GenCade Background

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CIRP Training on CMS and GenCade, Sept. 19-23, 2022

ERDC
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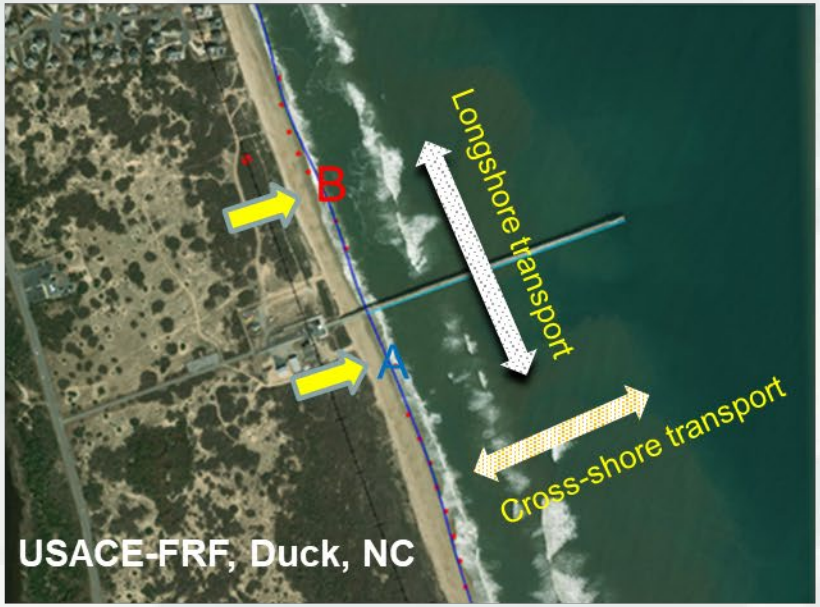
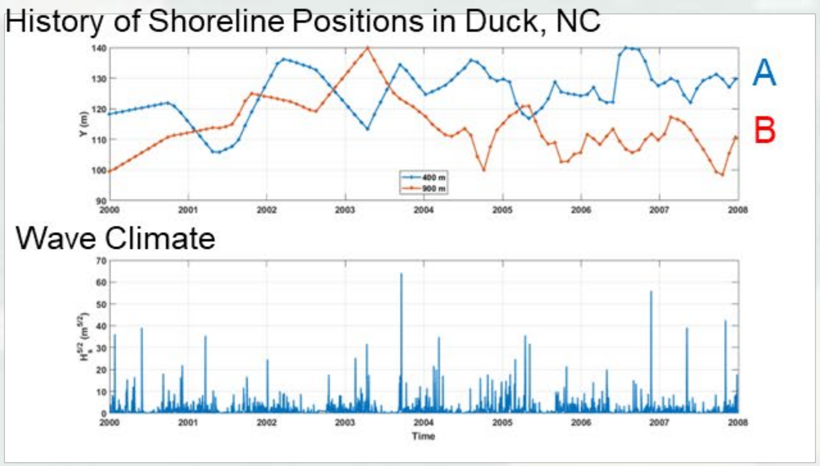
Outline

- Capabilities in GenCade:
  - Longshore Sediment Transport,
  - Shoreline Change,
  - Structures,
  - Beach Fill and Bypassing
  - Inlet Reservoir Model (IRM) for Sand Bypassing across Inlets

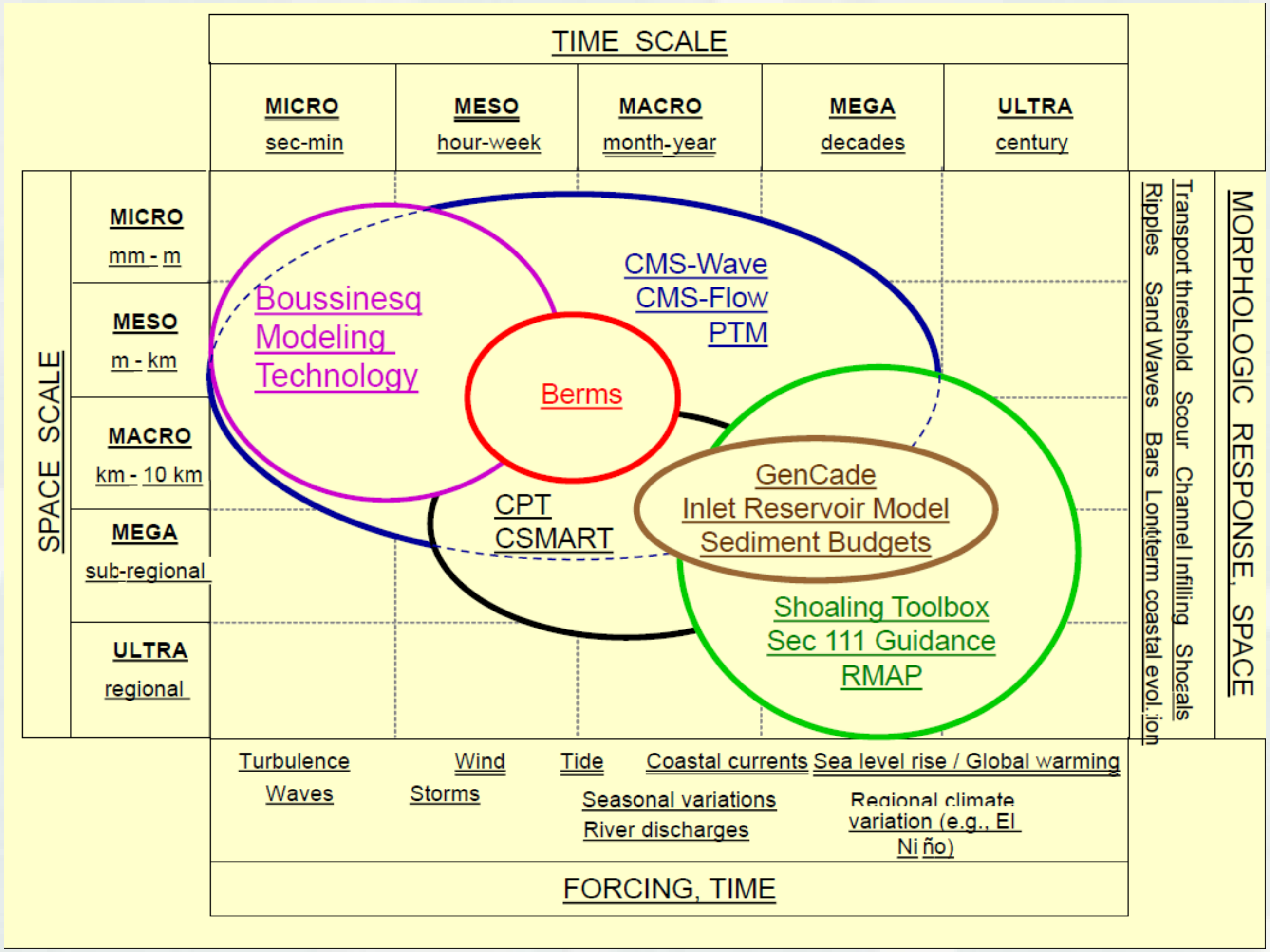
Long-Term and Regional Shoreline Changes

- Prediction of long-term shoreline changes is a key task in coastal management practices.
- Traditional shoreline evolution modeling is mainly based on the mass conservation of **longshore sediment transport** driven by waves and currents.
- **Cross-shore transport** also plays an important role in shoreline erosion and recovery (accretion)
- Physical processes driving cross-shore transport are complicated, including **waves**, **currents** (undertow), **gravitational effects**, sea level changes (tides, surges, and SLR), tectonic movement (subsidence), dune erosion due to aeolian transport, berm change, etc.
- Cross-shore sediment transport may play a dominant role in reshaping cross-shore profiles and shorelines in an initial stage of **beach fills** and **nourishment**.
- Shoreline changes induced by physical processes in general are highly irregular.





