traffic that once passed through it when it was part of the Intracoastal Waterway.

From **2006** to **2010**, the state undertook a dredging project that restored the canal to navigability, with a channel width of 35 feet (11 m) and a depth of 3 feet (0.91 m)

Bethany Loop Canal

Completed July 8, **1910**, the Bethany Loop Canal was excavated **for navigation**. The Bethany Loop Canal marked the end of a long journey for vacationers traveling to Bethany Beach in the town's early days. Since the shallow-draft motorboat Allie May could not back up, a loop was formed here at the First Street dock to allow the boat to turn around for the return trip. The Allie May ran 1910 to 1912.

Fresh Pond
Tide Gates

Two tide gates that once controlled Fresh Pond.

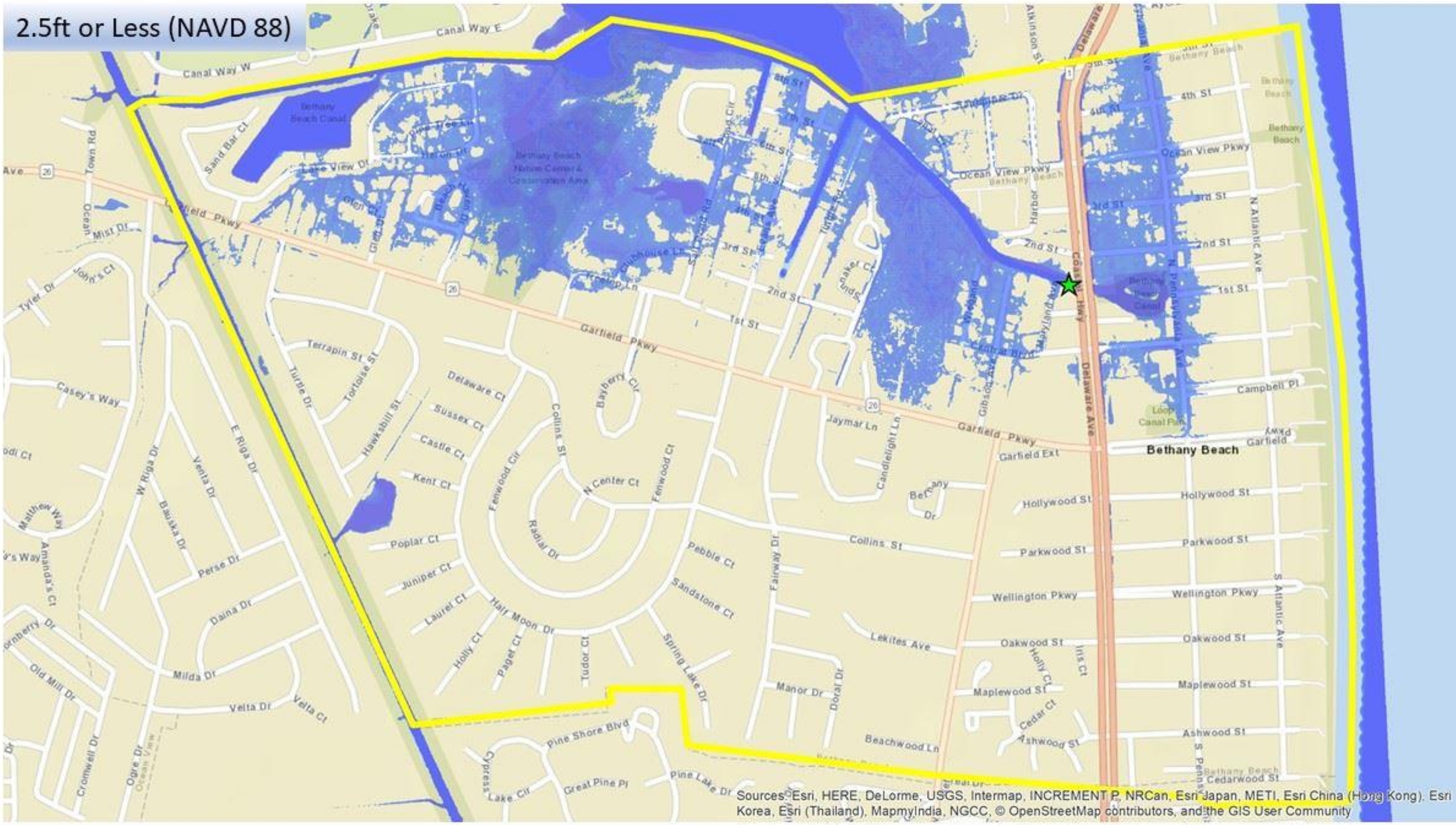
The tide gates let freshwater out and did not let salt water into the pond.

The tide gates are now gone and saltwater can ass through.

