Evaluating impacts of sea-level rise on groundwater resources in the Delaware coastal plain using a numerical model

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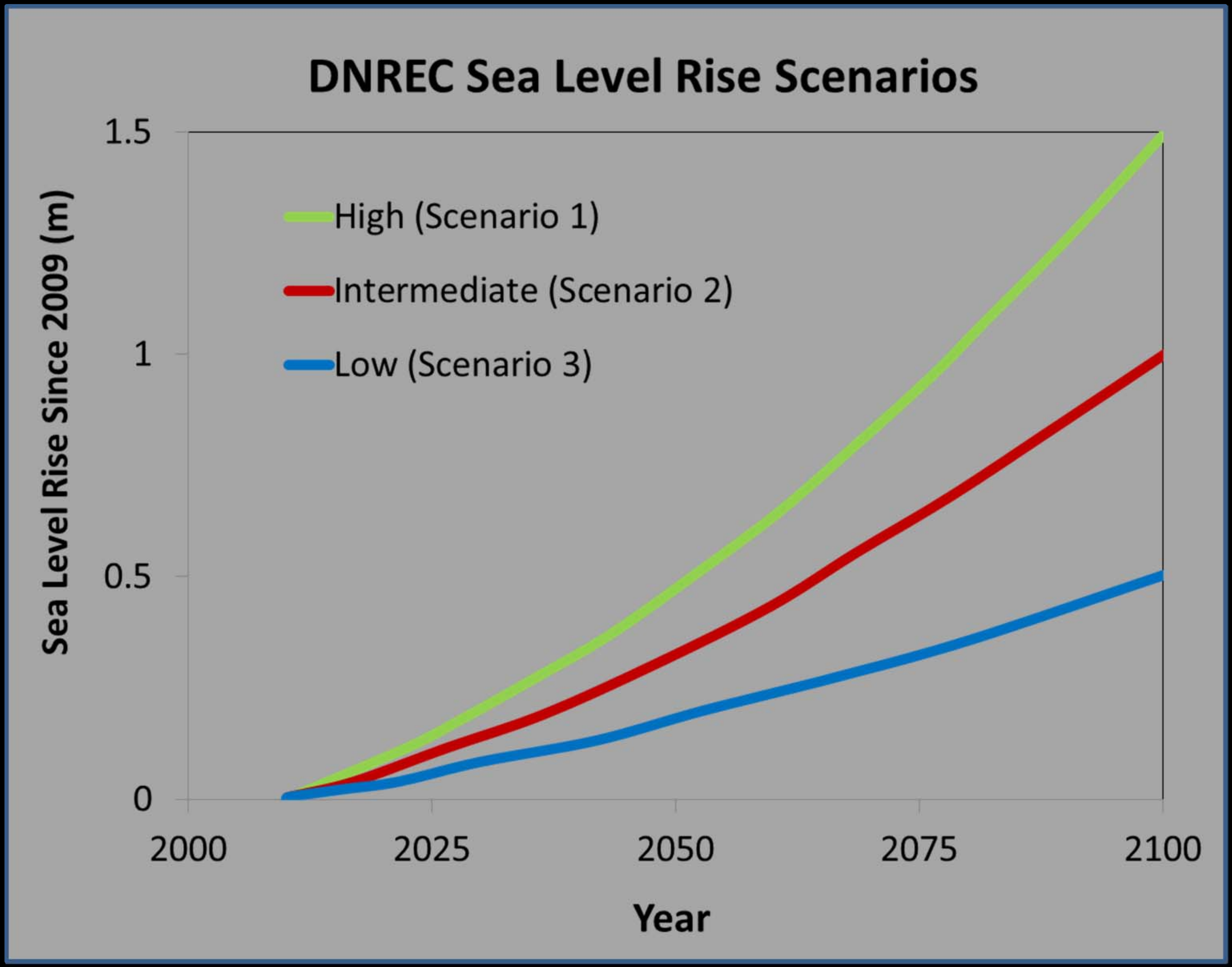
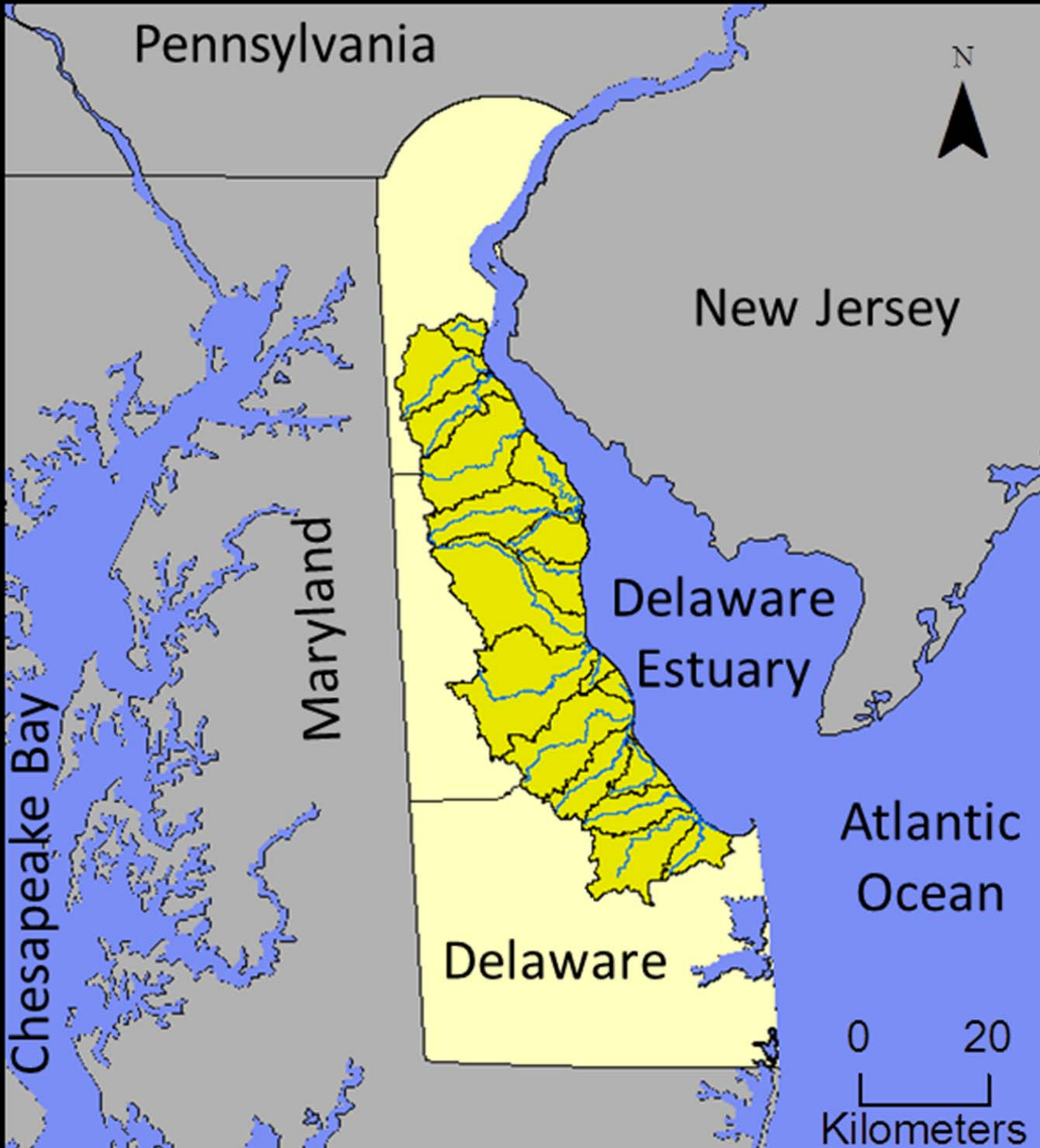
Project funded by:

- Delaware National Estuarine Research Reserve
- NOAA Office of Ocean and Coastal Resource Management
- Delaware Geological Survey



DNREC Sea Level Rise Technical Workgroup (2009)



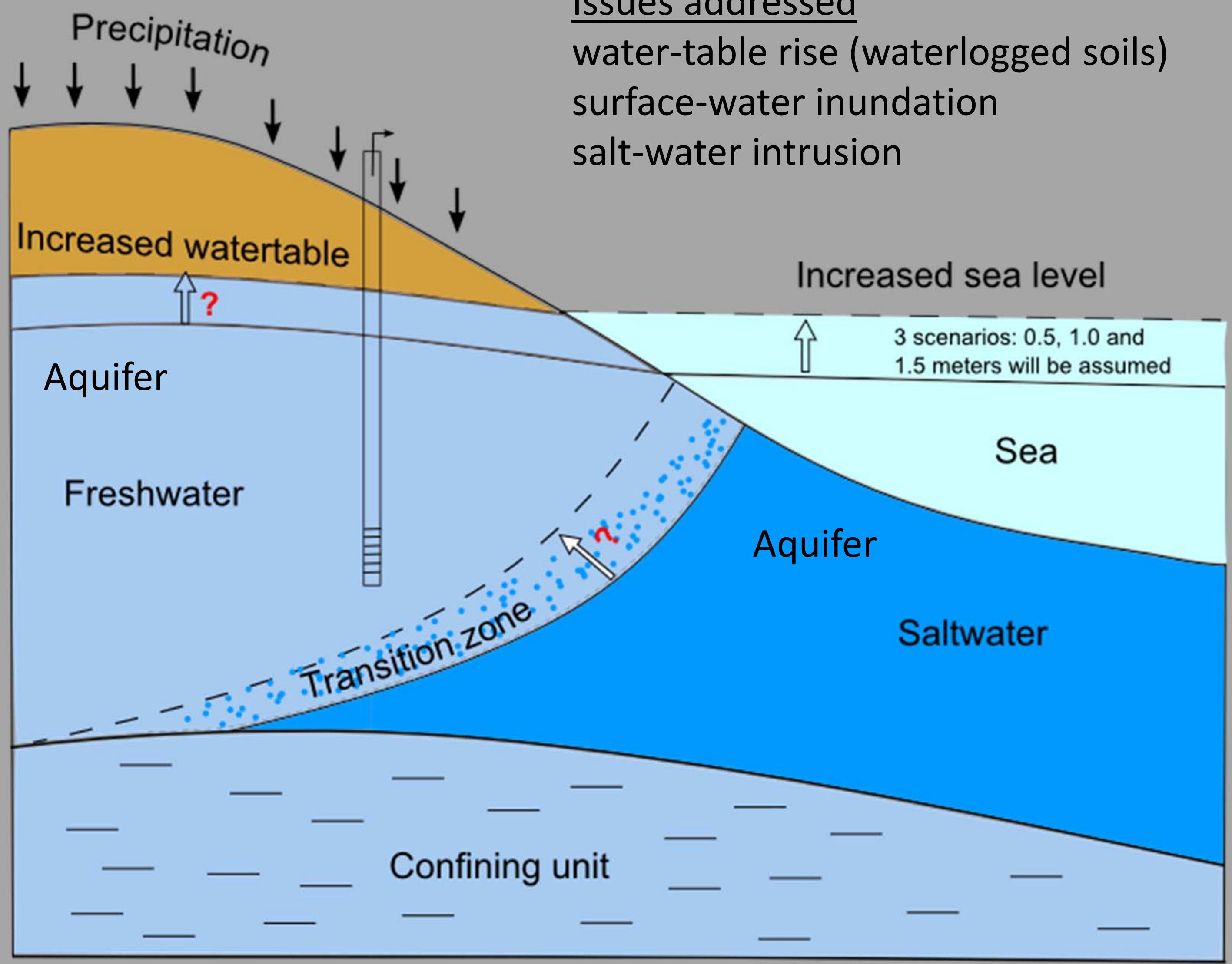
STUDY AREA

Delaware Bay watersheds

Augustine Creek
Appoquinimink River
Blackbird Creek
Smyrna River
Duck Creek
Leipsic River
Muddy Branch
Little River
Saint Jones River
Murderkill River
Brockonbridge Gut
Grecos Canal
Mispillion River
Cedar Creek
Slaughter Creek
Primehook Creek
Broadkill River
Old Mill Creek

Scenarios and Issues

Issues addressed
water-table rise (waterlogged soils)
surface-water inundation
salt-water intrusion



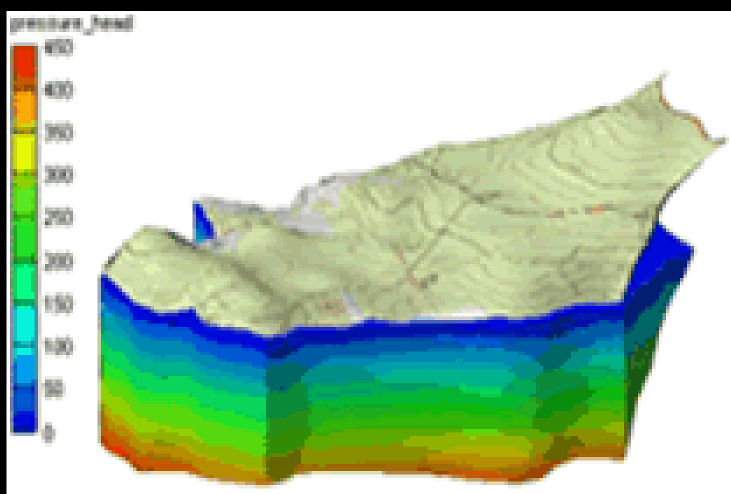
Columbia Aquifer

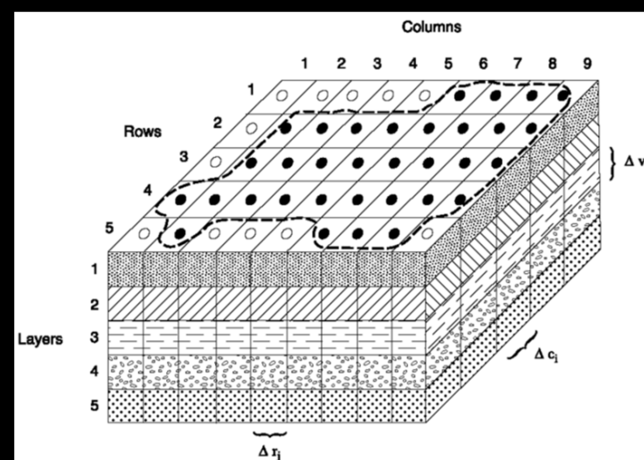
sand & gravel, high permeability

What is a numerical groundwater flow model?