Scales and Model Coverage



Shoreline Change and Coastal Protection Practices

- Construction or modification of inlets for navigational purpose
- Construction of harbors with breakwaters built in nearshore regions
- Beachfills (sand nourishment)
- Sand Bypass
- Sand Mining
- Dredging Material Disposals

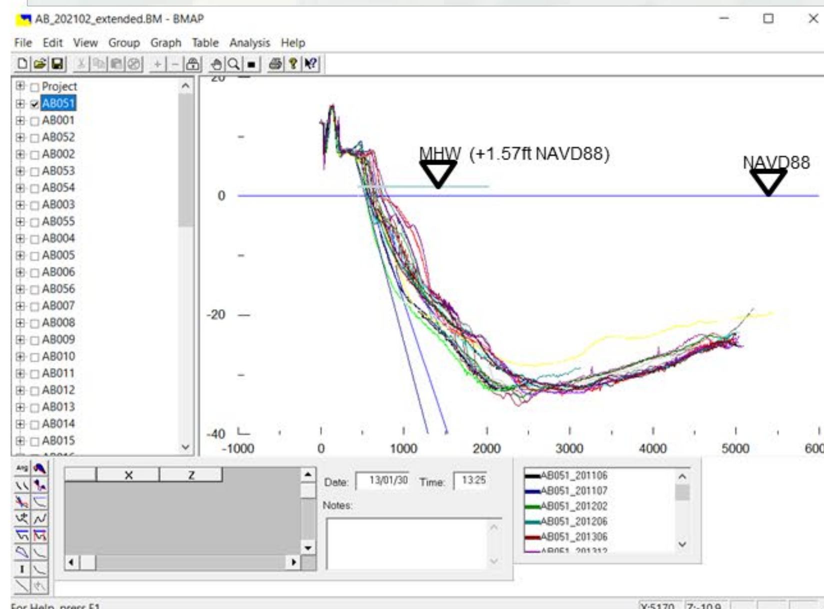
Fig. Headland for Erosion Protection

Fig. Sand Bypass in Indian River Inlet, DE

Shoreline Positions

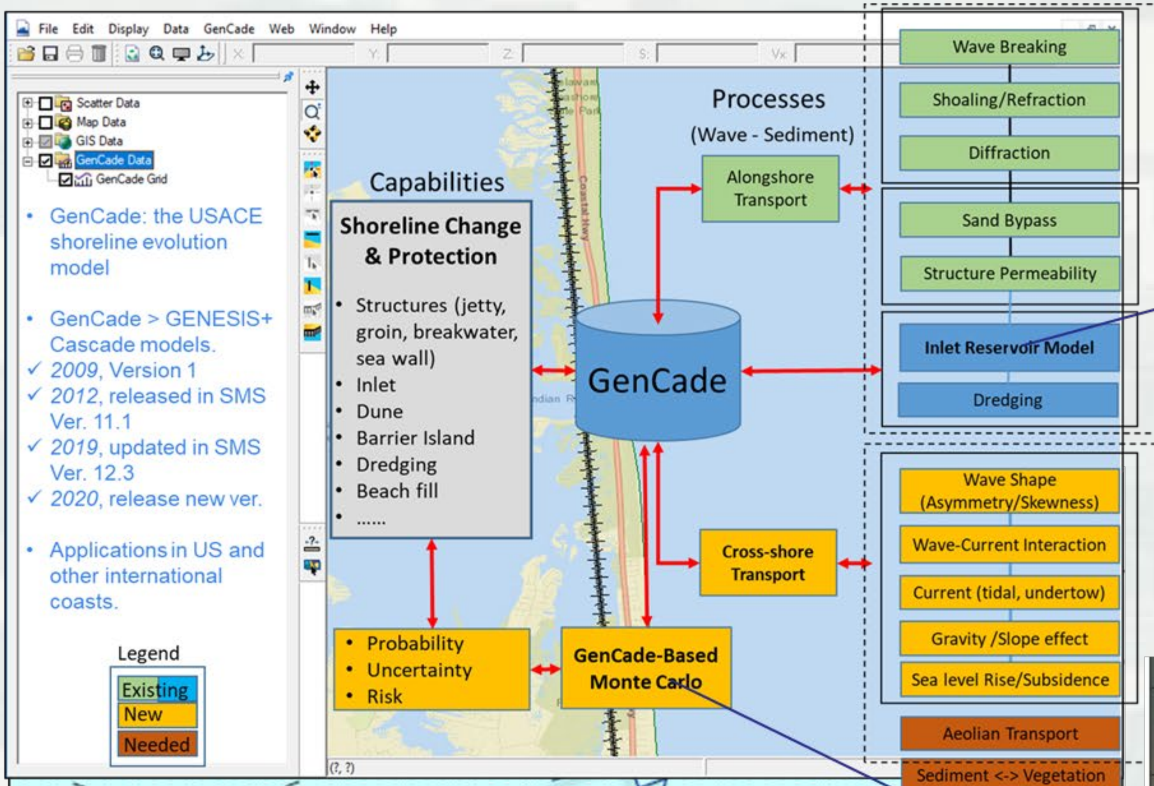
Extract shoreline positions at a vertical datum (e.g. MHW) from transect survey data

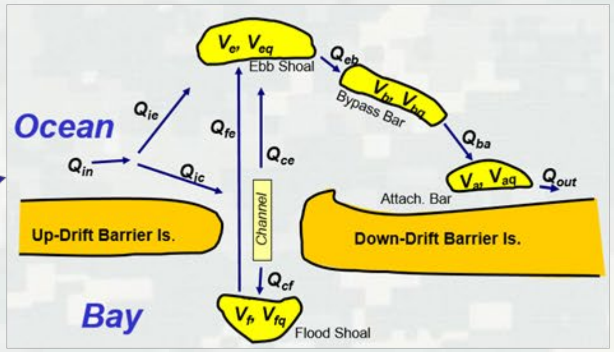
(a) Shore-normal transects on satellite imagery



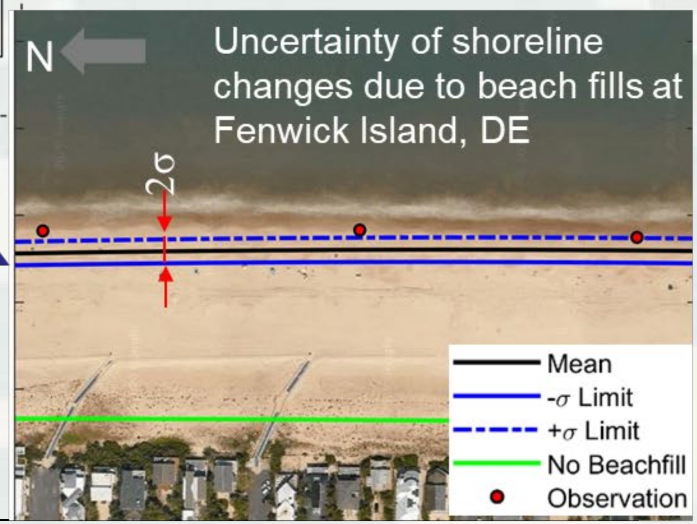
(b) Profiles on BMAP

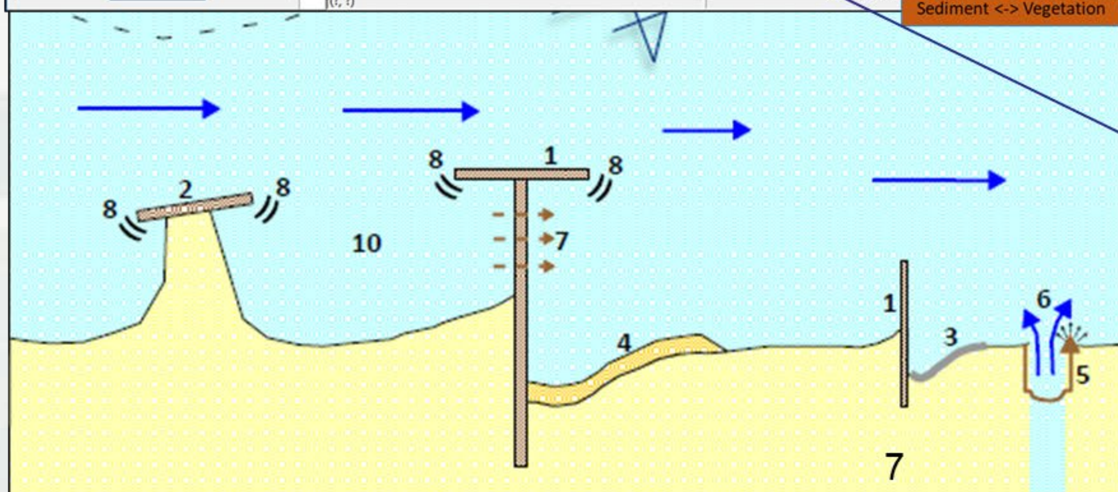
GenCade - USACE Shoreline Evolution Simulation Model





Inlet Reservoir Model





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New Version of GenCade for Shoreline Evolution Modeling

- Shoreline Change Equation with Sea Level Rise (SLR)

$$\frac{\partial y}{\partial t} + \frac{1}{D_s}\left(\frac{\partial Q}{\partial x} - q - \phi\right) + \frac{R+S}{\tan\beta} = 0$$

