Deltares

Consolidation and ripening modelling of Marker Wadden pilot

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23-12-2021

Objective of this work/presentation

- To explore the capability of TUD ripening model in predicting the consolidation and desiccation of the deposit at Marker Wadden pilot project;

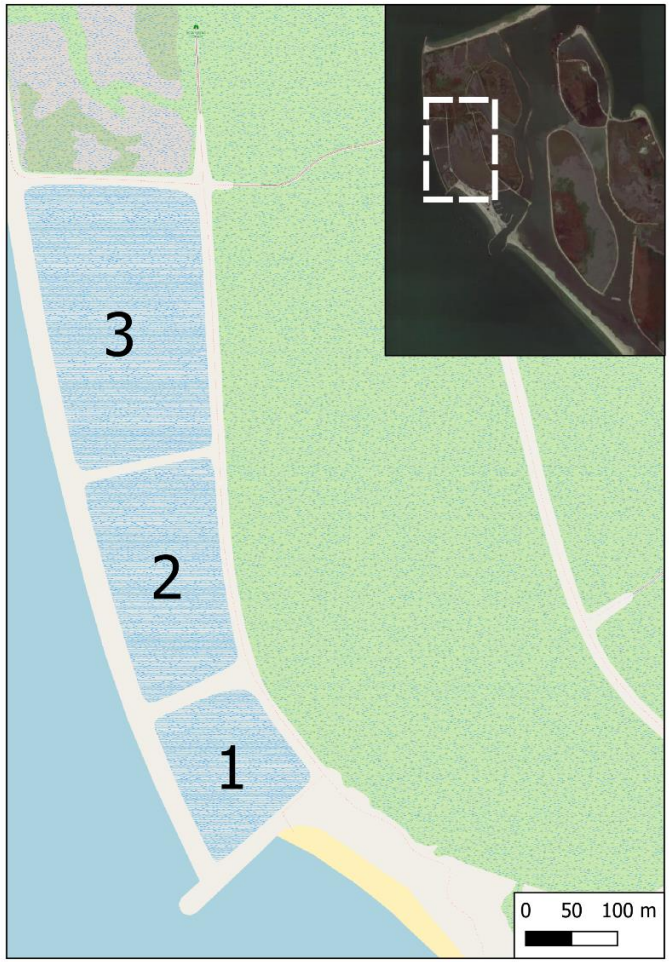
- To investigate and quantify possible heterogeneity in mud properties of different compartments at Marker Wadden pilot project;

- To perform a limited number of model scenario analyses, with the focus on investigating the effect of underwater/exposed deposit surface conditions.

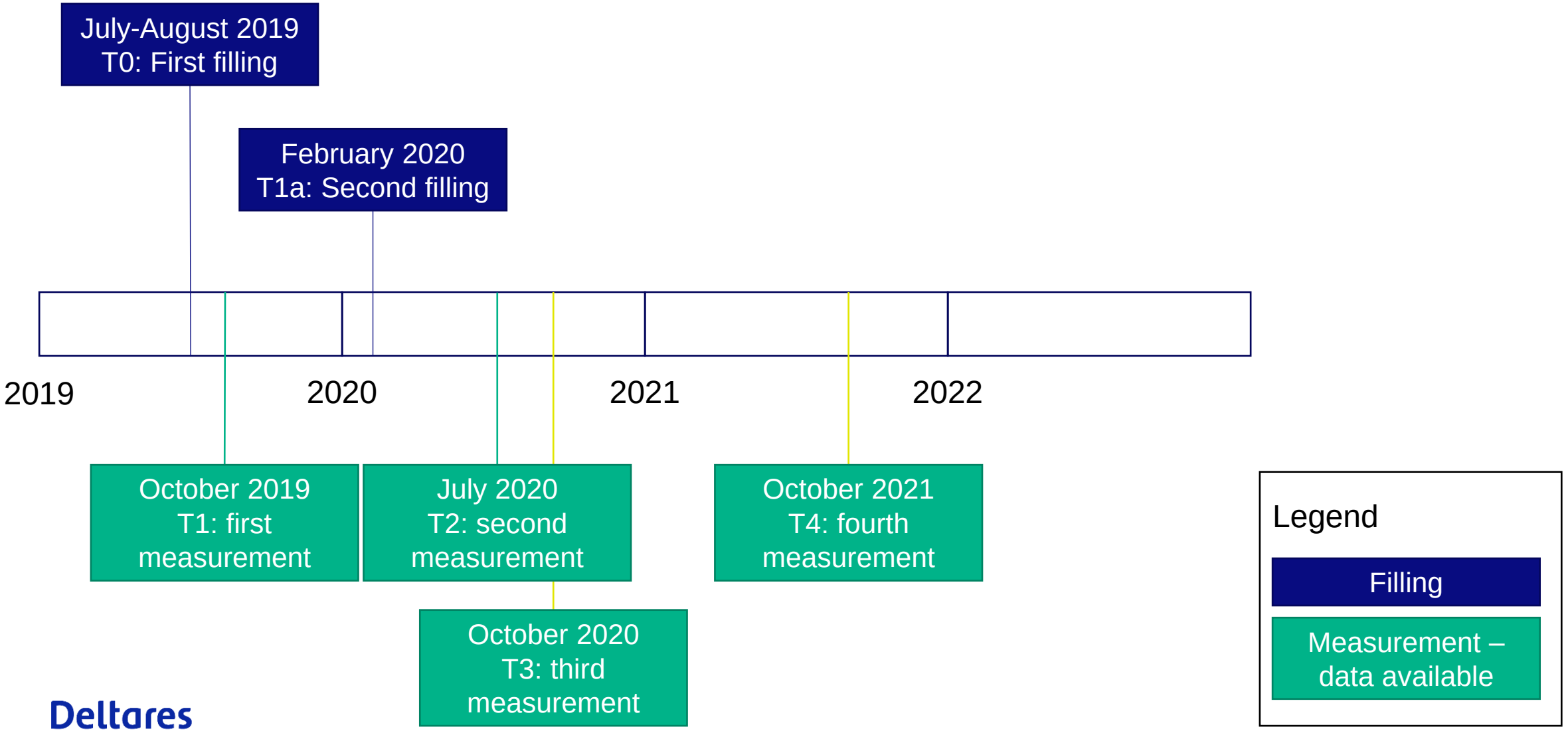
Table of contents

Case study: Marker Wadden pilot compartments

- Marker Wadden pilot compartments
  - In Dutch: *Dun Slib Compartimenten*
- Consists of three compartments, with a combined area of 100.000 m^2
- Fill material: Holocene (clayey) material dredged from the Markermeer bed
- Project duration: from 2019 until 2021



Timeline of pilot project



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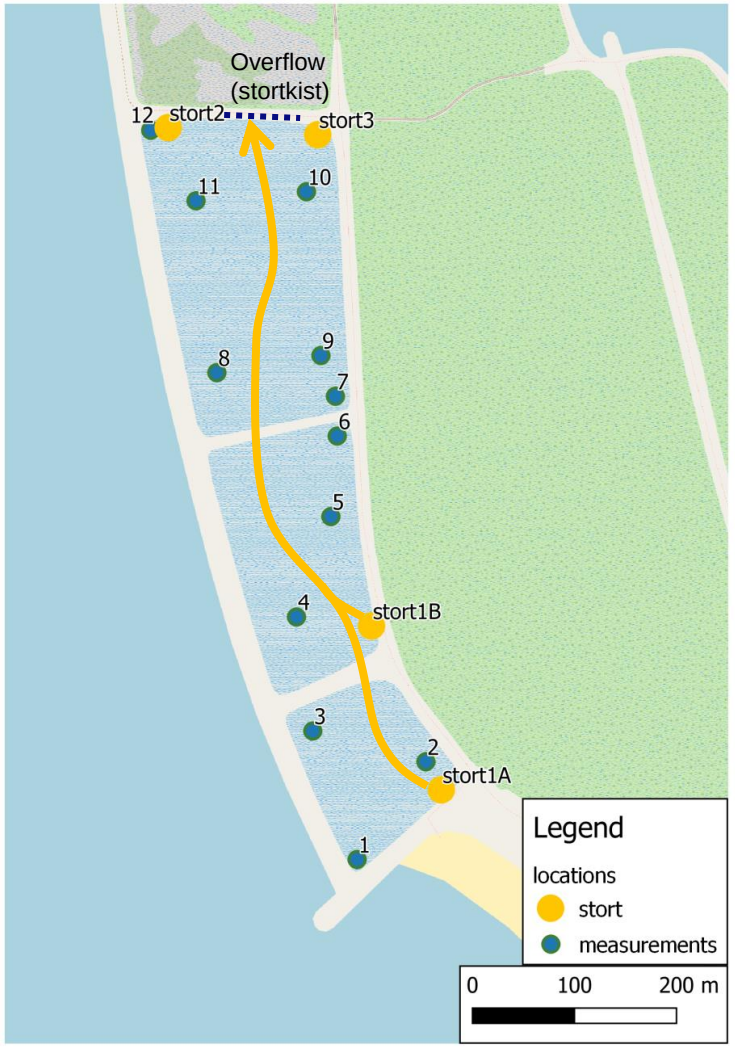
Filling of compartments

- T0: first filling July-August 2019
  - Filling from July 17 until August 25
  - From July 17- August 5 on location ‘stort1A’
  - From August 5-25 on location ‘stort1B’
  - Slurry flowed from these points to the other compartments.
  - Overflow at the end of compartment 3
- Production data first filling
  - Pumped 440.000 m^3
  - 75.000 m^3 overflow out of compartments
  - Net: 365.000 m^3 in compartments
  - Approx. 3.5 - 4.0 m thick layer
  - Bulk density approx. 1160 kg/m^3
- Second filling in February 2020
  - Mainly used to raise fill height in compartment 3
  - Filling locations ‘stort2’ and ‘stort3’
  - Production data not available



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Selected locations

- 12 measurement locations in 3 compartments.

