MODELING DELTA VEGETATION

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Some motivation: why are we working on this?

100+ Years of Land Change for Southeast Coastal Louisiana

SUMMARY
Coastal Louisiana has lost an average of 34 square miles of land, primarily marsh, per year for the last 50 years. From 1932 to 2000, coastal Louisiana has lost 1,049 square miles of land, roughly an area the size of the state of Delaware. If nothing is done to stop this land loss, Louisiana is expected to lose another 700 square miles of land, or about equal to the size of the greater Washington D.C.-Baltimore area, in the next 50 years. Further, Louisiana accounts for an estimated 90 percent of the coastal marsh loss in the lower 48 states during the 1990s. The area shown on this map represents over 75 percent of the total land loss for coastal Louisiana.

Prepared by
U.S. Geological Survey
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Some motivation: land losses in coastal Louisiana

Maximum rates of coast retreat since the 1830s: 8 - 19 m/yr
Morgan and Larimore, 1957

Rates of shoreline retreat: 3 - 16 m/yr
Craig, 1979

Rates of wetland/land loss: 8 - 120 km$^2$/yr
Penland et al., 1990
Some motivation: land gain in coastal Louisiana

Maximum rates of coast retreat since the 1830s: 8 - 19 m/yr
Advancing shorelines in the Bird-foot Delta and Chenier au Tigre (4 m/yr)

Rates of shoreline retreat: 3 - 16 m/yr
Rates of wetland/land loss: 8 - 120 km²/yr
Rates of shoreline progradation on the Eastern Chenier plain: 50 m/yr
Rates of growth of Atchafalaya and Wax Lake Delta: 3 km²/yr

Morgan and Larimore, 1957
Craig, 1979
Penland et al., 1990
Roberts et al, 1989
Roberts, 1998
Some motivation: why are land losses greater than land gain?

Some reasons:

- Construction of dams in the upstream basin reduced the sediment supply.
- Old River control structure prevents the avulsion of the Mississippi River in the Atchafalaya River.
- Levees caused a reduction of deposition of fine sediment on the wetlands.
- Extraction of water and hydrocarbons increased subsidence rates.
- Construction of highways and canals has altered the hydrology of the marshlands.
Some motivation: possible restoration strategies

“...various examinations of coastal restoration issues and potential solutions have been conducted

• in recent years, including Coast2050 (http://www.coast2050.gov), the Louisiana Coastal Area Ecosystem Restoration (http://lca.gov/) plan, and

• post-Hurricane Katrina, State Master Plan (http://www.lacpra.org) and US Army Corps of Engineers (http://lacpr.usace.army.mil/) planning documents that tie coastal, hurricane, and flood protection in South Louisiana (LACPR). LACPR has been recently reviewed by the National Academy of Sciences (NAS, 2008).

Significantly, none of these initiatives have agreed upon specific recommendations for the use or location of large water diversions from the Mississippi channel for land building.

Two main mechanisms have been suggested for rebuilding marsh areas:

1) water and sediment diversions from the Mississippi and its Atchafalaya distributary, and

2) long-distance pipelines to spoil dredged materials from the river beds as well as inland and offshore deposits.”

Allison and Meselhe, 2010
Some motivation: water and sediment diversions

Small or land sustaining to restore the overbank deposition of fine sediment. Can be effective for wetland restoration but they cannot build a significant amount of land.

Big or land building to capture a significant amount of sand and to deposit it into drowned areas. A hard-engineered structure controls the partition of water and sediment between the river and the artificial distributary channel. The development of new land in the drowned area is maintained by natural processes favoring the development of a healthy wetland ecosystem (Paola et al., 2010).
Can the land-building diversions really work?

With the land building model Kim et al. (2009) have demonstrated that creating a significant amount of new land in the Mississippi Delta at rates comparable with those observed in the Atchafalaya Bay (3km²/yr) is feasible over engineering time scales.

From Kim et al., 2009

The land building model has been then applied to predict the amount of new land created with a land building diversion in Myrtle Grove.

100 years subsequent to diversion, position of the shoreline 11-15 km, area 99 - 193 km²
Can the land-building diversions really work?

With the land building model it has been shown that building a significant amount of land is feasible over engineering time scales, but what sort of ecosystem will develop on the new land?

http://www.whoi.edu/cms/images/Chani_Dhora_boats_small_83315.jpg

http://www.thenakedscientists.com/HTML/articles/article/the_louisianawetlandsanintroduction/

Can the land-building diversions really work?

With the land building model it has been shown that building a significant amount of land is feasible over engineering time scales, but

what sort of ecosystem will develop on the new land?

Is the delta growth influenced by vegetation? How?


http://www.whsrn.org/sites/default/files/images/wetland.jpg
Delta modeling plan

1) BUILD A NUMERICAL MODEL (Inundation model)

2) TEST AND VERIFY THE MODEL WHERE WE HAVE DATA (the Wax Lake Delta)

3) APPLY THE MODEL TO LAND-BUILDING DIVERSIONS OF THE MISSISSIPPI RIVER
Modeling plan for the restoration of the Mississippi River Delta

DELTA MODEL

- Artificial distributary channel
- Drowned area
- New delta

RIVER MODEL

- Old River Control Structure
- Mississippi River
- Land-building diversion structure
- Delta model
- Mississippi River
Why inundation model?