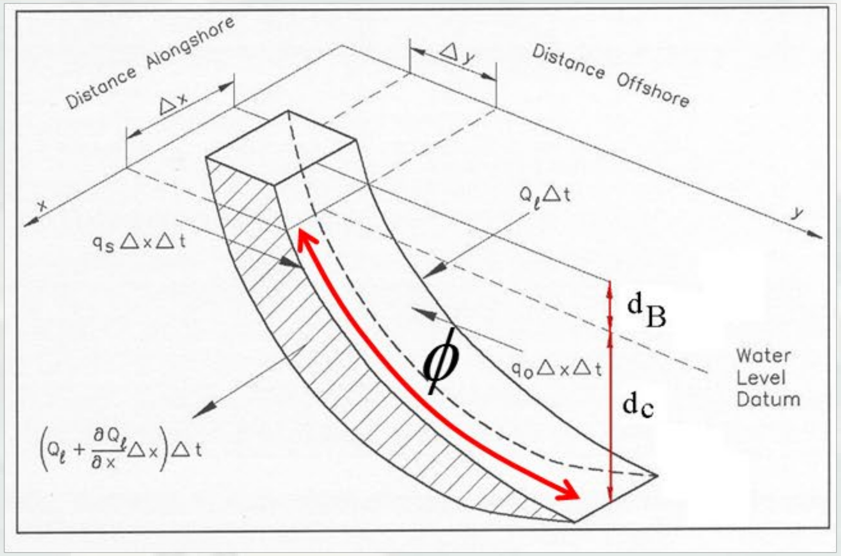
ϕ : Cross-shore sediment transport rate

R : Sea Level Change Rate

S : Subsidence Rate

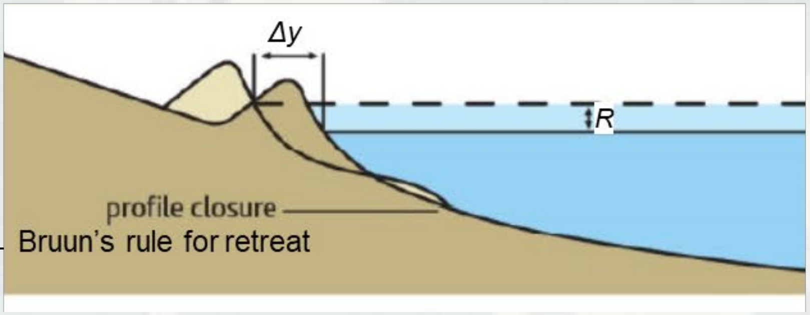
$tan\beta$: beach slope

$D_S = d_c + d_b(t)$: Total closure depth



- Berm height varies with sea level change

$$d_b(t) = d_{b0} - (R+S)t$$



Longshore Sediment Transport

- *Energy Flux Method (CERC formula)*

$$Q = H_b^2 C_{gb} \left(a_1 \sin 2\alpha_{bs} - a_2 \cos \alpha_{bs} \frac{\partial H_b}{\partial x} \right)$$

H_b : *Wave Height at breaker line*

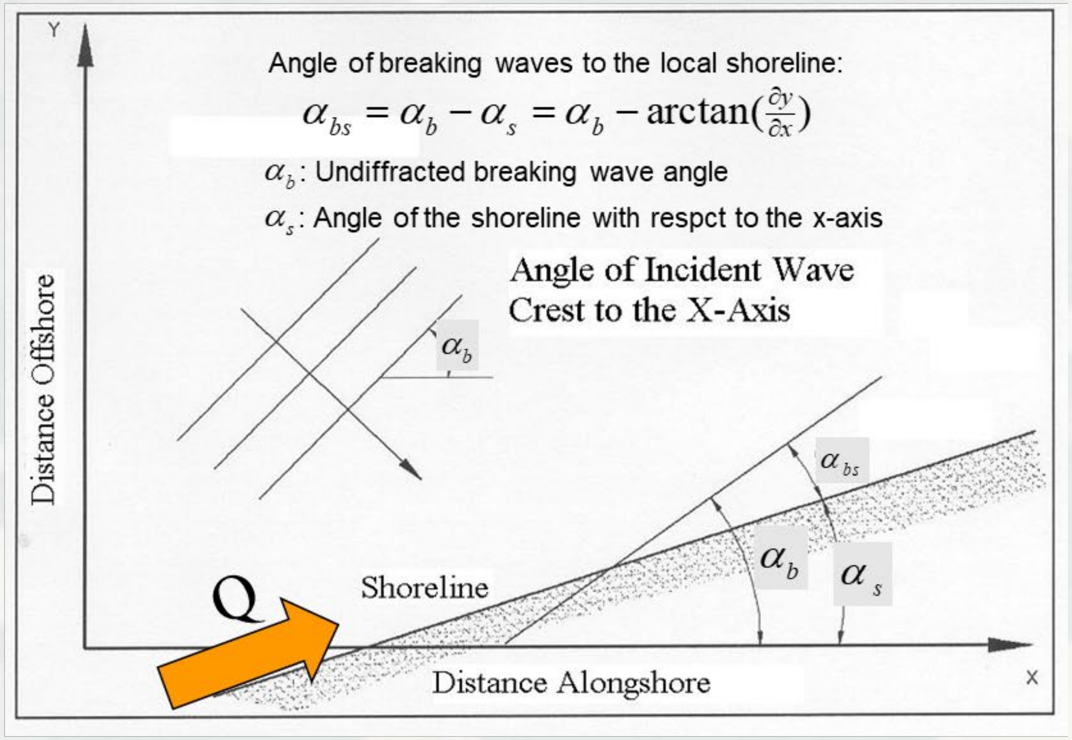
C_{gb} : *Group speed at breaker line*

$$a_1 = \frac{K_1}{16(s-1)(1-p)1.416^{2.5}}$$

$$a_2 = \frac{K_2}{8(s-1)(1-p)\tan\beta 1.416^{2.5}}$$

K_1, K_2 = *empirical coefficients*

Typically, $0.5K_1 < K_2 < 1.5K_1$



Special Topics for Using GenCade

Wave Diffraction around Structures

Wave Height (H_b) at P (at the lee side of a diffracting structure):

$$H_b = K_D(\theta_D, d_b) K_R(\theta_G, d_b) K_S(d_b) H_{tp}$$

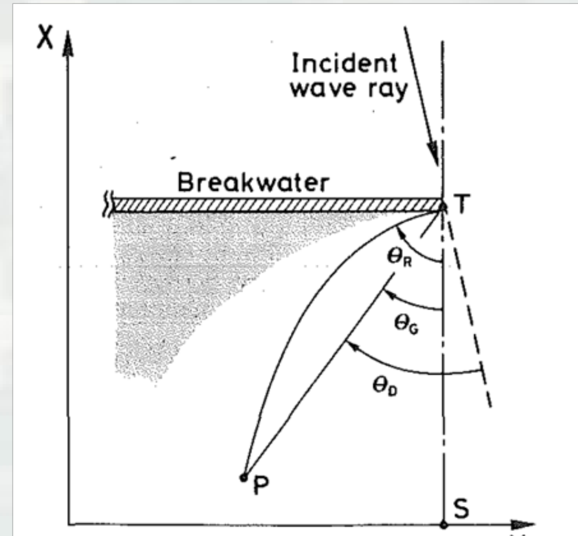
K_D = Diffraction coefficient at P

K_R = Refraction coefficient at P

K_S = Shoaling coefficient at P

d_b = water depth at P

H_{tp} = incident wave height at T



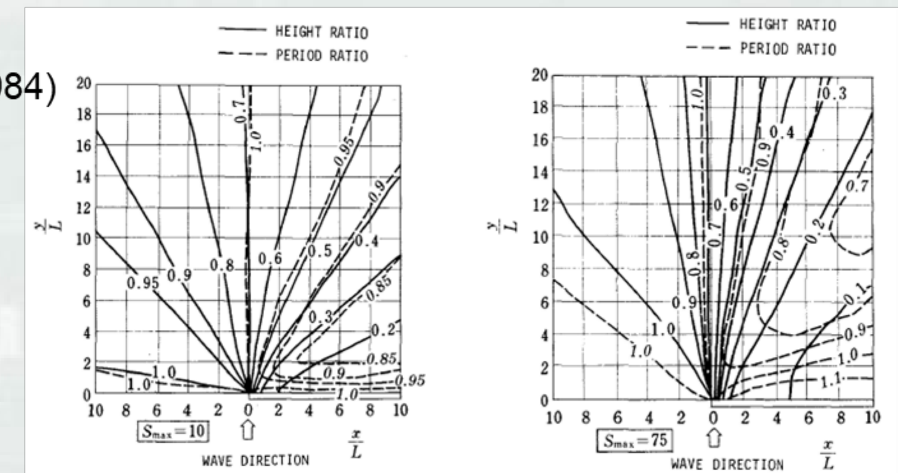
Kraus (1984)

Kraus' Approximation of the 2-D diffraction solution (Kraus 1984)

$$K_D(\theta_D, d_b) = \sqrt{0.5\left[1 + \tanh\left(\frac{S_{max}\theta_D}{W}\right)\right]}$$

$$W = 5.31 + 0.270 S_{max} - 0.000103 S_{max}^2$$

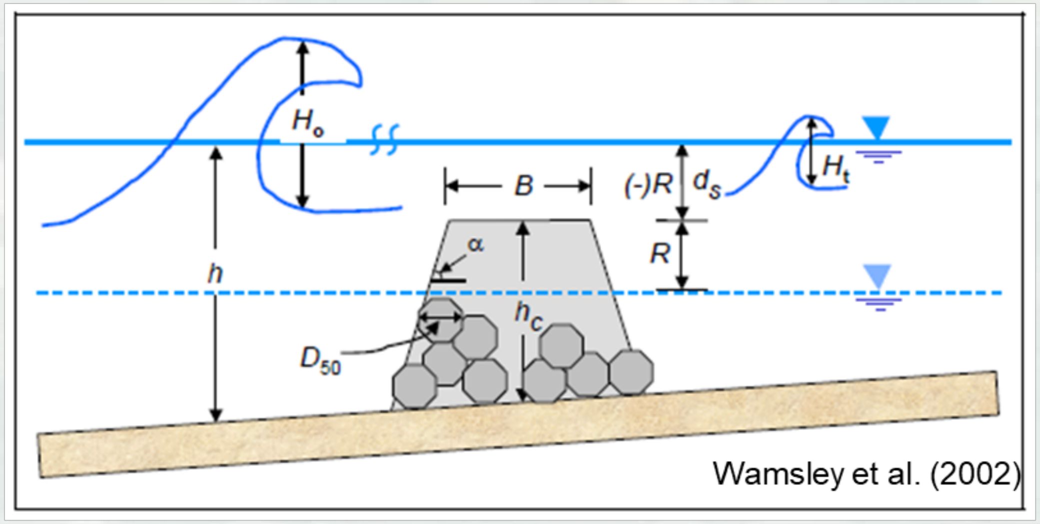
S_{max} = Maximum directional concentration parameter (10~75)