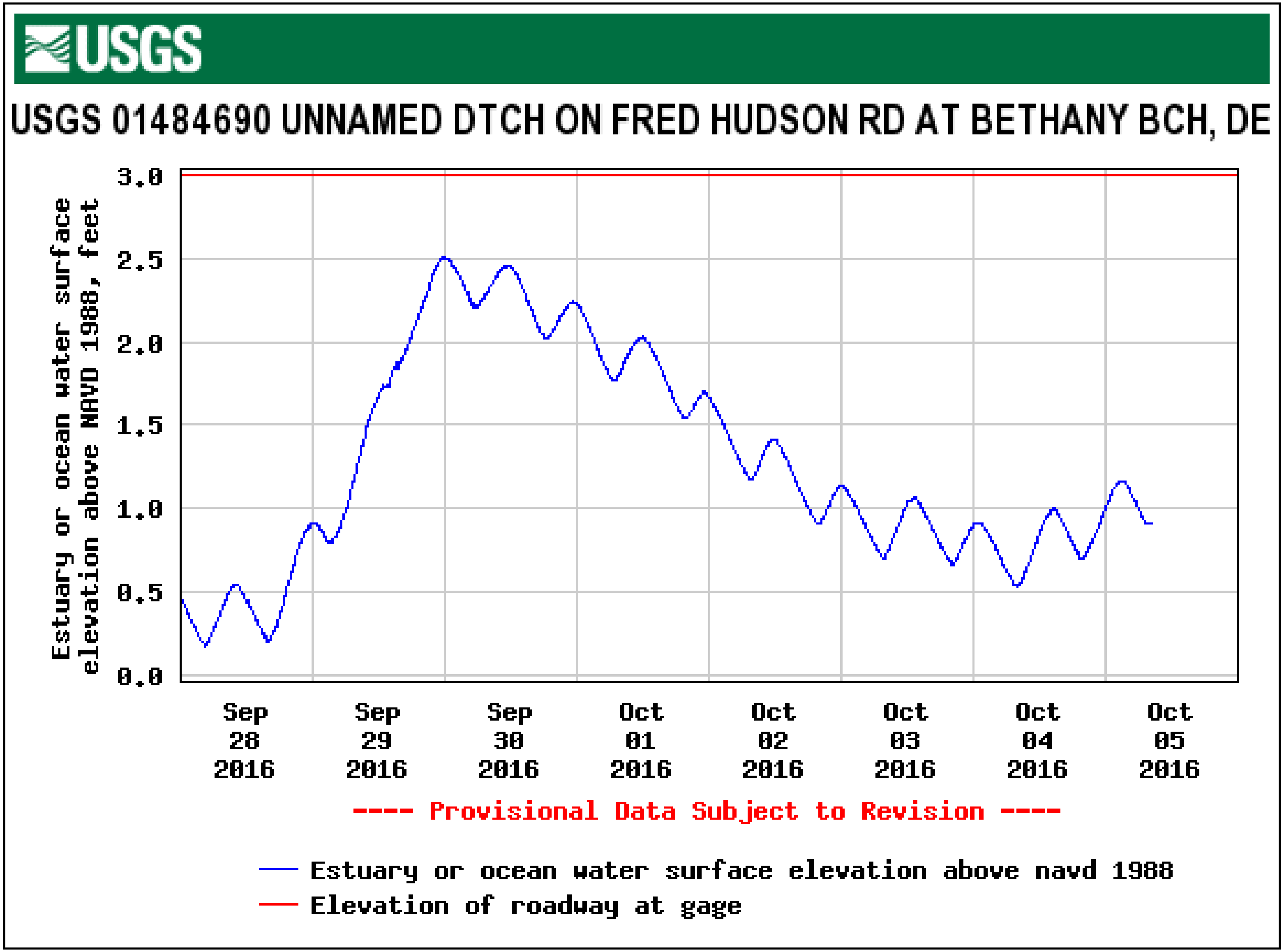
Fred Hudson Road Tide Gauge
https://waterdata.usgs.gov/de/nwis/uv?site_no=01484690

The gauging station is
located on the north side
of Route 360

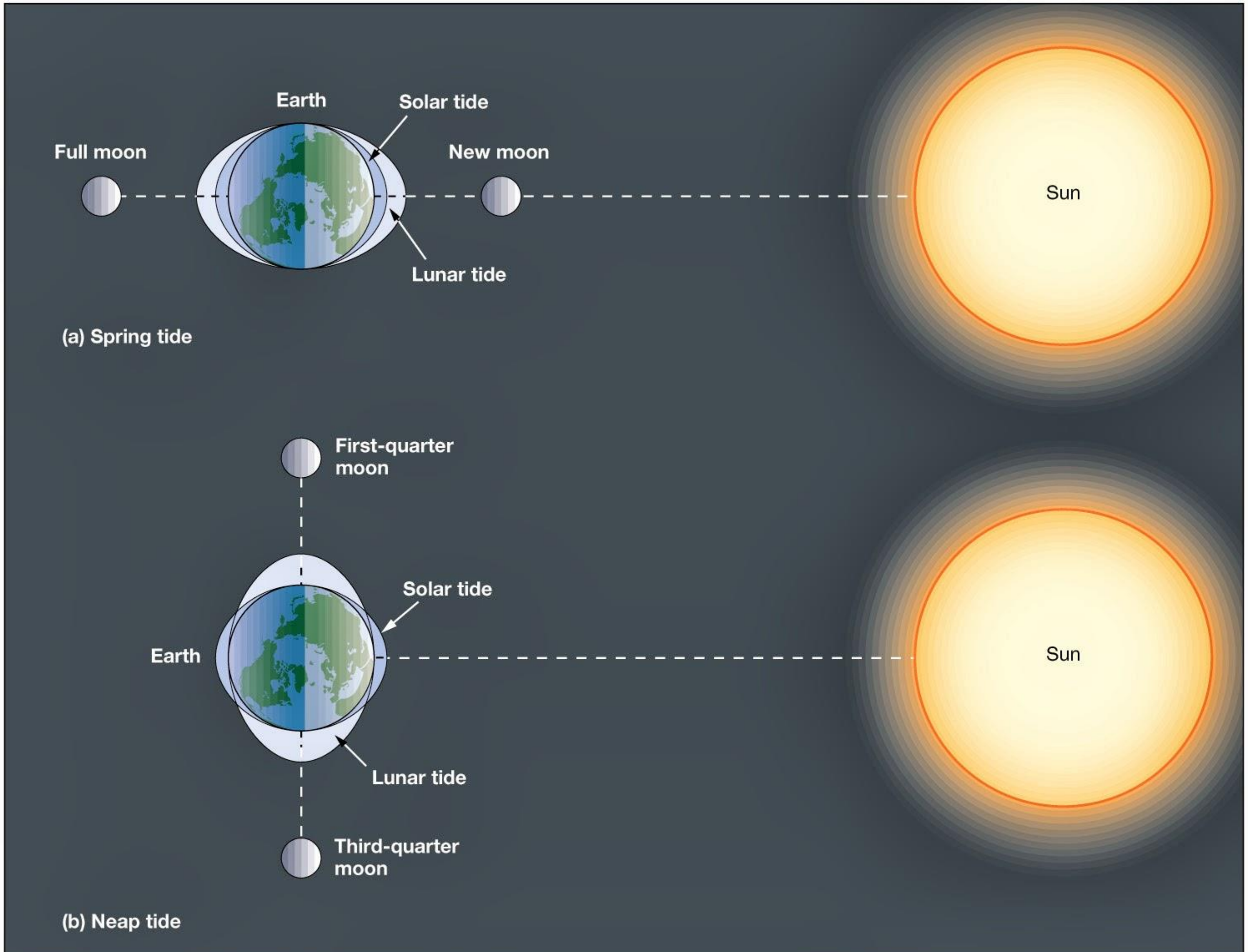
www.townofbethanybeach.com/492/Loop-Canal-Tides



Fred Hudson Road (Rt. 360) September 30, 2016


USGS
USGS 01484690 UNNAMED DTCH ON FRED HUDSON RD AT BETHANY BCH, DE
Estuary or ocean water surface elevation above NAVD 1988, feet
3.0
2.5
2.0
1.5
1.0
0.5
0.0
Sep 28 2016
Sep 29 2016
Sep 30 2016
Oct 01 2016
Oct 02 2016
Oct 03 2016
Oct 04 2016
Oct 05 2016
---- Provisional Data Subject to Revision ----
Estuary or ocean water surface elevation above navd 1988
Elevation of roadway at gage

Tides


Earth
Solar tide
Full moon
New moon
Sun
Lunar tide
(a) Spring tide
First-quarter moon
Solar tide
Earth
Sun
Lunar tide
Third-quarter moon
(b) Neap tide

Wetlands

All wetlands have three common features related to water:

("*hydro*" is taken from the ancient Greeks)

- **Water presence** – Wetlands have water above or below the soil surface at least a portion of the year. The field of study is called *hydrology*.