Filling likely led to segregation of the fill material. In turn, this led to:

- Differences in initial density across compartments
- Differences in grain size distribution across compartments

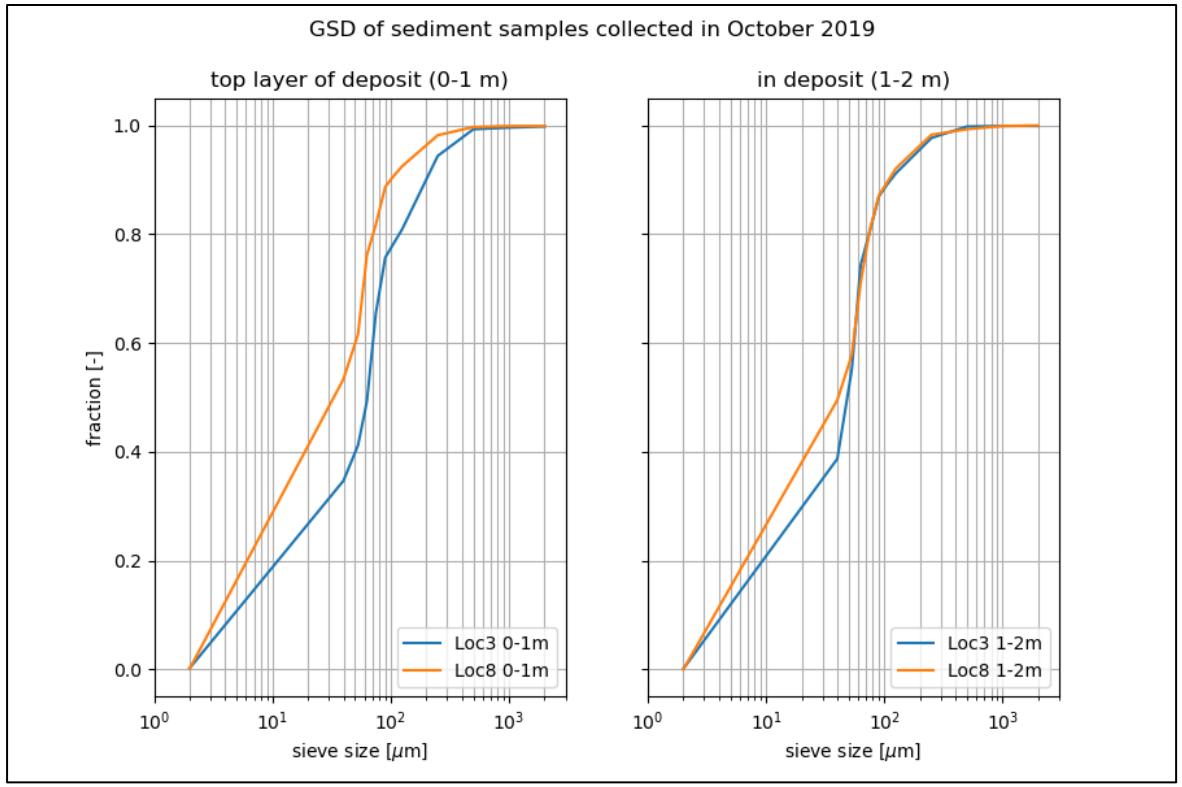
Two locations were selected to test and model this:

Compartment 3 – Location 8 (Loc8)
At far end of compartment
Relatively muddy deposit

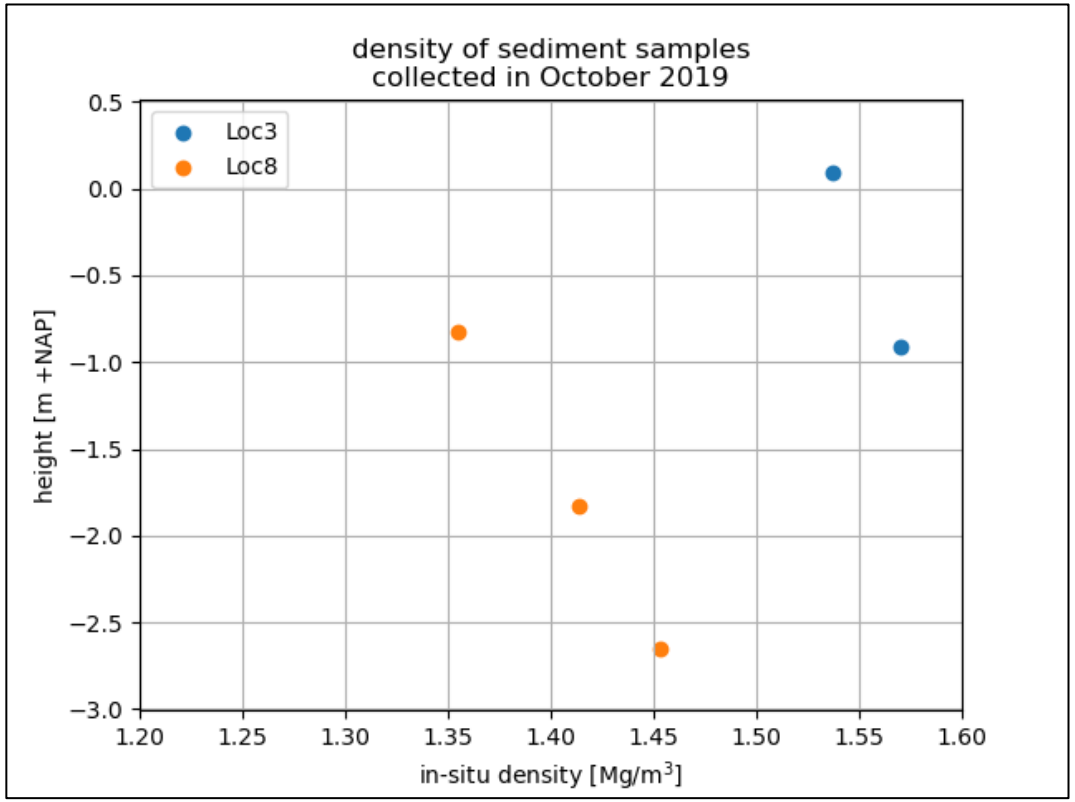
Compartment 1 – Location 3 (Loc3)
Close to filling locations
Relatively sandy deposit

Difference in material properties across compartments

- GSD: Loc8 is indeed somewhat muddier than Loc3, but differences are relatively limited



- Density: density at different heights in deposit is much higher at Loc3 than at Loc8. Also note the difference in deposit height
  - N.B. Samples collected at similar heights from deposit surface



