Forecasting Wave Runup & Overtopping

Tony Mignone
National Weather Service
Caribou Maine
anthony.mignone@noaa.gov

Service Assessment

Hurricane/Post-Tropical Cyclone Sandy
October 22-29, 2012

Finding 16:

- **NWS lacks sufficient forecast guidance on inundation associated with wave runup and coastal rivers making it difficult to forecast impacts from coastal storms.**

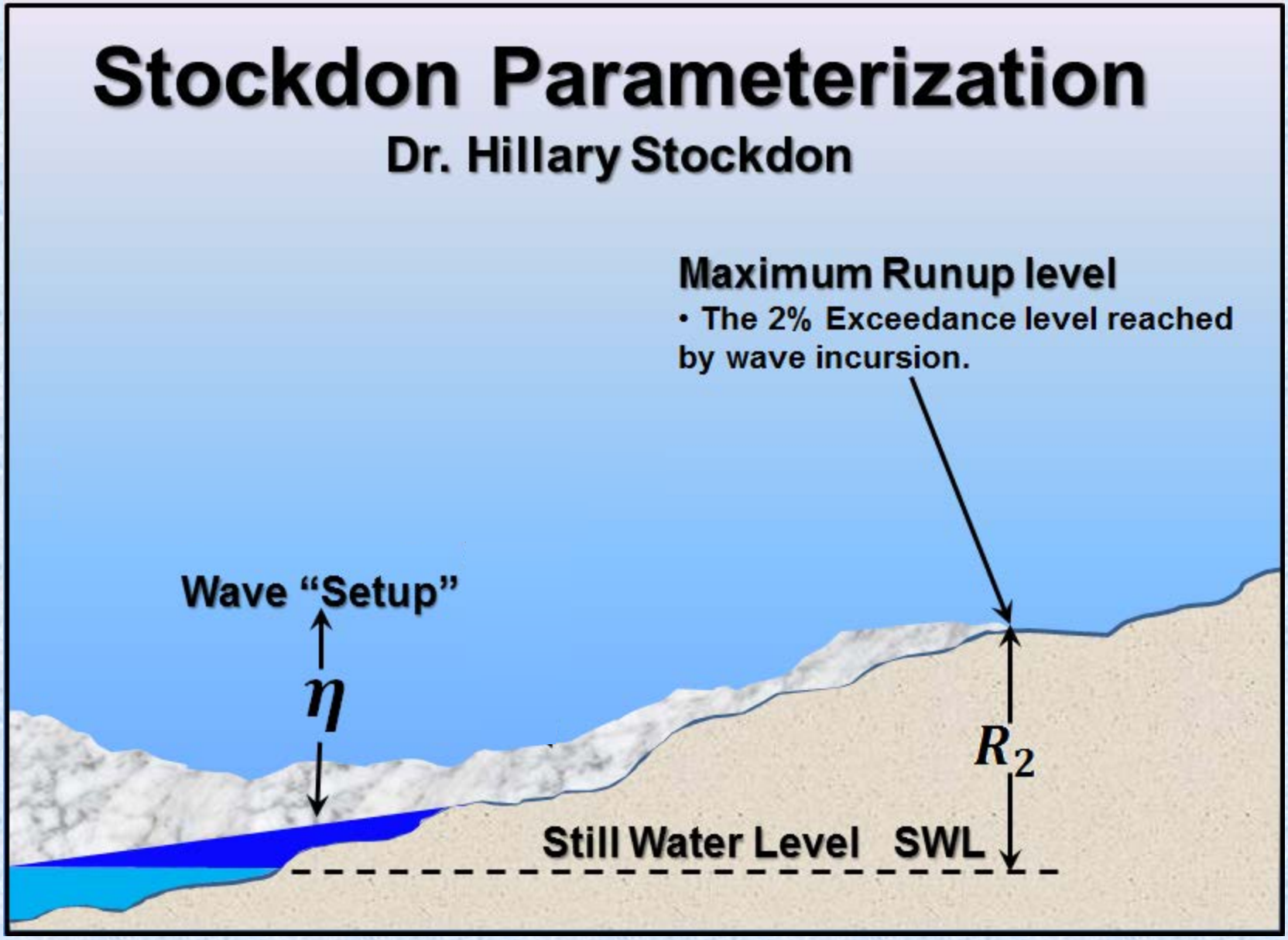
Introduce Tools to forecast Wave runup and overtopping

- Runup on Sandy Beaches
- Dune Erosion
- Overtopping of Seawalls
- Overtopping of Stone Armored Revetments

Runup on a Sandy Beach

Stockdon Parameterization

Dr. Hillary Stockdon



Parameterization for Runup Elevation

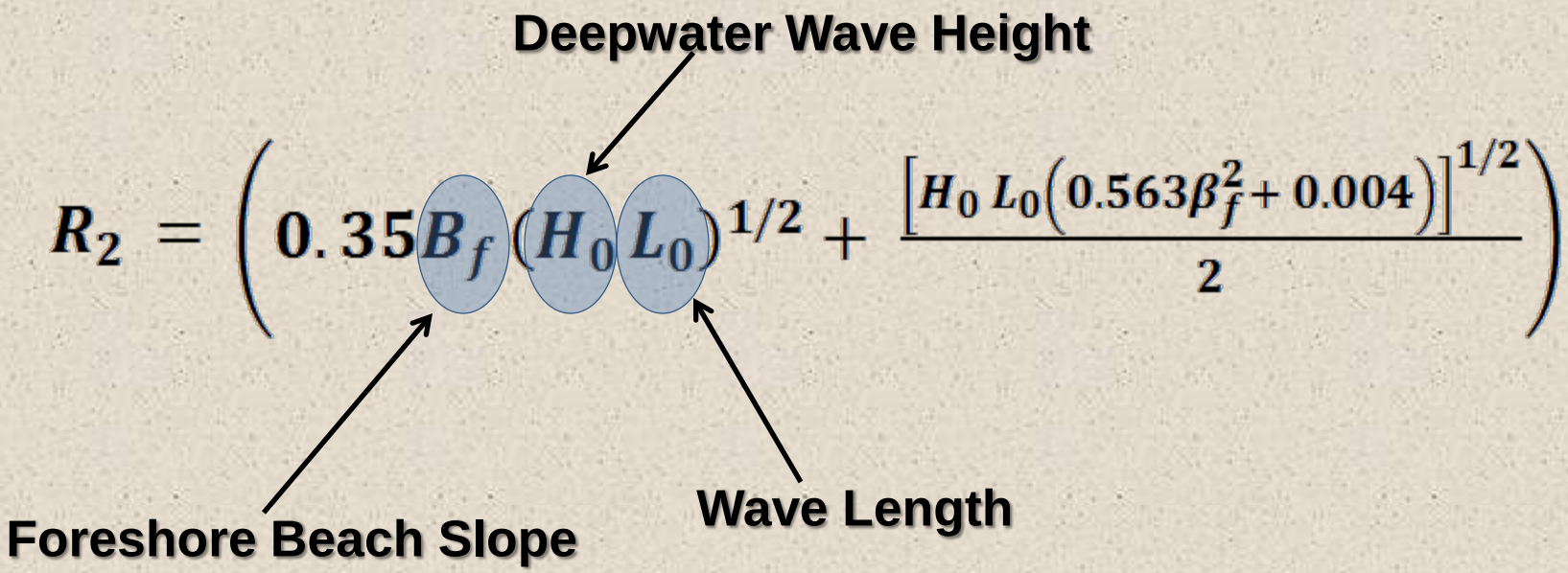
Dr. Hilary Stockdon

$$R_2 = \left(0.35 B_f \left(H_0 L_0 \right)^{1/2} + \frac{\left[H_0 L_0 \left(0.563 \beta_f^2 + 0.004 \right) \right]^{1/2}}{2} \right)$$

Ground truthed extensively

- **Tested in Hurricanes Bonnie, Floyd, Ike, and Ivan**
- **Real time forecasts done every season since Hurricane Ivan**

Input Parameters



Computing Wave Setup

$$R_2 = \left(0.35 B_f (H_0 L_0)^{1/2} + \frac{\left[H_0 L_0 \left(0.563 \beta_f^2 + 0.004 \right) \right]^{1/2}}{2} \right)$$

Wave Setup η

- **Super Elevated water level due to wave action**
- **Time averaged**

Wave Setup + Wave Runup

$$R_2 = \left(0.35 B_f (H_0 L_0)^{1/2} + \frac{\left[H_0 L_0 \left(0.563 \beta_f^2 + 0.004 \right) \right]^{1/2}}{2} \right)$$

Wave Setup

Swash

- **Time varying water level**
- **Large waves making incursions up the beach**

Infra-Gravity Waves

$$R_2 = \left(0.35 B_f (H_0 L_0)^{1/2} + \frac{\left[H_0 L_0 \left(0.563 \beta_f^2 + 0.004 \right) \right]^{1/2}}{2} \right)$$