- **Water soils** (called *hydric* soils) – Soils saturated with water most of the time, often very dark in color from decaying plants.

Pat Trochlell

Hydric soil on right.

- **Water plants** (called *hydrophytes*) – Plants adapted to wet conditions, like cattails and tamarack trees.

Delaware State Jurisdictional Wetlands

Delaware tidal wetlands are regulated under the Wetlands Act of 1973 (7 Del. Code Chapter 66. Sec. 6601-6620).

The Wetlands Act of 1973, defines "wetlands" as "those lands above the mean low water elevation including any bank, marsh, swamp, meadow, flat or other low land subject to tidal action in the State along the Delaware Bay and Delaware River, Indian River Bay, Rehoboth Bay, Little and Big Assawoman Bays, the coastal inland waterways, or along any inlet, estuary or tributary waterway or any portion thereof, including those areas which are now or in this century have been connected to tidal waters, whose surface is at or below an elevation of 2 feet above **local mean high water**, and **upon which may grow or is capable of growing** [any but not necessarily all of a series of wetland plants]". (**Delaware code does not define local mean high water**).

Regulated wetlands are depicted on official State Wetland Maps that were adopted as part of the Regulations. (**Maps lack correlation with the tidal benchmarks**)

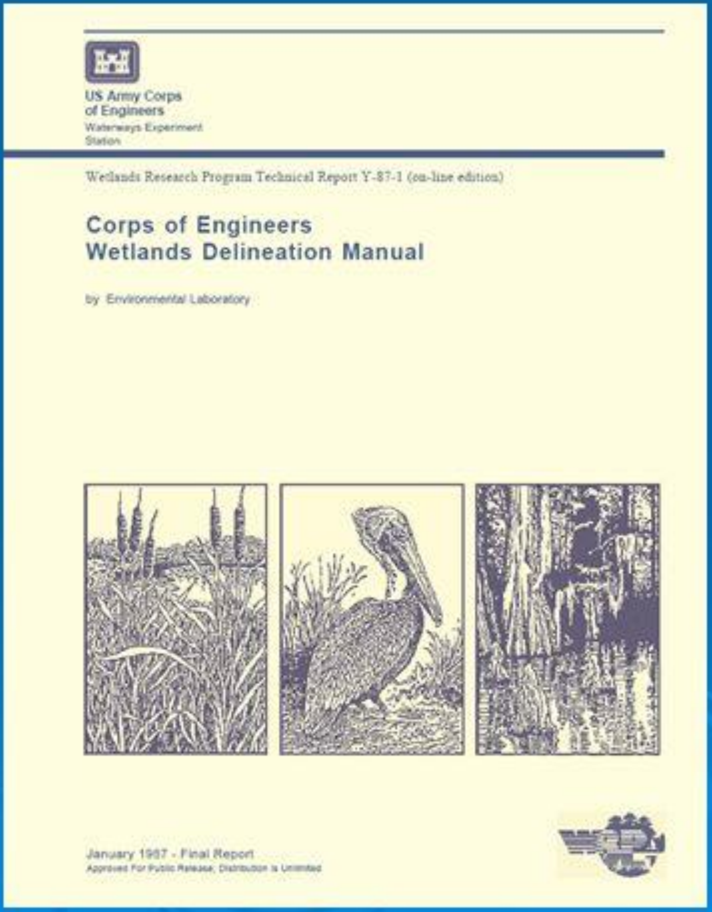
Delaware Plant List

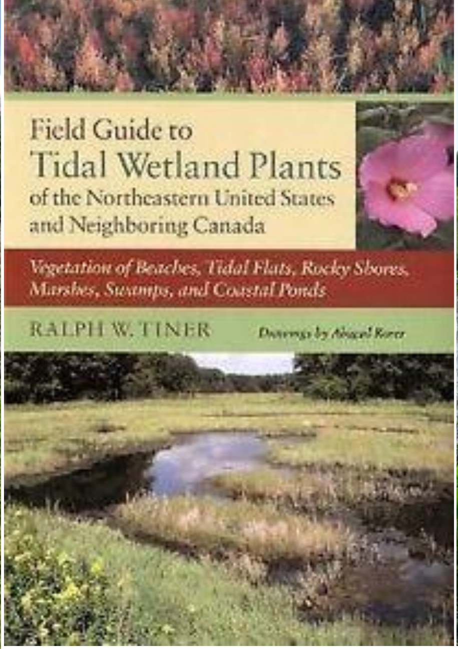
Eelgrass (Zostera marina), **Widgeon Grass** (Ruppia maritima), **Sago Pondweed** (Potamogeton pectinatus), **Saltmarsh Cordgrass** (Spartina alterniflora), **Saltmarsh Grass** (Spartina cynosuroides), **Saltmarsh Hay** (Spartina patens), **Spike Grass** (Distichlis spicata), **Black Grass** (Juncus gerardii), **Switch Grass** Panicum virgatum), **Three Square Rush** (Scirpus americanus), **Sea Lavender** (Limonium carolinianum), **Seaside Goldenrod** (Solidago sempervirens), **Seablite** (Suaeda maritima), **Sea Blite** (Suaeda linearis), **Perennial Glasswort** (Salicornia virginica), **Dwarf Glasswort** (Salicornia bigelovii), **Samphire** (Salicornia europaea), **Marsh Aster** (Aster tenuifolius), **Saltmarsh Fleabane** (Pluchea purpurascens var. succulenta), **Mock Bishop's Weed** (Ptilimnium capillaceum), **Seaside Plantain** (Plantago oliganthus), **Orach** (Atriplex patula var. hastata), **Marsh Elder** (Iva frutescens var. oraria), **Groundsel Bush** (Baccharis halimifolia), **Bladderwrack** (Fucus vesiculosus), **Swamp Rose Mallow**, **Seaside Hollyhock** or **March Mallow** (Hibiscus palustris), **Torrey Rush** (Scirpus torreyi), **Narrow-leaved Cattail** (Typha angustifolia), and **Broad-leaved Cattail** (T. latifolia).