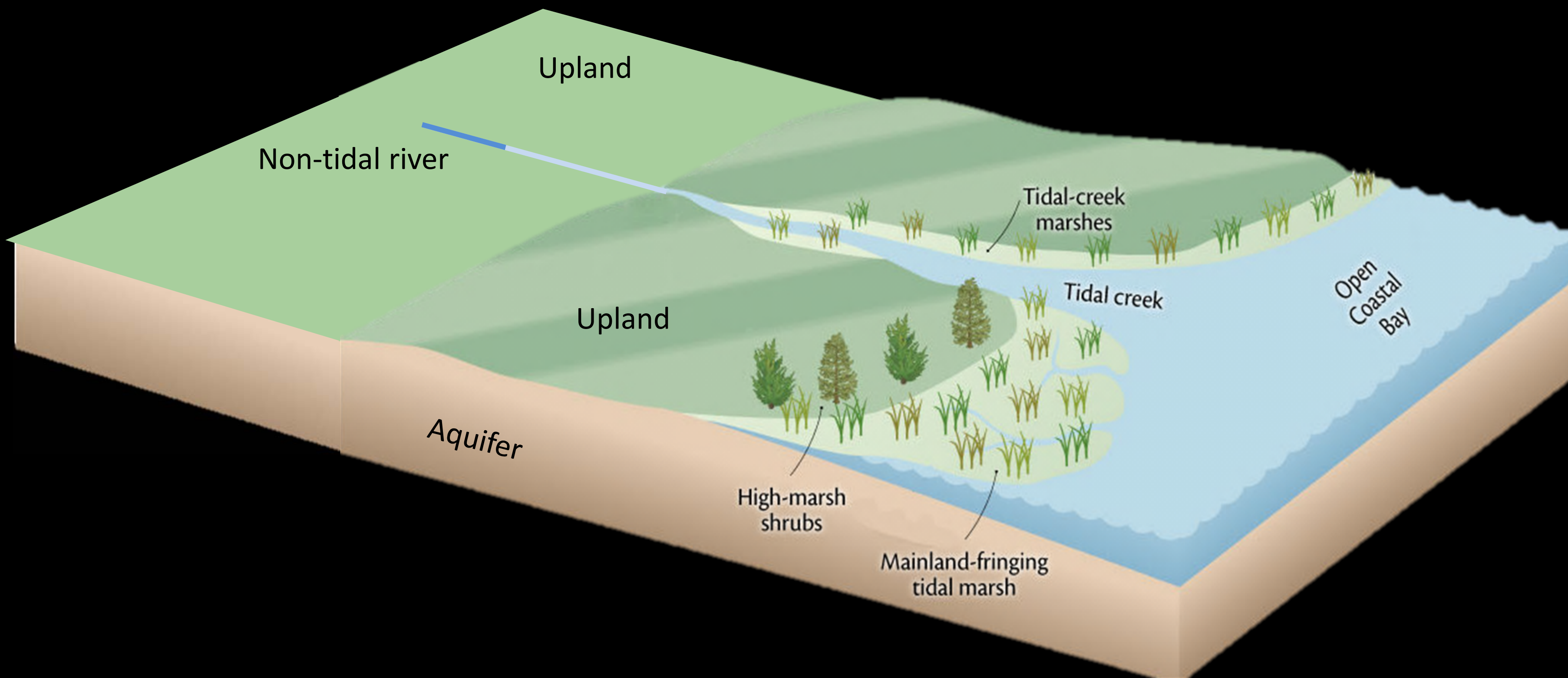
A groundwater flow model is a mathematical representation of a ground water system and includes assumptions and simplifications made for various specific purposes.

$$\frac{\partial}{\partial x}\left(K_x \frac{\partial h}{\partial x}\right)+\frac{\partial}{\partial y}\left(K_y \frac{\partial h}{\partial y}\right)+\frac{\partial}{\partial z}\left(K_z \frac{\partial h}{\partial z}\right)=S_s \frac{\partial h}{\partial t}-R$$





Simple Conceptual Model

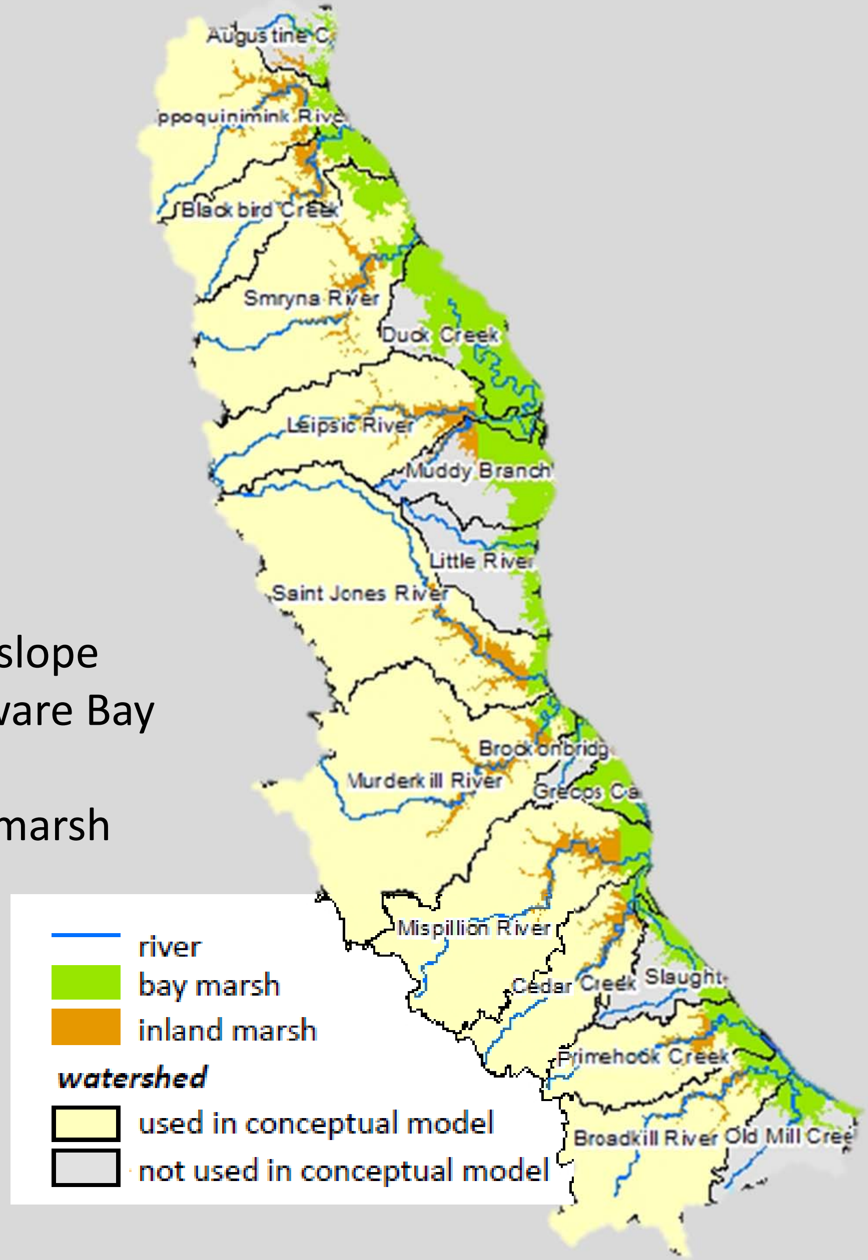


modified from University of Maryland Center for Environmental Science

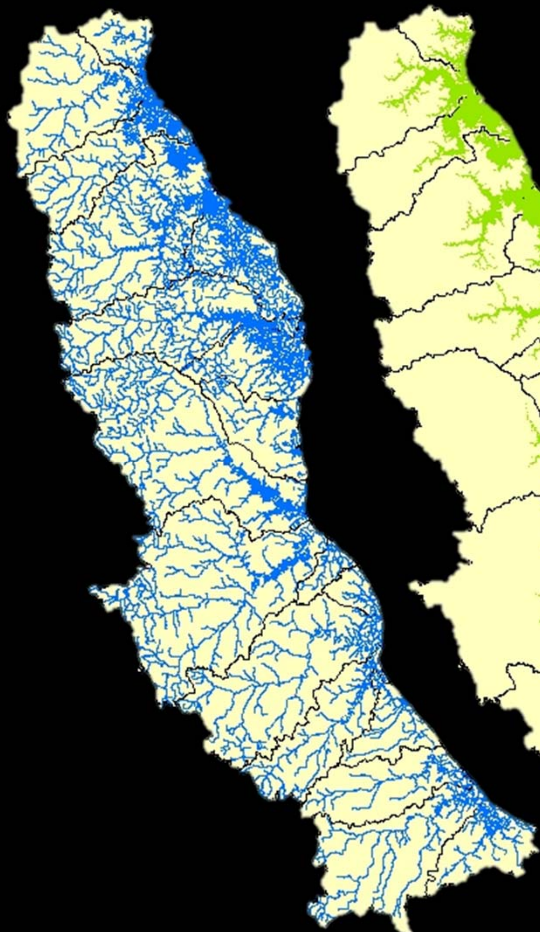
Delaware Bay watersheds, salt marshes, and primary rivers used to develop conceptual model.

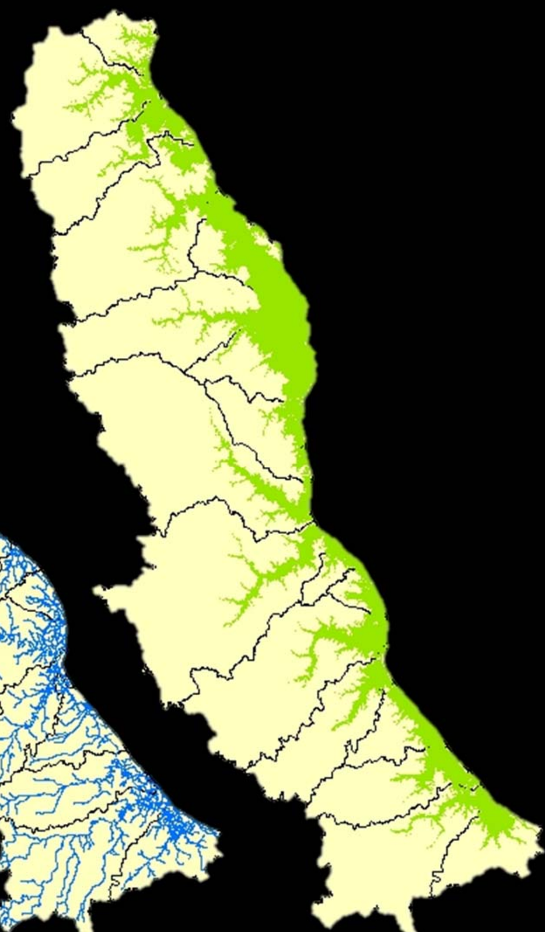
Spatial characteristics used to construct geometry of conceptual model

- Watershed length, width, and area
- Primary river total length, salt-water length, slope
- Bay-marsh width (marshes adjacent to Delaware Bay or behind coastal communities
- Marsh width at 0, 1, and 3 km inland of bay-marsh



Filling in the details of a conceptual model

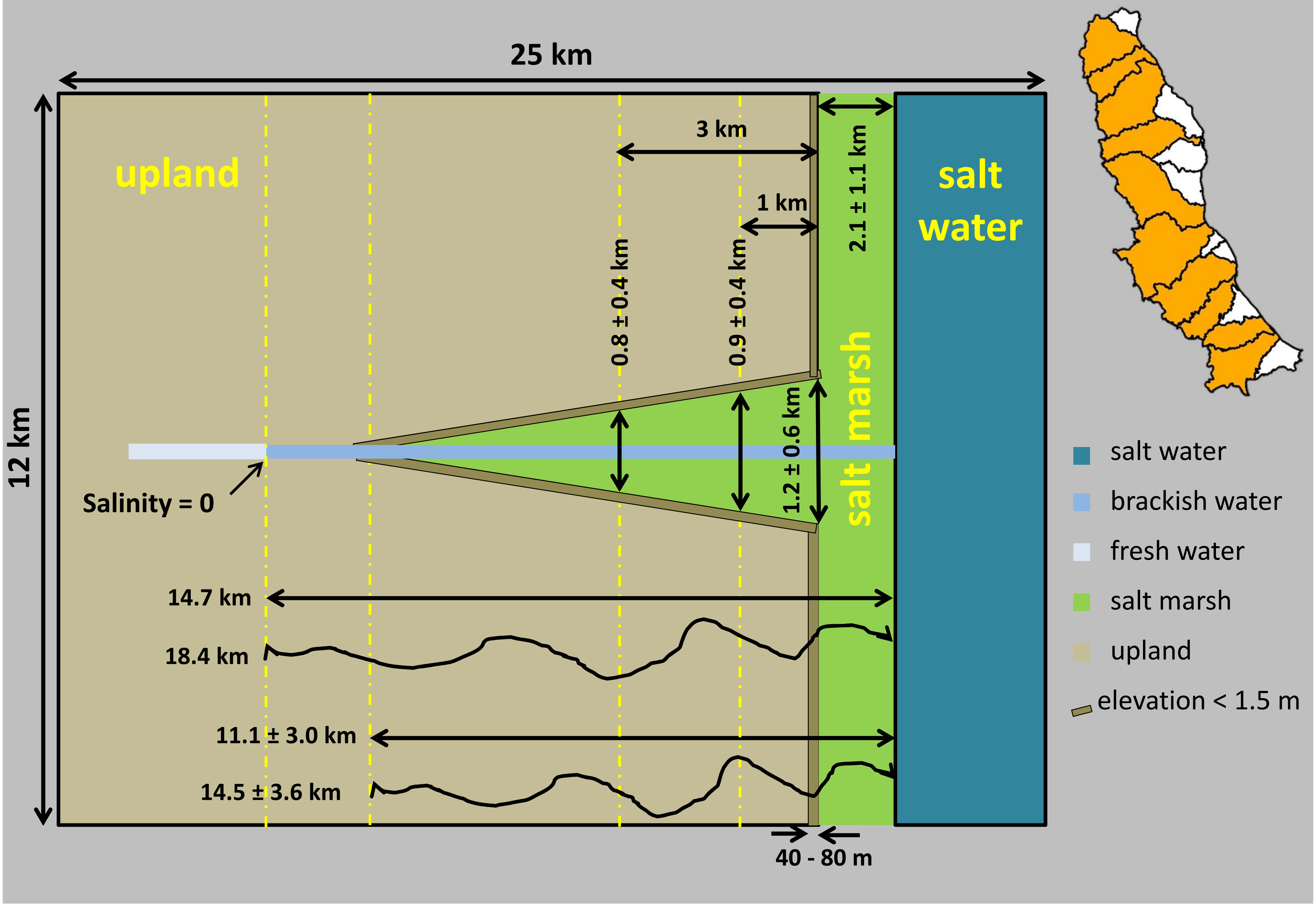




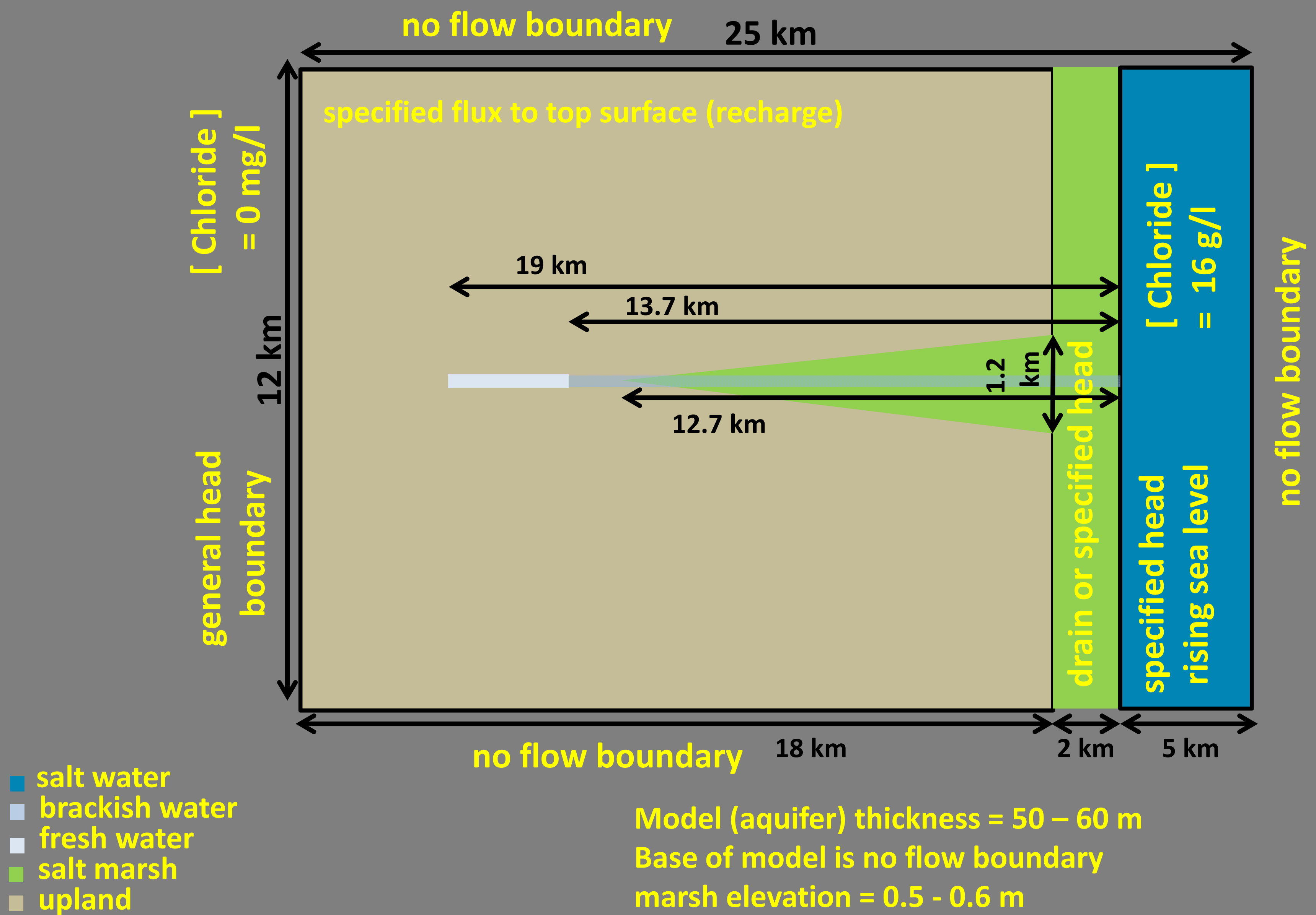
<u>Surface Water</u>
National Hydrology Dataset (NHD)

<u>Tidal wetlands</u>
DNREC State Wetland Mapping Project (SWMP)