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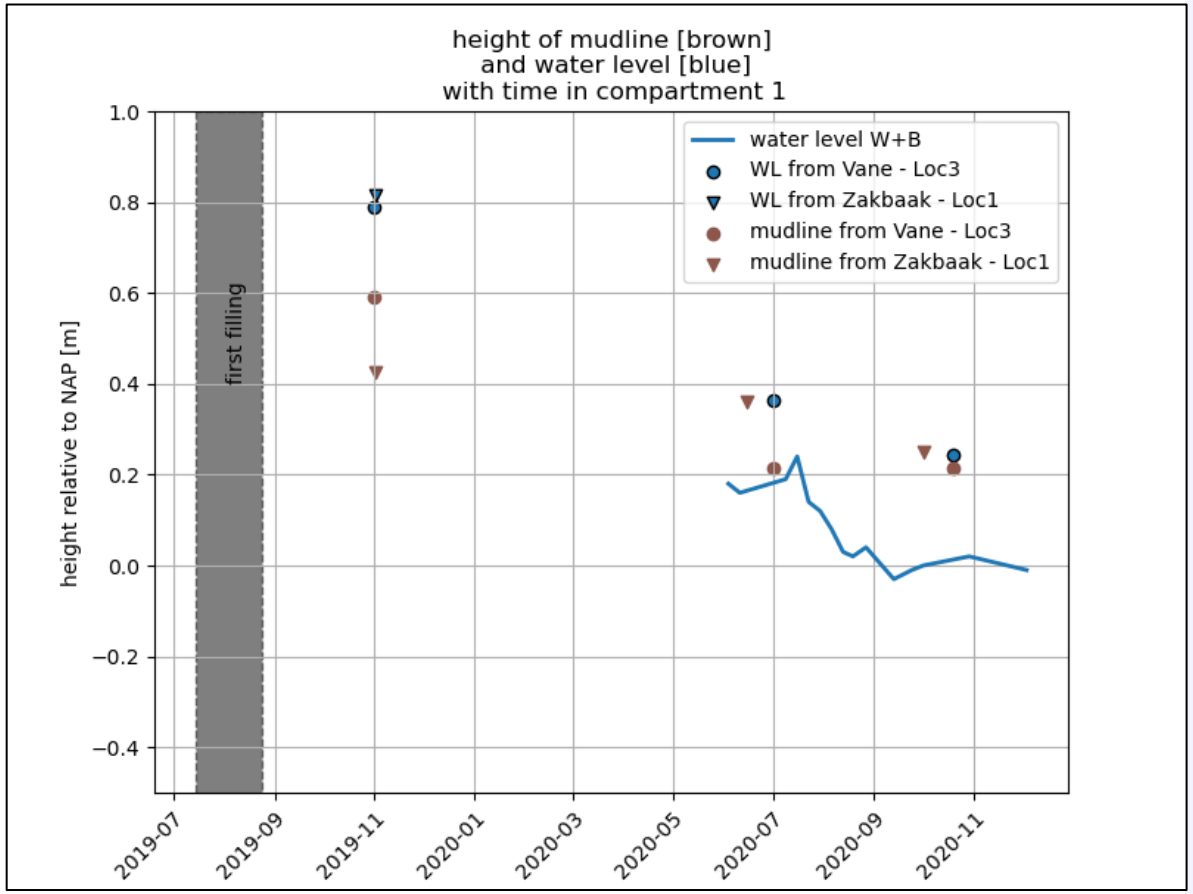
Model study setup

- Model period
  - Starting date: 25-08-2019
  - Model duration: 700-800 days (2nd half 2021)

- Model calibration for Loc3 and Loc8
  - Calibrate to find the correct deposit settlement
  - Initial conditions (deposit height and density)
  - Material properties
- Scenarios: overlying water (water level control)
  - This influences evaporation/precipitation at the upper boundary of deposit and thus swelling/shrinkage.
- Model outcome depends on both overlying water, initial conditions and material properties: iterative process!

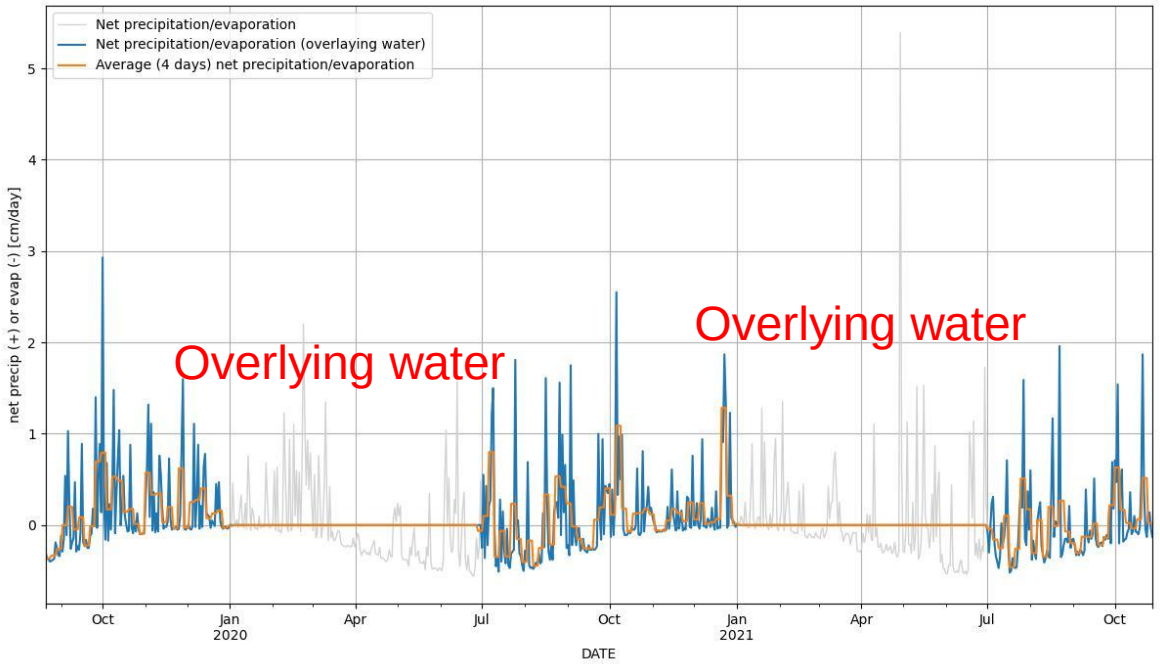


- Water level in compartments decreases with time
- Seasonal variation in water level (higher in winter & spring)
- Discrepancy between water levels measured at one point (W+B) and at measurement locations

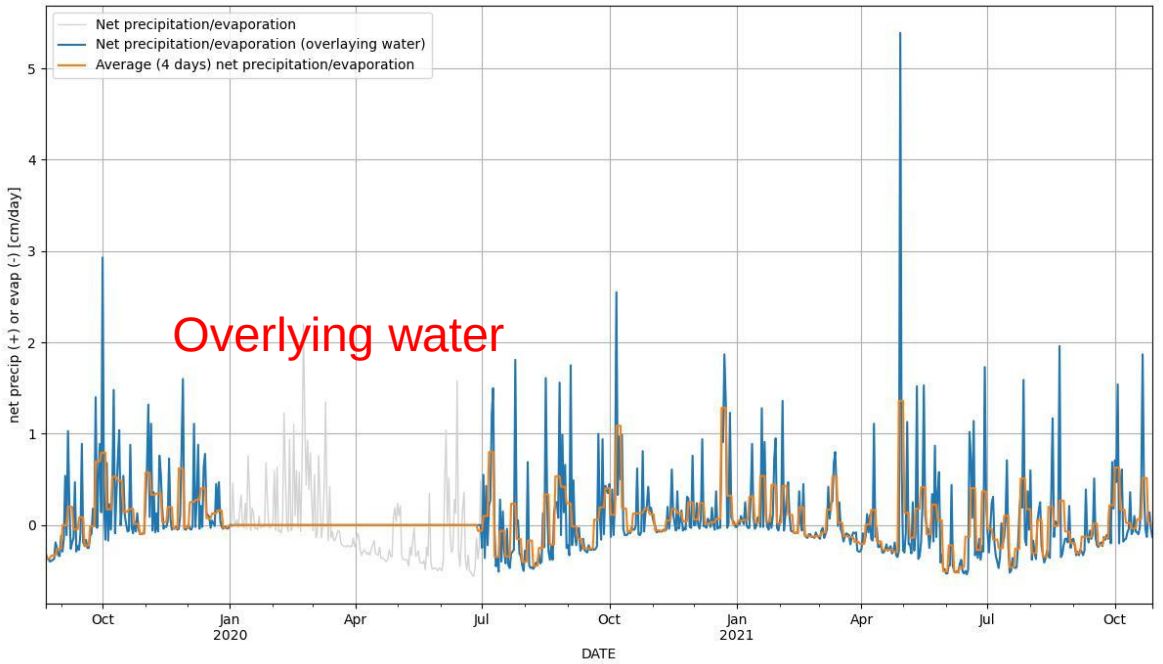
Scenario definition

Based on water level development in compartment 1, we define the following scenarios:

Scenario 1: Deposit is under water January – June, exposed to atmosphere July – December, every year
Scenario 2: Deposit is under water January 2020 – June 2020, exposed to atmosphere rest of pilot duration



Scenario 1



Scenario 2

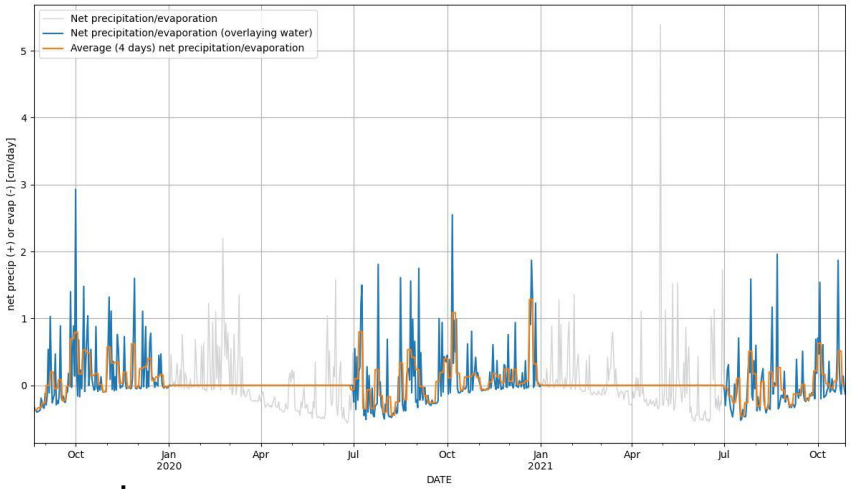
Model evaporation/precipitation based on KNMI station Lelystad