“Wetlands” also include: “those lands not currently used for agricultural purposes containing 400 acres or more of contiguous non-tidal swamp, bog, muck or marsh exclusive of narrow stream valleys where fresh water stands most, if not all, of the time due to high water table, which contribute significantly to ground water recharge, and which would require intensive artificial drainage using equipment such as pumping stations, drain fields or ditches for the production of agricultural crops.”

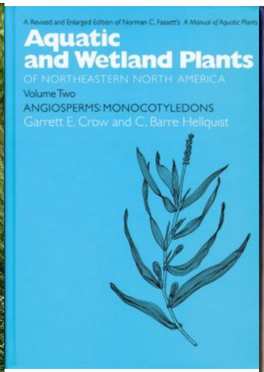
Corps of Engineers 1987 Wetland Delineation Manual

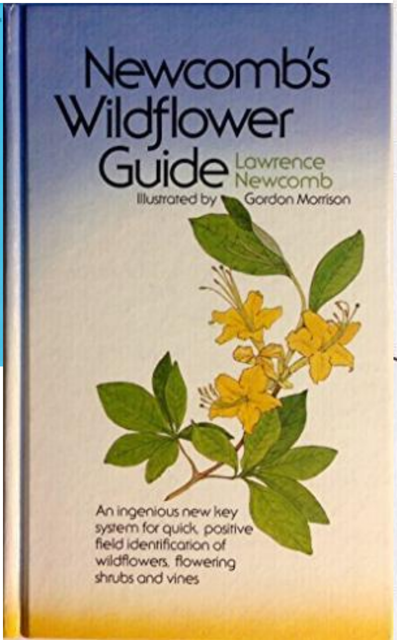
- Umbrella manual for all Clean Water Act wetland delineations
  - Definitions, criteria
    - Hydrophytic Vegetation
    - Wetland Hydrology
    - Hydric Soils
    - Problem Areas
    - Disturbed Areas