Information for building a representative conceptual model



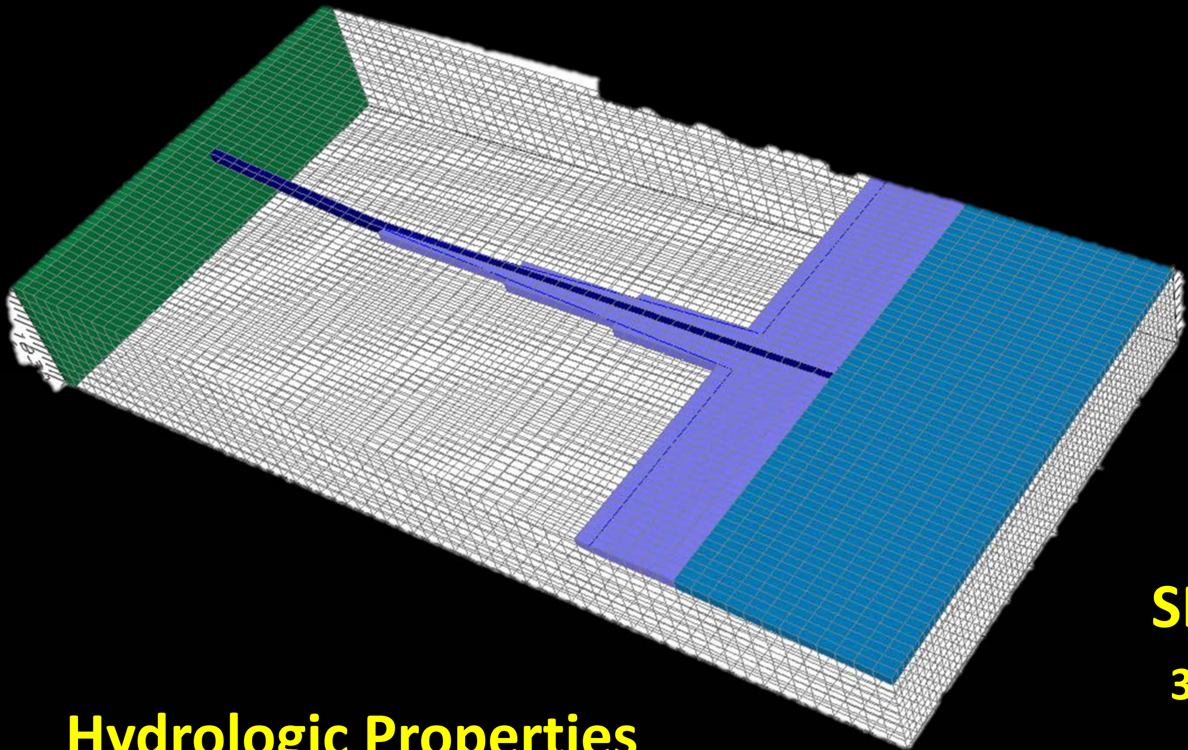
Final conceptual model and boundary conditions



Model (aquifer) thickness = 50 – 60 m
Base of model is no flow boundary
marsh elevation = 0.5 - 0.6 m
Initial condition: 1,000-yr ramp-up to steady-state

Numerical Model

computational mesh



Hydrologic Properties

Model Parameter	Value
Cell size	50 to 400 m
Hydraulic Conductivity	25 m/day
Longitudinal dispersivity	1 m
Effective porosity	0.25
Upland recharge	380 mm/year

SEAWAT simulation code

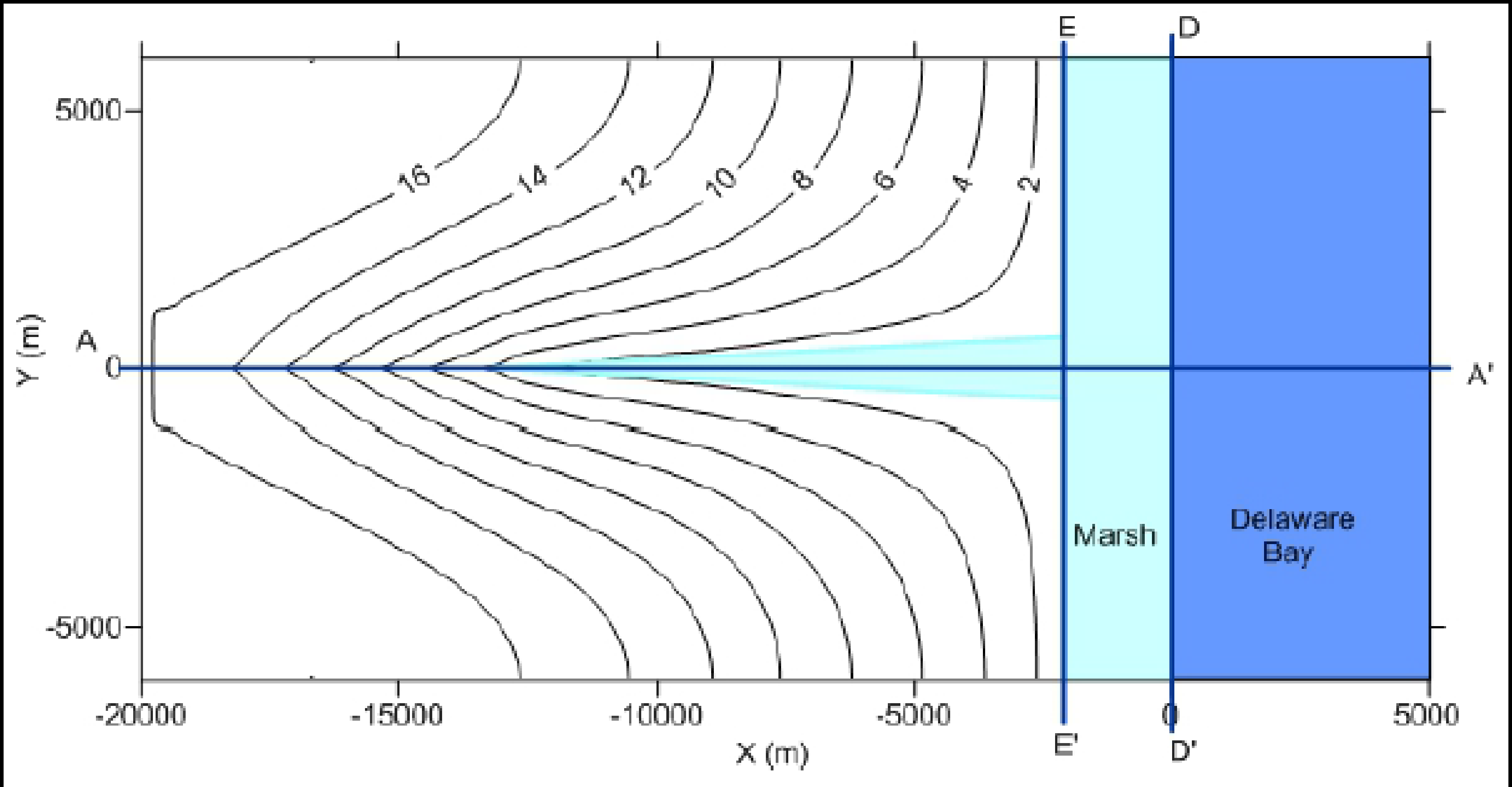
3-D, transient, variable density

Initial condition:
1,000-yr ramp-up to steady-state

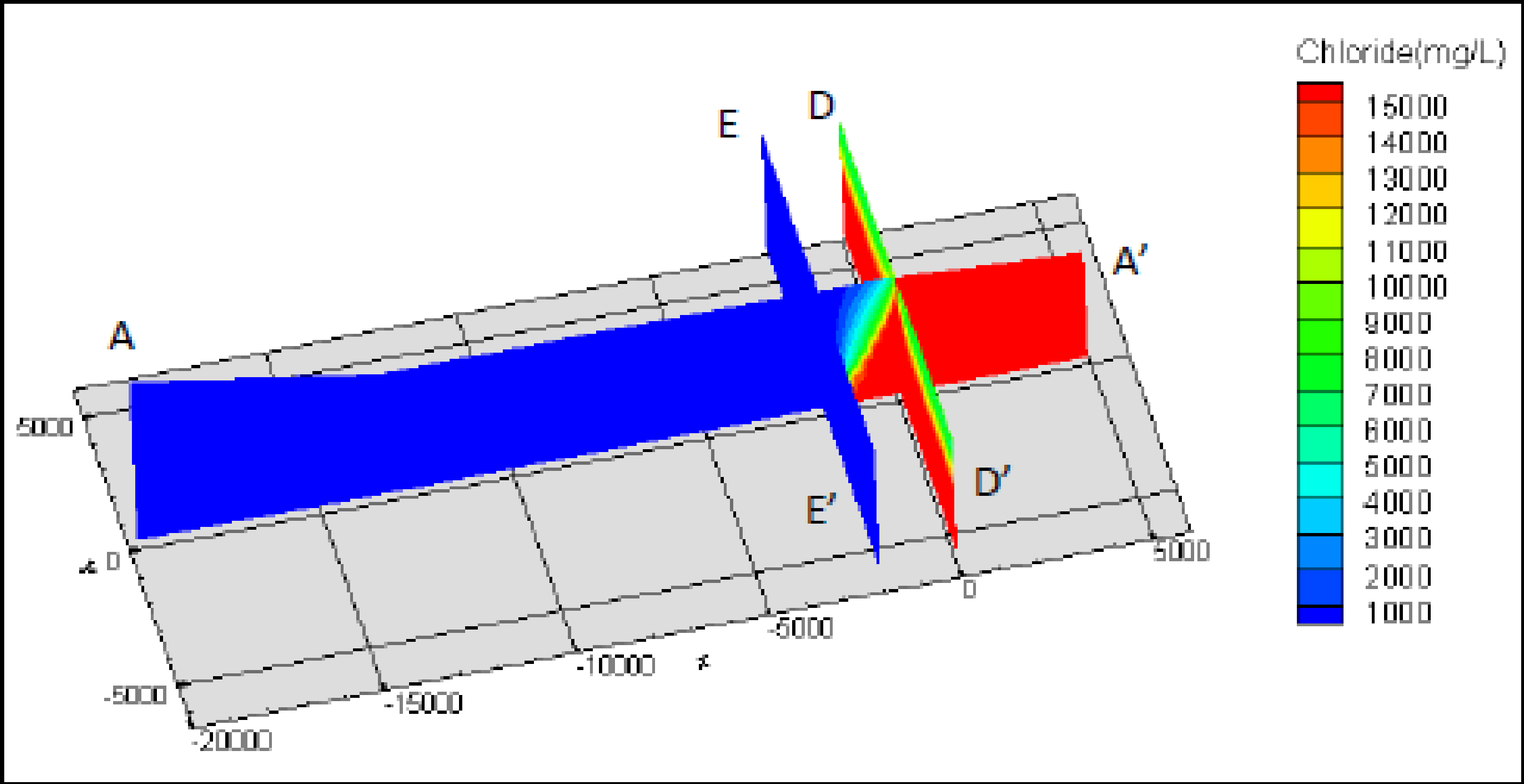
Assumptions:

- Tidal and seasonal variations of sea level are not simulated.
- The river stage and salinity increase through time to account for the effect of a laterally encroaching tidal prism due to sea level rise.
- In areas where the land surface is lower than the rising sea level, the cells in the first layer turn into constant head boundaries.
- The marsh is simulated as a drain. Groundwater discharges to the marsh until the sea level rises above the marsh land surface. Thereafter all submerged cells form a constant head boundary.
- The initial condition was obtained by running the model for 1,000 years with a constant sea level.

Contours of simulated water-table elevation (meters) at end of ramp-up model (1,000 years). This is used as the initial condition for sea-level rise scenarios.



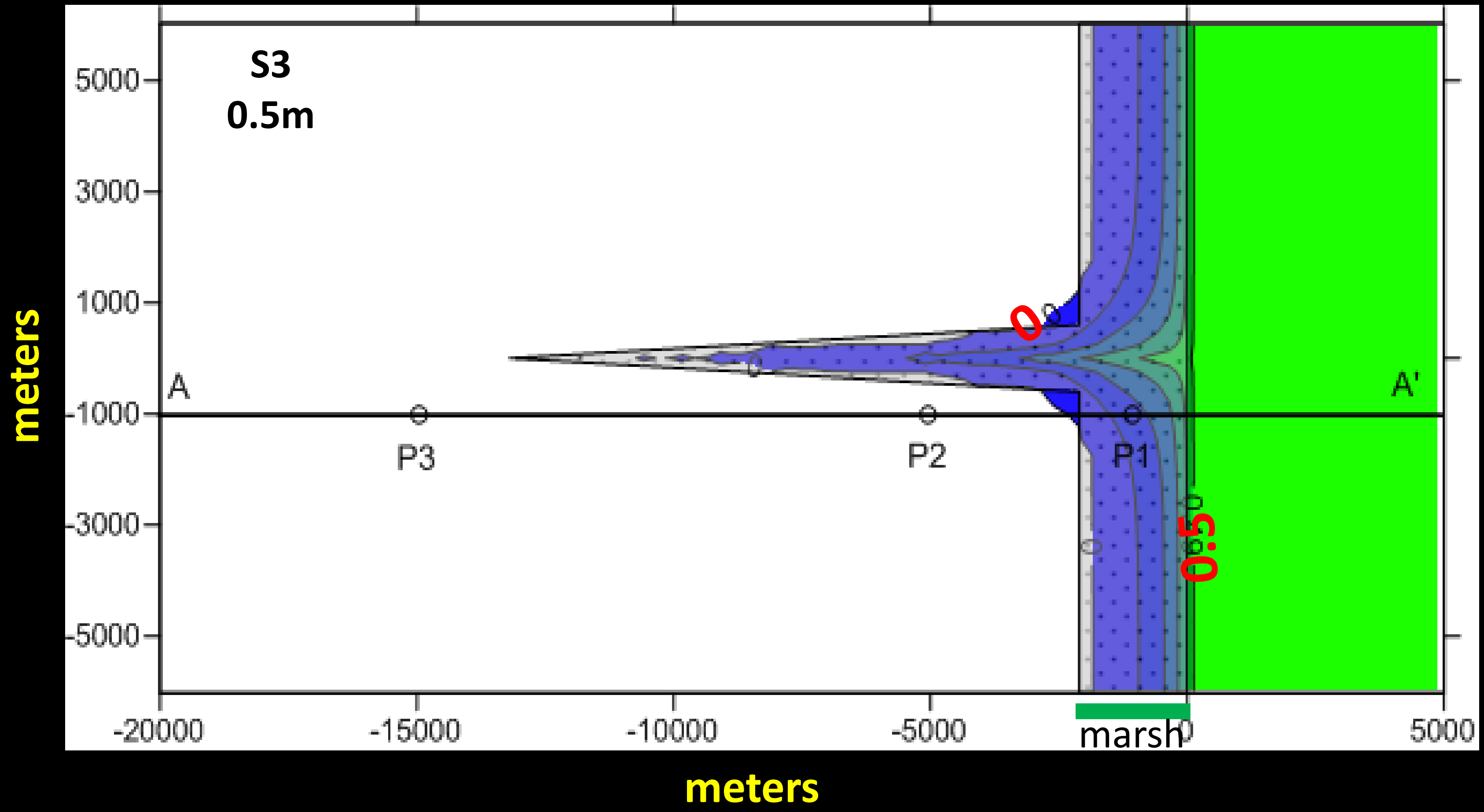
Simulated chloride concentration (mg/L) at end of ramp-up model (1,000 years) along cross sections shown in previous slide. This is used as the initial chloride concentration for sea level rise scenarios.