Location 3

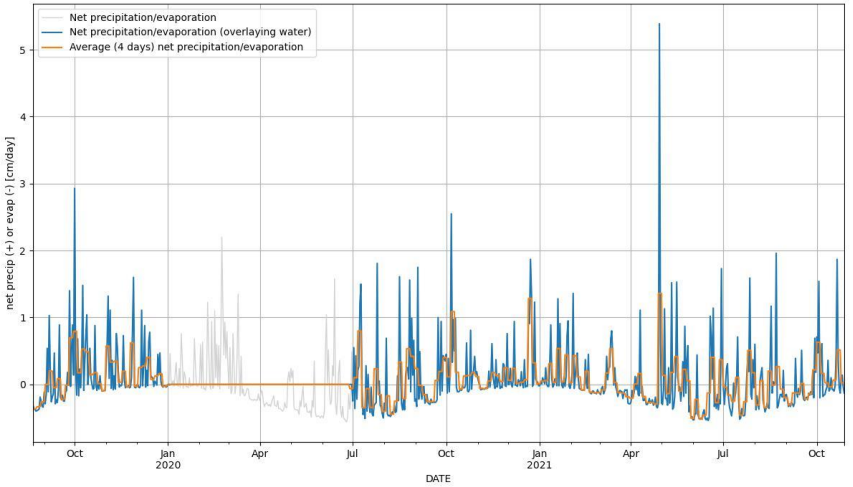
- Initial model parameters based on Kleirijperij study (Phase C1 of this project)
- Max water content for Water Retention (Van Genuchten curve) changed from 6 to 3
- Permeability parameters changed, based on lab results from *Wichman et al. (2016)*
- Initial deposit height: 360 cm
- Initial deposit density: 1350 kg/m3

		Kleirijperij (2021)	Loc 3 (2021)
Shrinkage	**Parameters/ Material**	Calibrated for D15	Relatively sandy
	A_{sh}	0.43	0.43
	B_{sh}	0.43	0.43
	C_{sh}	2.7	2.7
	ν_h	1	1
	ξ_h	1	1
Water retention	WCR	0.2	0.2
	WCS	**6**	**3**
	α_{WRC}	3	3
	n_{WRC}	1.15	1.15
	m_{WRC}	0.13	0.13
	a-modified	10000	100000
Permeability	A	**0.7**	**1.15**
	B	**4.5**	**5.2**
	δ	3	3
	ϵ_{dess}	**0.05**	**-**
	ξ_{dess}	**5**	**-**
	d_{dess}	**10**	**-**

Model evaporation/precipitation
difference in settlement – compartment 1, location 3

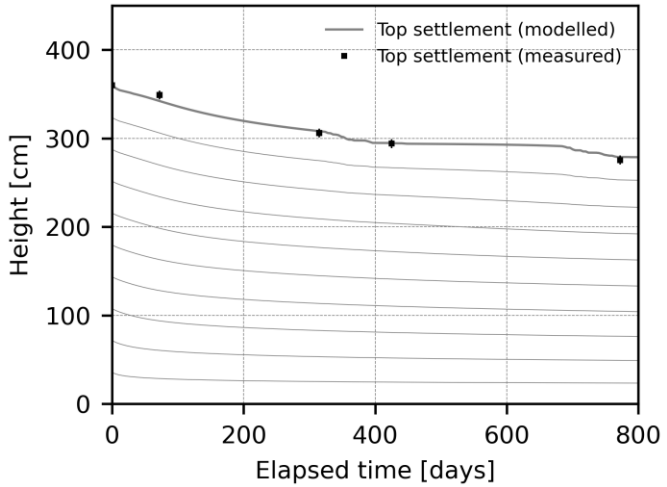


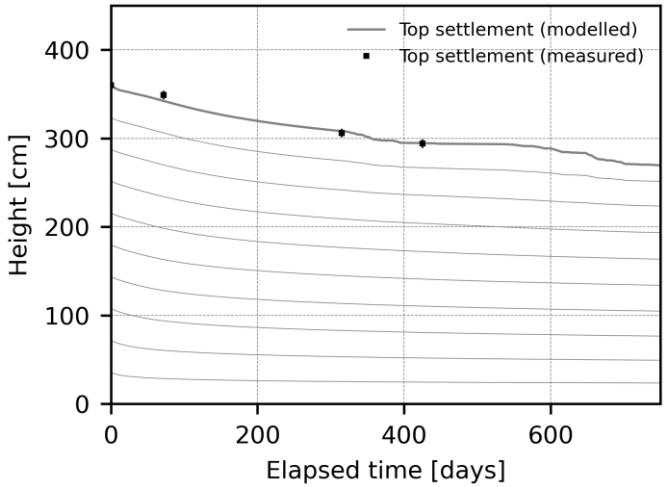
Scenario 1



Scenario 2

Most likely scenario:
- Field observations
- Good agreement with settlement
- Stable computation until end 2021





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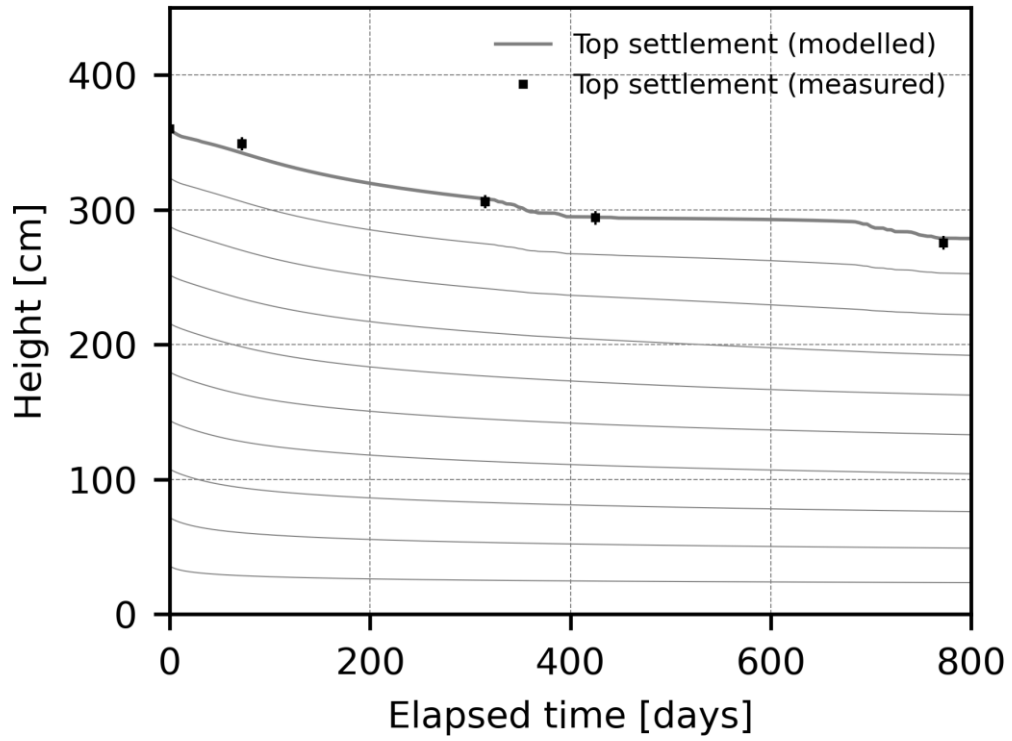
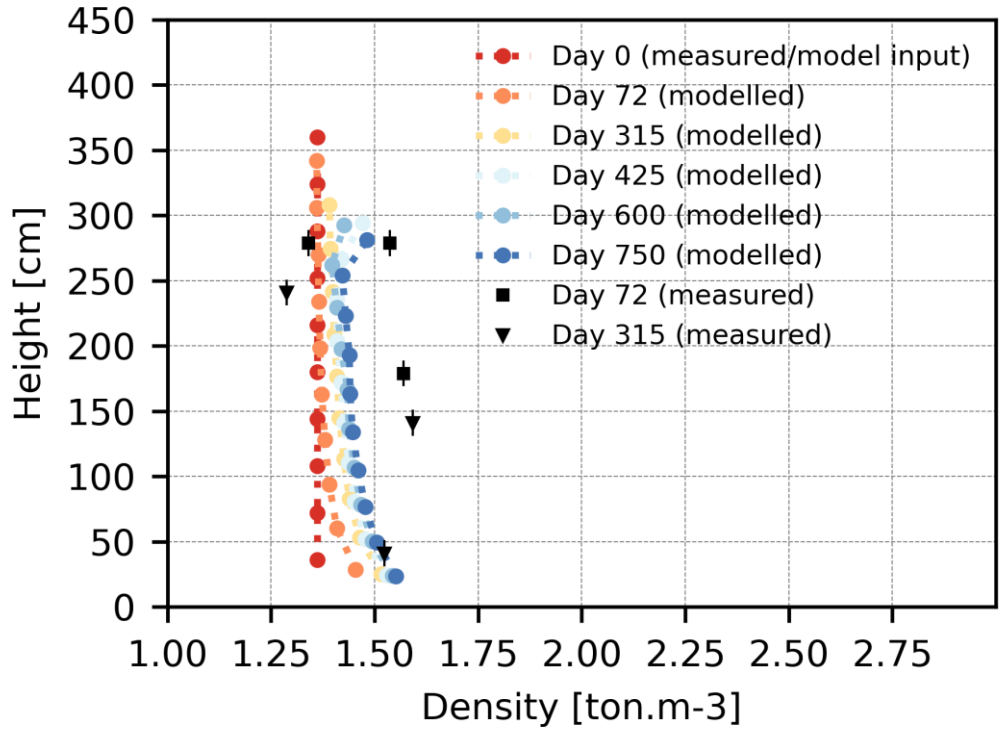
Modeled vs. measured settlement for Compartment 1 – Location 3 (Loc3), scenario 1