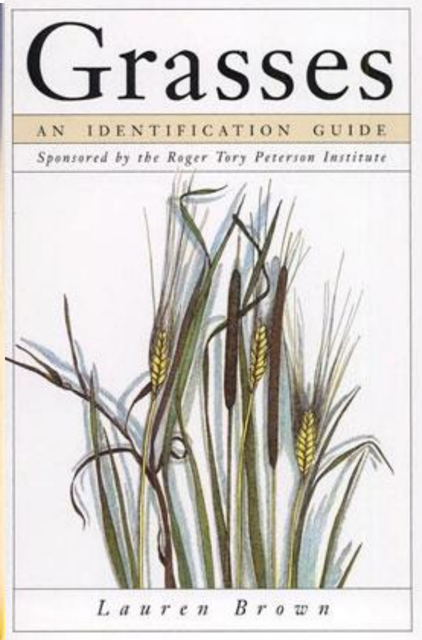




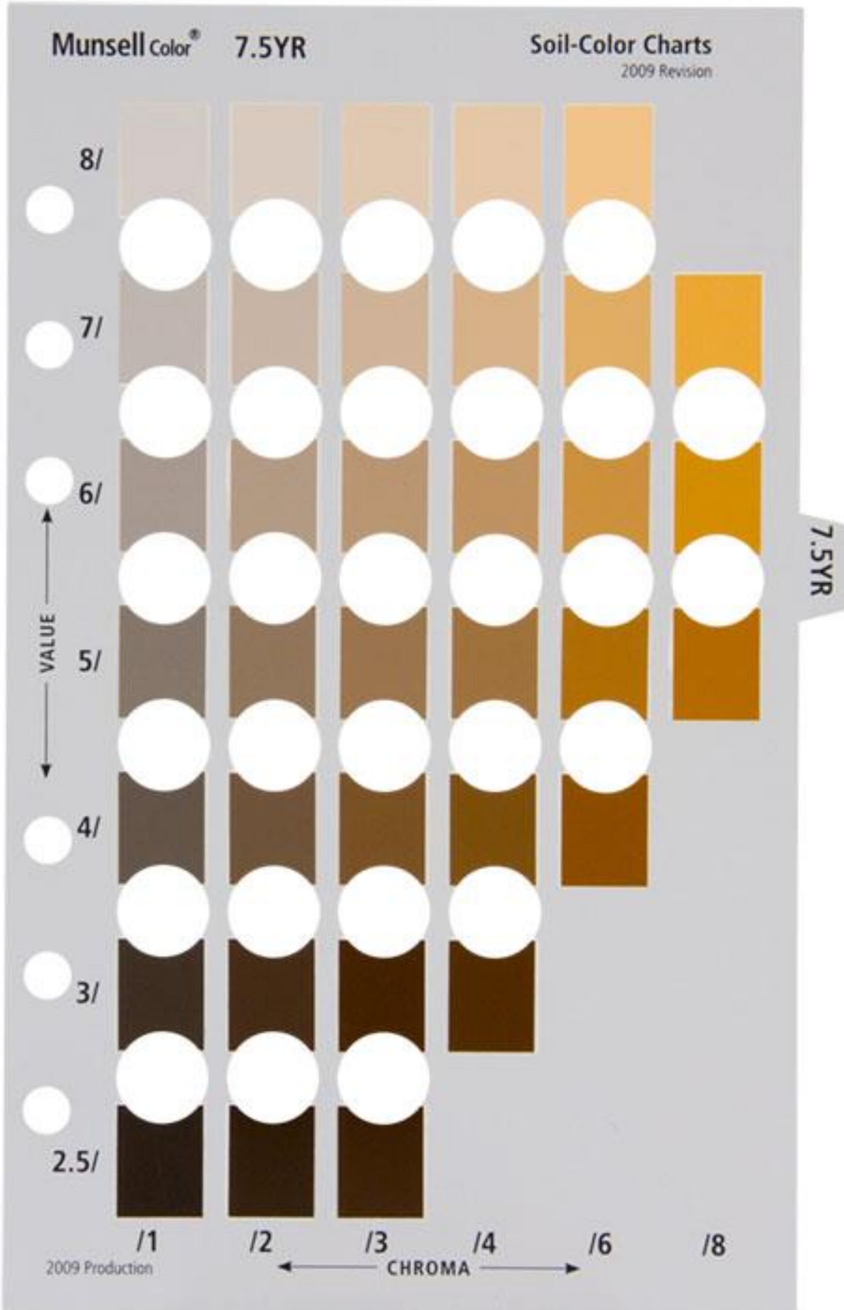
Plant Identification

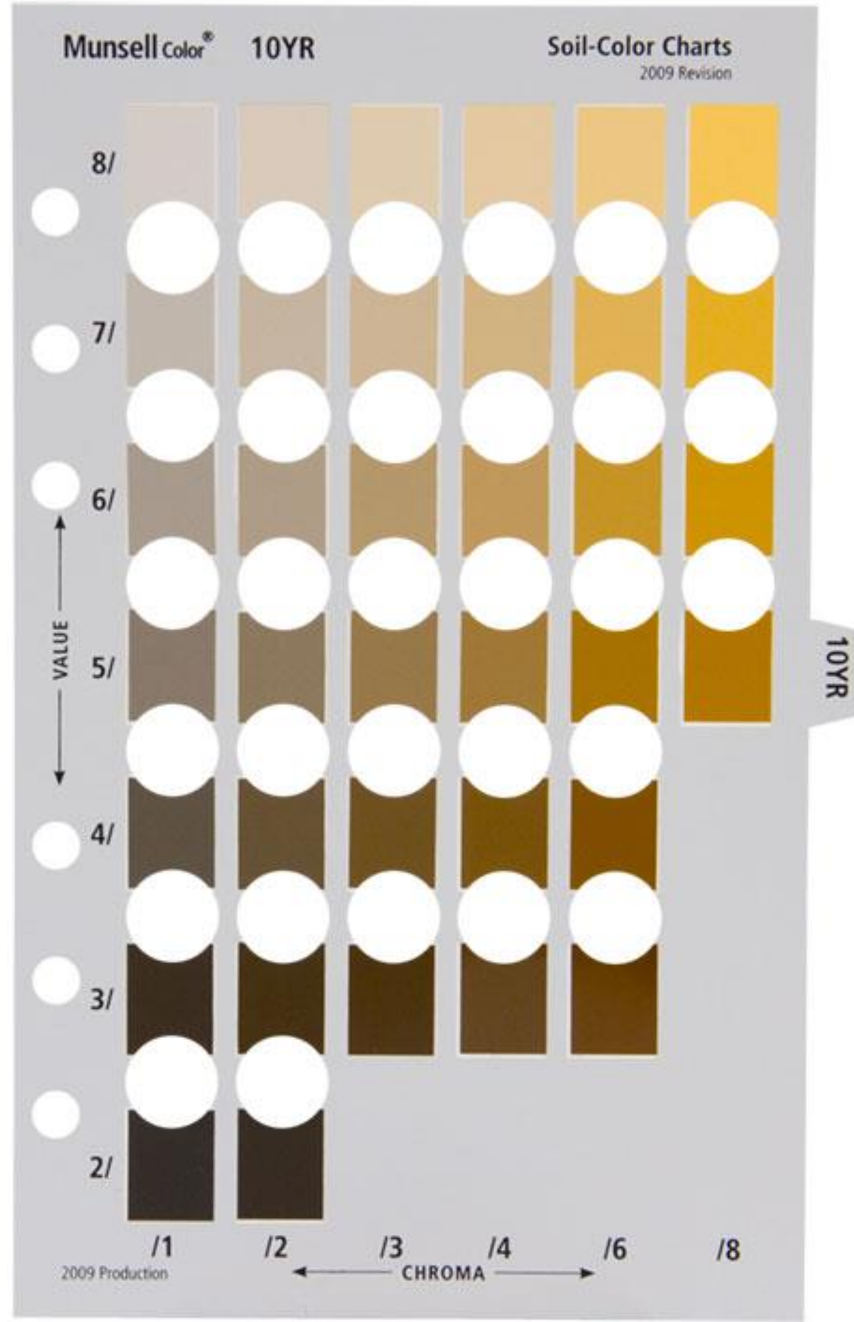






Soils


Munsell Color®
7.5YR
Soil-Color Charts
2009 Revision
8/
7/
6/
5/
4/
3/
2.5/
VALUE
/1
/2
/3
/4
/6
/8
CHROMA
2009 Production
7.5YR


Munsell Color®
10YR
Soil-Color Charts
2009 Revision
8/
7/
6/
5/
4/
3/
2/
VALUE
/1
/2
/3
/4
/6
/8
CHROMA
2009 Production
10YR

Hydrology

Springs

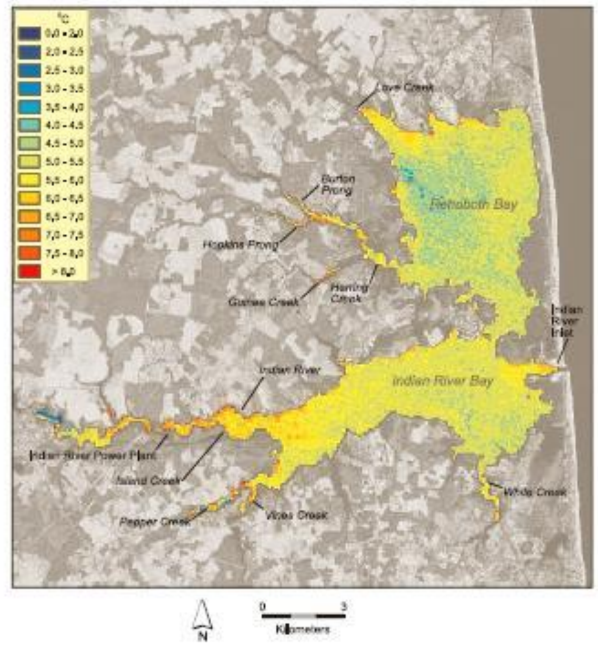
Springs and Fens occur around parts of Rehoboth and Indian River Bays. Springs also are found on the bottoms of both bays.

Springs do not seem to be an important part of the Bethany Beach hydrology.

State of Delaware
DELAWARE GEOLOGICAL SURVEY
John H. Talley, State Geologist

REPORT OF INVESTIGATIONS NO. 74

LOCATING GROUND-WATER DISCHARGE AREAS IN REHOBOTH AND INDIAN RIVER BAYS AND INDIAN RIVER, DELAWARE USING LANDSAT 7 IMAGERY