Results

Simulation results for water table

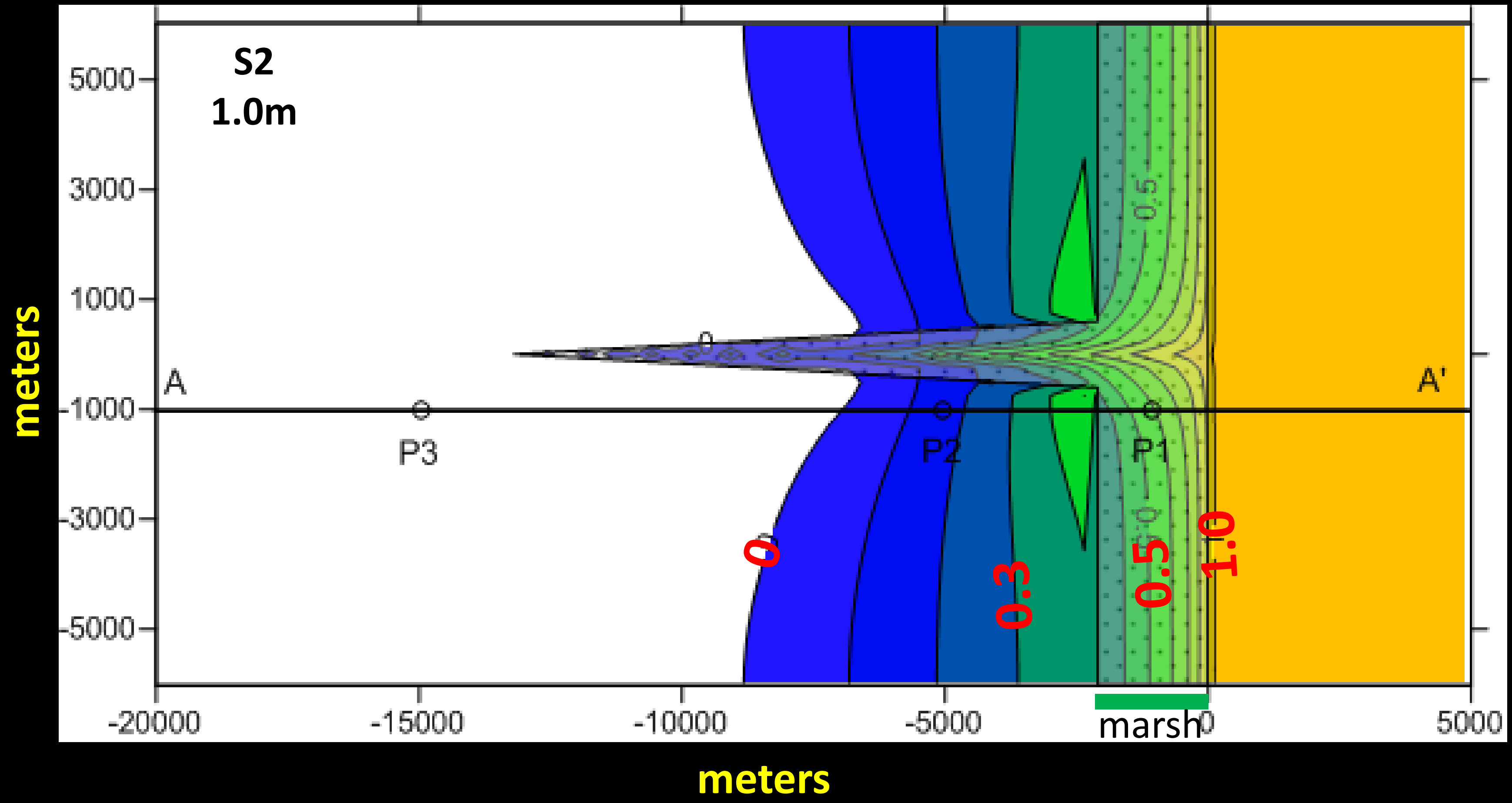
Map view for Scenario 3 (0.5m SLR)



Contour map of head change (m) in the water table aquifer due to sea level rise (year 2100)

Simulation results for water table

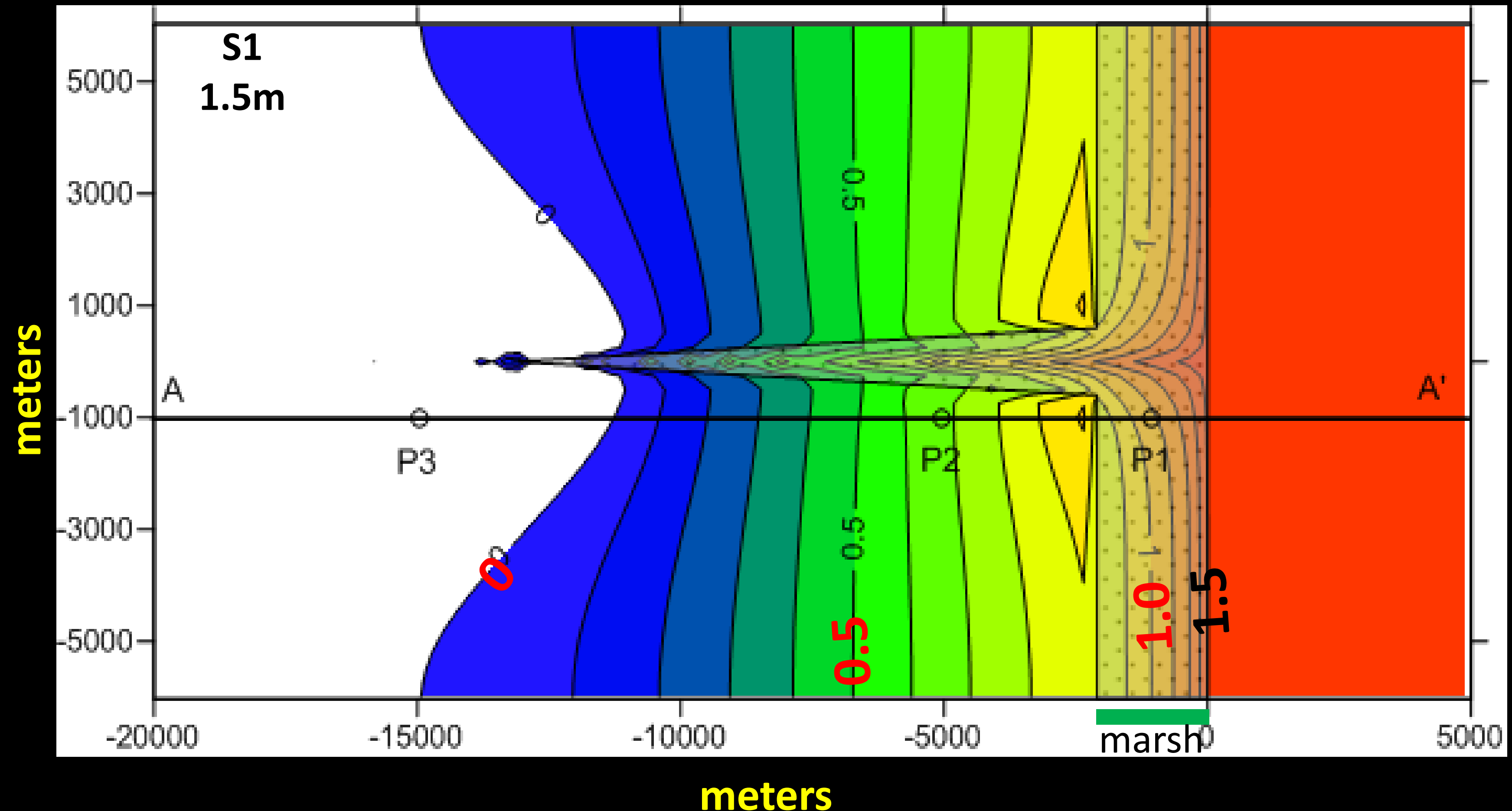
Map view for Scenario 2 (1.0m SLR)



Contour map of head change (m) in the water table aquifer due to sea level rise (year 2100)

Simulation results for water table

Map view for Scenario 1 (1.5m SLR)

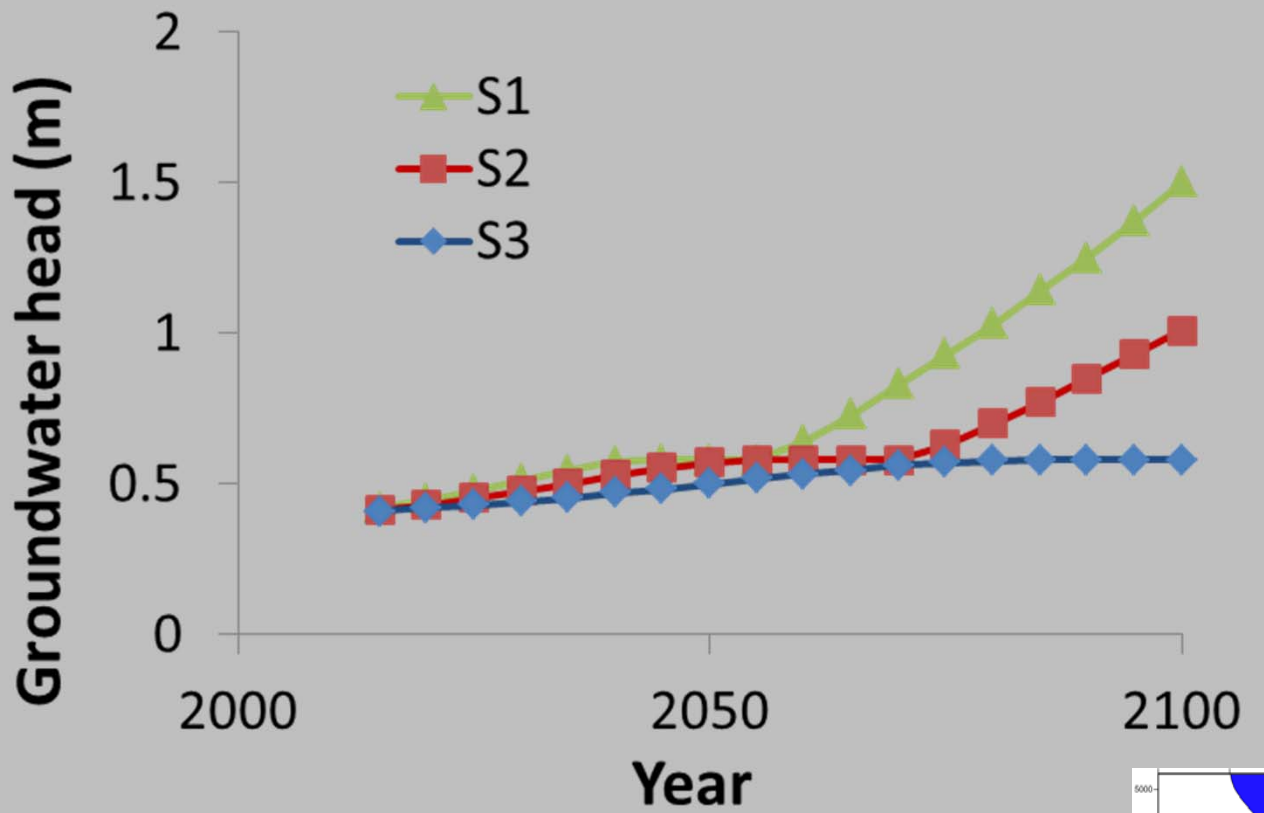


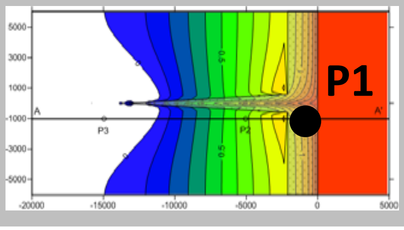
Contour map of head change (m) in the water table aquifer due to sea level rise (year 2100)

Simulation results for water table

Time series of water table changes over time at observation point P1

1 km inland from bay

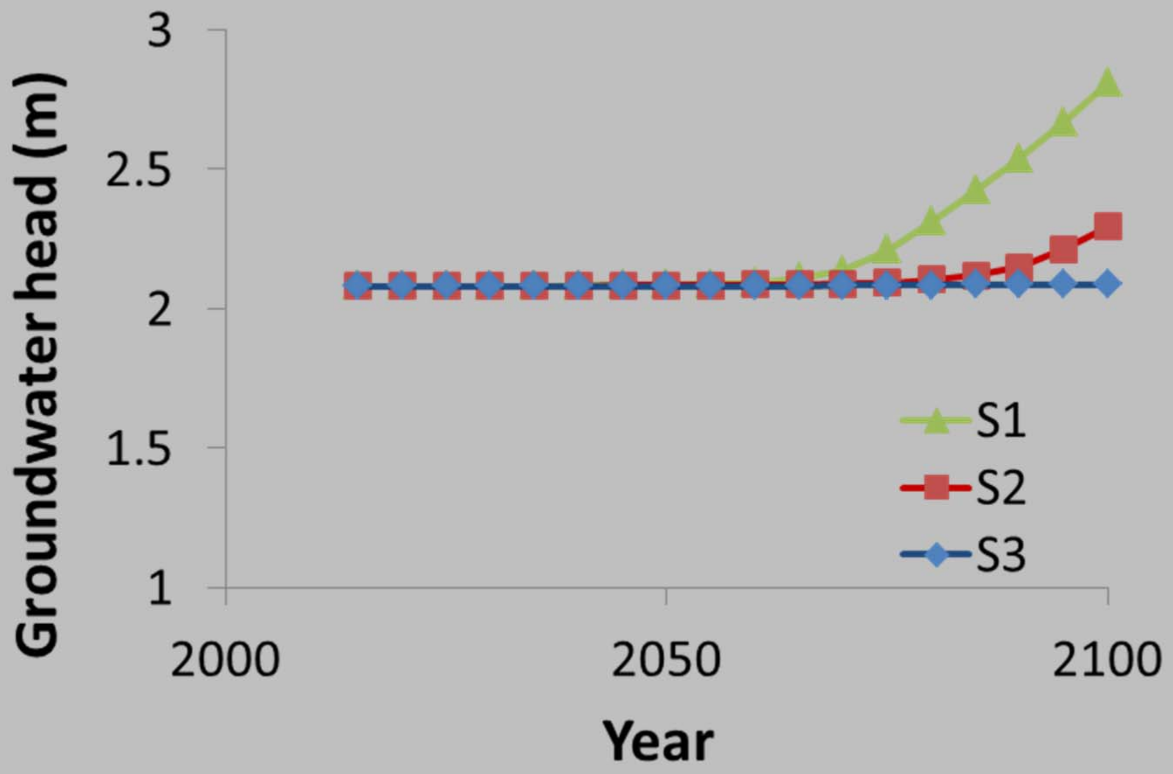


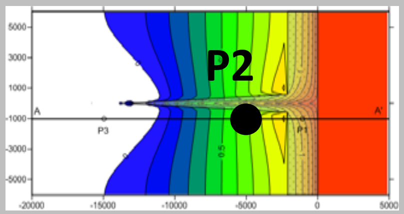


Simulation results for water table

Time series of water table changes over time at observation point P2

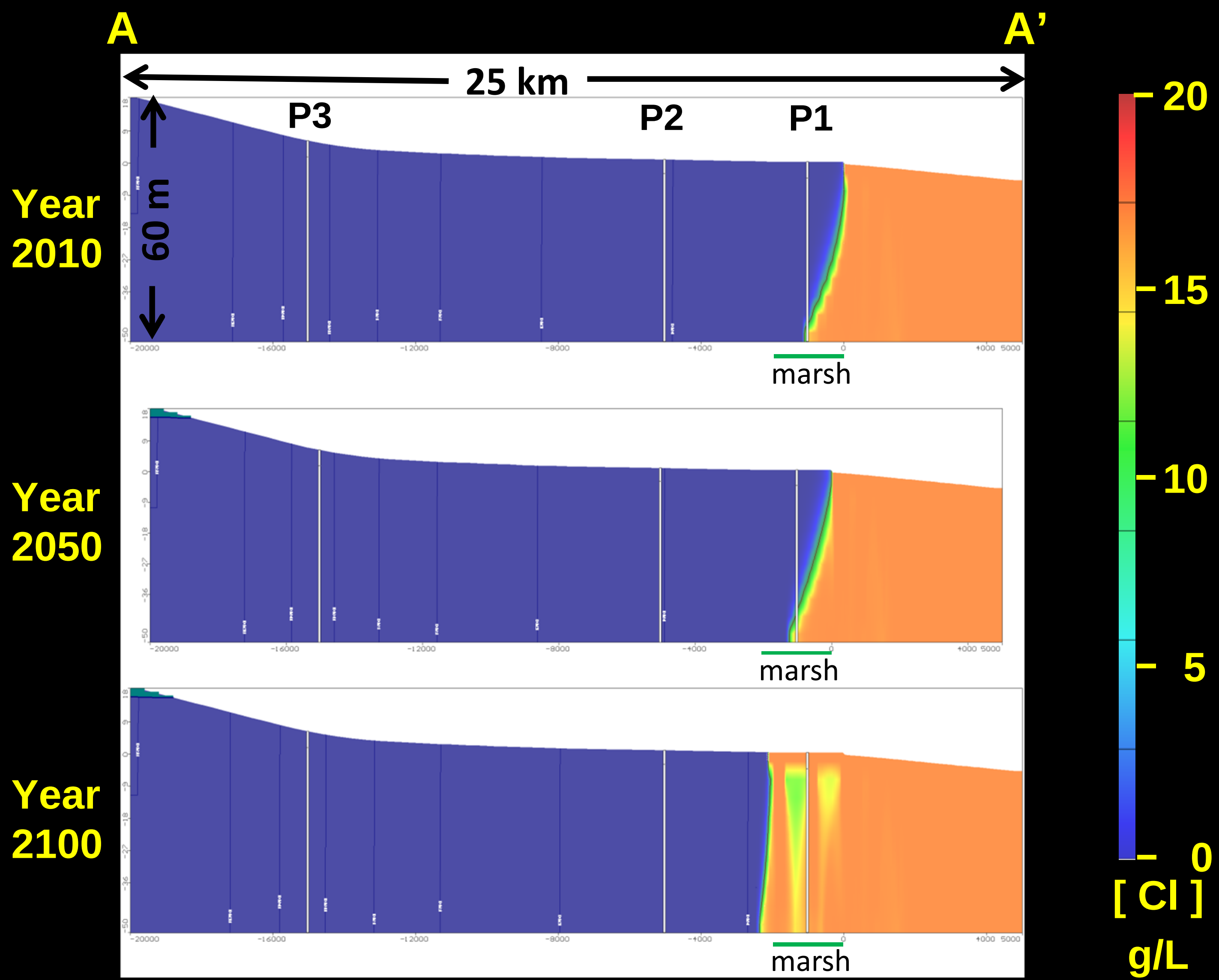
5 km inland from the bay





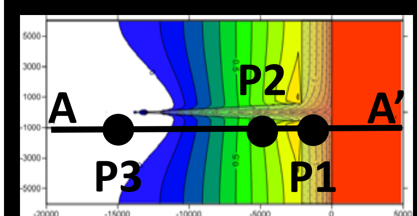
Simulation results for salt-water intrusion