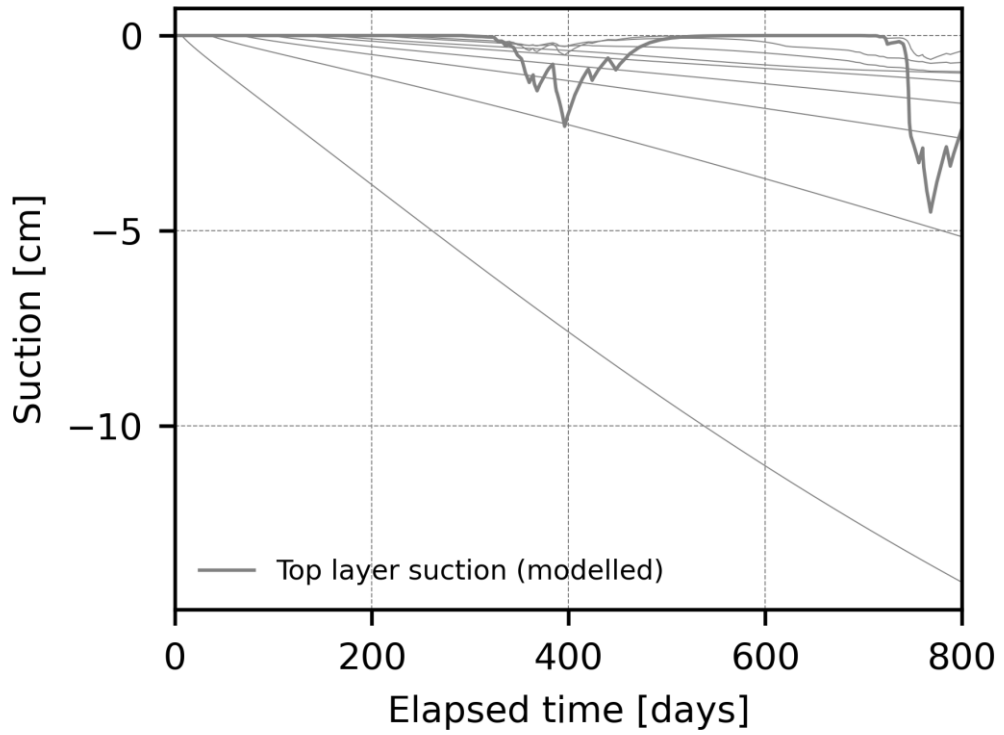
	Parameters/Material	Loc 3 (2021) Relatively sandy
Shrinkage	A_{sh}	0.43
	B_{sh}	0.43
	C_{sh}	2.7
	ν_h	1
	ξ_h	1
Water retention	WCR	0.2
	WCS	3
	α_{WRC}	3
	n_{WRC}	1.15
	m_{WRC}	0.13
	a-modified	100000
Permeability	A	1.15
	B	5.2
	δ	3
	ϵ_{dess}	-
	ξ_{dess}	-
	d_{dess}	-

Modeled vs. measured density for Compartment 1 – Location 3 (Loc3), scenario 1



		Loc 3 (2021)
	Parameters/Material	Relatively sandy
Shrinkage	A_{sh}	0.43
	B_{sh}	0.43
	C_{sh}	2.7
	ν_h	1
	ξ_h	1
Water retention	WCR	0.2
	WCS	3
	α_{WRC}	3
	n_{WRC}	1.15
	m_{WRC}	0.13
	a-modified	100000
Permeability	A	1.15
	B	5.2
	δ	3
	ϵ_{dess}	-
	ξ_{dess}	-
	d_{dess}	-

Modeled top layer suction for Compartment 1 – Location 3 (Loc3), scenario 1



	Parameters/Material	Loc 3 (2021) Relatively sandy
Shrinkage	A_{sh}	0.43
	B_{sh}	0.43
	C_{sh}	2.7
	ν_h	1
	ξ_h	1
Water retention	WCR	0.2
	WCS	3
	α_{WRC}	3
	n_{WRC}	1.15
	m_{WRC}	0.13
	a-modified	100000
Permeability	A	1.15
	B	5.2
	δ	3
	ϵ_{dess}	-
	ξ_{dess}	-
	d_{dess}	-

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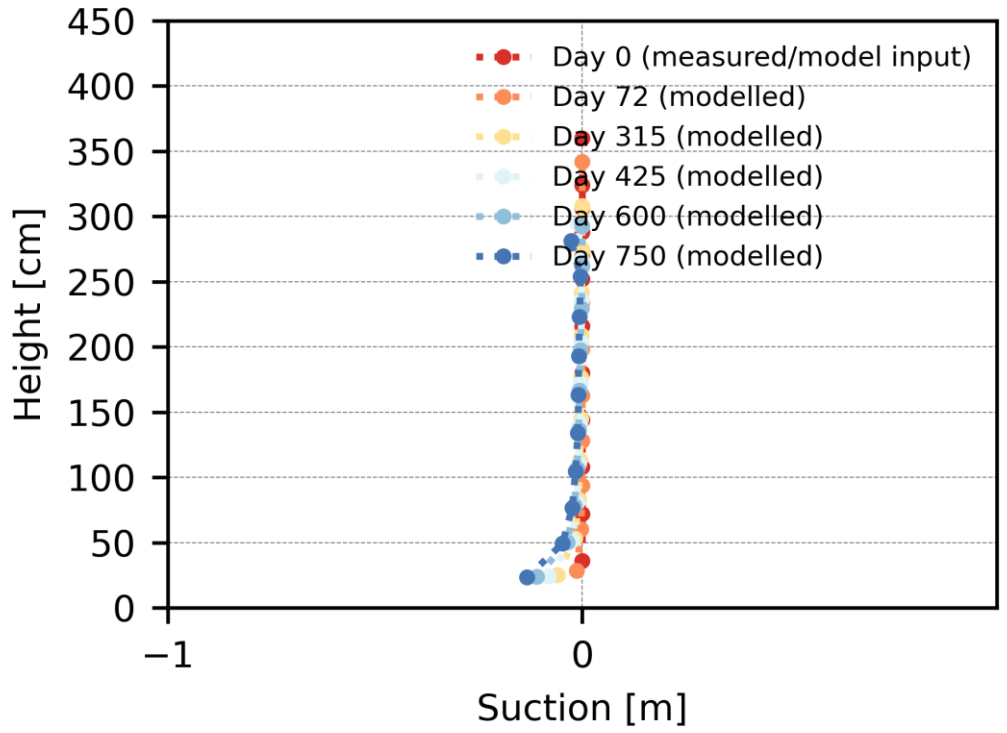
Modeled suction for Compartment 1 – Location 3 (Loc3), scenario 1



		Loc 3 (2021)
	Parameters/Material	Relatively sandy
Shrinkage	A_{sh}	0.43
	B_{sh}	0.43
	C_{sh}	2.7
	ν_h	1
	ξ_h	1
Water retention	WCR	0.2
	WCS	3
	α_{WRC}	3
	n_{WRC}	1.15
	m_{WRC}	0.13
	a-modified	100000
Permeability	A	1.15
	B	5.2
	δ	3
	ϵ_{dess}	-
	ξ_{dess}	-
	d_{dess}	-

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Location 8

- Calibration based on Loc3 material parameters

Main differences:

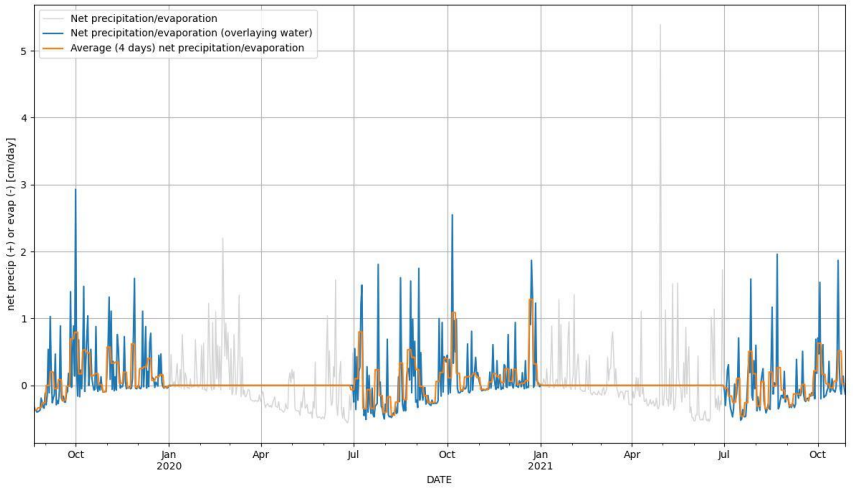
- Initial deposit height: 385 cm
- Initial deposit density: 1205 kg/m^3