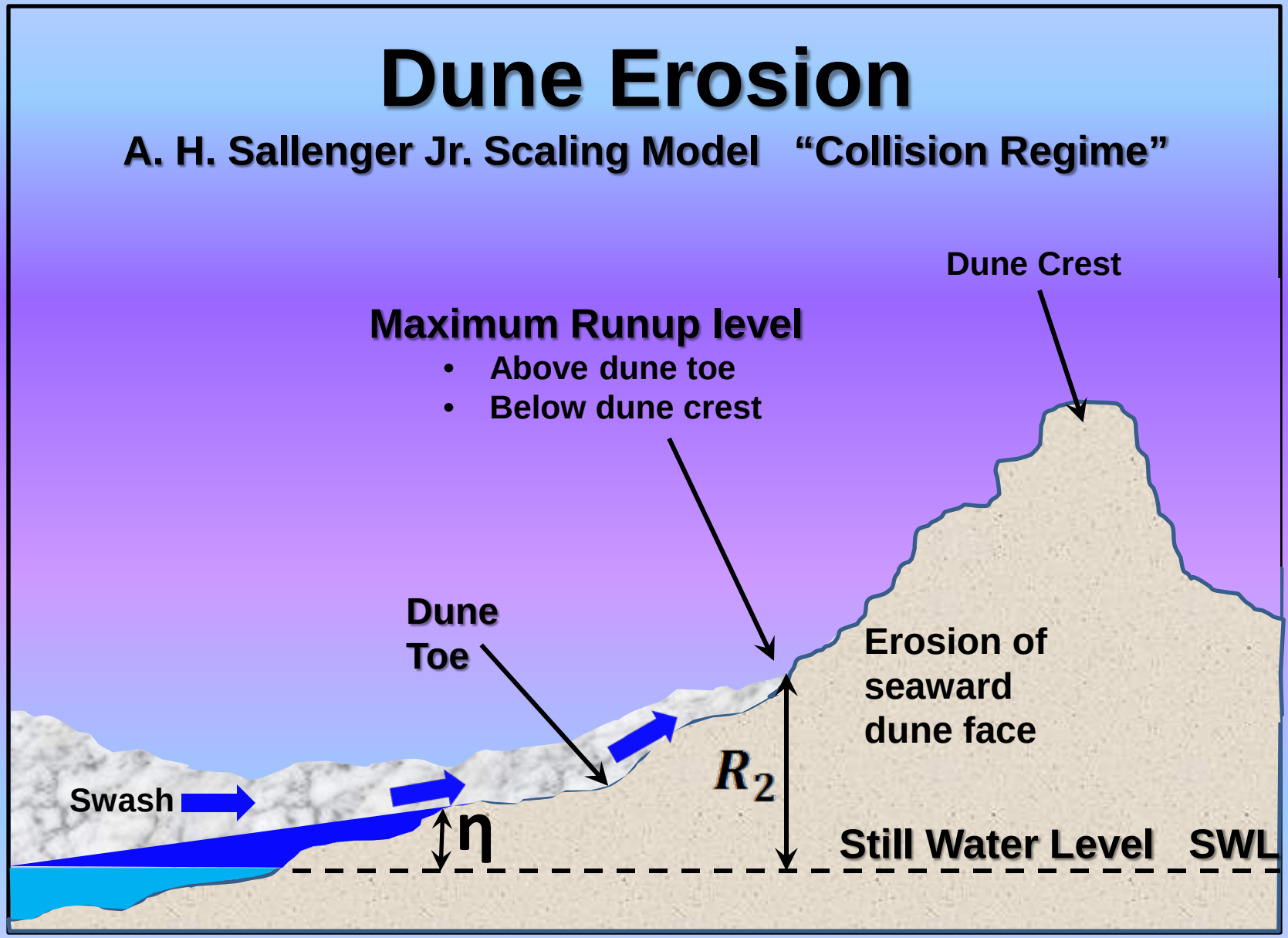
Infra-Gravity Waves

- **Long period waves of 3 to 30 minutes**
- **Generated in areas of differential Radiation stress in swell groups in transit from the fetch area to the coast.**