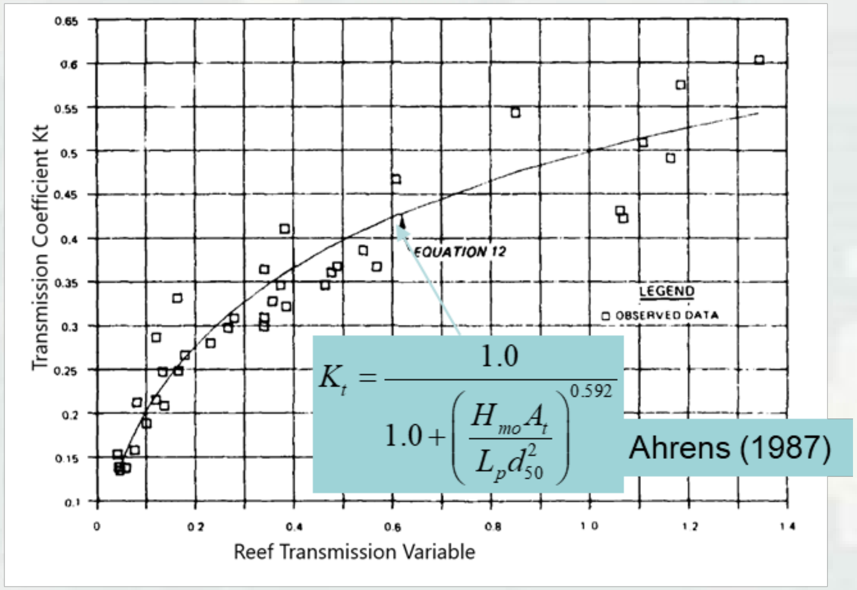


Goda et al. (1978)

Fig. 6 Diffraction Diagrams of a Semi-Infinite Breakwater for Directional Random Waves of Normal Incidence

Wave Transmission through Breakwater





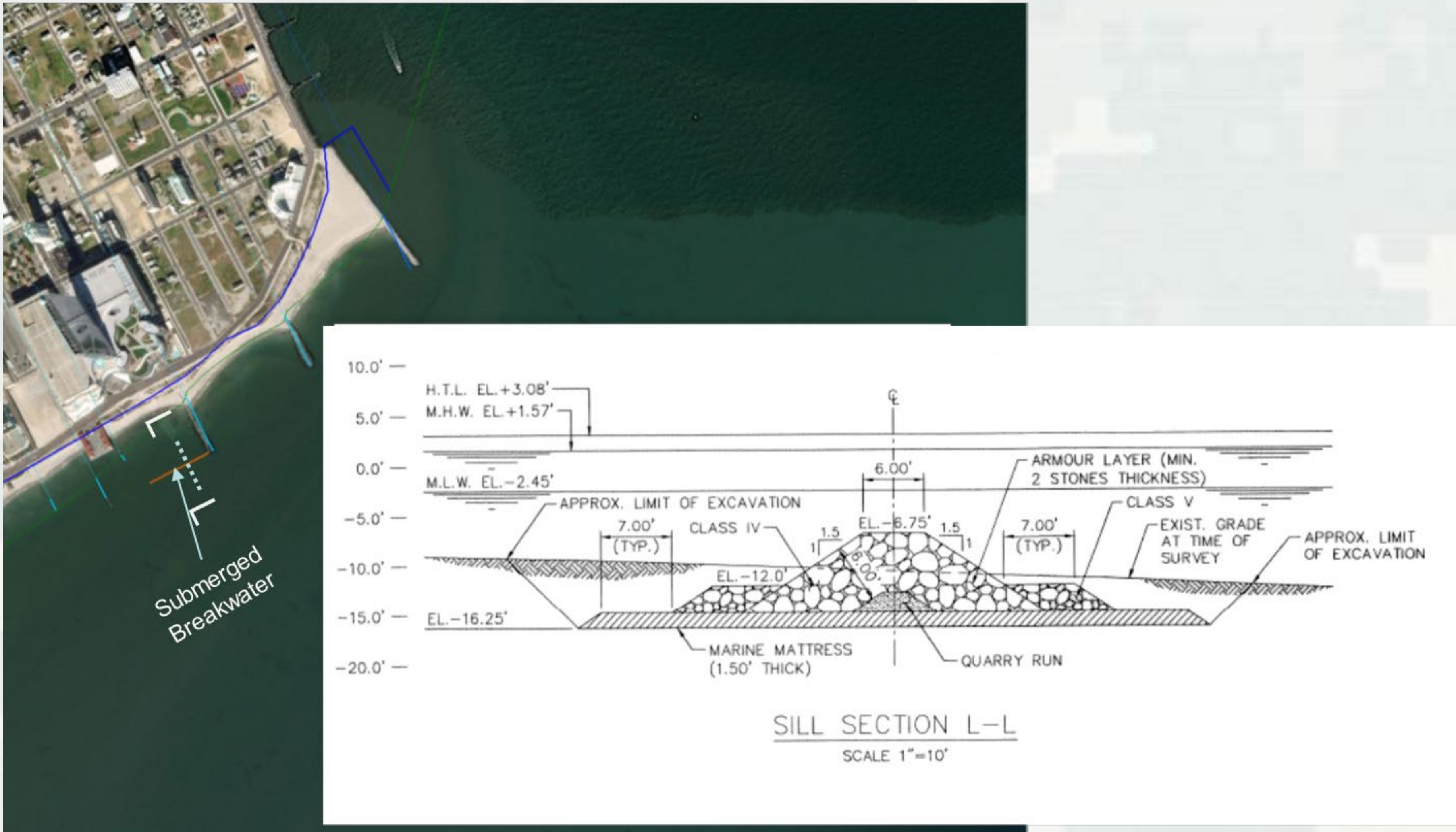
Wave transmission coefficient $K_t = H_t / H_o$

K_t can be determined by means of the experimental studies on the features of structures;

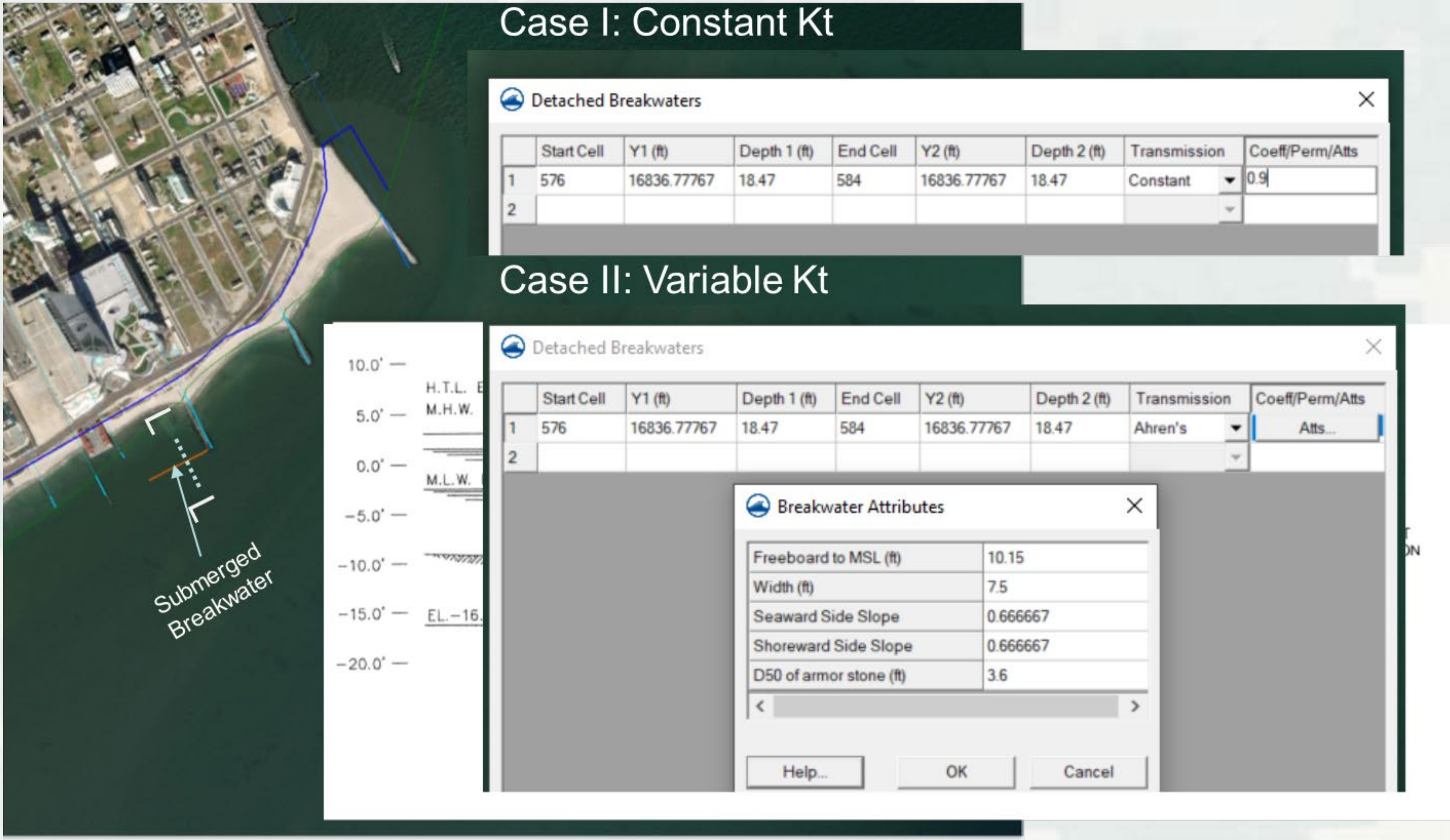
GenCade includes constant transmission and three equations for time-dependent wave transmission (Wamsley et al. 2002, CHETN-II-45) :