- Not included in computations:
  - Second filling (since production data for this filling is not available)
  - Deposit is likely submerged for majority of model period (i.e. no suction in deposit)

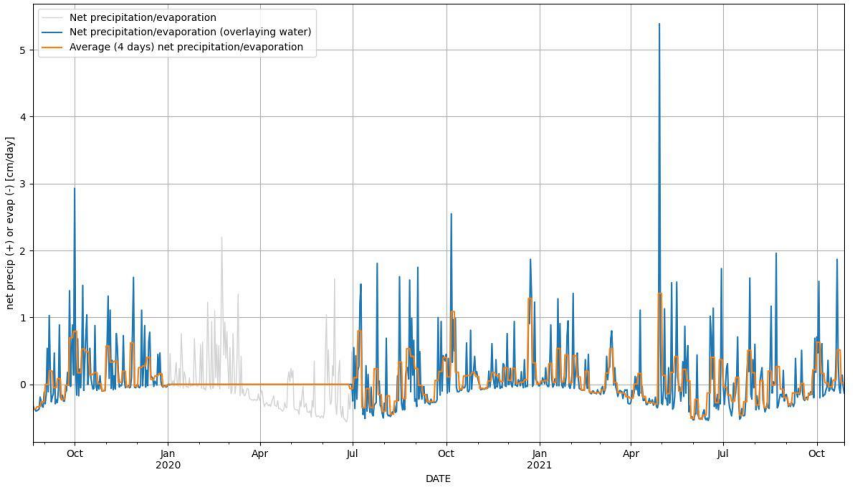
- XX CHANGE PLOTS FROM HERE

		Loc 3 (2021)	Loc 8 (2021)
Shrinkage	**Parameters/ Material**	Relatively sandy	Relatively muddy
	A_{sh}	0.43	0.43
	B_{sh}	0.43	0.43
	C_{sh}	2.7	2.7
	ν_h	1	1
	ξ_h	1	1
Water retention	WCR	0.2	0.2
	WCS	3	3
	α_{WRC}	3	3
	n_{WRC}	1.15	1.15
	m_{WRC}	0.13	0.13
	a-modified	100000	100000
Permeability	A	**1.15**	**1.15**
	B	**5.2**	**5.2**
	δ	3	3
	ϵ_{dess}	-	-
	ξ_{dess}	-	-
	d_{dess}	-	-

Model evaporation/precipitation
difference in settlement – compartment 3, location 8

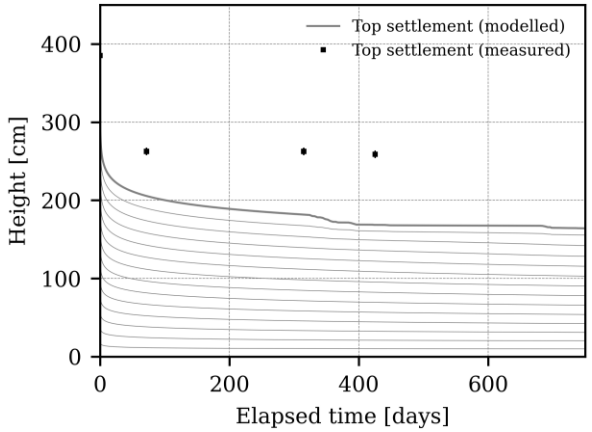


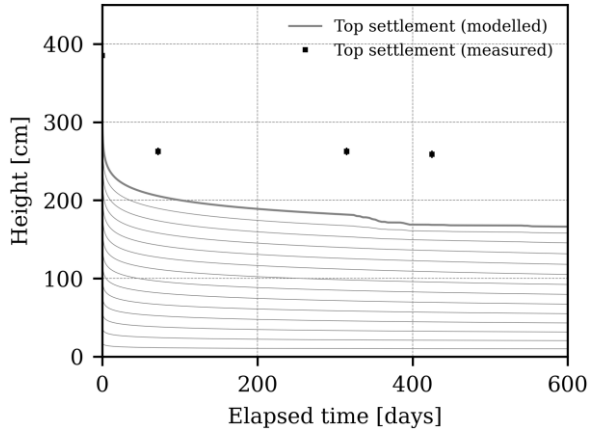
Scenario 1



Scenario 2

For consistency with Loc3, we choose this scenario





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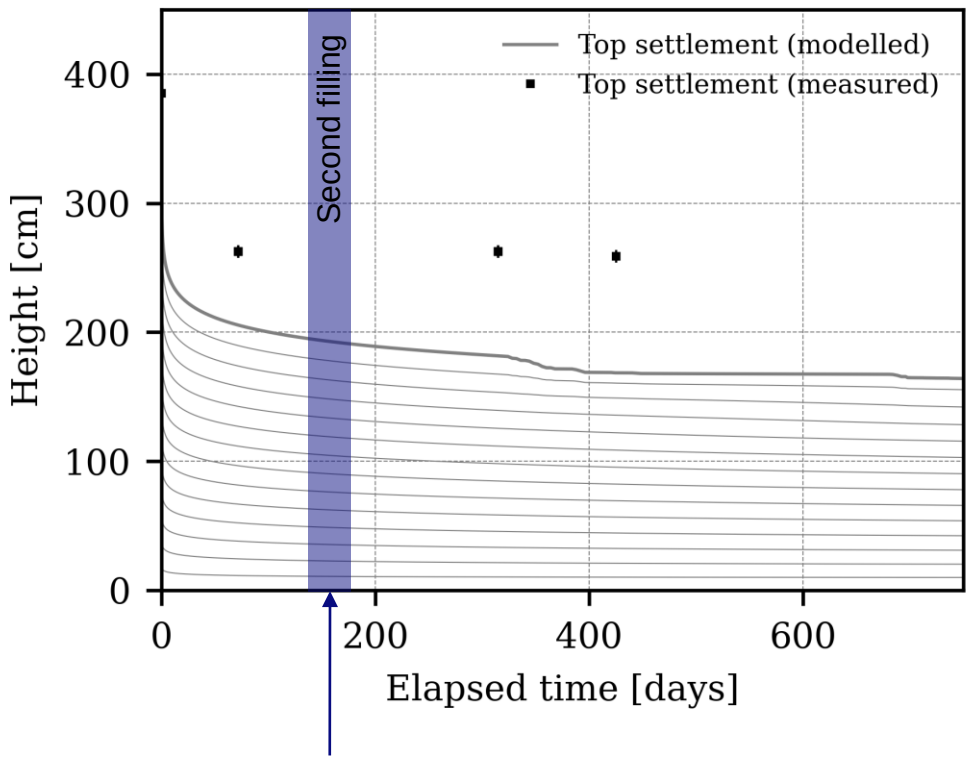
Modeled vs. measured settlement for Compartment 3 – Location 8 (Loc8), scenario 1



Not included in computations!

	Parameters/Material	Loc 8 (2021) Relatively muddy
Shrinkage	A_{sh}	0.43
	B_{sh}	0.43
	C_{sh}	2.7
	ν_h	1
	ξ_h	1
Water retention	WCR	0.2
	WCS	3
	α_{WRC}	3
	n_{WRC}	1.15
	m_{WRC}	0.13
	a-modified	100000
Permeability	A	1.15
	B	5.2
	δ	3
	ϵ_{dess}	-
	ξ_{dess}	-
	d_{dess}	-

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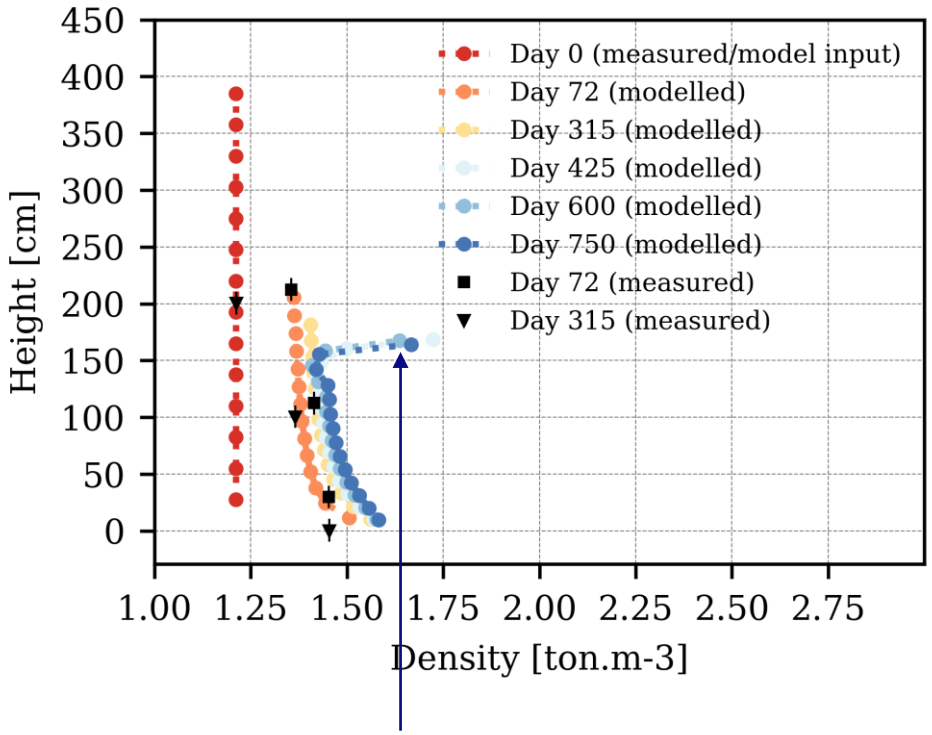
Model vs. measured density for Compartment 3 – Location 8 (Loc8), scenario 1