Dune Erosion

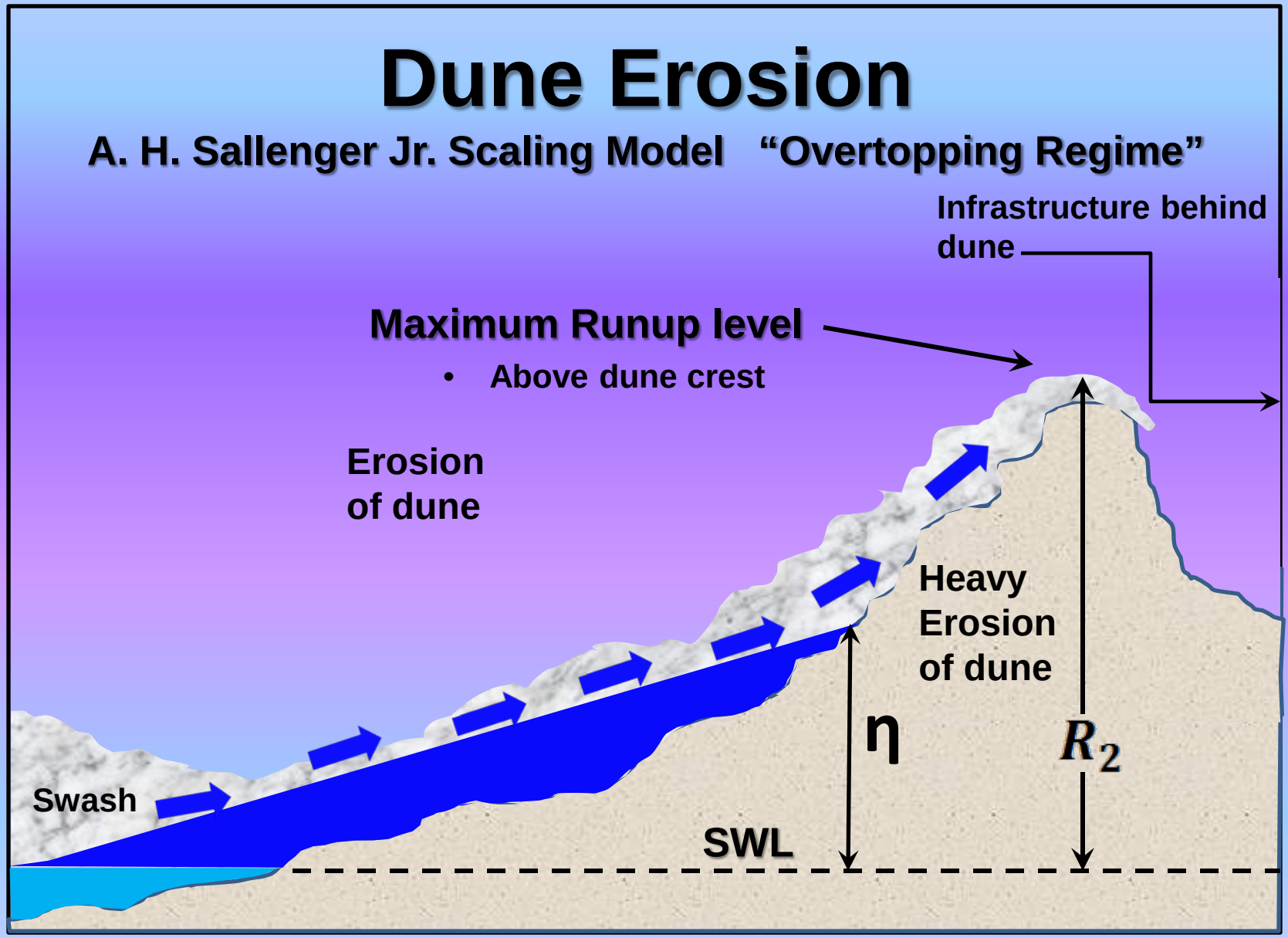
Dune Erosion

A. H. Sallenger Jr. Scaling Model "Collision Regime"



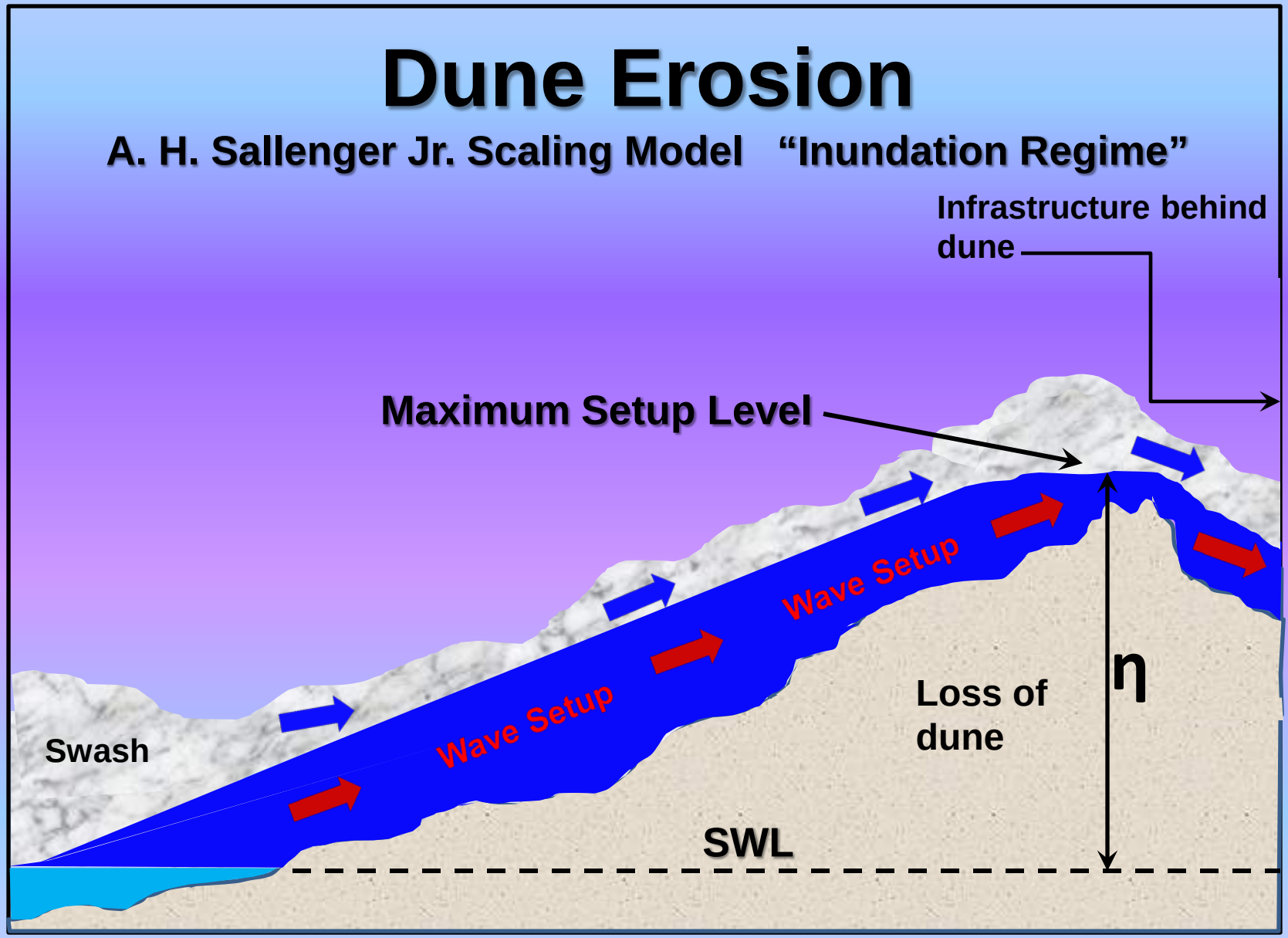
Dune Erosion

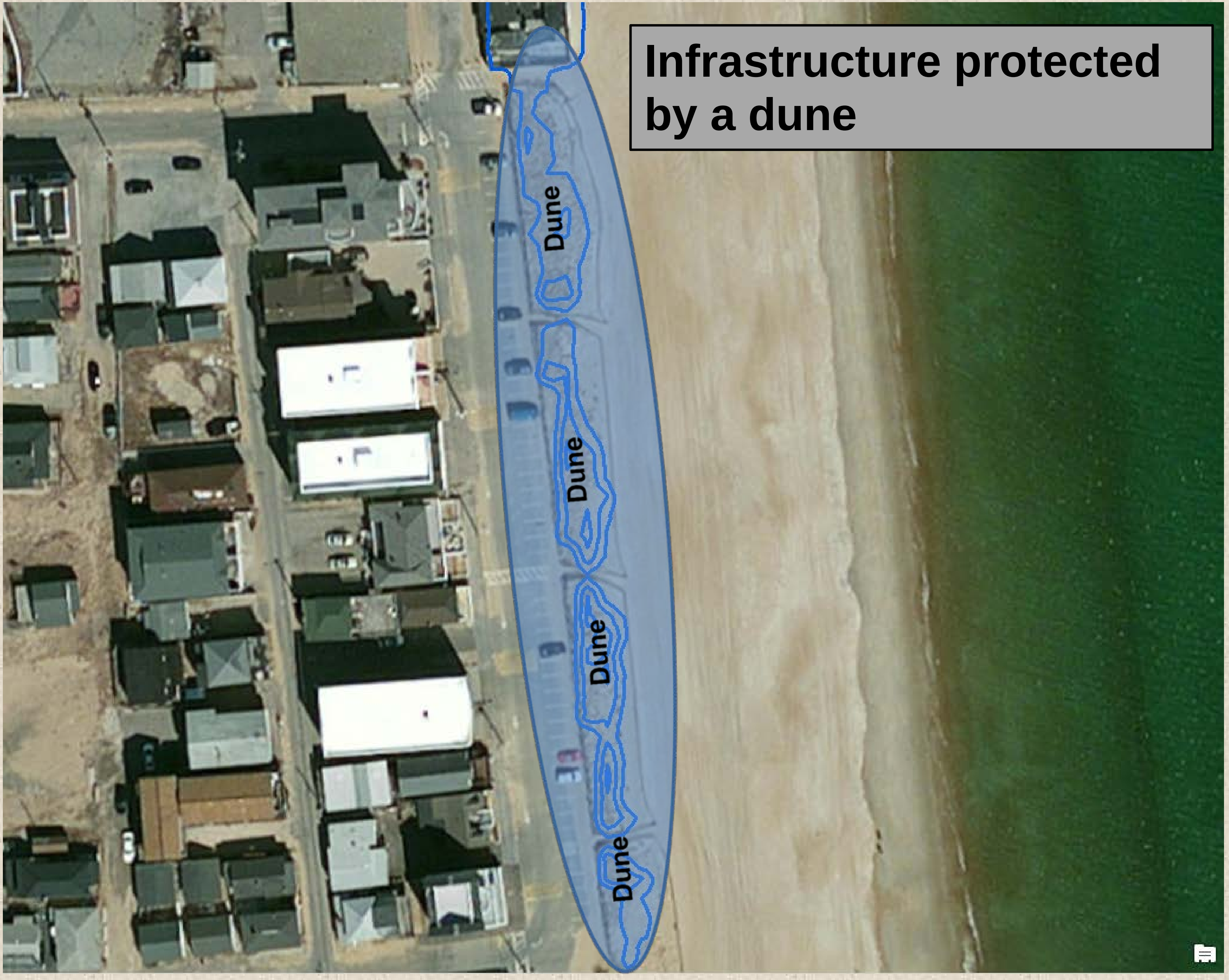
A. H. Sallenger Jr. Scaling Model "Overtopping Regime"



Dune Erosion

A. H. Sallenger Jr. Scaling Model "Inundation Regime"




Infrastructure protected by a dune
Dune
Dune
Dune
Dune

Runup Matrices

Using the Stockdon Parameterization

Roque Bluffs Test Site

Matrices for April 7-8, 2016 Storm

```
$$
MEZ030-080915-
ROQUE BLUFFS - WASHINGTON COUNTY
44.56N 67.46W ELEV. TOE 11.36 FT CREST 15.36 FT
354 PM EDT THU APR 7 2016

DATE        04/07/16                                                FRI 04/08/16
EDT HRLY 17 18 19 20 21 22 23 00 01 02 03 04 05 06 07 08 09 10 11 12 13 14 15 16
UTC HRLY 21 22 23 00 01 02 03 04 05 06 07 08 09 10 11 12 13 14 15 16 17 18 19 20

WND DIR   S  S  S  S  S  S  S  S  S  S  S  S  S  S  S  S  S  S  S  S  S  S  S  S
WND SPD  35 36 37 39 40 40 40 39 37 36 32 27 24 20 18 19 20 21 21 21 21 21 21 20