- Ahrens (2001): for submerged and emergent (high) breakwaters
- Seabrook and Hall (1998): Only for submerged breakwater
- d'Angremond et al (1996) : For deeply submerged and relatively high structures, the d'Angremond formulation is not recommended ($0.75 < R/H_0 < 0.5$)

Wave Transmission in GenCade

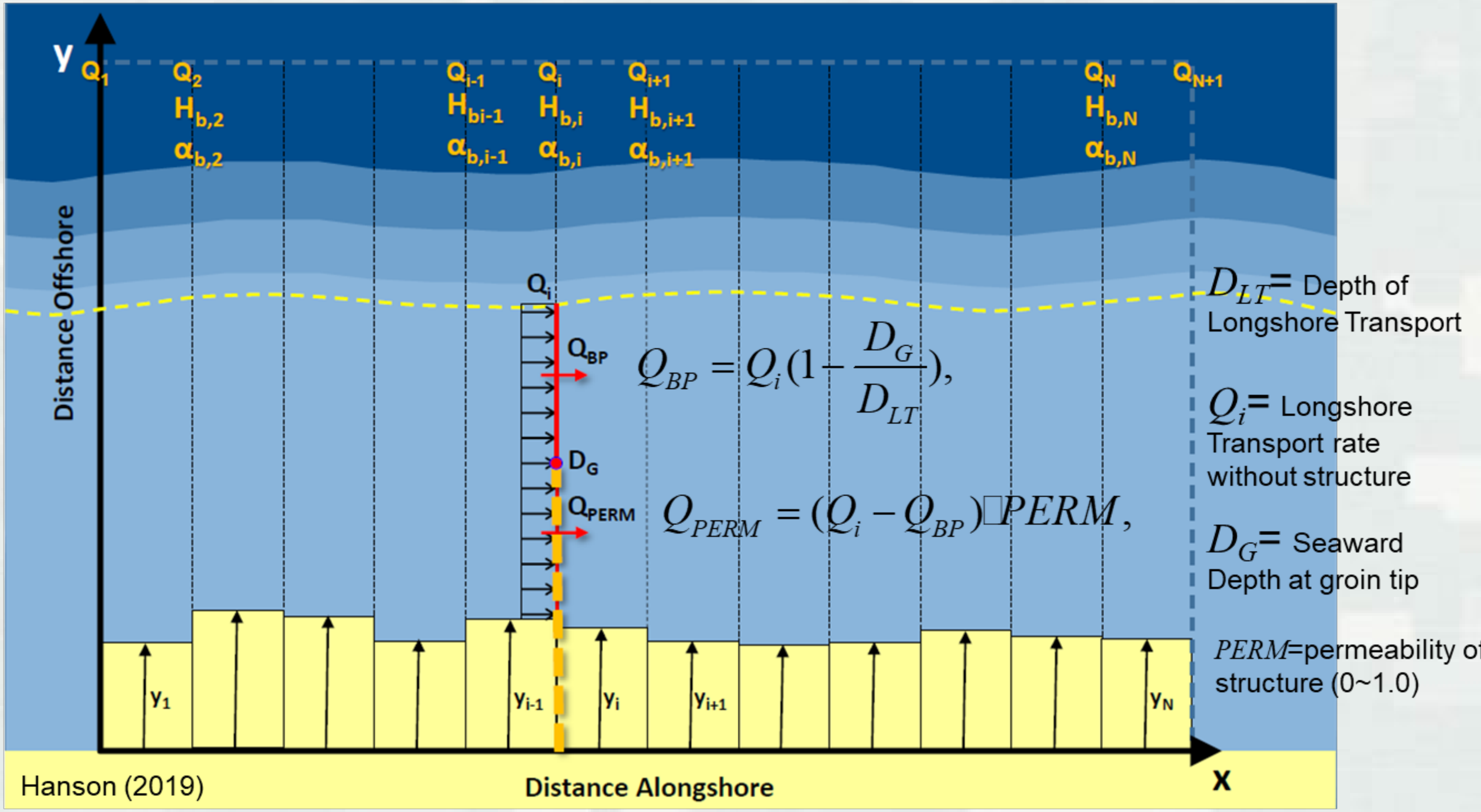


Wave Transmission in GenCade



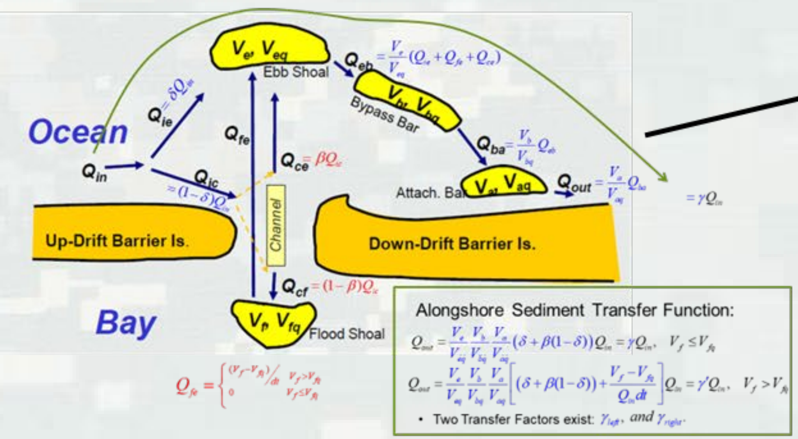
Sediment Bypassing through Groin

Transport through permeable groins/jetties



Flux at downdrift side: $Q_i^* = Q_{BP} + Q_{PERM} = Q_{BP} + (Q_i - Q_{BP}) \cdot PERM$