By

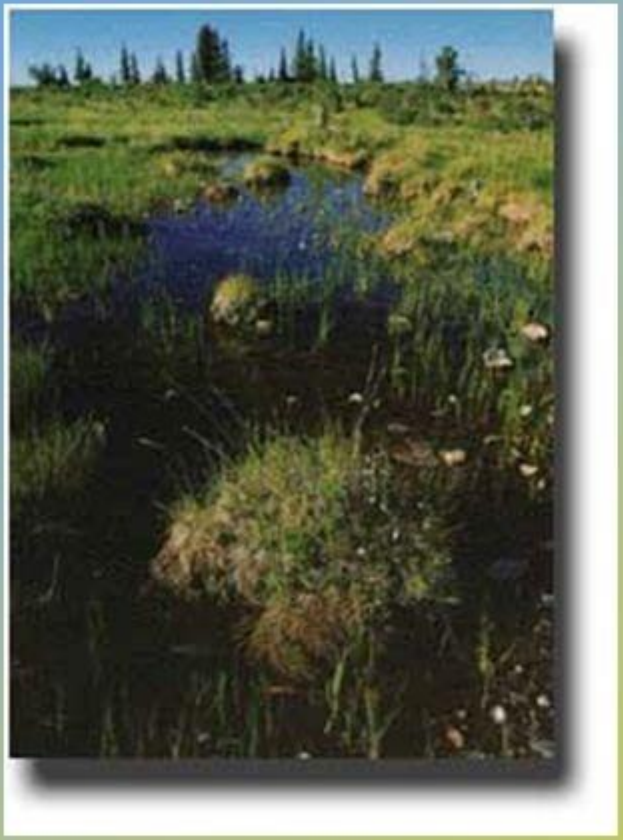
Lillian T. Wang[1], Thomas E. McKenna[1], and Tracy L. DeLiberty[2]

University of Delaware
Newark, Delaware

2008

FEN

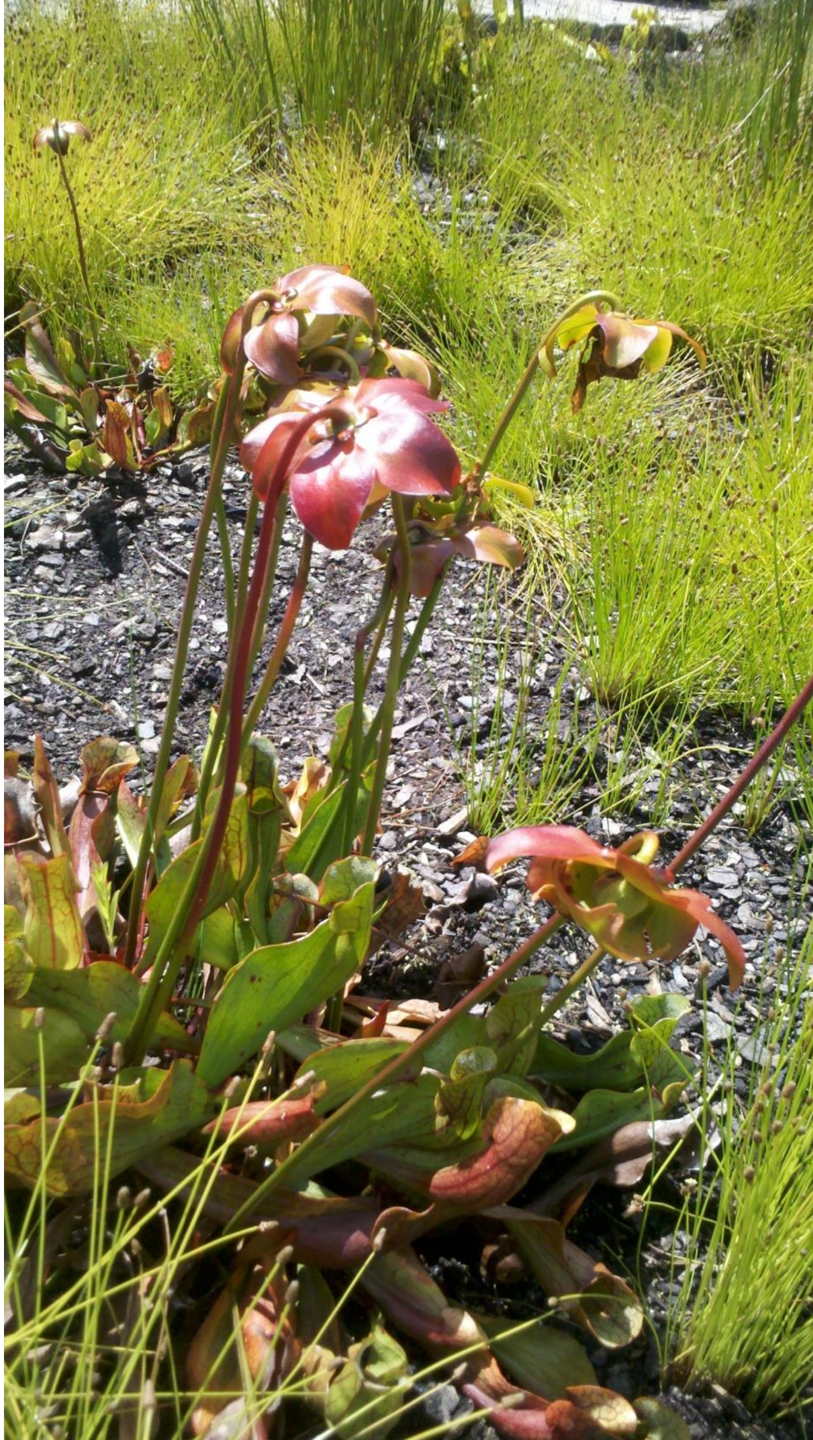
A fen is a type of wetland fed by alkaline, mineral-rich groundwater and characterized by a distinctive flora. Fens are often confused with bogs, which are fed primarily by rainwater and often inhabited by sphagnum moss, making them acidic. Like other wetlands, fens will ultimately fill in and become a terrestrial community such as a woodland through the process of ecological succession.