WND GST  42 43 46 47 48 48 48 47 46 43 39 33
WAVES     5  5  5  7  8  9 11 11 10  9  8  6  5  5  5  5  7  8  8  9  8  8  7  5
PERIOD    8  8  9  9  9 10 10 10 10 10 10 10 10 10 10 10 11 11 11 11 11 11 11 11
WTR LVL  -7 -7 -4 -1  2  6  9  9  7  3 -1 -5 -7 -8 -7 -4  0  3  6  8  7  4  1 -3
RHIGH    -3 -3  0  4  8 13 16 16 14 10  5  1 -2 -3 -2  1  6  9 13 15 14 11  7  3
RLOW     -6 -5 -3  1  4  8 12 11  9  6  2 -3 -6 -6 -5 -2  2  5  9 10 10  7  3 -1
EROSION   N  N  N  N  N  Y  Y  Y  Y  N  N  N  N  N  N  N  N  N  Y  Y  Y  N  N  N
OVRWASH   N  N  N  N  N  N  Y  Y  N  N  N  N  N  N  N  N  N  N  N  N  N  N  N  N
INUNDTN   N  N  N  N  N  N  N  N  N  N  N  N  N  N  N  N  N  N  N  N  N  N  N  N
```

Sallenger Regime levels are Predicted in Matrices


Dune
Roque Bluffs Beach

Roque Bluffs Verification Results

April 7-8, 2016 Storm

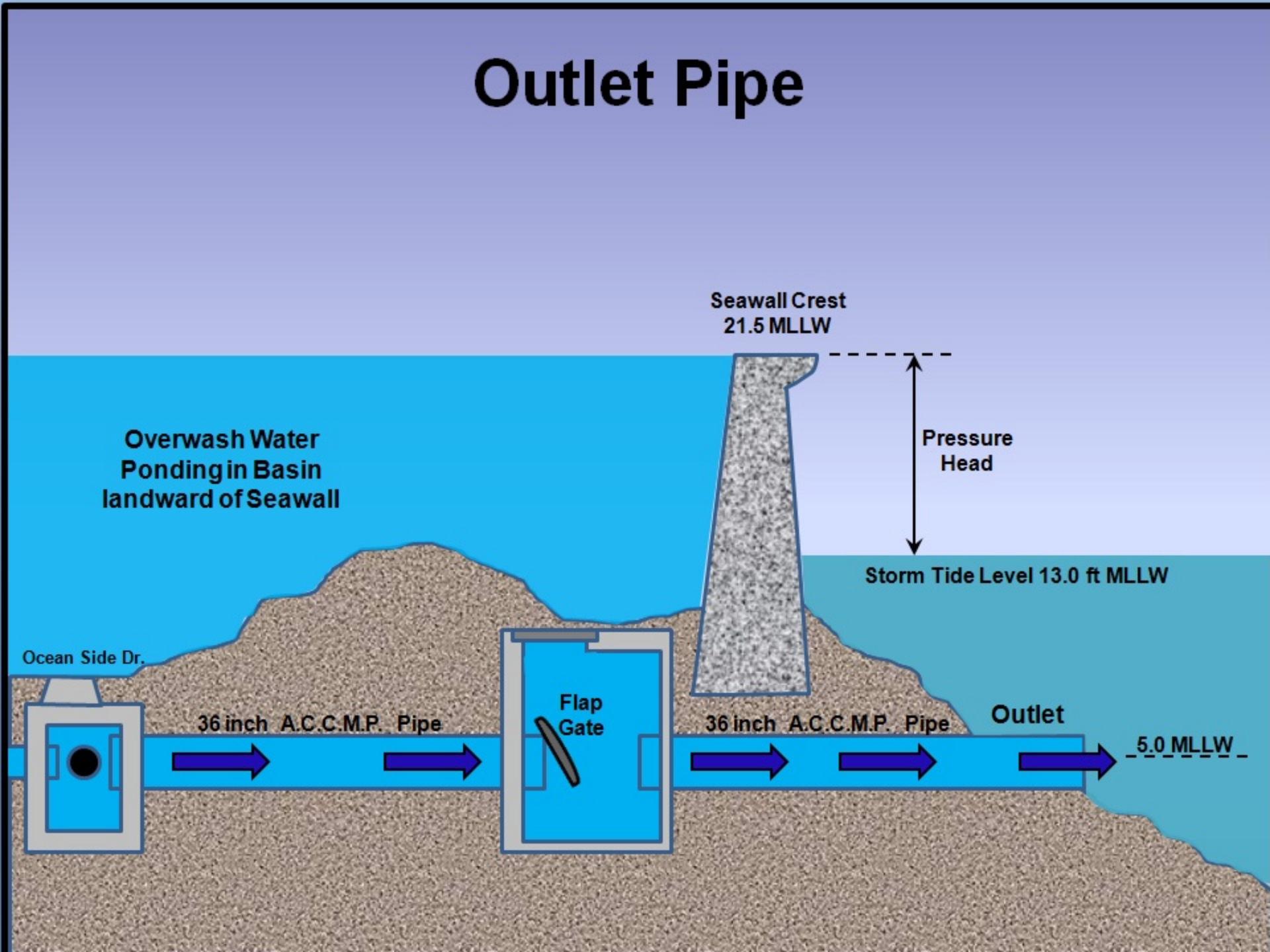
Lead Time	Erosion	Overwash	Inundation
70 hours	yes	yes	no
58 hours	yes	yes	no
46 hours	yes	yes	no
34 hours	yes	yes	no
22 hours	yes	yes	no
10 hours	yes	yes	no
	Occurred	Occurred	Did Not Occur