Inlet Reservoir Model and Inlet Morphologic Features

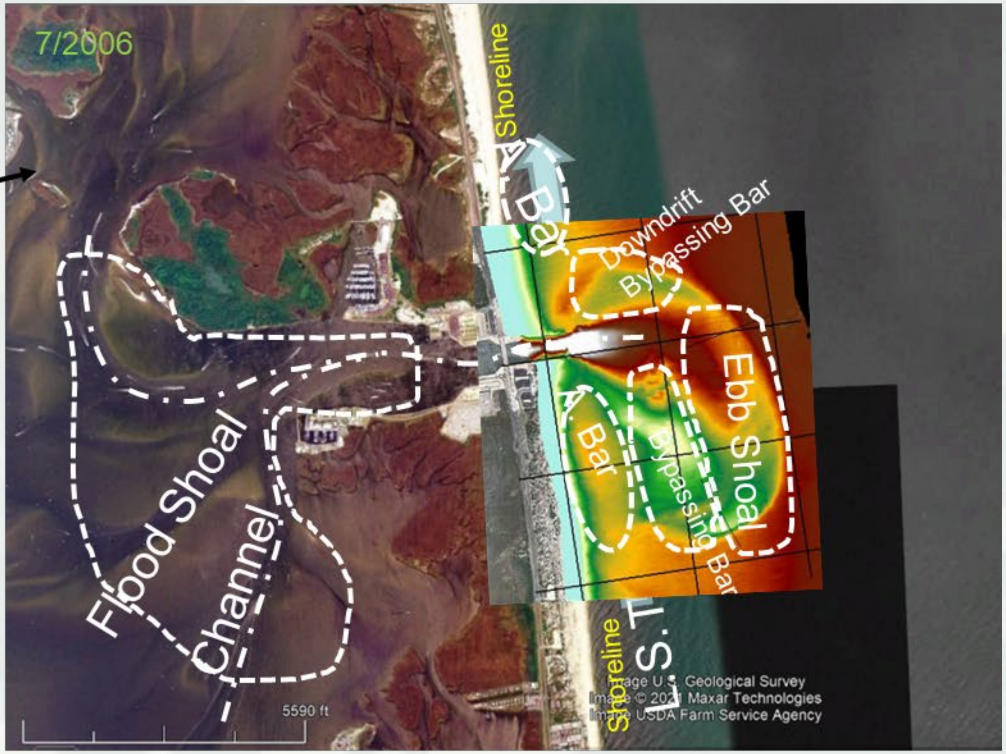


Inlet Reservoir Model (IRM)
for Simulation of Inlet Morphology Evolution

Parameters required: V_{x0} =initial volumes

V_{xq} =equilibrium volumes

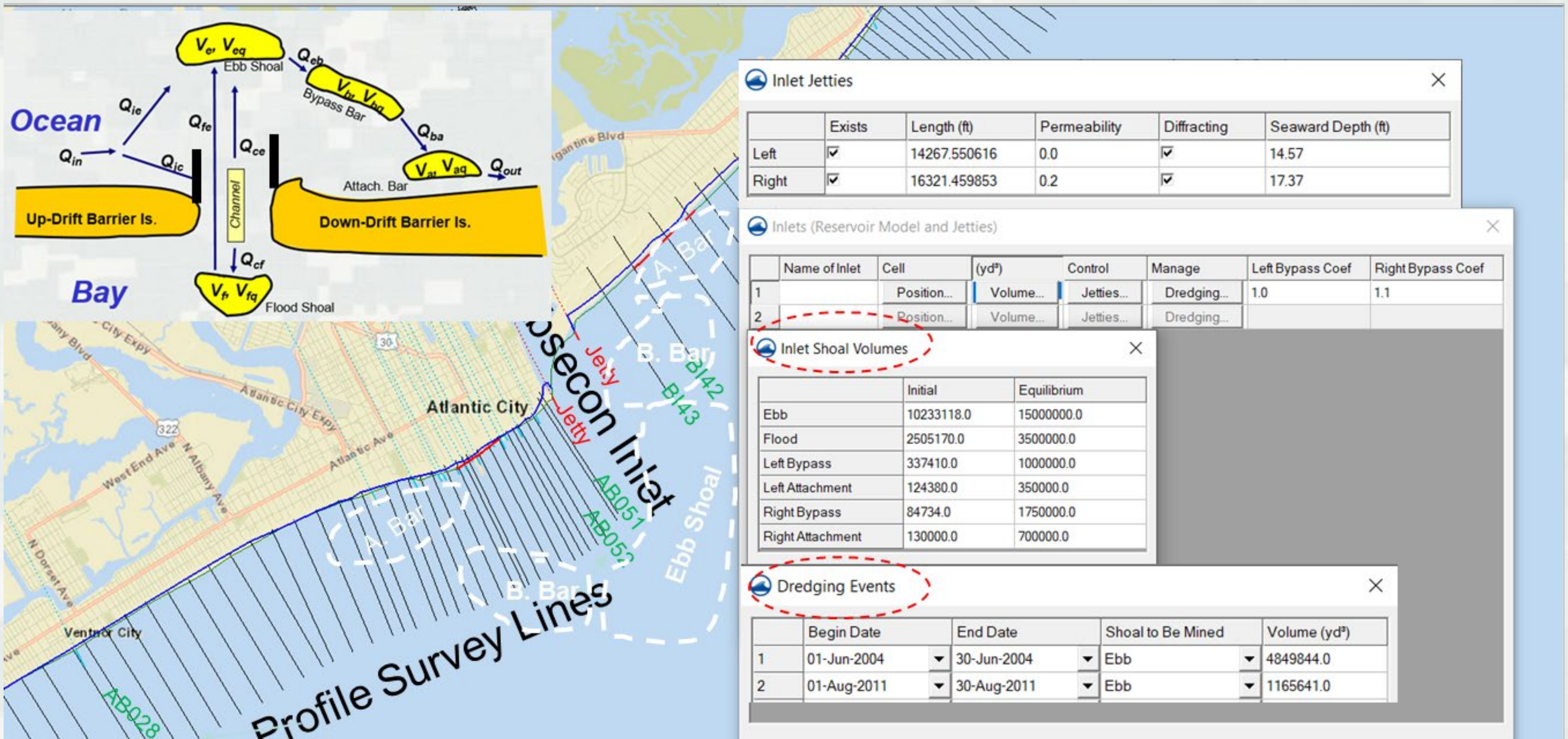
Q_{in} =Long-shore Sediment Transport (LST)



Indian River Inlet, DE

Dredging/Mining: ΔV from shoal or bar

Inlet Reservoir Model (IRM) and Dredging: Example



Inlet Jetties

	Exists	Length (ft)	Permeability	Diffracting	Seaward Depth (ft)
Left	☑	14267.550616	0.0	☑	14.57
Right	☑	16321.459853	0.2	☑	17.37

Inlets (Reservoir Model and Jetties)

	Name of Inlet	Cell	(yd³)	Control	Manage	Left Bypass Coef	Right Bypass Coef
1		Position...	Volume...	Jetties...	Dredging...	1.0	1.1
2		Position...	Volume...	Jetties...	Dredging...		

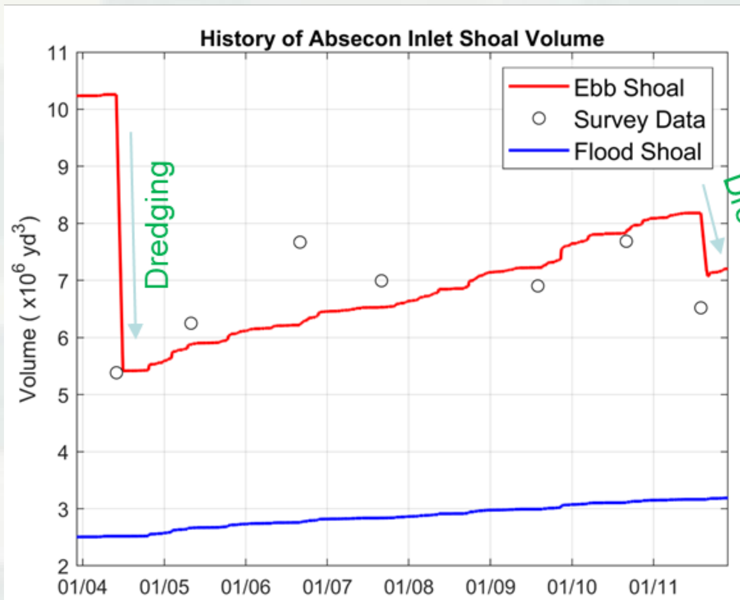
Inlet Shoal Volumes

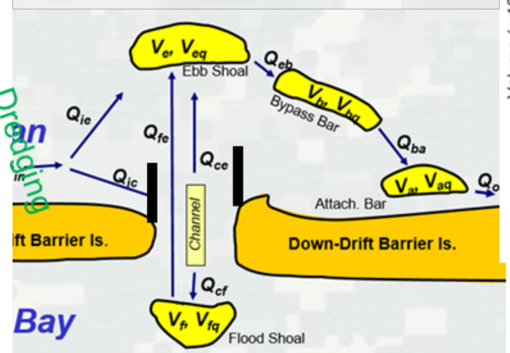
	Initial	Equilibrium
Ebb	10233118.0	15000000.0
Flood	2505170.0	3500000.0
Left Bypass	337410.0	1000000.0
Left Attachment	124380.0	350000.0
Right Bypass	84734.0	1750000.0
Right Attachment	130000.0	700000.0

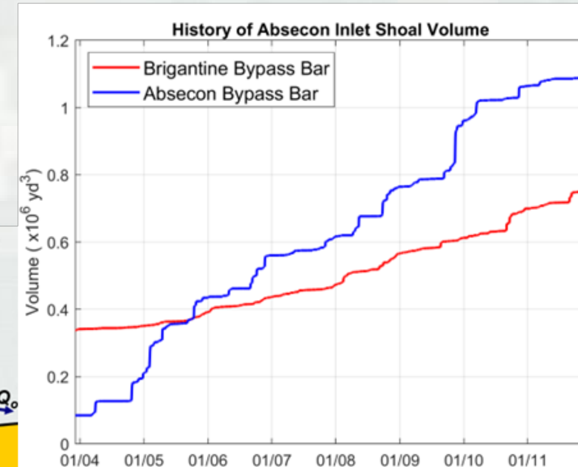
Dredging Events

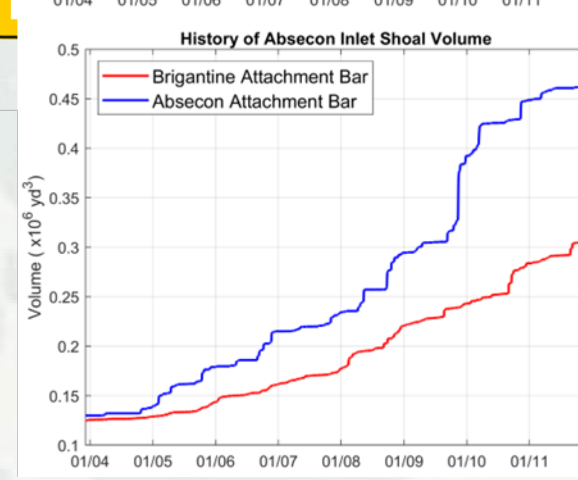
	Begin Date	End Date	Shoal to Be Mined	Volume (yd³)
1	01-Jun-2004	30-Jun-2004	Ebb	4849844.0
2	01-Aug-2011	30-Aug-2011	Ebb	1165641.0