	Parameters/Material	Loc 8 (2021) Relatively muddy
Shrinkage	A_{sh}	0.43
	B_{sh}	0.43
	C_{sh}	2.7
	ν_h	1
	ξ_h	1
Water retention	WCR	0.2
	WCS	3
	α_{WRC}	3
	n_{WRC}	1.15
	m_{WRC}	0.13
	a-modified	100000
Permeability	A	1.15
	B	5.2
	δ	3
	ϵ_{dess}	-
	ξ_{dess}	-
	d_{dess}	-

Model predicts crust formation: at Loc8 likely did not happen, deposit was submerged

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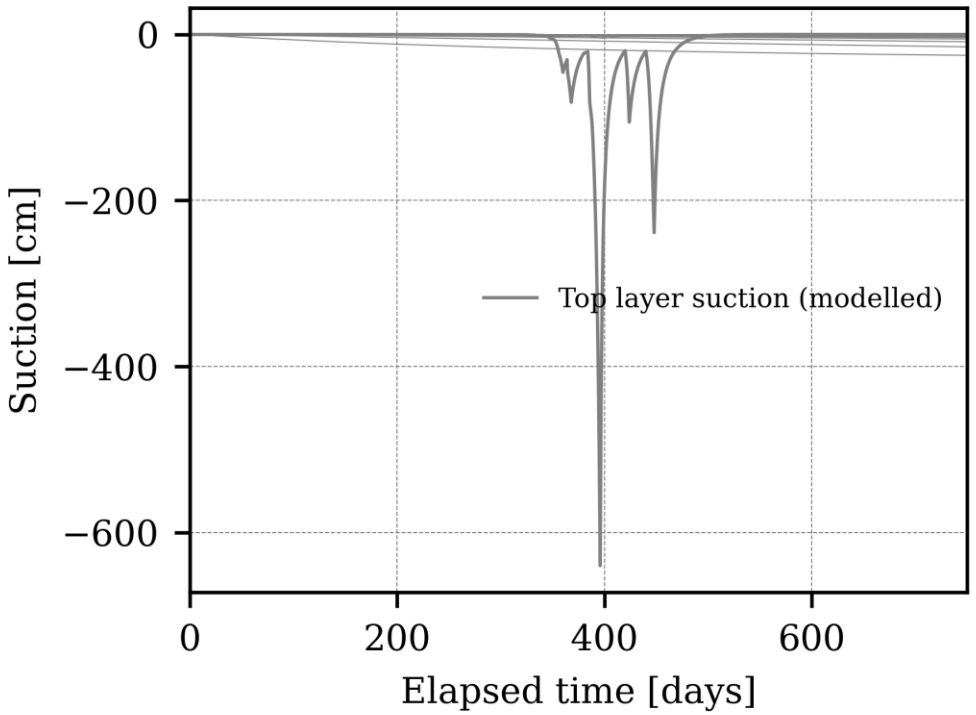
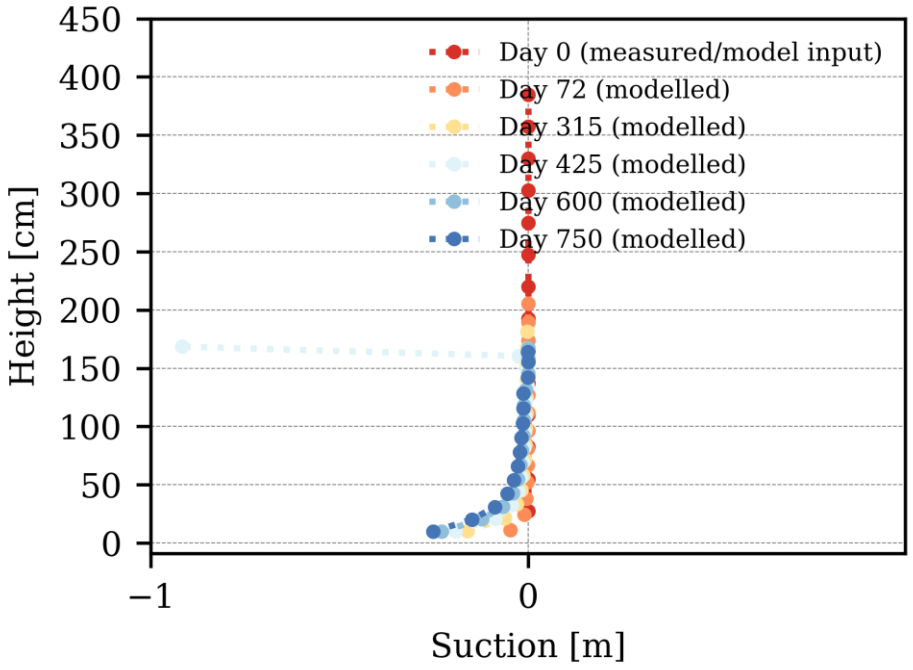
Modeled top layer suction for Compartment 3 – Location 8 (Loc8), scenario 1



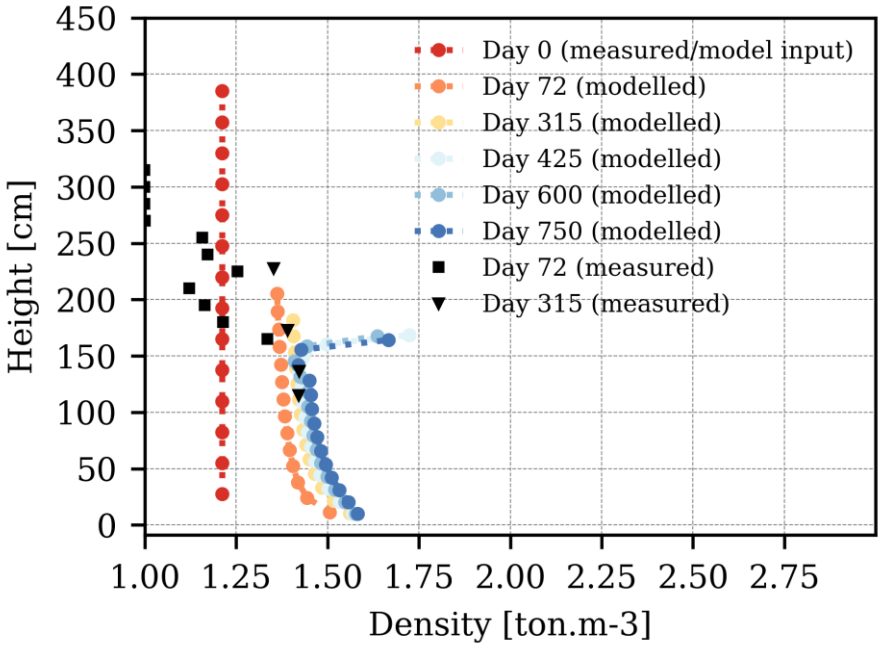
	Parameters/Material	Loc 8 (2021) Relatively muddy
Shrinkage	A_{sh}	0.43
	B_{sh}	0.43
	C_{sh}	2.7
	ν_h	1
	ξ_h	1
Water retention	WCR	0.2
	WCS	3
	α_{WRC}	3
	n_{WRC}	1.15
	m_{WRC}	0.13
	a-modified	100000
Permeability	A	1.15
	B	5.2
	δ	3
	ϵ_{dess}	-
	ξ_{dess}	-
	d_{dess}	-

Modeled suction for Compartment 3 – Location 8 (Loc8), scenario 1



	Parameters/Material	Loc 8 (2021) Relatively muddy
Shrinkage	A_{sh}	0.43
	B_{sh}	0.43
	C_{sh}	2.7
	ν_h	1
	ξ_h	1
Water retention	WCR	0.2
	WCS	3
	α_{WRC}	3
	n_{WRC}	1.15
	m_{WRC}	0.13
	a-modified	100000
Permeability	A	1.15
	B	5.2
	δ	3
	ϵ_{dess}	-
	ξ_{dess}	-
	d_{dess}	-

Model vs. measured density for Compartment 3 – Location 8 (Loc8), scenario 1



Rheotune (S9_nov2019 and 102_jul2020)