Overtopping A Vertical Seawall

Overtopping of a Seawall

Scituate, MA January 27, 2015

Outlet Pipe


Seawall Crest
21.5 MLLW
Overwash Water
Ponding in Basin
landward of Seawall
Pressure
Head
Storm Tide Level 13.0 ft MLLW
Ocean Side Dr.
36 inch A.C.C.M.P. Pipe
Flap
Gate
36 inch A.C.C.M.P. Pipe
Outlet
5.0 MLLW

Overtopping Parameterization for Seawalls

Jansen and van der Meer

Mean overtopping discharge
m³/s per meter of structure length

$$q = \frac{Q_b * \sqrt{gH_s^3}}{\sqrt{\frac{S_{op}}{\tan\alpha}}}$$

Off shore wave steepness

$$S_{op} = \frac{2\pi H_s}{gT_p^2}$$

Dimensionless Freeboard for slopes

$$R_b = \frac{R_c}{H_s}\frac{\sqrt{S_{op}}}{\tan\alpha}\frac{1}{\lambda_b\lambda_h\lambda_f\lambda_\beta}$$

Adjusted Dimensionless Freeboard for slopes (Bruce)

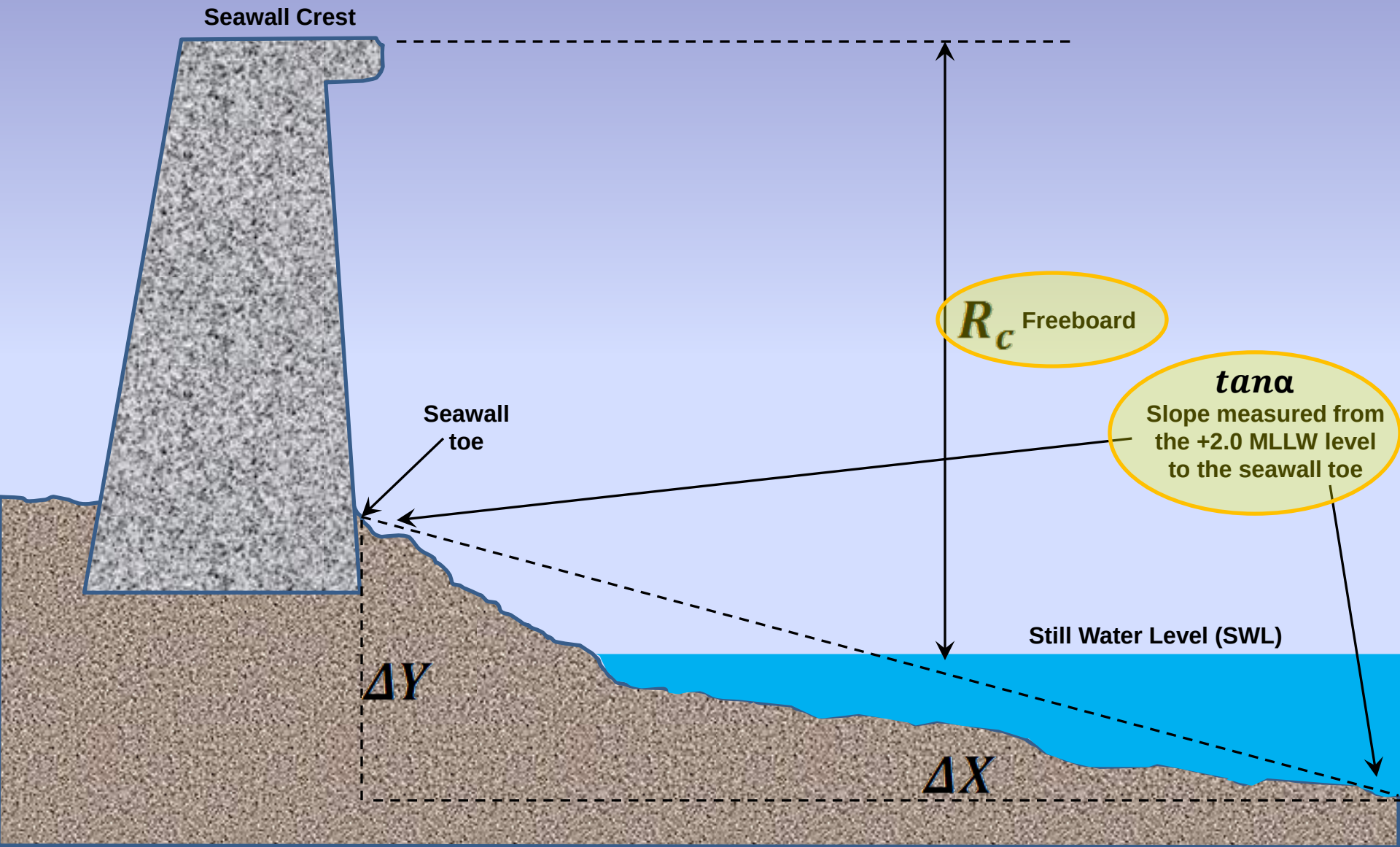
$$R_{ba} = R_b S_{op}^{-0.17}$$

Plunging wave dimensionless discharge

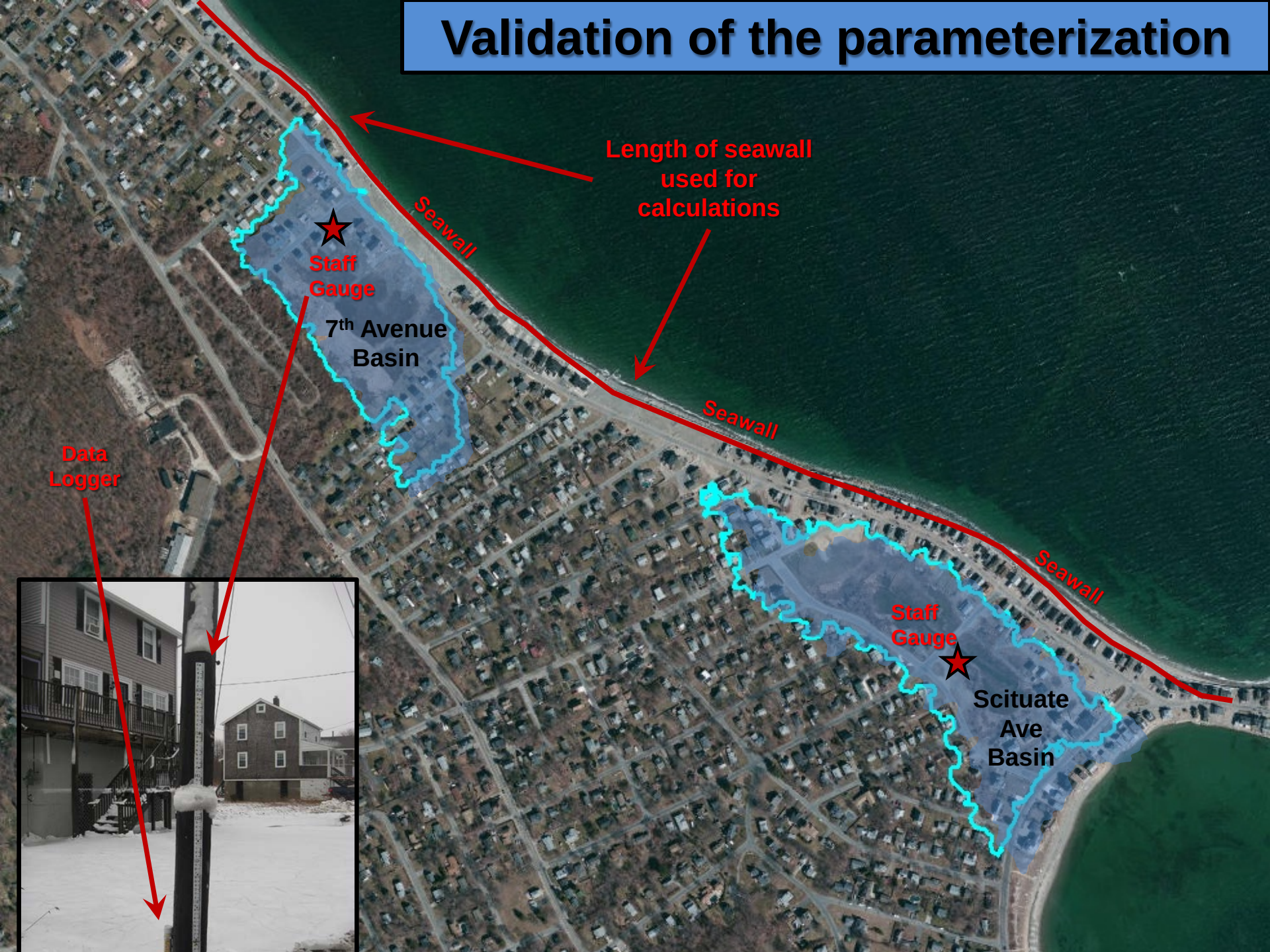
$$Q_b = 0.06e^{-4.7R_{ba}}$$

Input Parameters

Freeboard & Slope

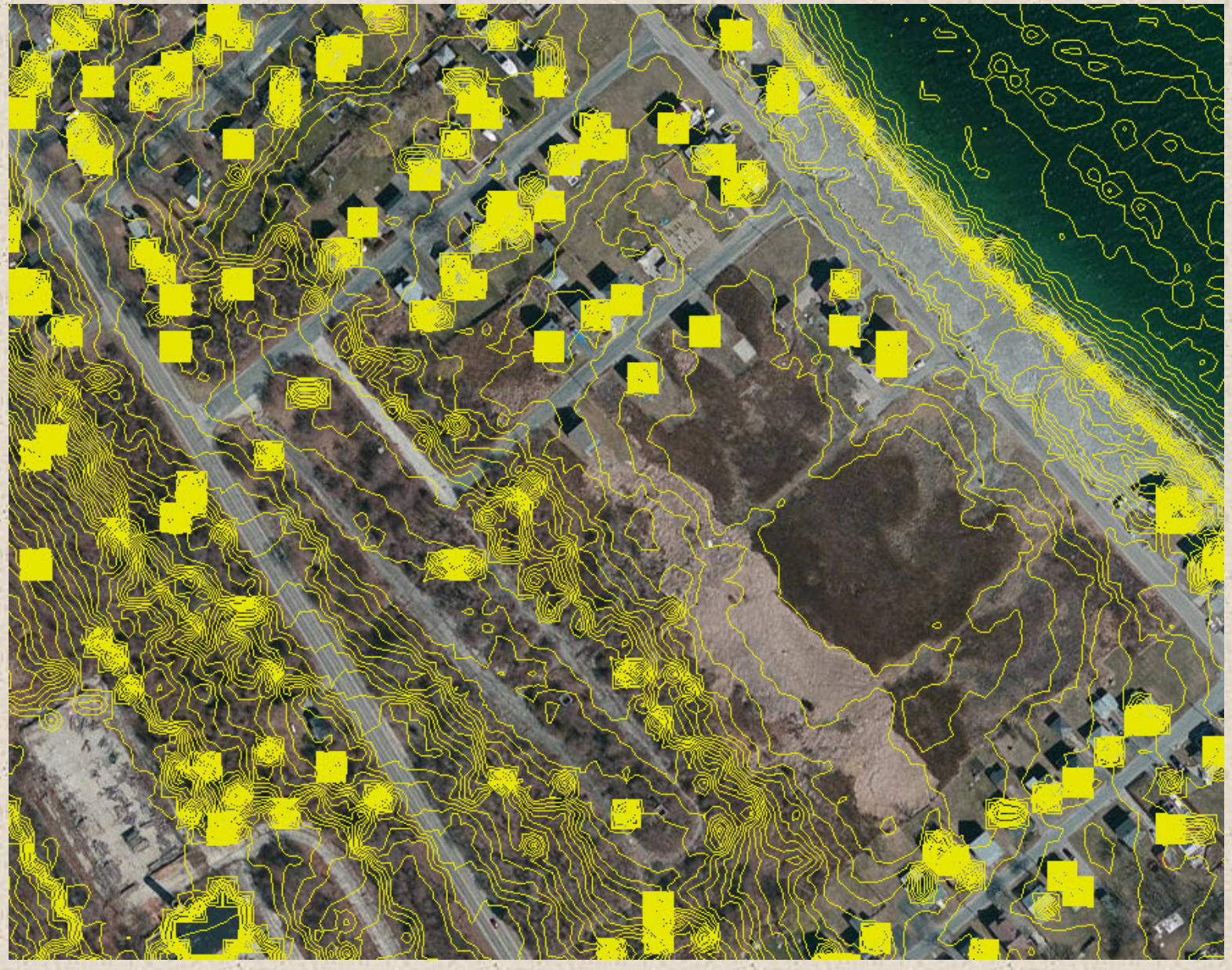


Validation of the parameterization



LiDAR Elevations plotted in 1 foot intervals

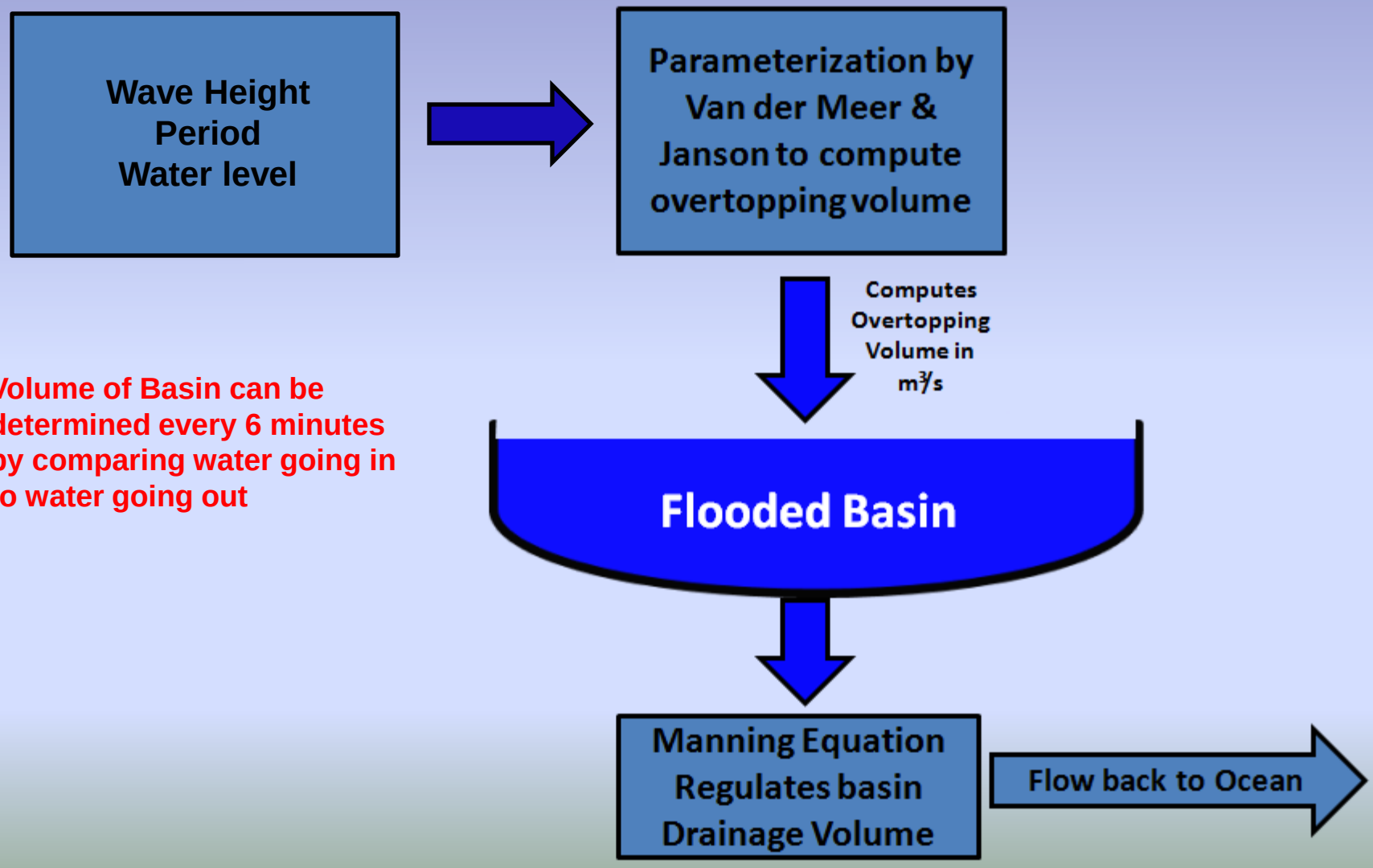
GIS used to compute volume of basin from LiDAR