Cross-section view for Scenario S1 (1.5m SLR)

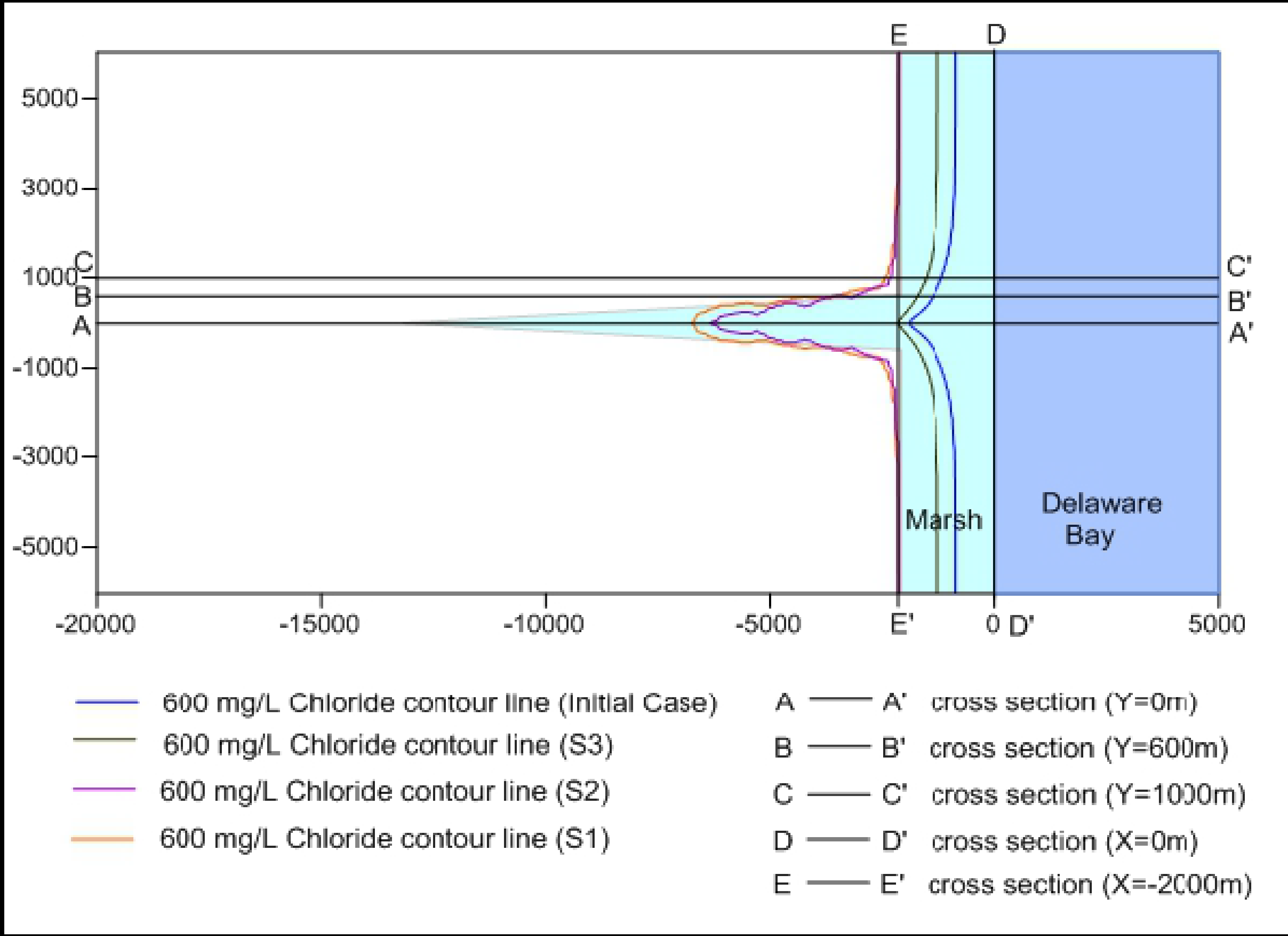


bay-parallel marsh location in 2010

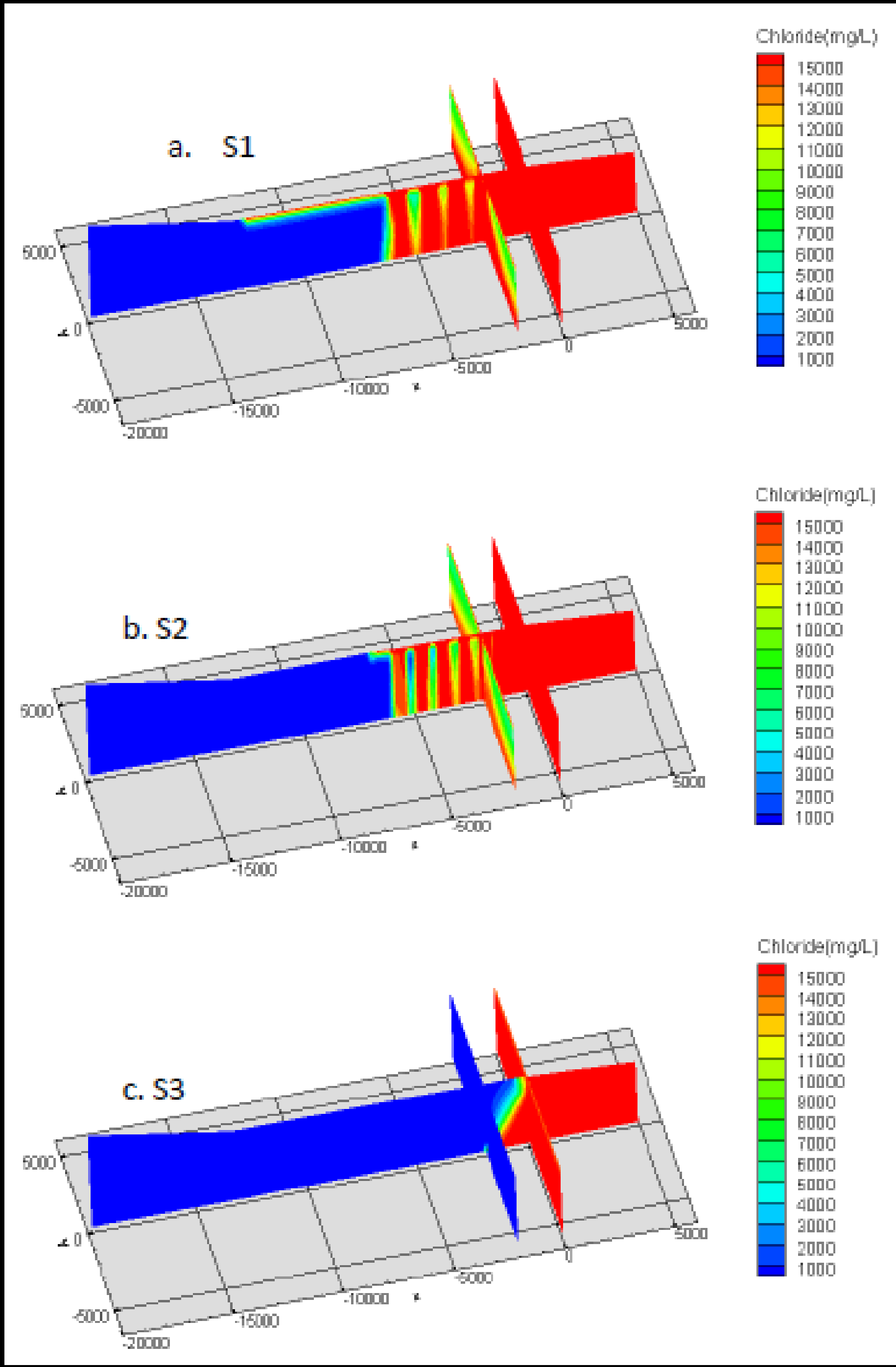
Cross section is 1 km from river



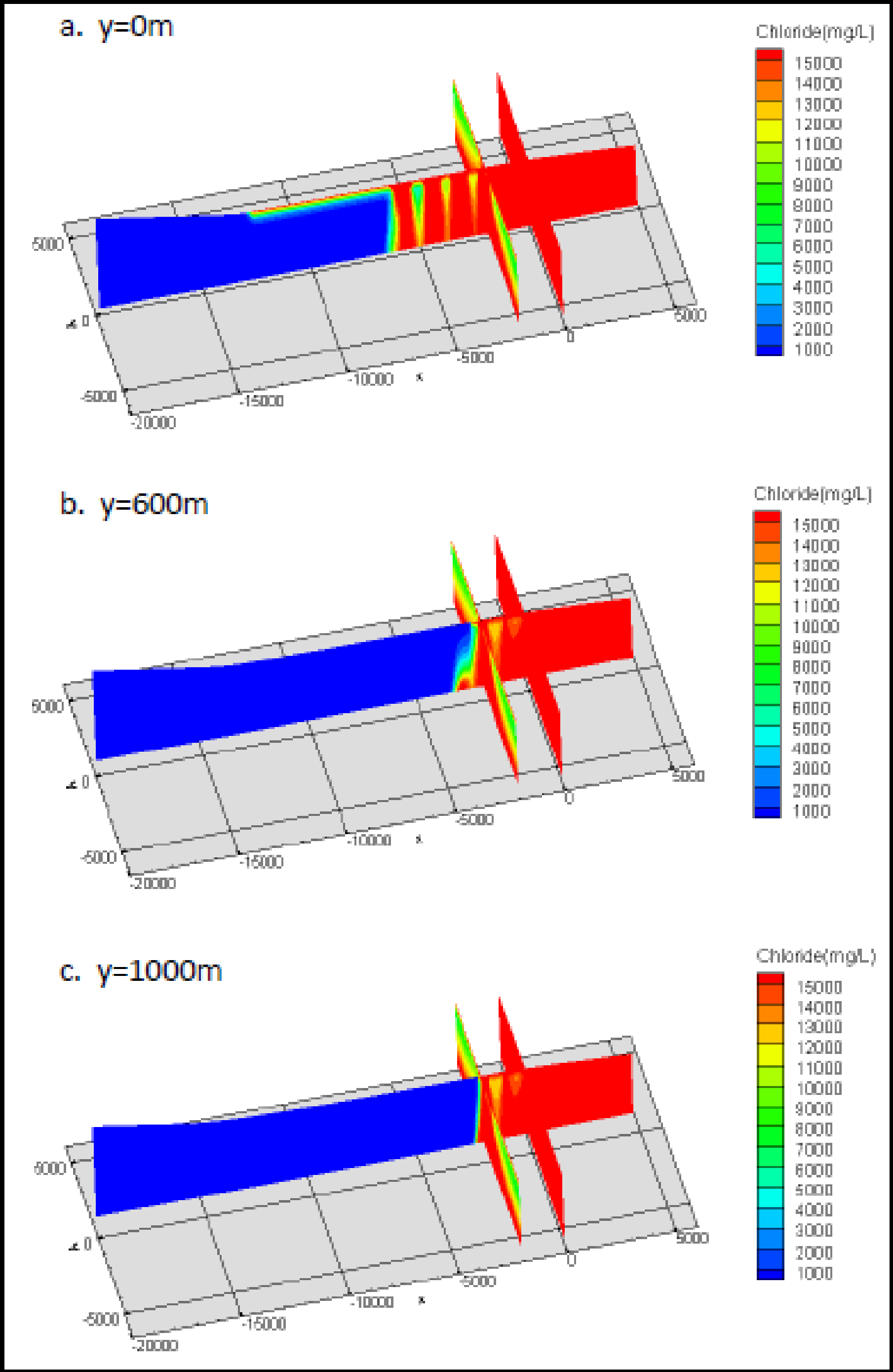
Map with isochlors (600 mg/L [Cl]) for initial case and scenarios S1, S2, and S3.



Chloride distribution under the river at the end of simulation (year 2100) for the three scenarios.

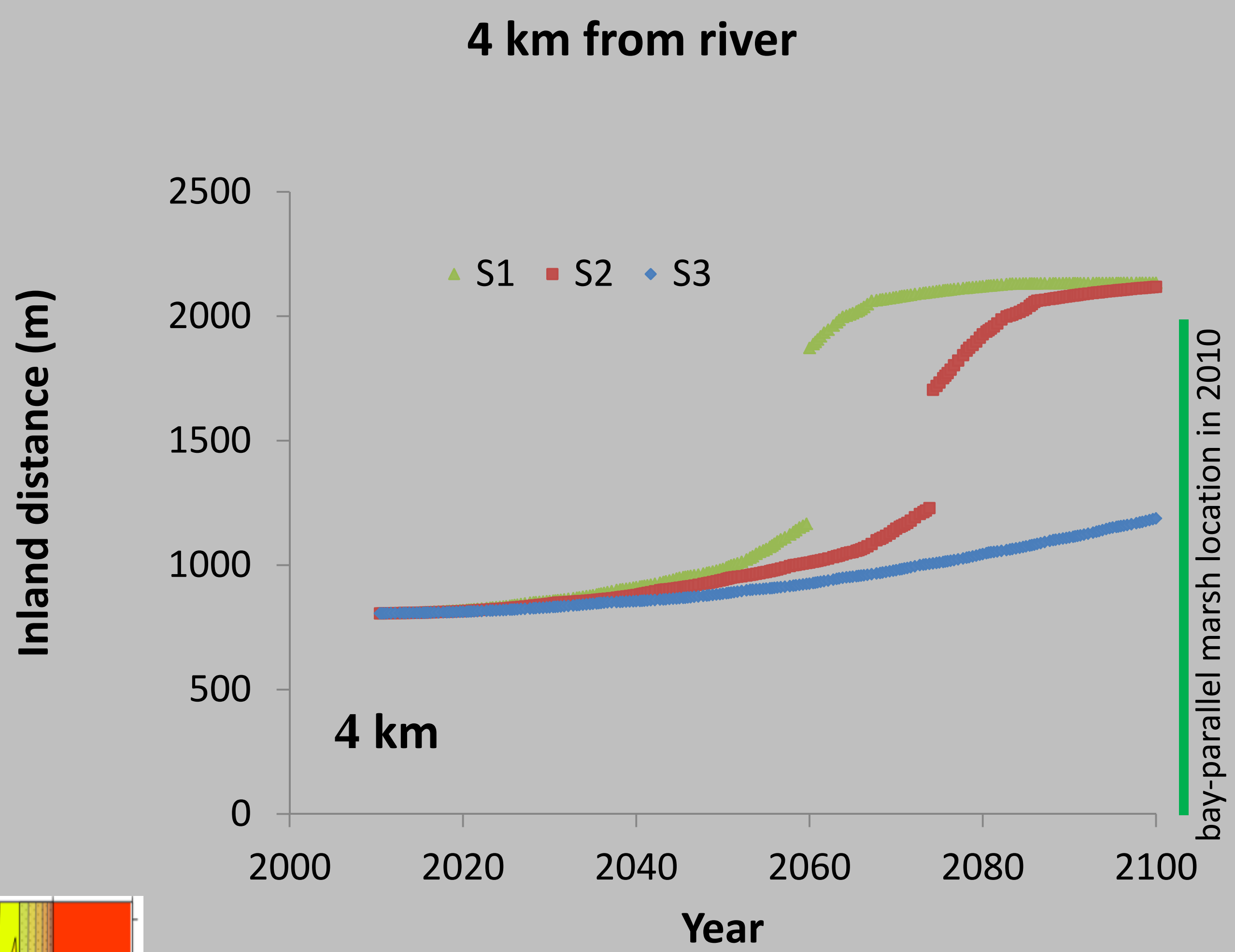


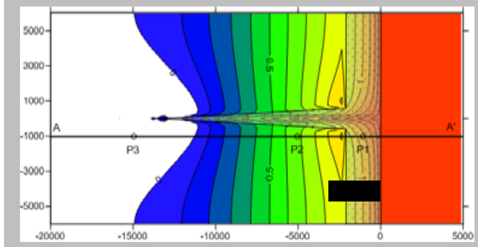
Chloride distribution at the end of simulation (year 2100) in different cross sections for scenario 1 (1.5m).