	Parameters/Material	Loc 8 (2021)
		Relatively muddy
Shrinkage	A_{sh}	0.43
	B_{sh}	0.43
	C_{sh}	2.7
	ν_h	1
	ξ_h	1
Water retention	WCR	0.2
	WCS	3
	α_{WRC}	3
	n_{WRC}	1.15
	m_{WRC}	0.13
	a-modified	100000
Permeability	A	1.15
	B	5.2
	δ	3
	ϵ_{dess}	-
	ξ_{dess}	-
	d_{dess}	-

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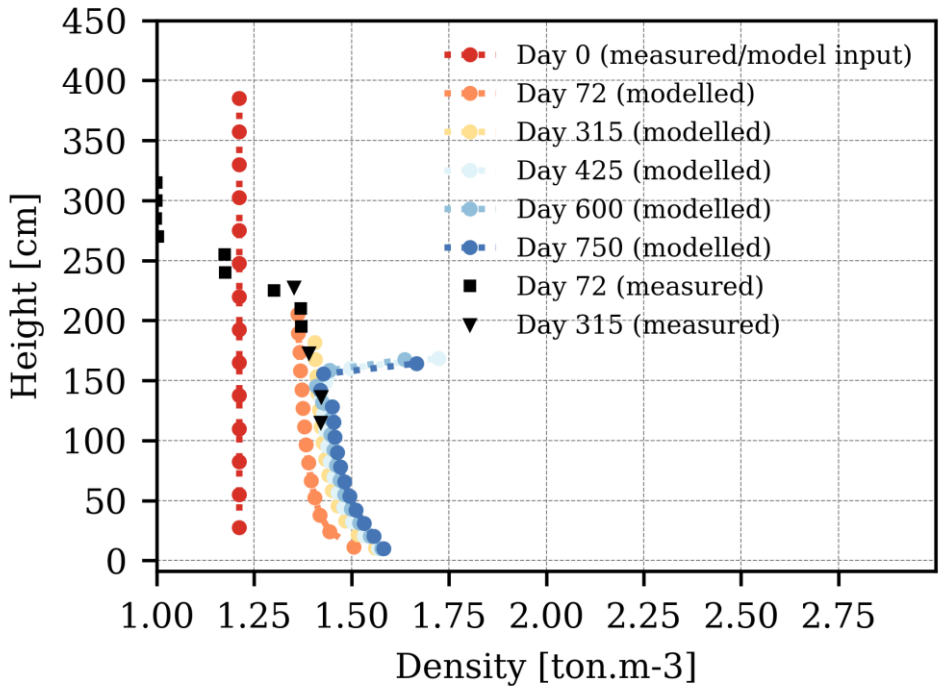
Model vs. measured density for Compartment 3 – Location 8 (Loc8), scenario 1



		Loc 8 (2021)
	Parameters/Material	Relatively muddy
Shrinkage	A_{sh}	0.43
	B_{sh}	0.43
	C_{sh}	2.7
	ν_h	1
	ξ_h	1
Water retention	WCR	0.2
	WCS	3
	α_{WRC}	3
	n_{WRC}	1.15
	m_{WRC}	0.13
	a-modified	100000
Permeability	A	1.15
	B	5.2
	δ	3
	ϵ_{dess}	-
	ξ_{dess}	-
	d_{dess}	-

Rheotune (S9-2_nov2019 and 102_jul2020)

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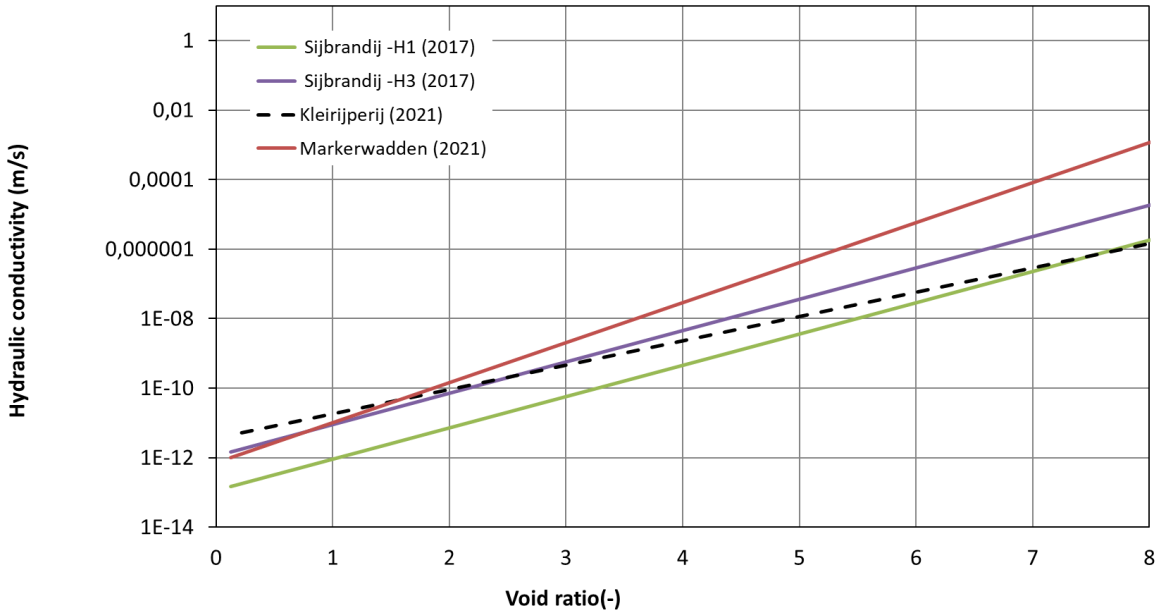
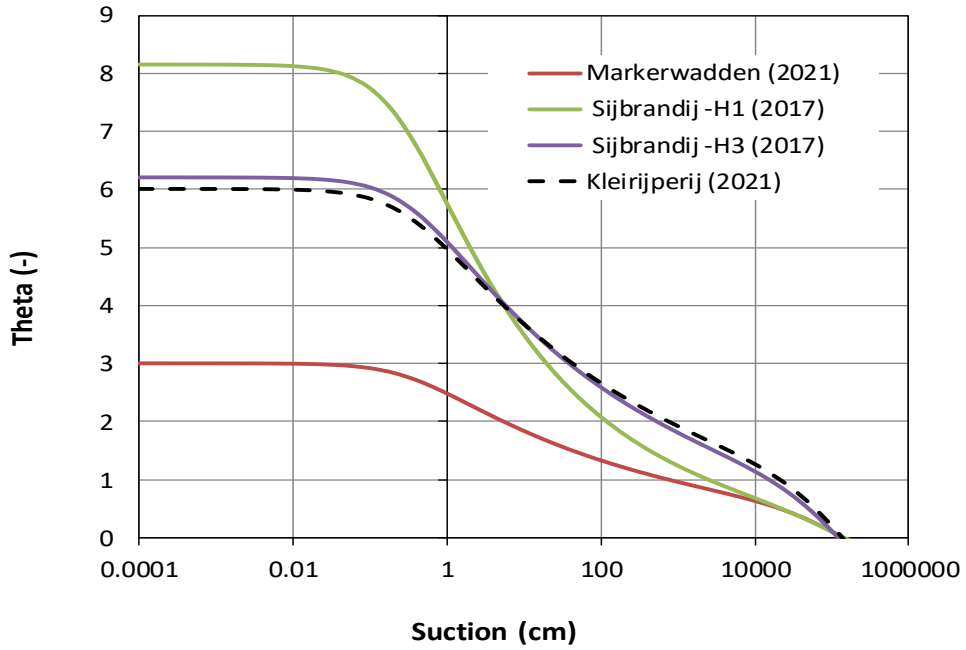
Summary of calibrated material parameters

		Kleirijperij (2021)	Markerwadden (2021)
Shrinkage	**Parameters/Material**	Calibrated for D15	Calibrated for Loc3, also used at Loc8
	A_{sh}	0.43	0.43
	B_{sh}	0.43	0.43
	C_{sh}	2.7	2.7
	ν_h	1	1
	ξ_h	1	1
Water retention	WCR	0.2	0.2
	WCS	**6**	**3**
	α_{WRC}	3	3
	n_{WRC}	1.15	1.15
	m_{WRC}	0.13	0.13
	a-modified	**10000**	**100000**
Permeability	A	**0.7**	**1.15**
	B	**4.5**	**5.2**
	δ	3	3
	ϵ_{dess}	**0.05**	**-**
	ξ_{dess}	**5**	**-**
	d_{dess}	**10**	**-**

Comparing permeability and water retention of Markerwadden deposit with earlier work





Takeaways

- The Vardon model was successfully applied to the Marker Wadden pilot project
  - Calibrated for settlement and applied to two different locations within the pilot compartments

- In general, simulation results are in good agreement with field data for the first year, with regard to both settlements and density profiles.

- This model is suitable for scenario analysis of Marker Wadden pilot project

- Differences between two selected locations:
  - Difference in material properties (sandy vs muddy)
  - Large difference in initial deposit height and initial density (dominant over material properties!)

- Not modelled:
  - Second filling in pilot compartment 3
  - Different exposure to atmosphere due to different deposit heights