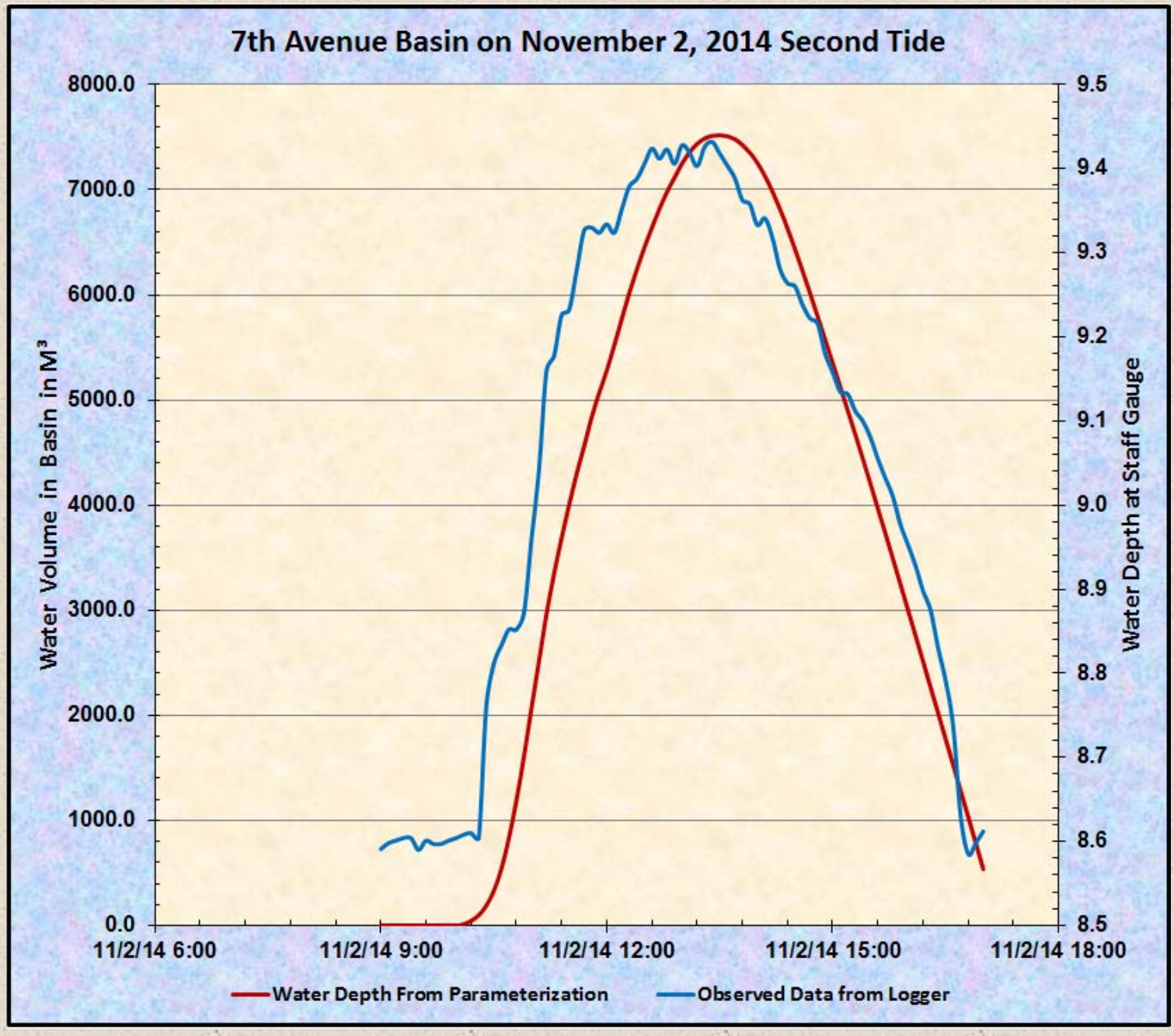
Test Events

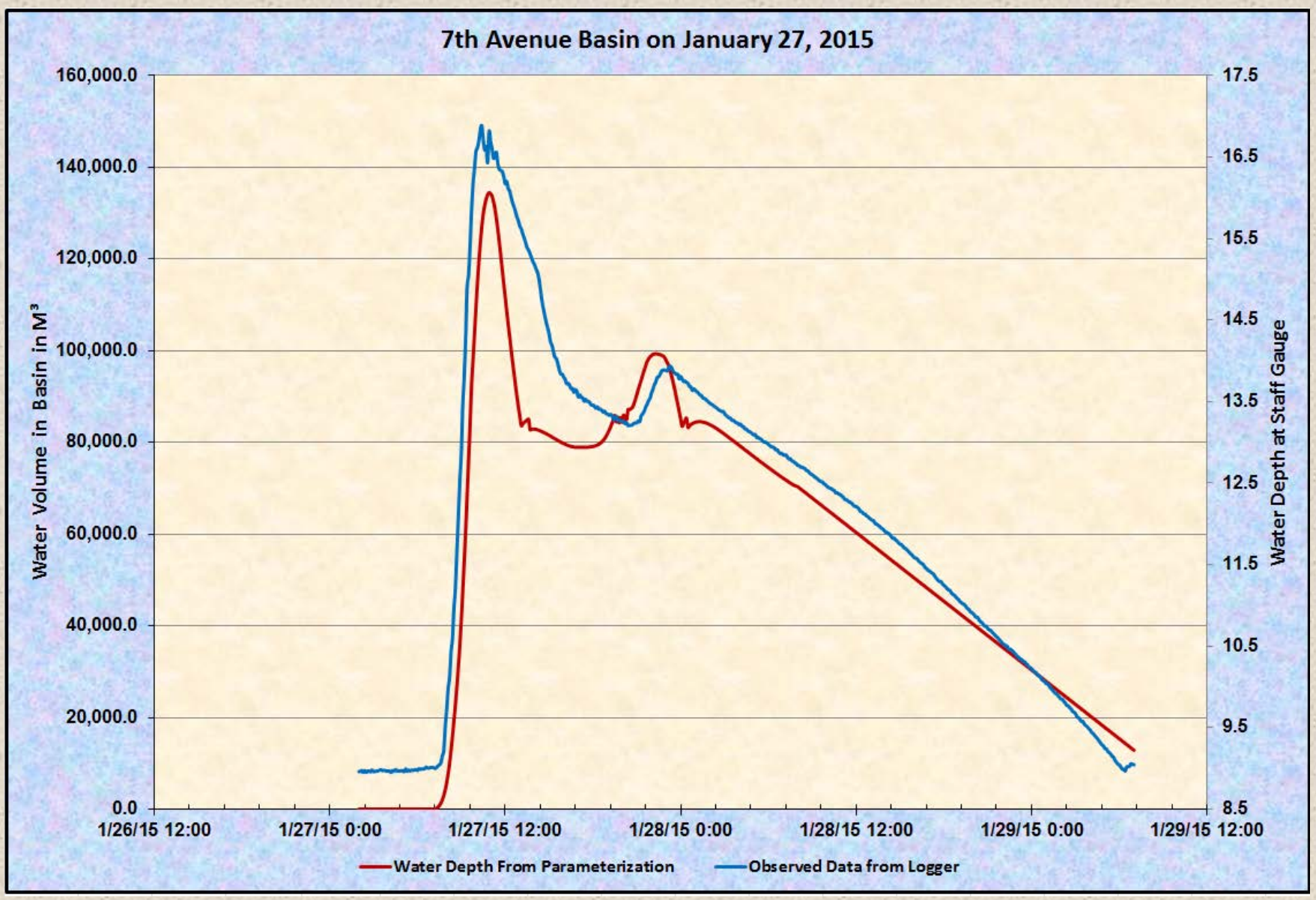
- Deploy Data Logger prior to event
- Records water level every 6 min.
- Volume determined from water level

Modeling the Avenues Basin



Volume of Basin can be determined every 6 minutes by comparing water going in to water going out


7th Avenue Basin on November 2, 2014 Second Tide
Water Volume in Basin in M³
8000.0
7000.0
6000.0
5000.0
4000.0
3000.0
2000.0
1000.0
0.0
Water Depth at Staff Gauge
9.5
9.4
9.3
9.2
9.1
9.0
8.9
8.8
8.7
8.6
8.5
11/2/14 6:00
11/2/14 9:00
11/2/14 12:00
11/2/14 15:00
11/2/14 18:00
Water Depth From Parameterization
Observed Data from Logger


7th Avenue Basin on January 27, 2015
Water Volume in Basin in M³
160,000.0
140,000.0
120,000.0
100,000.0
80,000.0
60,000.0
40,000.0
20,000.0
0.0
Water Depth at Staff Gauge
17.5
16.5
15.5
14.5
13.5
12.5
11.5
10.5
9.5
8.5
1/26/15 12:00
1/27/15 0:00
1/27/15 12:00
1/28/15 0:00
1/28/15 12:00
1/29/15 0:00
1/29/15 12:00
Water Depth From Parameterization
Observed Data from Logger

Overtopping A Stone Armored Revetment

Overtopping Parameterization for Stone Armored Revetments

Jansen and van der Meer

Mean overtopping discharge
m³/s per meter of structure length

$$q = \frac{Q_b * \sqrt{g H_s^3}}{\sqrt{\frac{S_{op}}{\tan \alpha}}}$$

Off shore wave steepness

$$S_{op} = \frac{2\pi H_s}{g T_p^2}$$

Dimensionless Freeboard for slopes

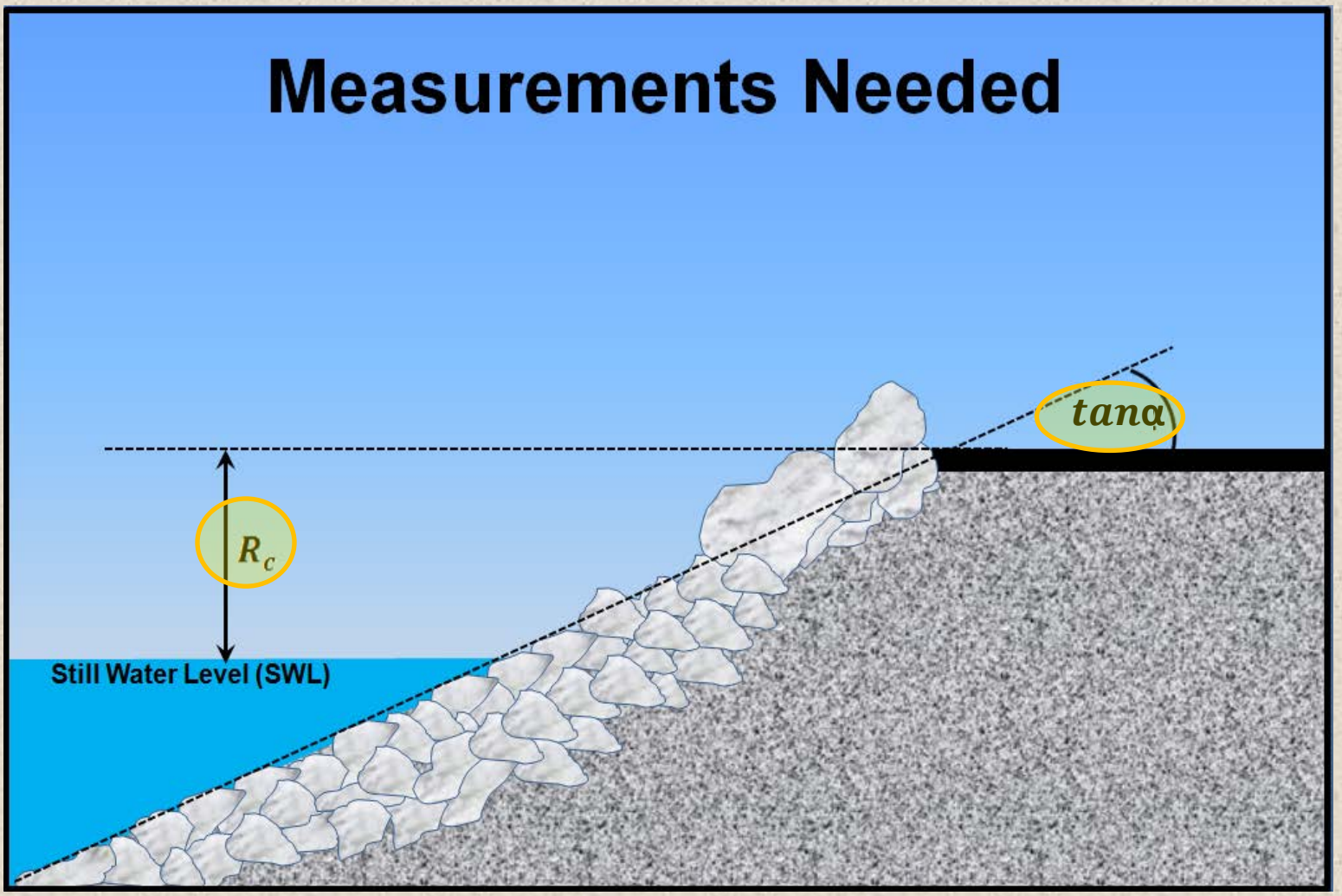
$$R_b = \frac{R_c}{H_s} \frac{\sqrt{S_{op}}}{\tan\alpha} \frac{1}{\lambda_b \lambda_h \lambda_f \lambda_\beta}$$