Simulation results for salt-water intrusion

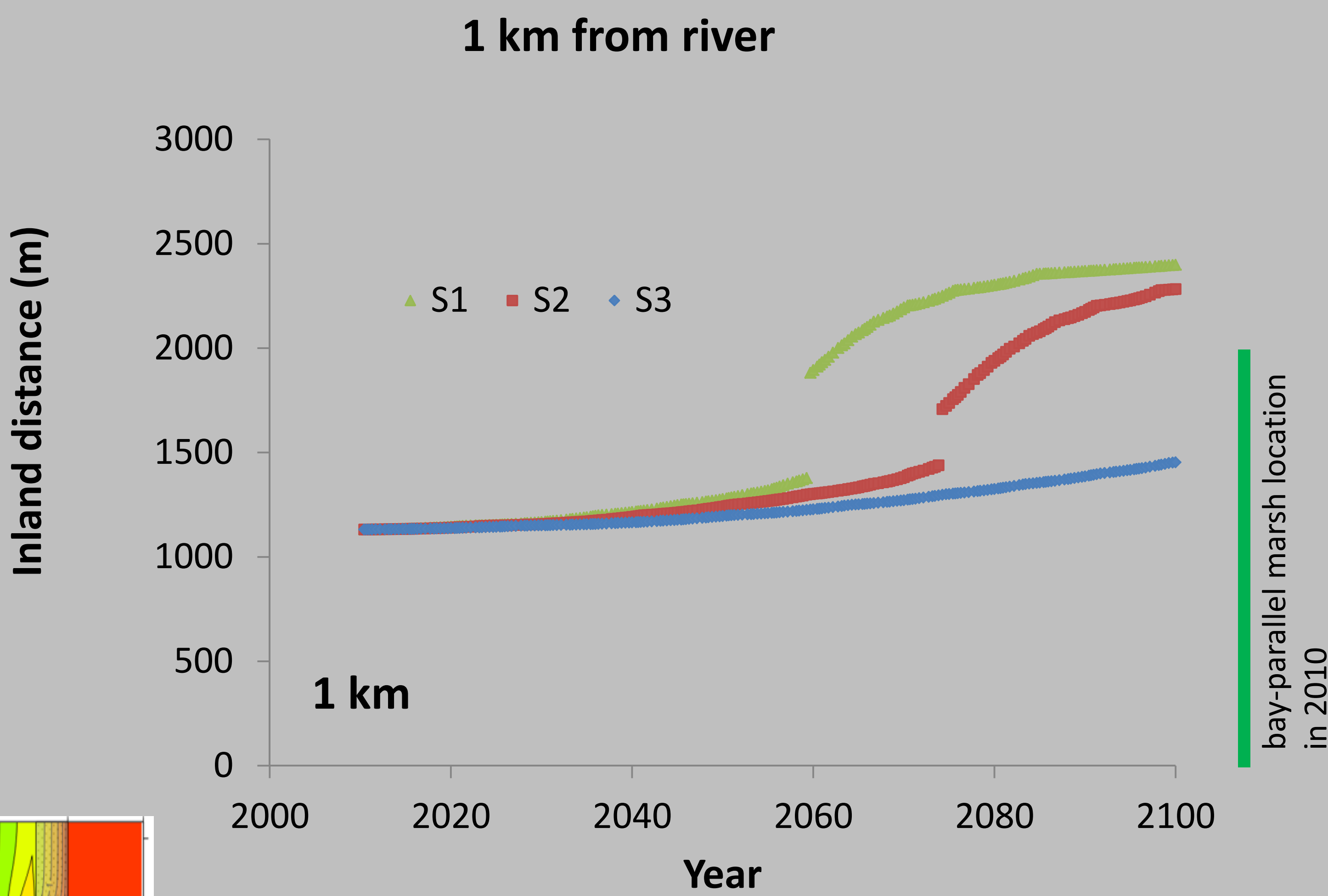
Calculated inland position of the salt water front at base of aquifer

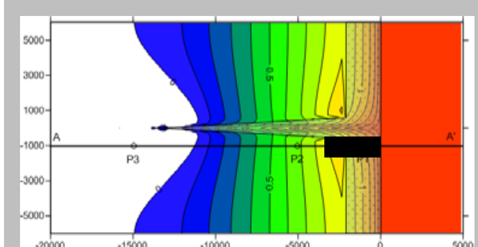




Simulation results for salt-water intrusion

Calculated inland position of the salt water front at base of aquifer

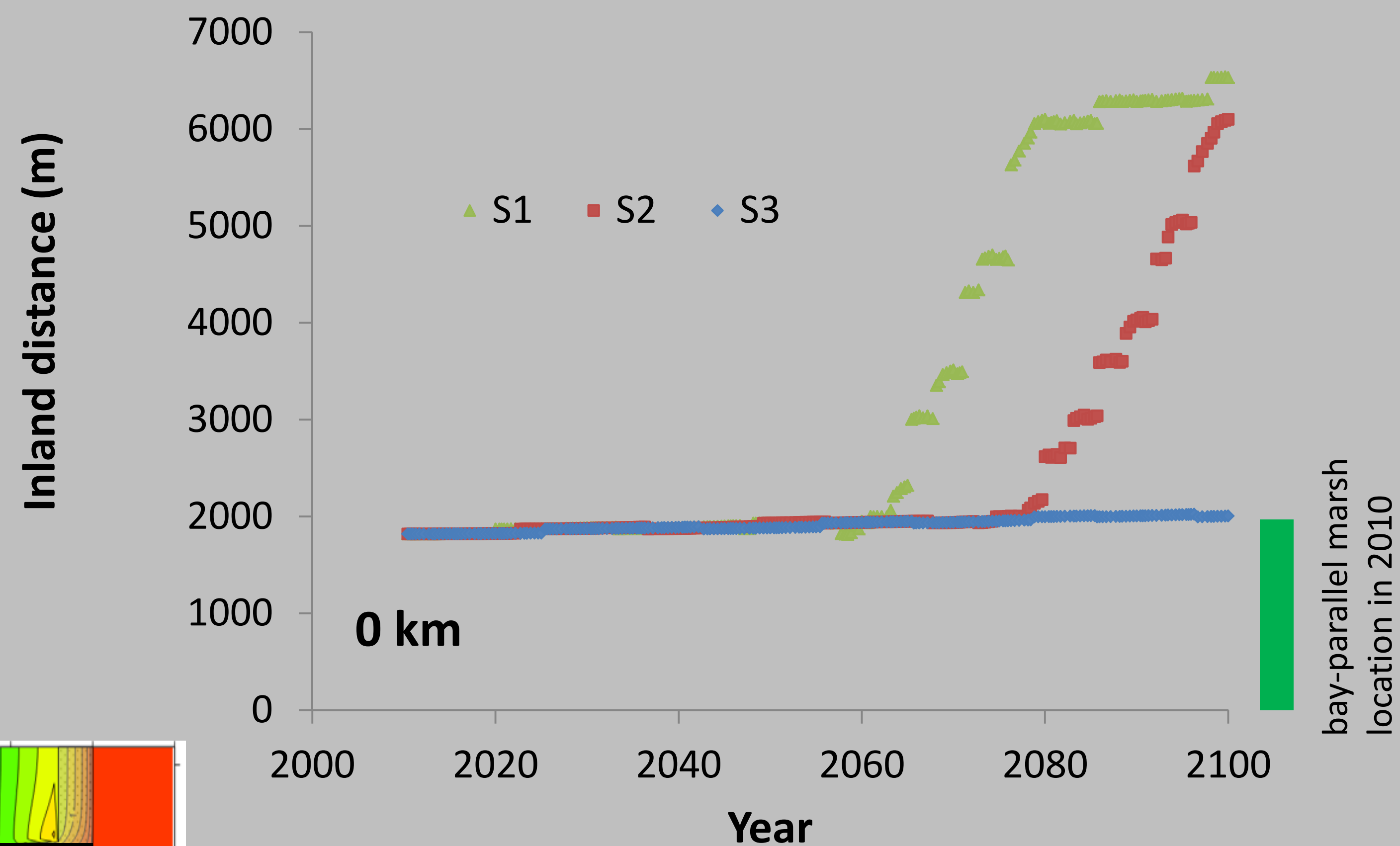


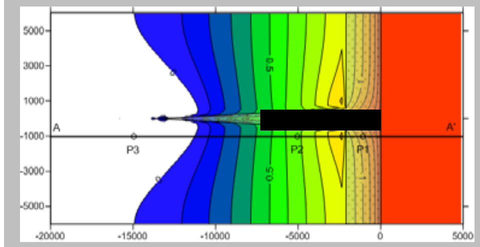


Simulation results for salt-water intrusion

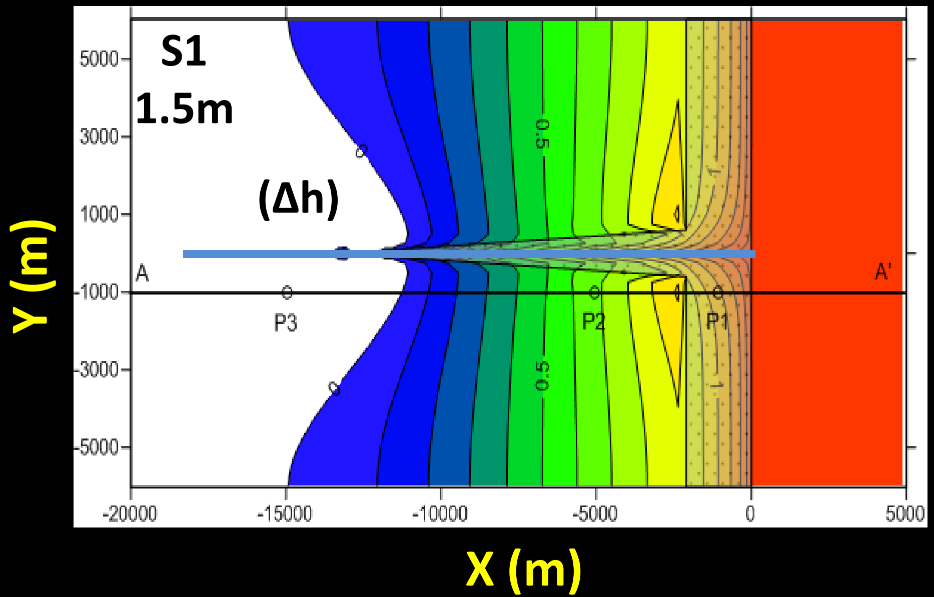
Calculated inland position of the salt water front at base of aquifer

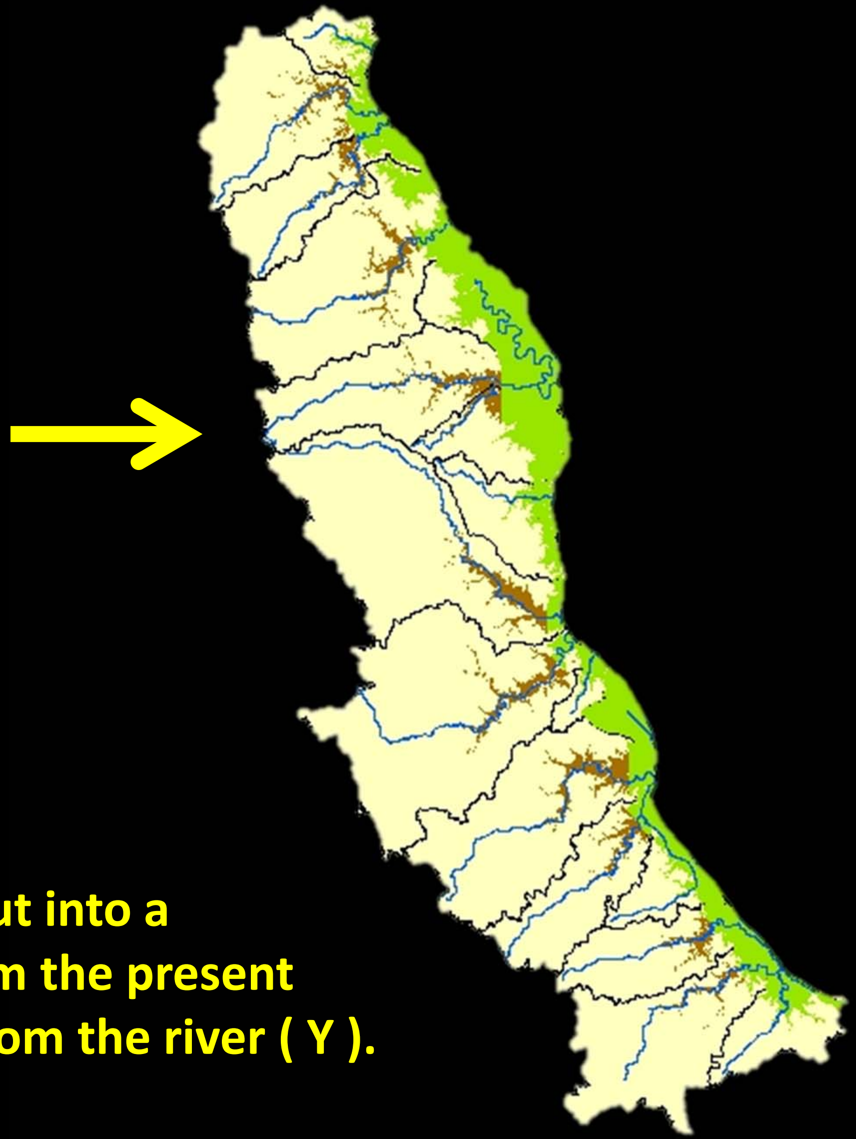
under the river (0 km)





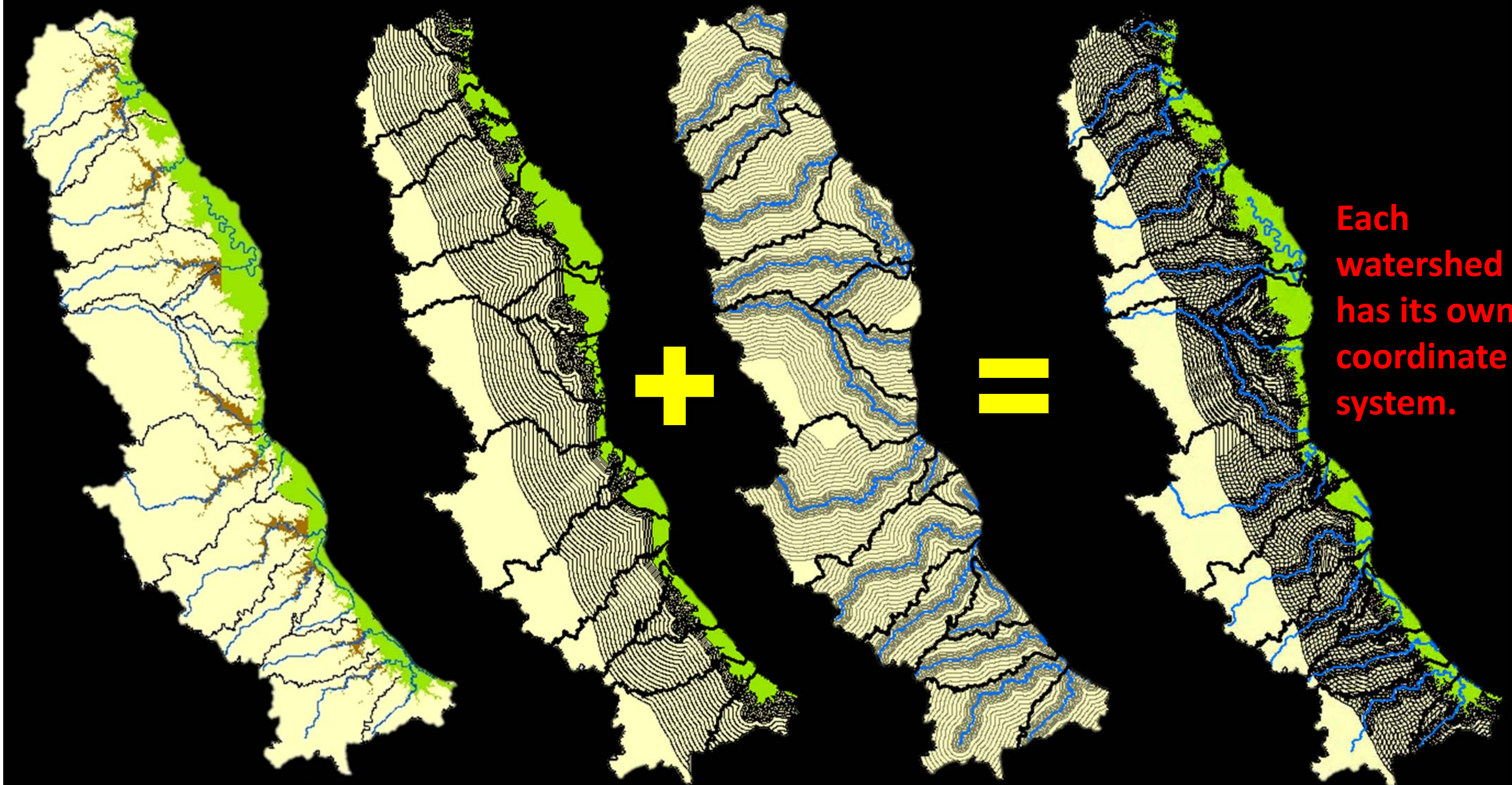
Applying modeled water-table rise to Delaware Bay watersheds