Evolution of Inlet Shoals and Attachment Bars

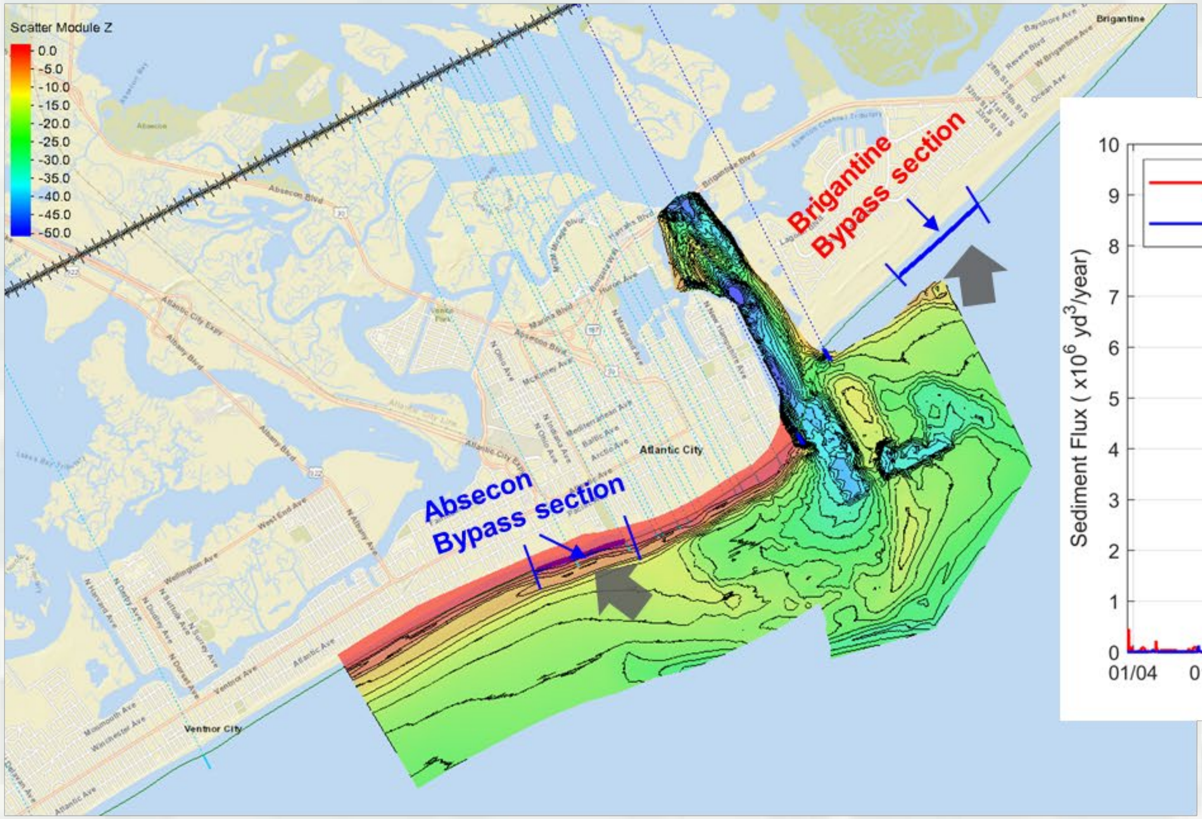


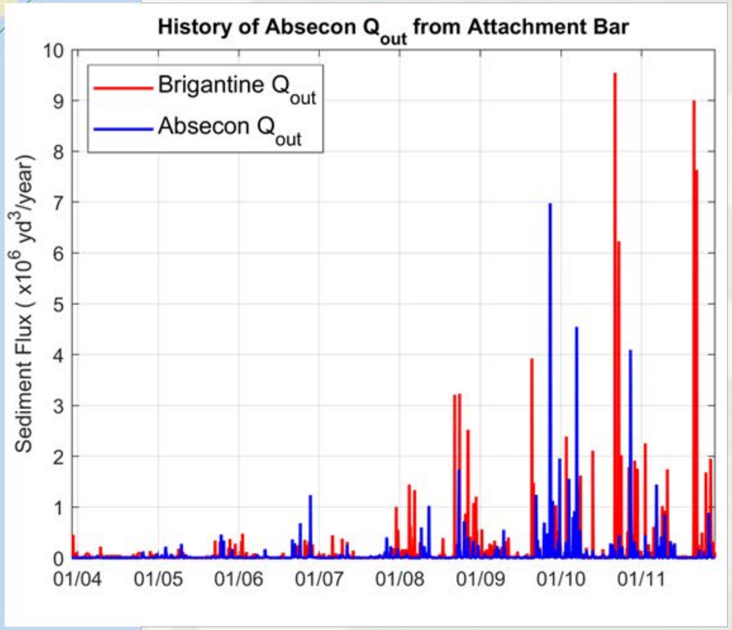






Inlet Bypass Estimated by IRM model (2003-2011)



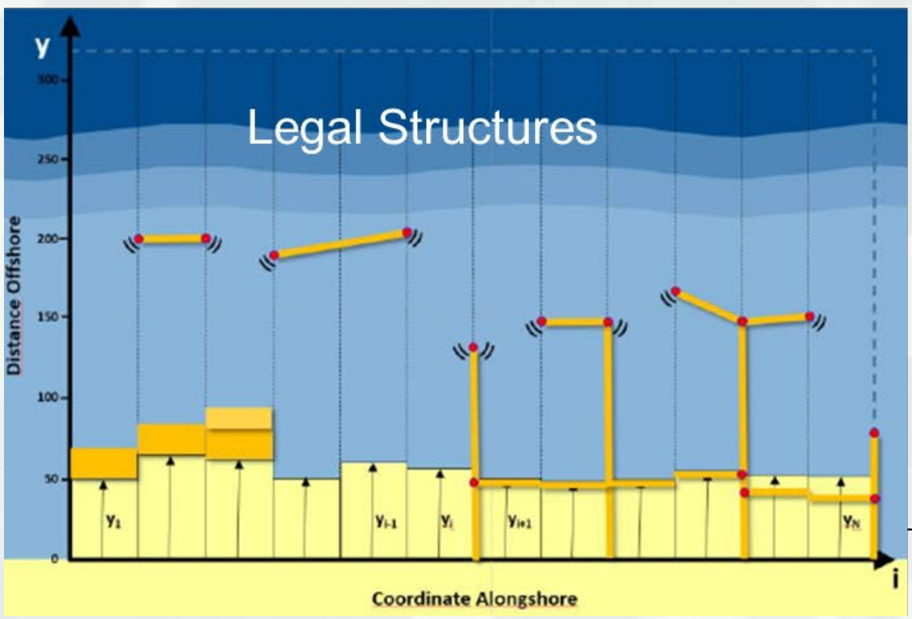


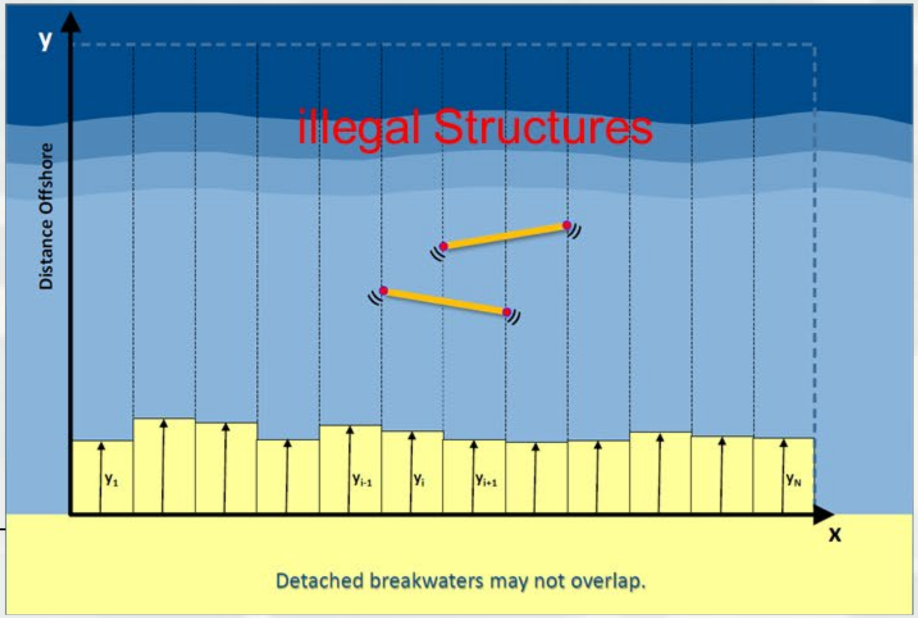
Data Requirements for Shoreline Modeling

- Shoreline Positions (beach profiles, topobathy, satellite imagery)
- Sediment properties (e.g., d50, slope)
- Wave data (height, period, direction)
- Tidal levels, SLR data
- History of engineering activities (structures, beachfills, mining/dredging, hydro survey data): locations, dates, dimensions, properties, etc
- Regional transport (longshore and cross-shore transport paths, sediment budget)
- Regional Geology (sediment source/sink, long-term trends in shoreline change, SLR, subsidence)
- Impact of extreme events (e.g., severe retreat by storms, structure failures, inlet close/opening, overtopping/overwash)
- Dune morphology changes
- Inlet data (hydro survey for mapping inlet morphology, dredging/mining, bypassing, etc.)