Plunging wave dimensionless discharge

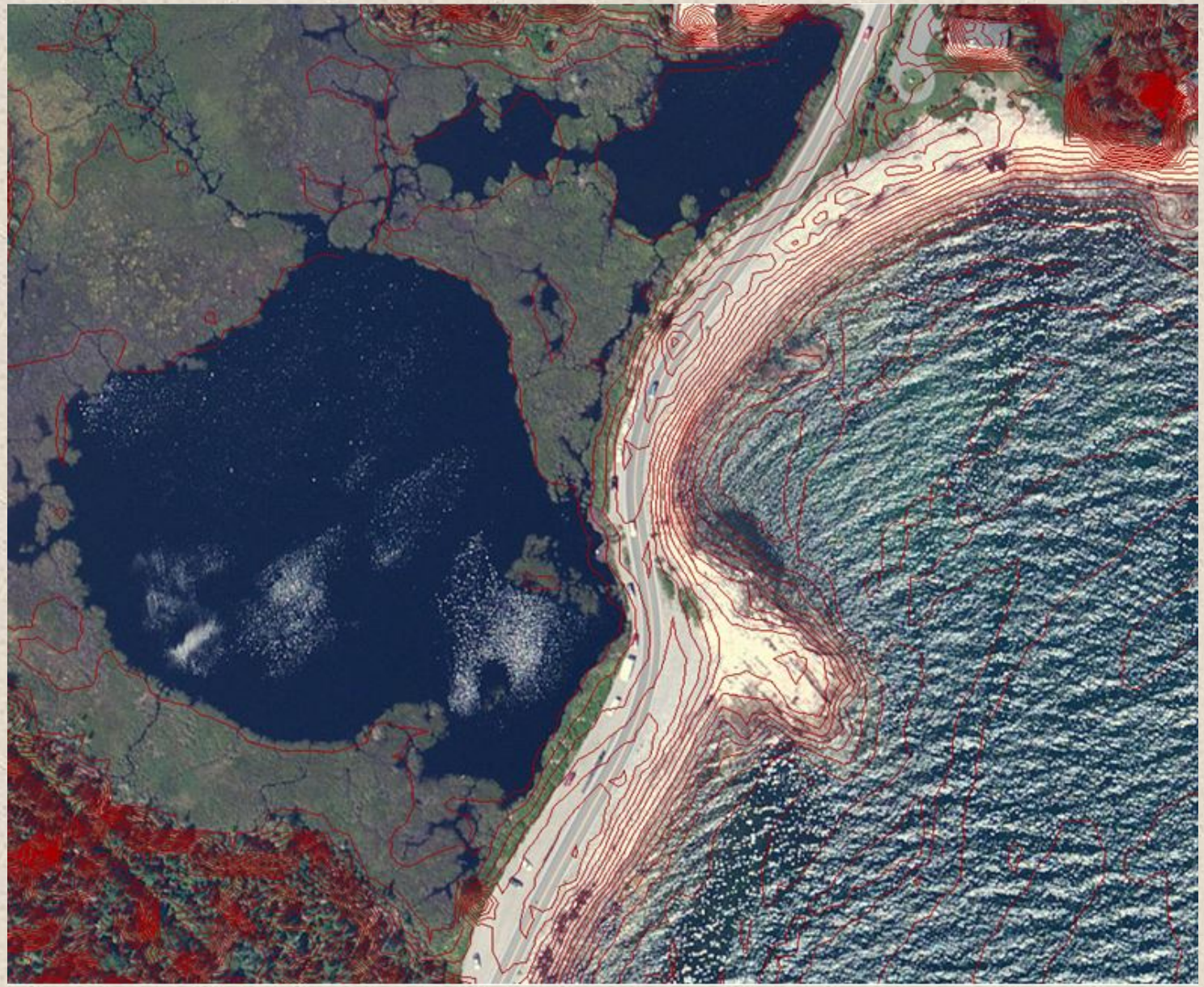
$$Q_b = 0.06 * e^{-5.2 R_b}$$

Input Parameters

Freeboard & Slope



Seawall Road LiDAR Elevations



Forecast Matrices for Overtopping Discharge Volume

Seawall Road Test Site

Matrices for April 7-8, 2016 Storm

MEZ029-082115-
SEAWALL ROAD - HANCOCK COUNTY
44.24N 68.30W ELEV. CREST 11.55 FT
311 AM EST MON FEB 8 2016

DATE	MON 02/08/16																						TUE
EST HRLY	04	05	06	07	08	09	10	11	12	13	14	15	16	17	18	19	20	21	22	23	00	01	02	03
UTC HRLY	09	10	11	12	13	14	15	16	17	18	19	20	21	22	23	00	01	02	03	04	05	06	07	08
WND DIR	NE	NE	NE	NE	NE	NE	NE	NE	NE	NE	NE	NE	NE	NE	N	N	N	N	N	N	N	N	N	N
WND SPD	23	24	26	27	28	28	28	28	28	28	29	31	31	31	31	31	29	27	26	25	25	24	23	20
WND GST			32	33	34	34	34	34	34	34	35	36	36	36	36	36	35	33	32					
WAVES	5	6	6	6	7	7	7	7	7	7	7	7	7	7	8	8	8	8	8	8	8	7	7	7
PERIOD	6	6	6	7	7	7	7	7	7	8	8	8	8	8	8	9	9	9	9	10	10	11	12	12
WTR LVL	-5	-4	-2	1	3	5	6	6	4	1	-2	-5	-6	-6	-4	-2	1	4	5	6	4	2	-1	-4
DVOLUME	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
INUNDTN	N	N	N	N	N	N	N	N	N	N	N	N	N	N	N	N	N	N	N	N	N	N	N	N

DATE	TUE 02/09/16																						WED
EST HRLY	04	05	06	07	08	09	10	11	12	13	14	15	16	17	18	19	20	21	22	23	00	01	02	03
UTC HRLY	09	10	11	12	13	14	15	16	17	18	19	20	21	22	23	00	01	02	03	04	05	06	07	08
WND DIR	N	N	N	N	N	N	N	N	N	N	N	N	N	N	N	N	N	N	N	N	N	N	N	N
WND SPD	19	18	18	17	16	14	13	12	11	10	10	10	11	11	11	11	11	11	10	9	9	8	8	
WND GST																								
WAVES	7	8	9	9	10	10	10	10	10	9	9	8	8	7	7	6	6	5	5	5	5	4	4	4
PERIOD	13	14	15	15	15	15	14	14	14	14	13	13	13	13	12	12	12	12	11	11	11	11	11	11
WTR LVL	-5	-6	-4	-2	1	4	6	6	6	3	0	-3	-5	-6	-6	-4	-1	2	5	6	6	4	1	-2
DVOLUME	0	0	0	0	0	1	2	4	2	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
INUNDTN	N	N	N	N	N	N	N	N	N	N	N	N	N	N	N	N	N	N	N	N	N	N	N	N

Impact Index Scale

Discharge Volume Versus Impact

For Seawall Road

DVOLUME Code	Impact to Road
01	Minor Splash-over
02 – 03	overwash…small rocks on road
04	overwash…medium rocks on road
05 – 06	overwash…large rocks on road
07 +	Damage to road pavement

Recommendations

- Statement Not Required/Optional
- Issue Coastal Flood Advisory
- Issue Coastal Flood Warning

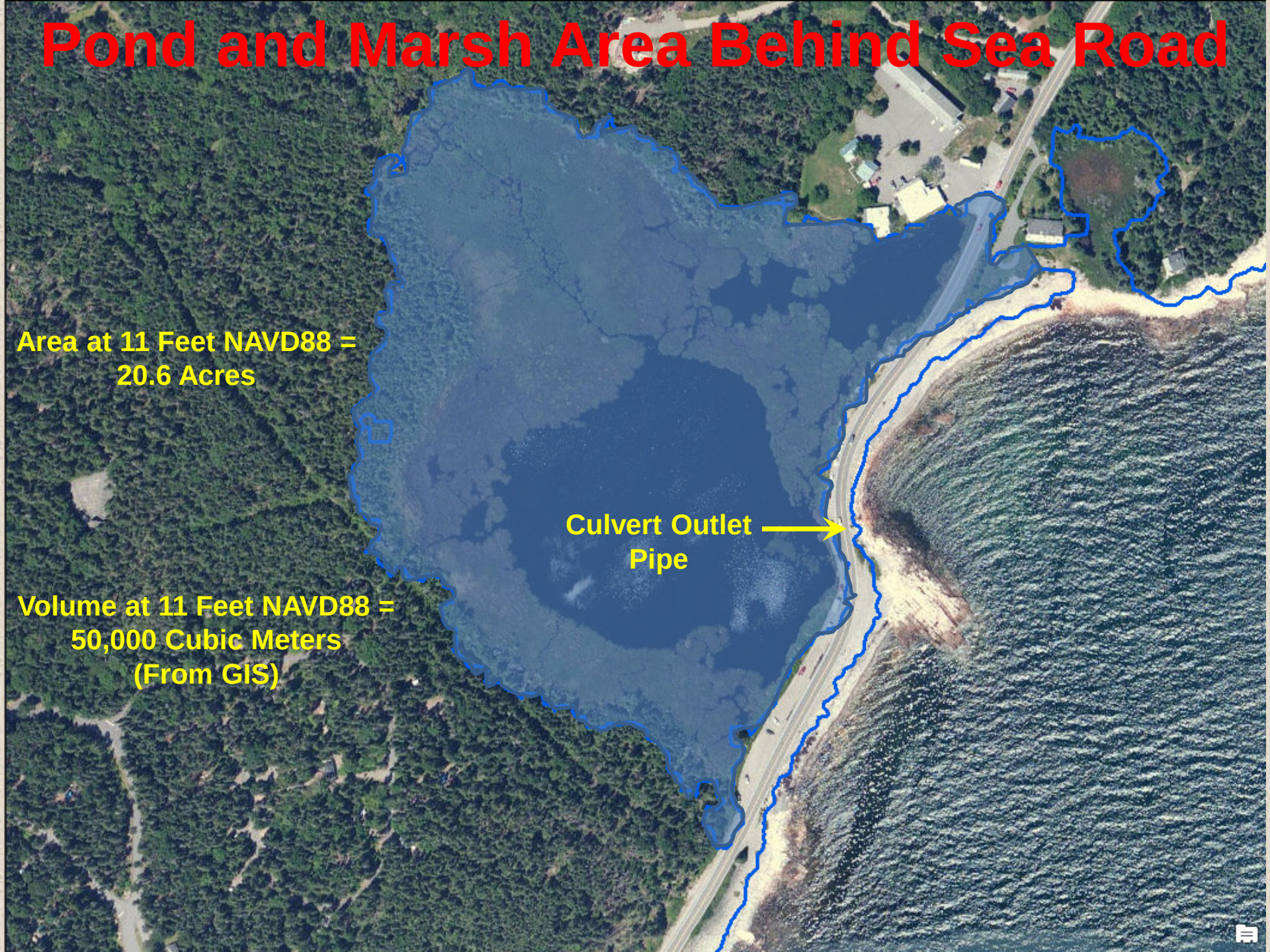
Currently predicted volume is treated as an index with correlated impacts