The predicted change in head (Δh) was output into a coordinate system representing distance from the present upland/marsh boundary (X) and distance from the river (Y).

creating a curvilinear coordinate system



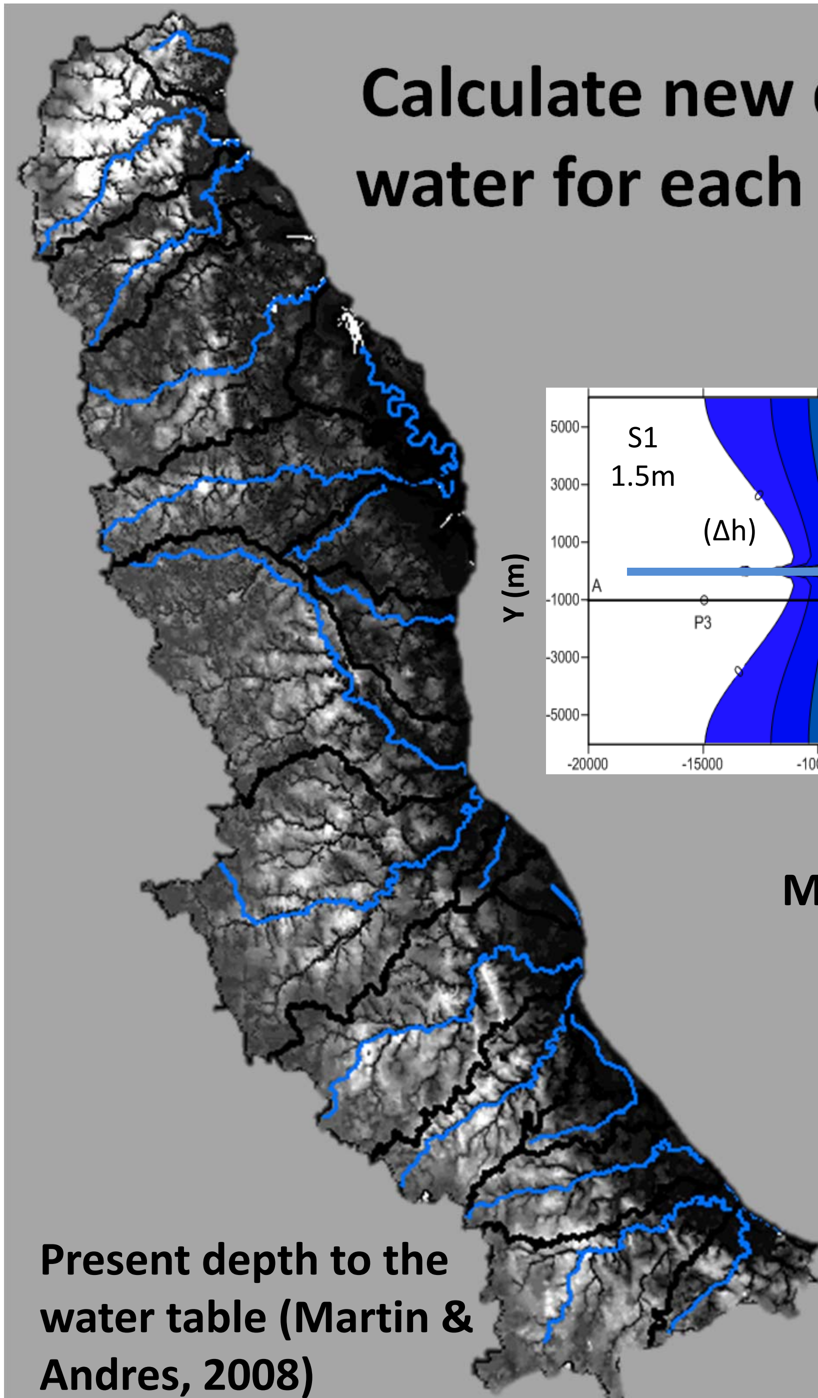
watersheds with simplified hydrology and bay-parallel marsh

multi-ring buffer from bay-parallel marsh

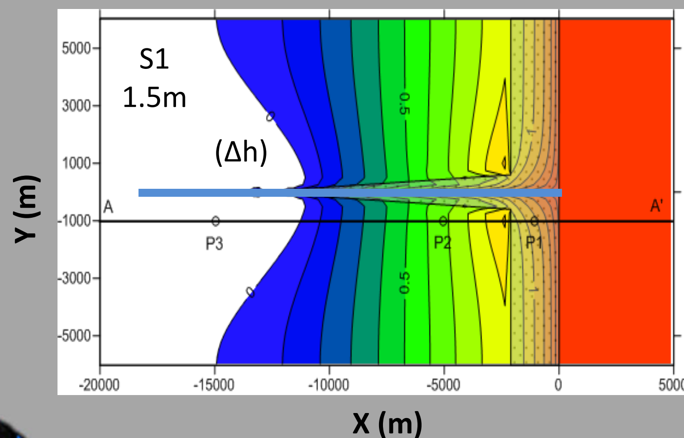
multi-ring buffer around each river

curvilinear coordinate system

Calculate new depth to water for each scenario

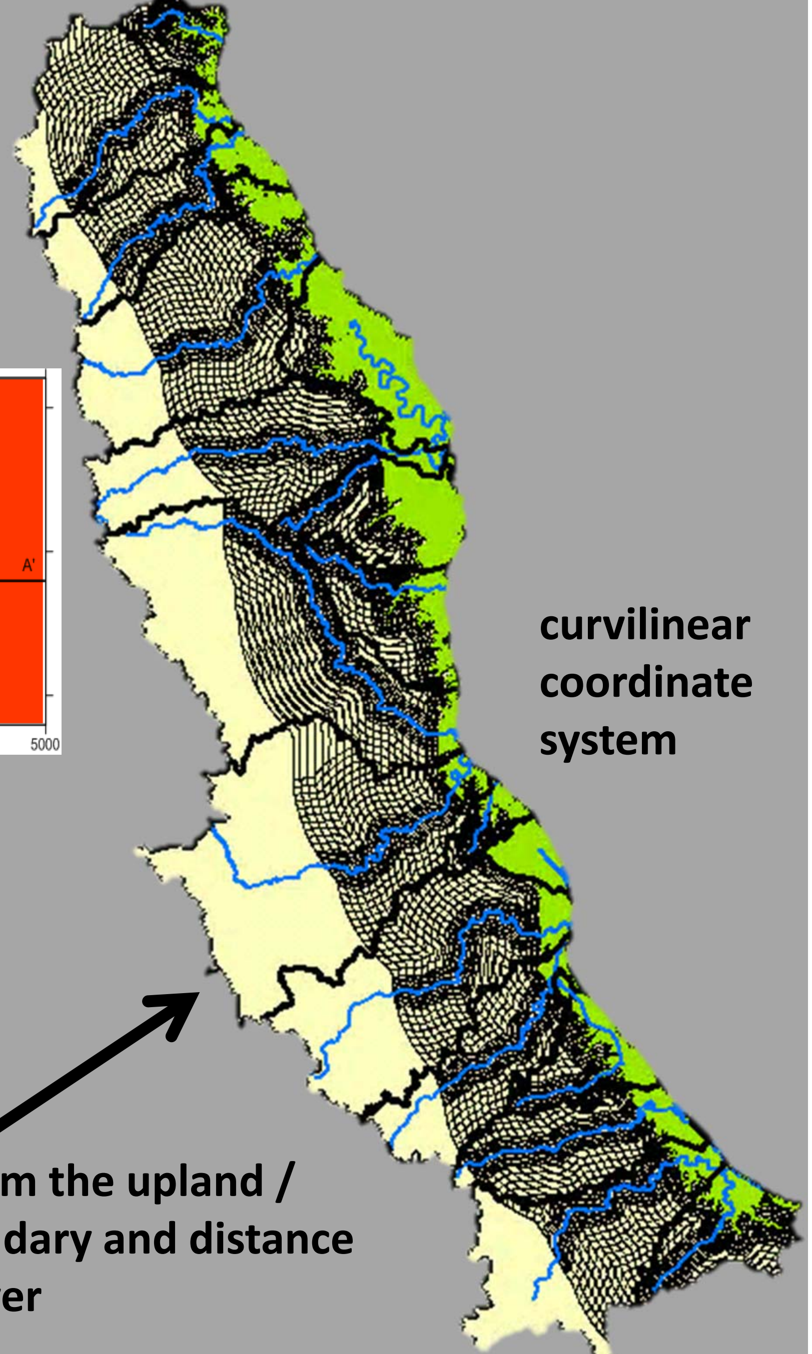


Present depth to the water table (Martin & Andres, 2008)



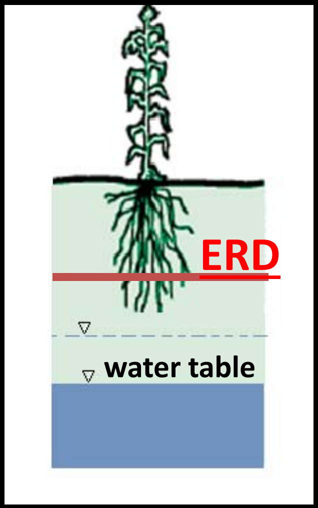
Model results

distance from the upland / marsh boundary and distance from the river



curvilinear coordinate system

Primer to Next Results



Critical depth to water

depth where there are impacts to a land use.

Two critical conditions were used:

0 m **water at land surface**

0.5 m **water at conservative effective rooting depth (ERD)**

Actual ERDs of local crops

corn & winter wheat	**0.9 m**
soybeans	**0.6 m**

Tidal Wetlands

Tidal wetlands are fully inundated in year 2100 for all three scenarios, assuming no landward migration or vertical accretion.

Primer to Results *some more*

In calculations of impacted area:

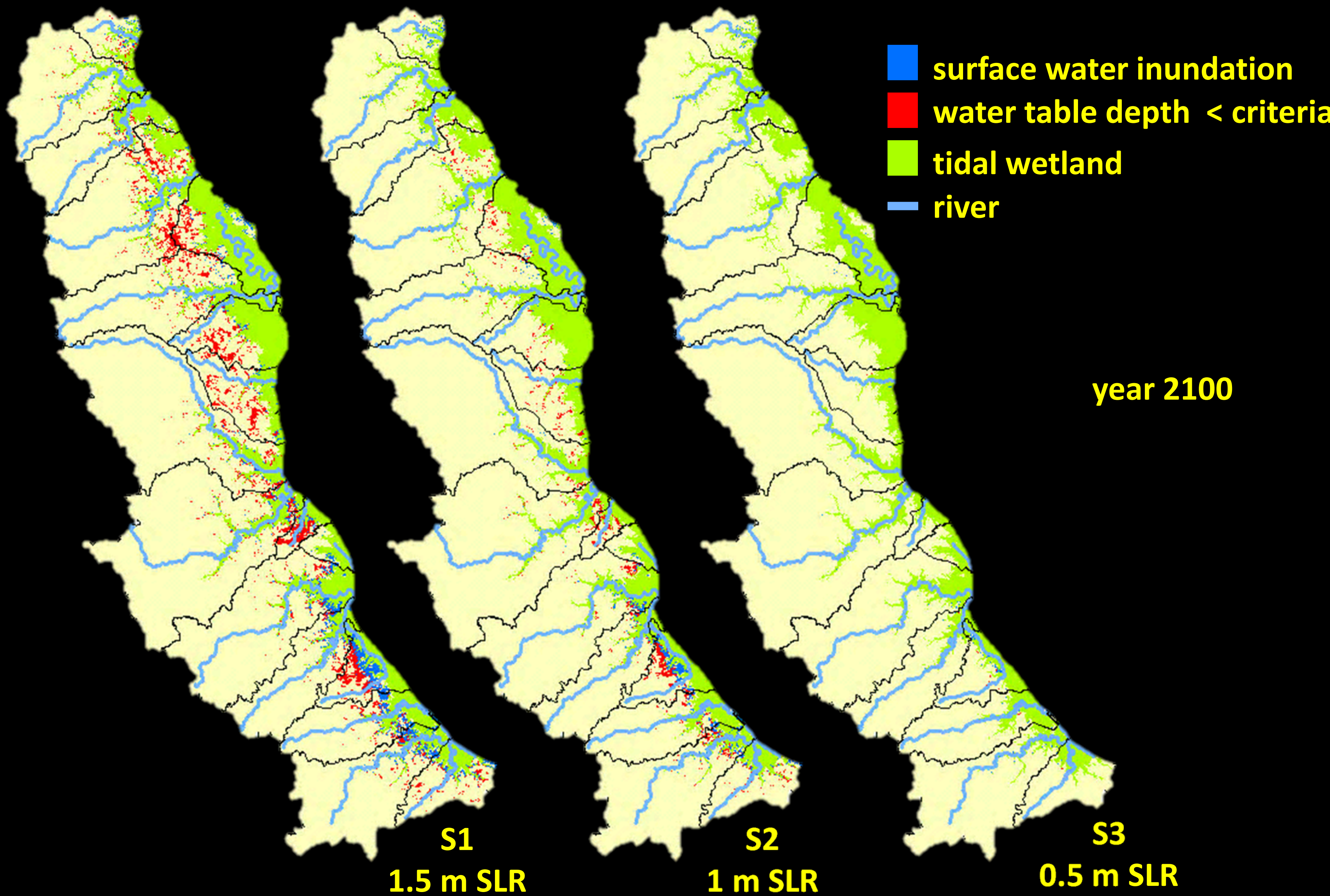
Wetlands

Present-day tidal and non-tidal wetlands are excluded from all areal calculations even if the critical depth to water is exceeded.

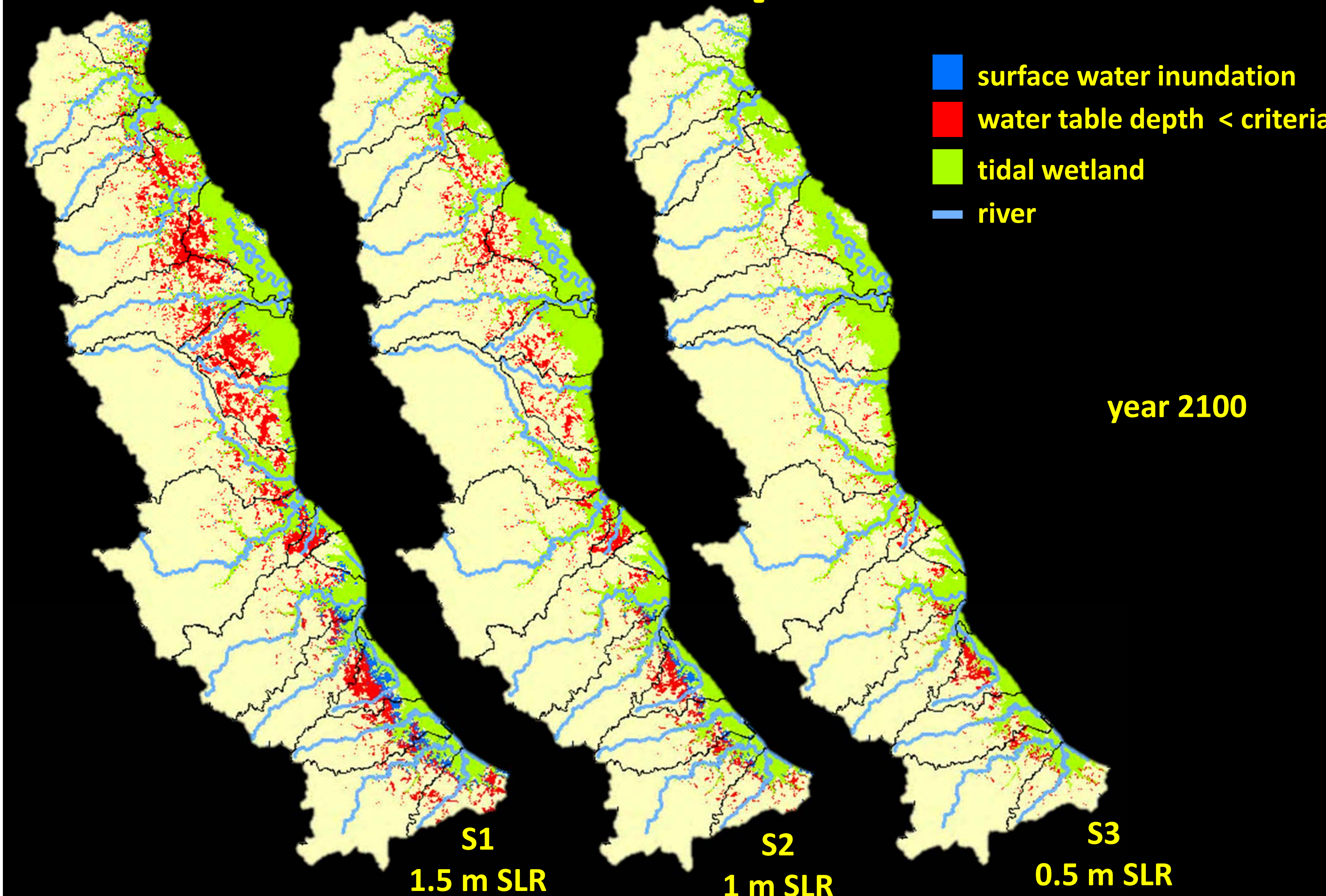
Delaware Bay beaches

All areas bayward of present-day bay-parallel marsh are excluded from areal calculations as they are not captured in conceptual model.