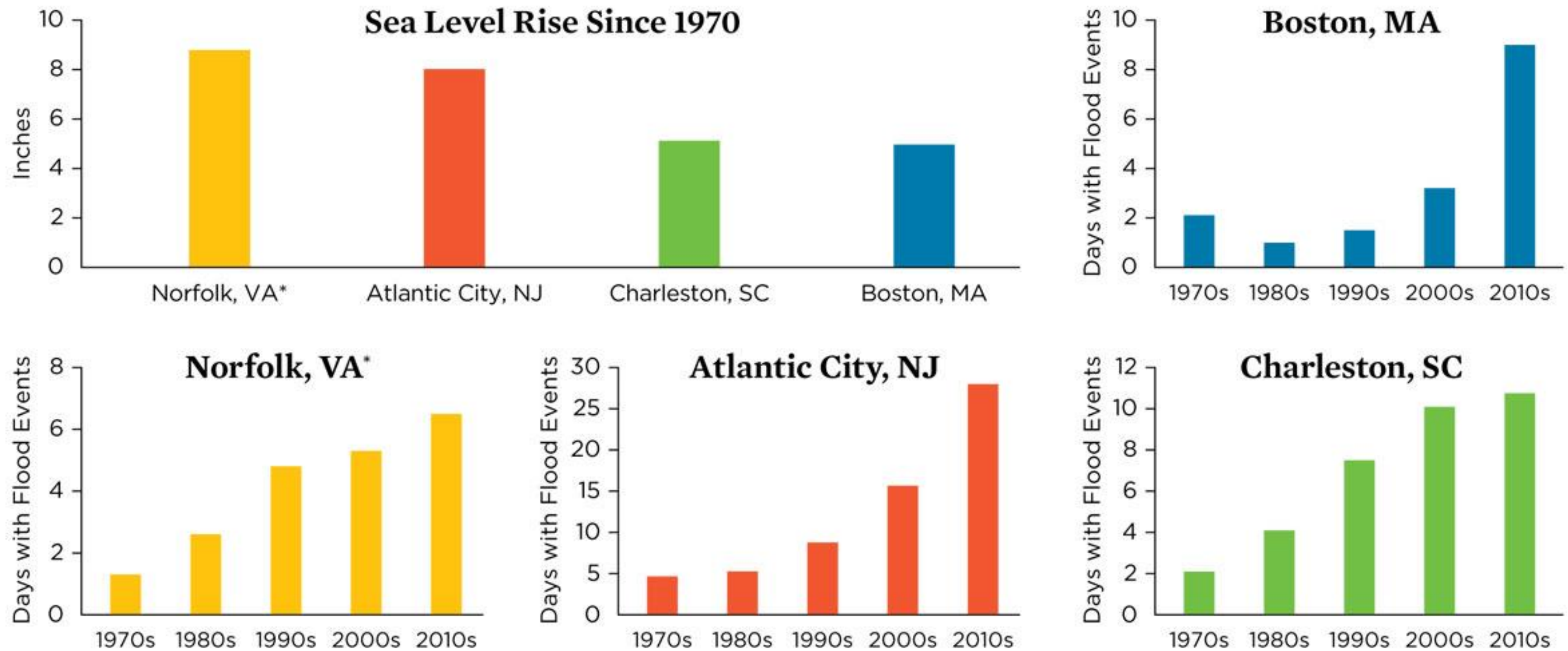
Fens, like bogs, are peatlands, but because they are fed by groundwater they are not so acidic as bogs.

Coastal Plain Seepage Fens

Coastal Plain seepage fens are rare, open habitats characterized by groundwater seepage through acidic, sandy, or gravelly soils along margins of headwater coastal plain streams, at the base of slopes. The typically small openings often support pitcher plants, orchids, and a diverse array of sedges. An extremely globally rare community fed by low mineral water is a **Delmarva poor fen**. There are two known sites in Delaware and two sites in Maryland. This community is dominated by twig rush, sphagnum, pitcher plants, orchids, and a large number of other rare plants. These habitats are threatened by encroaching tree canopy, eutrophication, hydrological changes, and in some cases sea level rise.



Local Sea Level Rise and Tidal Flooding, 1970–2012



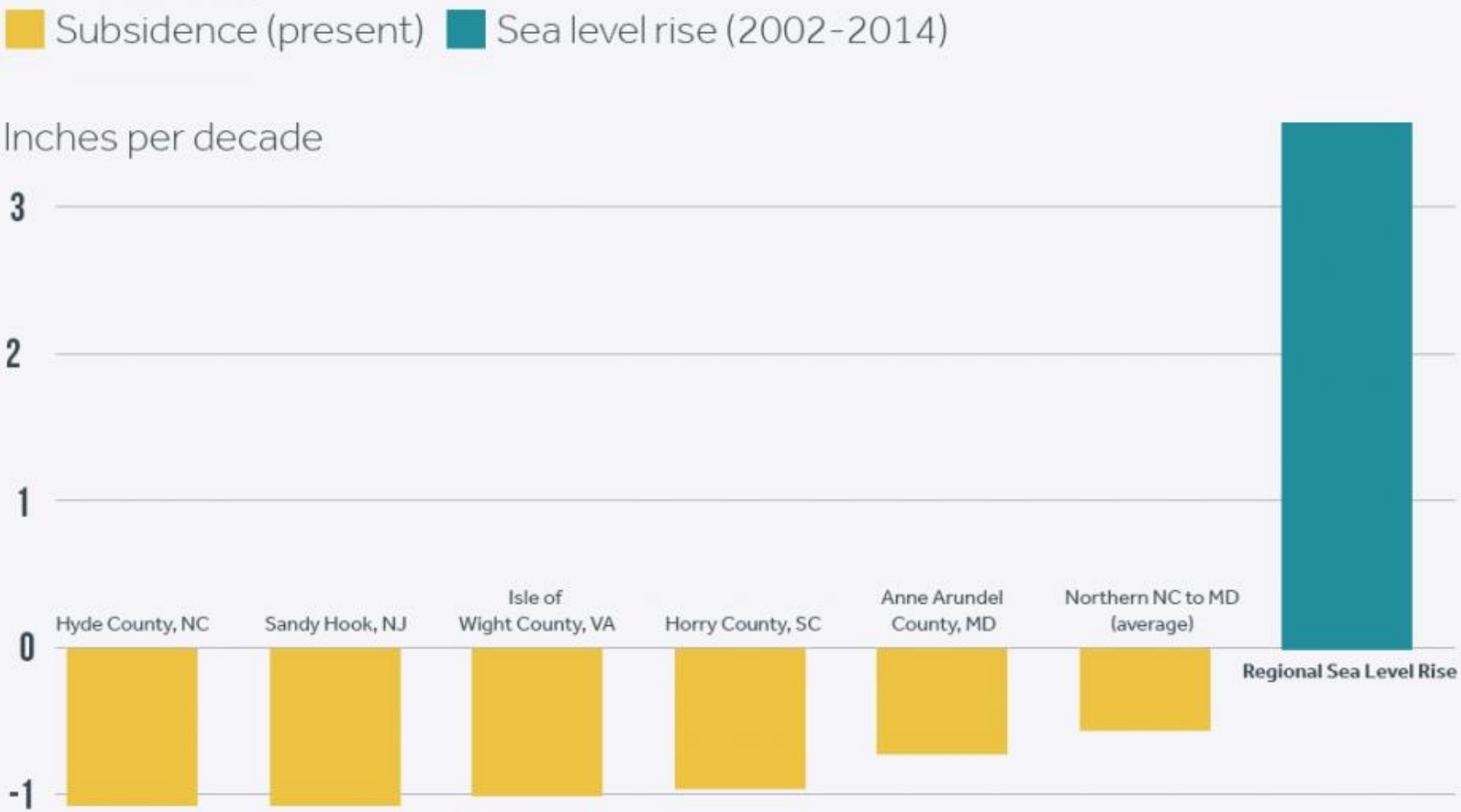
Sea level has risen by about 3.5 inches globally—but more along the East Coast—since 1970. At Sewells Point, VA, for example, sea level has risen more than eight inches, and at Boston, about five inches. Rising seas mean that communities up and down the East and Gulf Coasts are seeing more days with tidal flooding. Charleston, SC, for example, faced just two to three days with tidal flooding a year in the 1970s. The city now averages 10 or more such days annually.