February 8, 2016

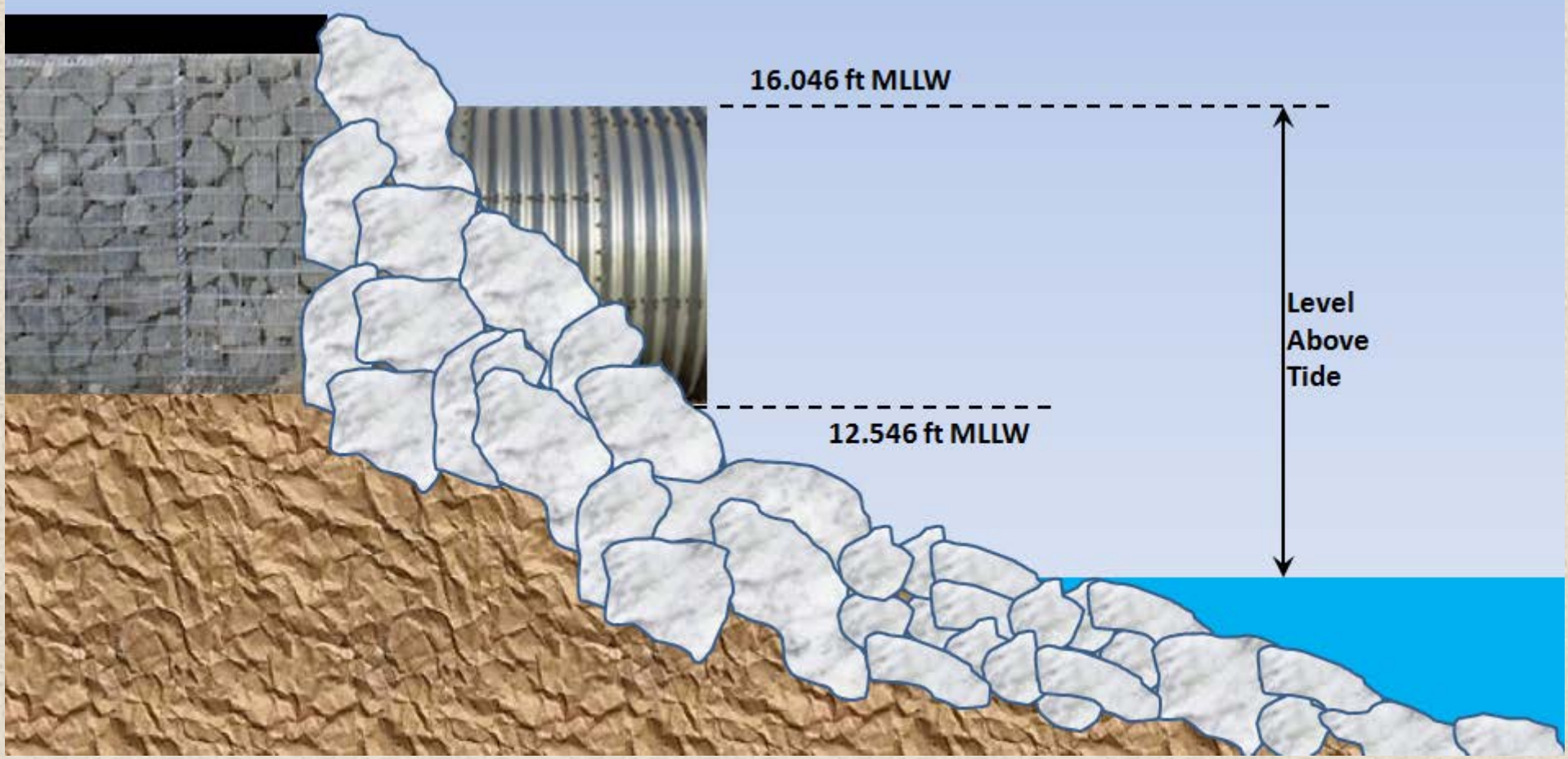
Attempt to Validate predicted volume

Pond and Marsh Area Behind Sea Road

Pond and Marsh Area Behind Sea Road

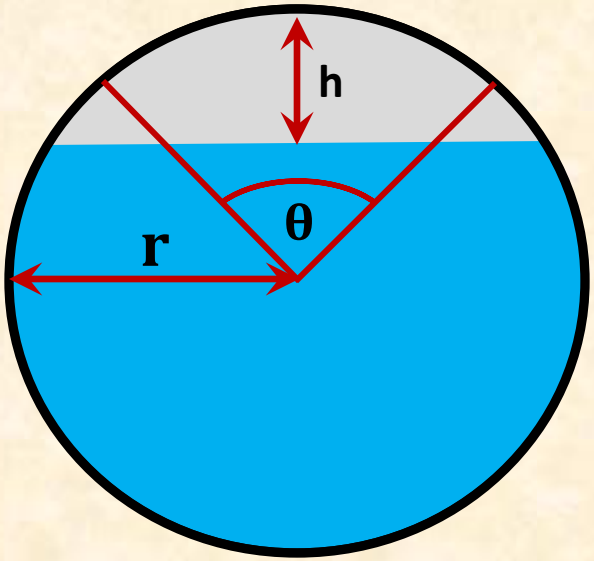


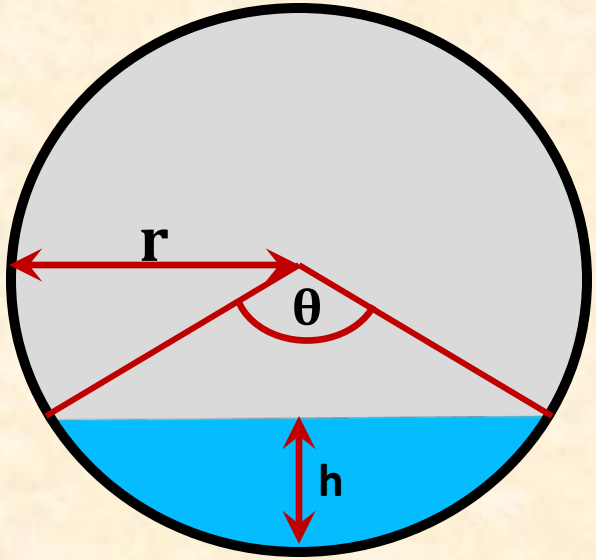
Seawall Pond Water Level Regulated by Culvert Outlet Pipe



Manning Equation

Used to Compute volume flowing through pipe





More than half full

$r = {}^{D}/_{2}$ h = 2r - y

θ = 2 arc cos $\left(\frac{r-h}{r}\right)$

A = πr^2 - $\frac{r^2(\theta - sin\theta)}{2}$

P = 2πr – rθ

R_h = A/P

Less than half full

$r = {}^{D}/_{2}$ h = y

θ = 2 arc cos $\left(\frac{r-h}{r}\right)$

A = $\frac{r^2(\theta - sin\theta)}{2}$

P = rθ

R_h = A/P

$Q = (1.49/n)A\left(R_h{}^{2/3}\right)S^{1/2}$

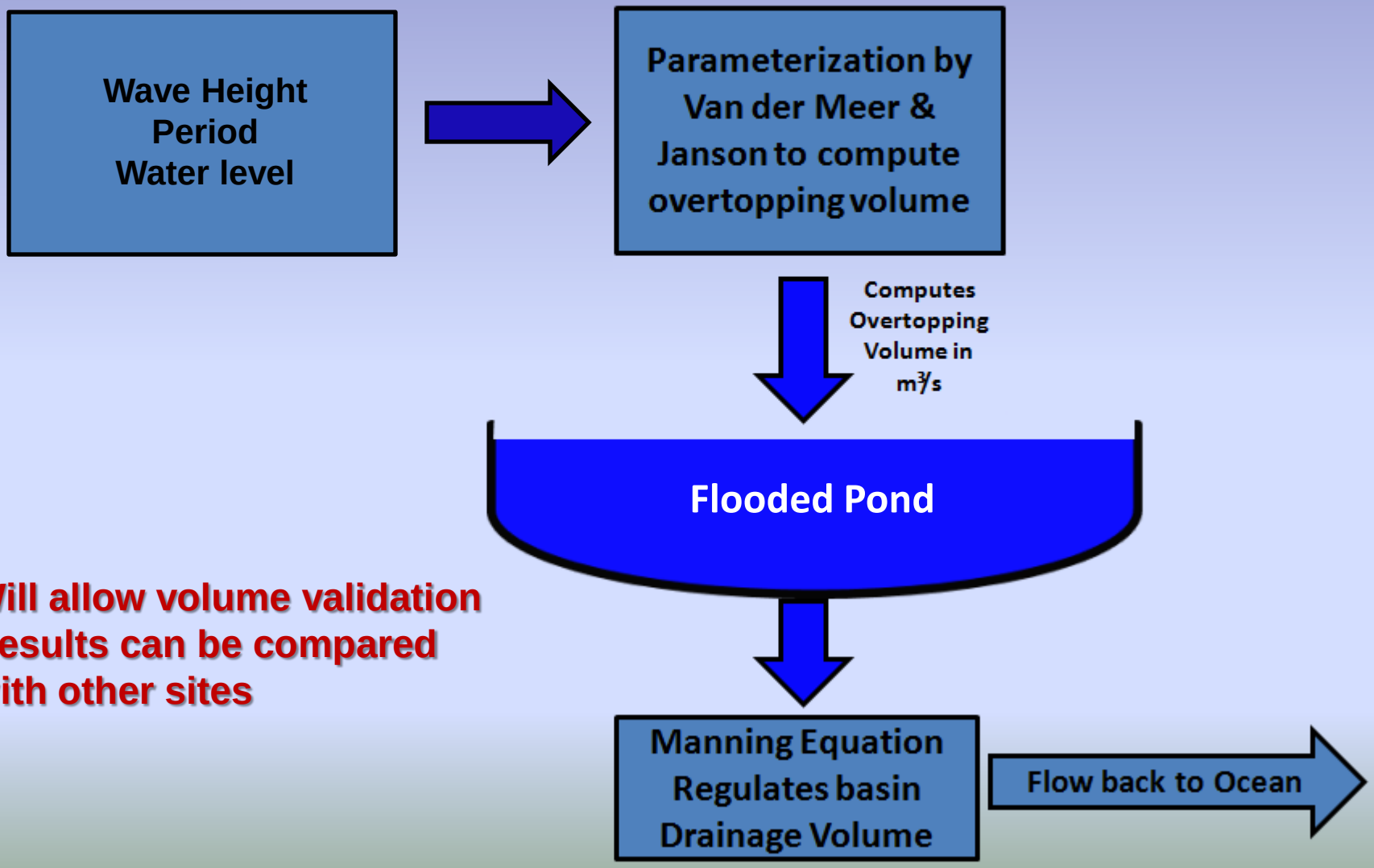
$Q = ft.^3/second$

S = bottom slope of channel

n = Roughness Coefficient


016-06-25 06:32:21 PM
ideWatch
Seawall Road Webcam
Can deploy data logger or
install staff rod that can
be read from webcam

Modeling Seawall Road



- Will allow volume validation
- Results can be compared with other sites

Questions ??