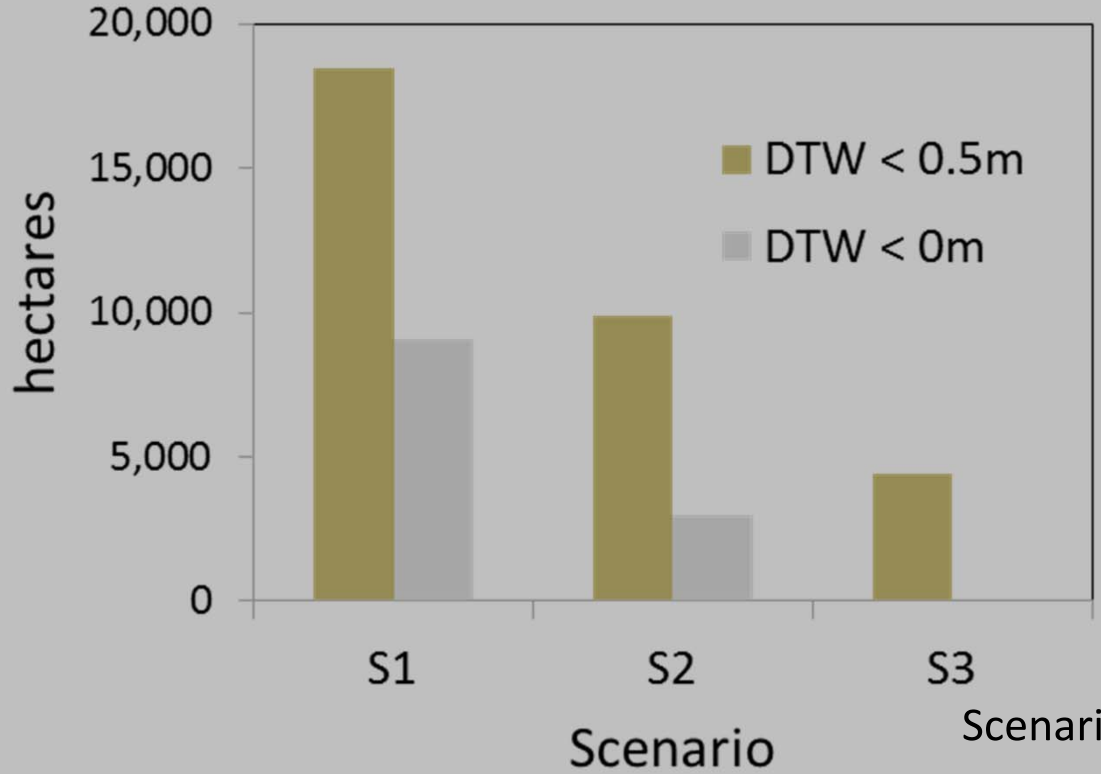
water table depth < 0 m



water table depth < 0.5 m



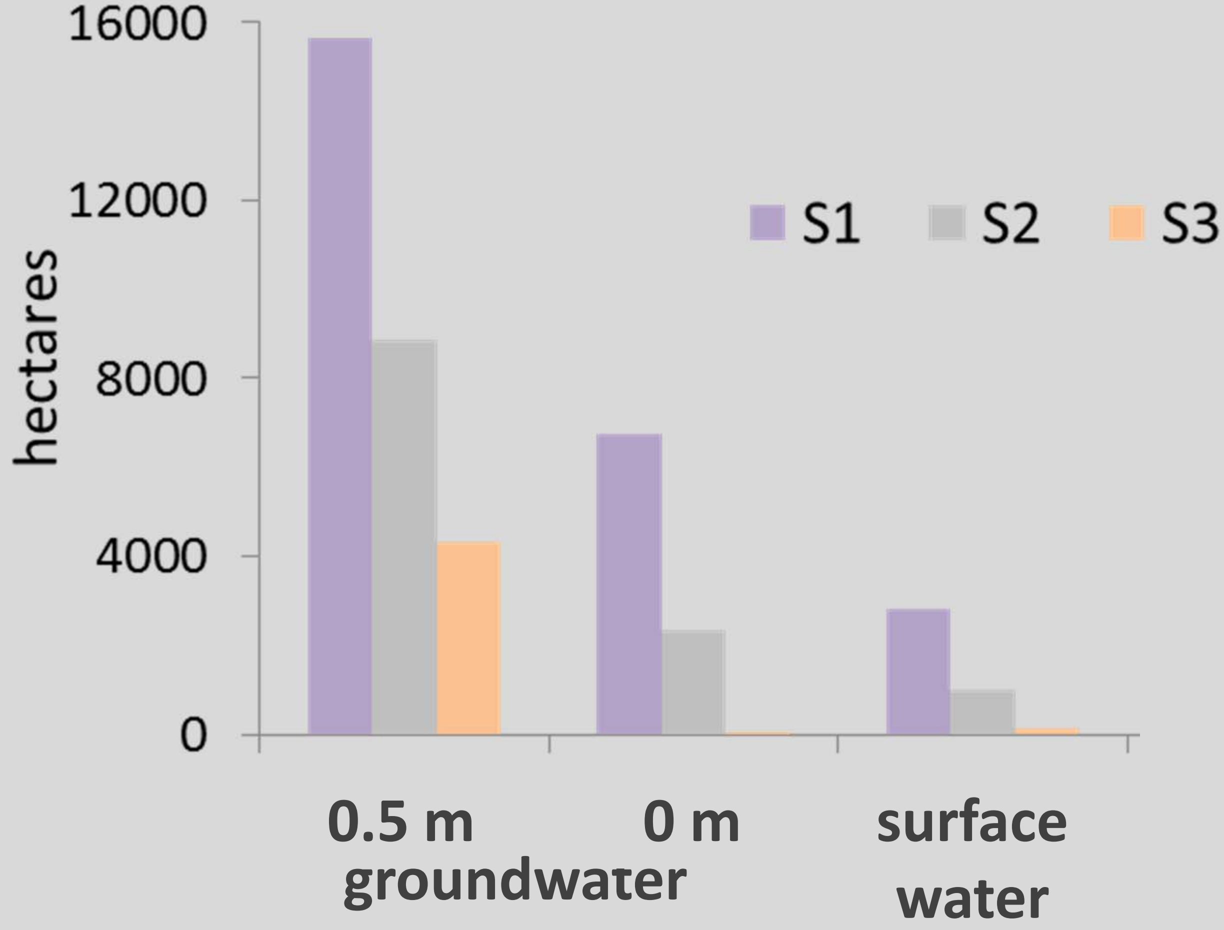
Impacted land area for the two depth criteria



Scenario	hectares DTW <0.5 m	hectares DTW < 0m
S1	18,500	9,100
S2	9,900	3,000
S3	4,400	60

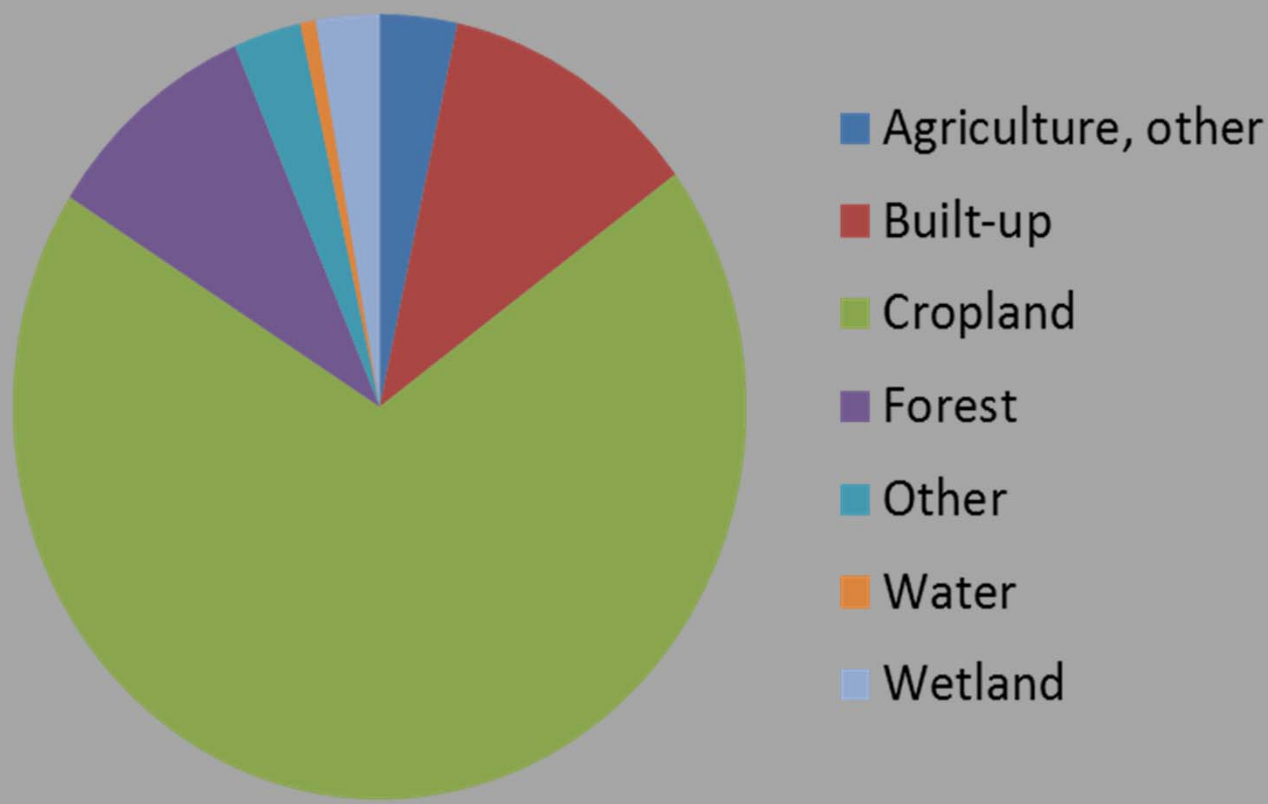
18,500 hectares is about 3x the size of Dover. Del

Areas inundated by rising sea (surface water) vs waterlogged due to a rising water table (groundwater)

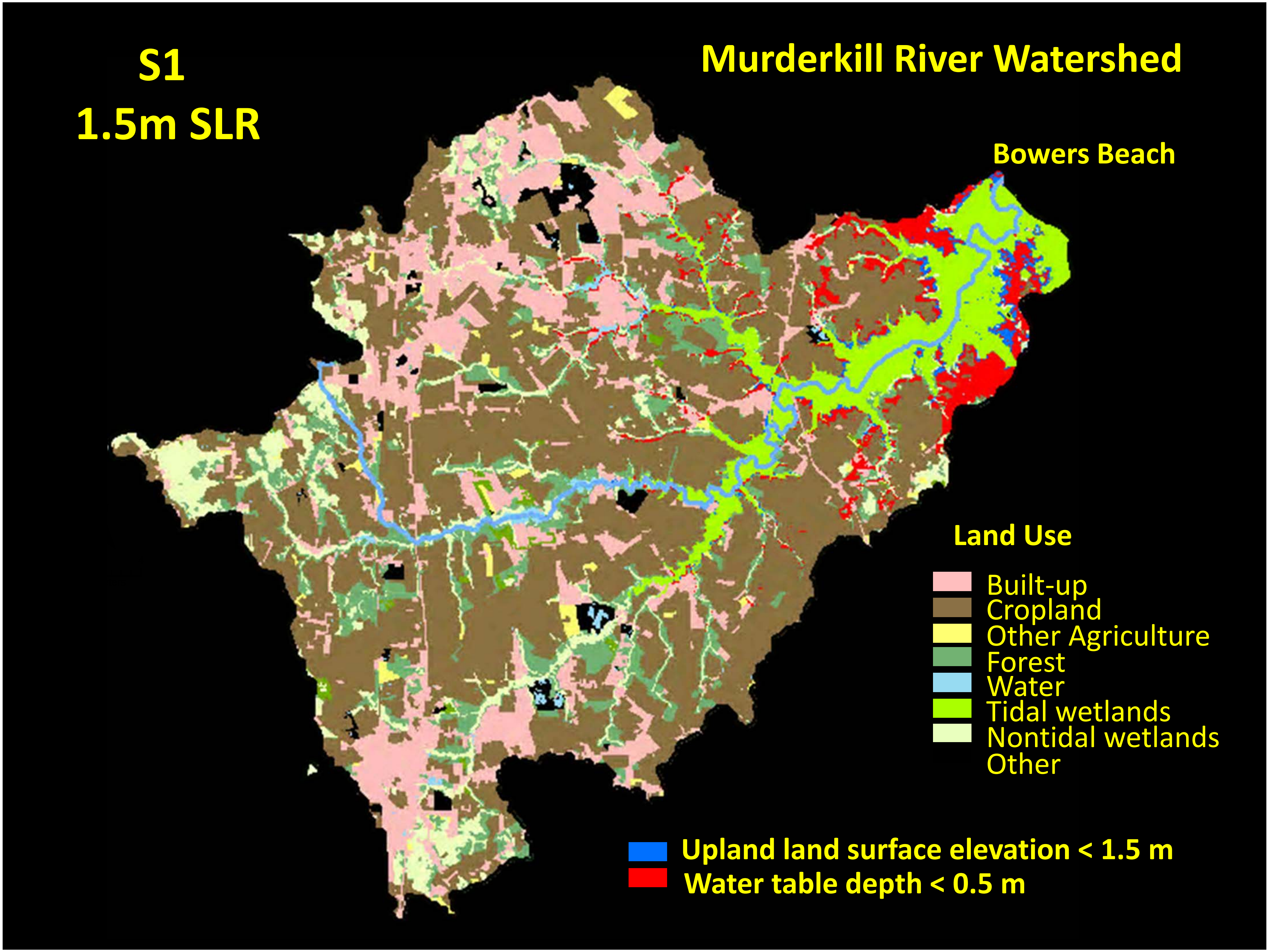


Land use impacted

S1 (1.5m) & 0.5m critical depth



In all scenarios, over 60% of the area impacted by water-table rise is cropland.


S1
1.5m SLR
Murderkill River Watershed
Bowers Beach
Land Use
Built-up
Cropland
Other Agriculture
Forest
Water
Tidal wetlands
Nontidal wetlands
Other
Upland land surface elevation < 1.5 m
Water table depth < 0.5 m

Conclusions

Water-table rise and surface-water inundation

- Total land area impacted in year 2100 ranges from 60 hectares (ha) for 0.5m SLR with critical depth of 0m to 18,500 ha for 1.5m SLR with critical depth of 0.5m (18,500 hectares is about 3x the size of Dover).
- Over 60% of the area impacted in all scenarios is cropland.
- 3 to 9 times more area is impacted by a rising water table than from surface-water inundation for all scenarios except 0.5 m SLR with the 0.5m condition where it is 38 times more area.

Conclusions

Salt-water intrusion

- By year 2100, for 1.0m and 1.5m SLR, the salt water in the base of the aquifer under the river migrates 4.6 km inland from the marsh/upland boundary. For the 0.5 m SLR scenario the salt water interface remains under the bay-parallel marsh.
- By year 2100, at 4 km from the river, salt water in the base of the aquifer migrates 200 m from the marsh/upland boundary for 1.0 m and 1.5 m SLR. For the 0.5 m SLR scenario the salt water interface remains under the bay-parallel marsh.