GenCade Limitations

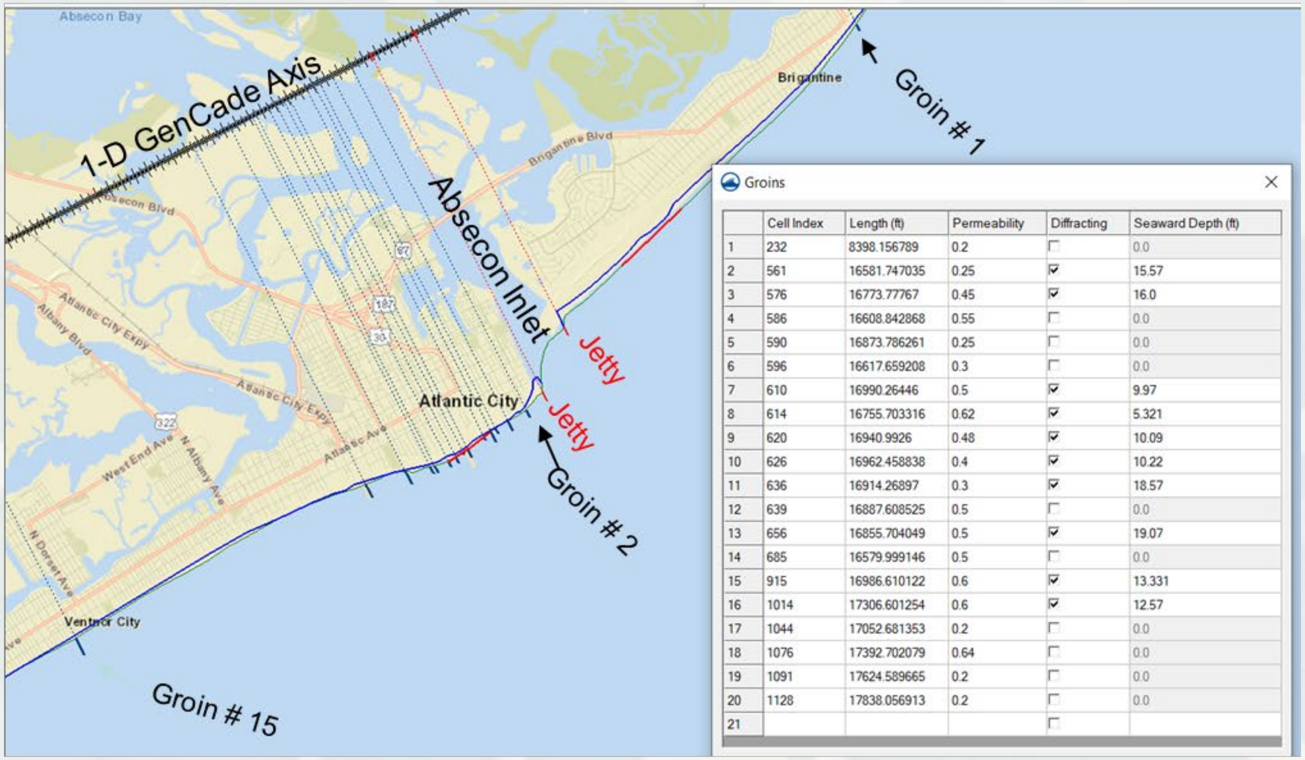
- No wave reflection
- Some restrictions on structure shape, orientation, and placement
- No structure properties changing with time
- No profile changes with time (not yet)
- No dune change (Aeolian transport)
- No diffracting structure behind detached breakwater
- Restrictions on buried structures (no structures hidden into beach/berm)





Parameters for Defining Structure's effect on LST

- **Diffracting Structures**: Groins, Piers
- Non-Diffracting Structures: Short groins, outfalls
- **Seaward depth** at the tip of groin is given from transect profile near the structure
- **Length:** the distance from the seaward tip to the GenCade 1-D Axis.
- Permeability (sand transmission capability through the structure): **calibrated**



	Cell Index	Length (ft)	Permeability	Diffracting	Seaward Depth (ft)
1	232	8398.156789	0.2	☐	0.0
2	561	16581.747035	0.25	☑	15.57
3	576	16773.77767	0.45	☑	16.0
4	586	16608.842868	0.55	☐	0.0
5	590	16873.786261	0.25	☐	0.0
6	596	16617.659208	0.3	☐	0.0
7	610	16990.26446	0.5	☑	9.97
8	614	16755.703316	0.62	☑	5.321
9	620	16940.9926	0.48	☑	10.09
10	626	16962.458838	0.4	☑	10.22
11	636	16914.26897	0.3	☑	18.57
12	639	16887.608525	0.5	☐	0.0
13	656	16855.704049	0.5	☑	19.07
14	685	16579.999146	0.5	☐	0.0
15	915	16986.610122	0.6	☑	13.331
16	1014	17306.601254	0.6	☑	12.57
17	1044	17052.681353	0.2	☐	0.0
18	1076	17392.702079	0.64	☐	0.0
19	1091	17624.589665	0.2	☐	0.0
20	1128	17838.056913	0.2	☐	0.0
21				☐	

Calibrated Parameter for Structures

Groins

	Cell Index	Length (ft)	Permeability	Diffracting	Seaward Depth (ft)
1	232	8398.156789	0.2	☐	0.0
2	561	16581.747035	0.25	☑	15.57
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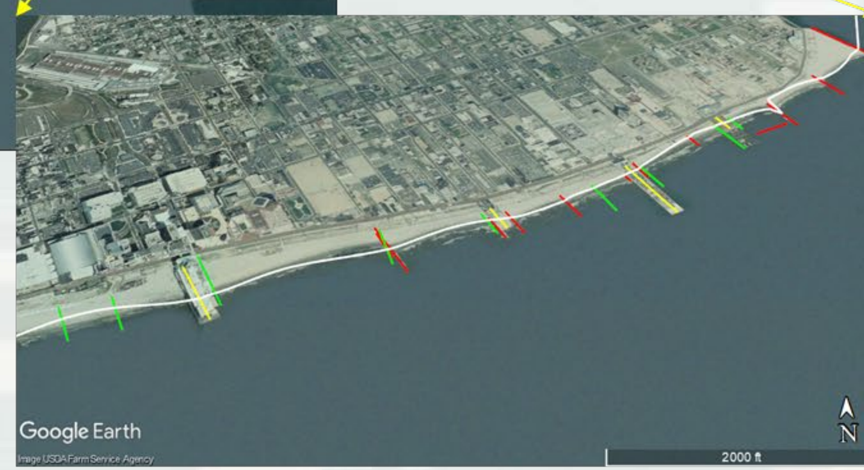
15	915	16986.610122	0.6	☑	13.331
16	1014	17306.601254	0.6	☑	12.57

Help... OK Cancel

Display Simulated Shoreline on Historical Imagery (May-28-2008)

Laying simulated shoreline on historical images can further compare changes of shoreline curvature along the coast at different times and confirm the impact of structures on sediment transport.



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- Thornton, E., Humiston, R., Birkemeier, W., (1996). Bar-trough generation on a natural beach. J. Geophys. Res 101, 12097–12110.

Recent Publications on GenCade

- Frey, A. E., Connell, K. J., Hanson, H., Larson, M., Thomas, R. C., Munger, S., Zundel, A., (2012) *GenCade version 1 Model theory and user's guide*. US Army, Engineer Research and Development Center, ERDC/CHL TR-12-25, 169 pp.
- Ding, Yan, Kim, Sung-Chan, and Frey, Ashley, (2018). Probabilistic Shoreline Evolution Modeling in Response to Sea Level Changes, In Proceedings of the ASCE-EWRI 2018 Congress, June 3-7, 2018, Minneapolis, NM, 13p. (https://doi.org/10.1061/9780784481424.021)
- Ding, Y., Kim, S.-C., Frey, A.E., Permenter, R. L., and Styles, R. (2018). Probabilistic modeling of long-term shoreline changes in response to sea level rise and waves, In: Scour and Erosion IX: Proceedings of the 9th International Conference on Scour and Erosion, K.-C. Yeh Ed., pp203-211, Taylor & Francis Group, London, ISBN 978-0-367-07467-8
- Ding, Y., Kim, S.-C., Permenter, R.L., Styles, R., and Beck, T.M. (2019). Cross-shore sediment transport for modeling long-term shoreline changes in response to waves and sea level changes, In: Proceedings of Coastal Sediment 2019.
- Ding, Y., Styles, R., Kim, S.-C., Permenter, R.L., and Frey A.E. (2021a). Cross-shore sediment transport for modeling long-term shoreline evolution, J. Waterway, Port, Coastal, Ocean Eng., 2021, 147(4): 04021014, 25pp., DOI: 10.1061/(ASCE)WW.1943-5460.0000644
- Ding, Y., S. C. Kim, R. Permenter, R. Styles, and Gebert, J. A. (2021b). Simulations of Shoreline Changes along the Delaware Coast, ERDC/CHL TR-21-1, Vicksburg, MS: US Army Engineer Research and Development Center, http://dx.doi.org/10.21079/11681/39559, January 2021

Thank you for your attention!

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