*Norfolk statistics recorded at the Sewells Point tide gauge.

SOURCES: UCS ANALYSIS; MORALES AND ALSHEIMER 2014; NOAA TIDES AND CURRENTS 2014; NOAA TIDES AND CURRENTS 2013B.

Where The Land Sinks

Some of the greatest recorded rates of East Coast land subsidence

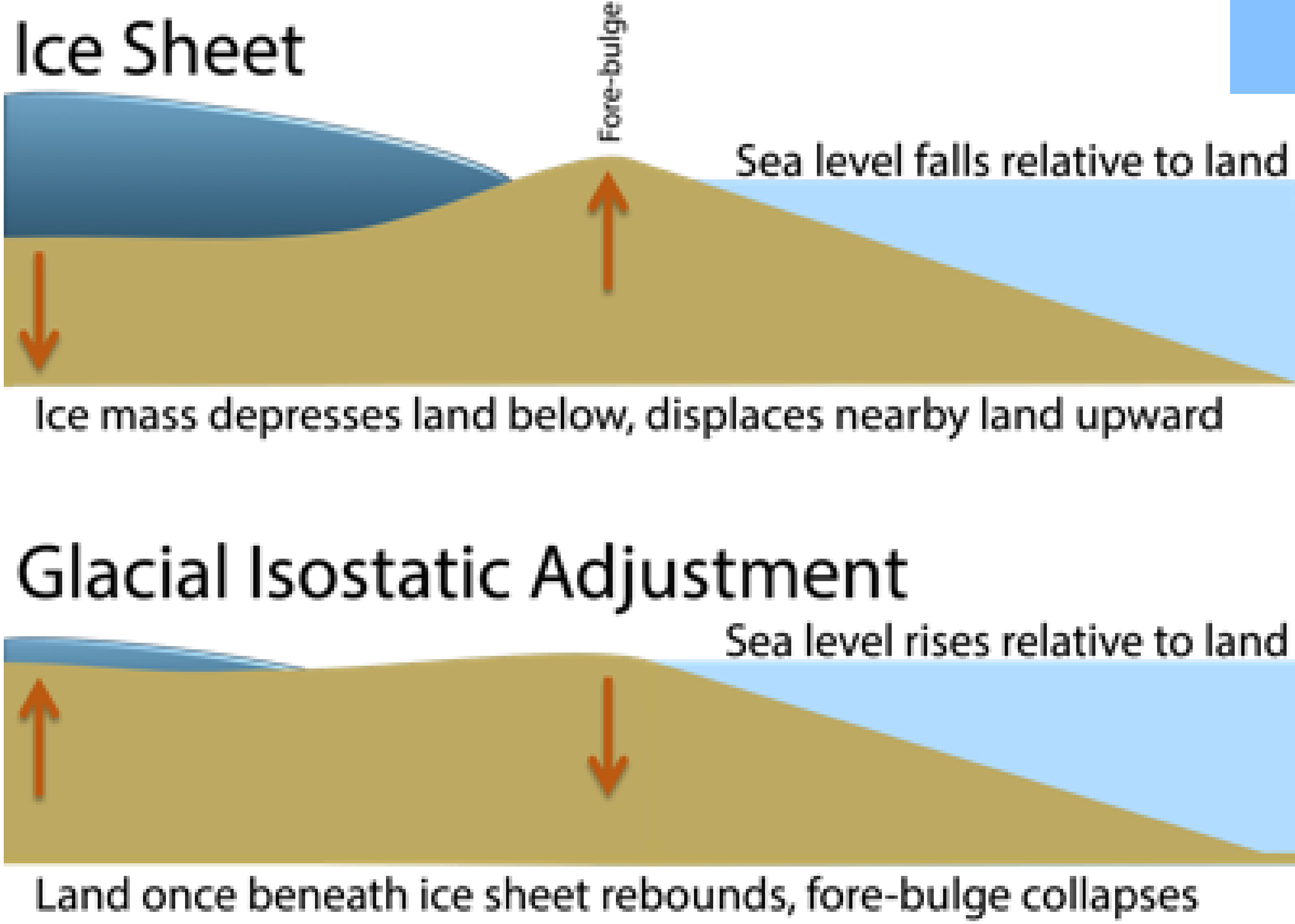


Source: Karegar et al., Subsidence along the Atlantic Coast of North America: Insights from GPS and late Holocene relative sea level data. GRL, 2016.
Rietbroek et al., "Revisiting the contemporary sea-level budget on global and regional scales." PNAS, 2016

CLIMATE CENTRAL

Why does subsidence occur?

Laurentide



Sea Level Rise	Land Subsidence	Charlii's Age	Total Change
-3.5mm/yr.		68.5 yr.	-9.44 in.
-3.5mm/yr.	-1.4mm/yr.	68.5 yr.	-13.21 in.
-3.5mm/yr.	-2.8mm/yr.	68.5 yr.	-16.99 in.

Getting rid of the Storm water.

Soaking into the ground	– very little room above the water table
Draining it away on the surface	– relies on low tides
Evaporation	- sun and wind
Transpiration	- by plants in the growing season
Pumps	- Holland and New Orleans, cost to operate

Preventing Tidal Surge.

Limited by the flat topography

Inflatable dam	- restricts flow, retains storm water, increases flooding elsewhere
Solid tide barrier	- restricts flow, retains storm water, increases flooding elsewhere

Bladder Dam - restricts flow, retains storm water, increases flooding elsewhere behind it.

Water can rise above the land surrounding a Water Control Structure.

Traditional Wind Powered Pumps

New Orleans Pump Stations

EMPTYING THE BOWL

New Orleans sits below sea level and is shaped like a bowl. Rainwater can not drain out of the city because it can not defy gravity, so it must be pumped out. The system in New Orleans can only handle 1 inch of rain for the first hour and only 0.5 inches every hour after that. One location in New Orleans was inundated with 9.6 inches in 4 hours on Saturday, far more than the system can handle.