In low-gradient deltas, vegetation patterns are primarily controlled by local conditions such as salinity and frequency of inundation. Small changes in these conditions may result in a significant variation of the ecosystem on the delta top (e.g. Paola et al., 2010)

Table 9.1. Restrictions in salinity and inundation for the major habitat types.

<table>
<thead>
<tr>
<th>Habitat</th>
<th>Salinity (yearly average)</th>
<th>Source for Salinity Restrictions</th>
<th>Inundation (% of year)</th>
<th>Source for Inundation Restrictions</th>
</tr>
</thead>
<tbody>
<tr>
<td>Bottomland Hardwood</td>
<td>&lt; 2 ppt</td>
<td>Conner et al. (1997)</td>
<td>&lt; 30%</td>
<td>Conner et al. (1997)</td>
</tr>
<tr>
<td>Fresh Floating Marsh</td>
<td>&lt; 2 ppt</td>
<td>Chabreck (1970), Hester et al. (2002)</td>
<td>Not Applicable</td>
<td></td>
</tr>
<tr>
<td>Fresh Attached Marsh</td>
<td>&lt; 2 ppt</td>
<td>Chabreck (1970)</td>
<td>Up to whole year if not stagnant and below 30 cm of water on marsh</td>
<td>Evers et al. (1998)</td>
</tr>
<tr>
<td>Intermediate Marsh</td>
<td>2-6 ppt</td>
<td>Chabreck (1970)</td>
<td>Up to whole year if not stagnant and below 30 cm of water on marsh</td>
<td>Evers et al. (1998)</td>
</tr>
<tr>
<td>Brackish Marsh</td>
<td>6-15 ppt</td>
<td>Chabreck (1970)</td>
<td>&lt; 64%A</td>
<td>Sasser (1977)</td>
</tr>
<tr>
<td>Saline Wetlands</td>
<td>&gt; 15 ppt</td>
<td>Chabreck (1970)</td>
<td>&lt; 80%A</td>
<td>Sasser (1977)</td>
</tr>
</tbody>
</table>

Table from Robert Twilley
The inundation model: the flow of the calculations

- Initial and boundary conditions
- The land building model predicts the coarse structure of the delta
- The inundation procedure predicts the downdelta variation of frequency of inundation
- A salinity model predicts the downdelta variation of salinity
- A vegetation model updates predicts the downdelta variation of the vegetation cover

Update some parameters, and maybe store stratigraphy
The present version of the inundation model: the flow of the calculations

1. Initial and boundary conditions
2. The land building model predicts the coarse structure of the delta
3. The inundation procedure predicts the downdelta variation of frequency of inundation
4. Prediction of the type of vegetation
The land-building model

(Kim et al., 2009)

The model expresses time-averaged delta evolution.

The model calculates the characteristics of an effective channel that amalgamates the major active channels during floods, but the channel is not specifically located.

The channel is assumed to migrate, avulse, and flood in such a way as to maintain overall radial symmetry of the delta as it builds land.

It thus yields the average downstream bed slope and elevation profiles of the delta, the height of the foreset, position of the shoreline and delta area as functions of time.
The land-building model: characteristics

(Kim et al., 2009)

1) The delta is assumed axially symmetric with a specified angle $\theta_f$.
2) The radial coordinate from the vertex is denoted with $r$.
3) The width of each radial transect is $B_f = \theta_f r$.
4) The model allows for an engineered guide channel of specified width and length to carry the water and sediment to the vertex of the growing delta.
5) Sand is deposited in the virtual channel, but the implicit shift of this channel spreads the sand across the entire delta.
6) For each unit of sand deposited within the delta, a specified unit, $\Lambda$, of mud (wash load) is deposited with it.
7) The basement can be allowed to subside at a prescribed rate, $\sigma$. The subsidence is assumed to be spatially uniform.
8) Mean sea level is allowed to rise at a specified, and constant rate, $\zeta$, for each model run.

Exner equation

\[
(1 - \lambda_p) r \left( \frac{\partial \eta_t}{\partial t} + \sigma \right) = -I \left( 1 + \Lambda \right) \frac{\partial Q_t}{\partial r}
\]
The land-building model: assumptions
(Kim et al., 2009)

1) Flood discharge is abstracted into an effective, morphologically active flood flow, \( Q \), continued for a specified fraction of time per year, \( l_f \).
2) Bed material load, \( Q_t \), is computed with the relation of Engelund and Hansen (1967),
3) Flood flow has attained a constant, channel-forming Shields number, \( \tau^*_{\text{form}} = 1.86 \) (Parker et al., 1998),
4) Flood flow is approximated as steady and uniform (i.e. normal flow approximation). The dimensions of the virtual channel, and in particular its width, are computed via a closure method using a Chezy formulation (friction coefficient \( C_f \)),

Equations

\[
Q_t = B_c \sqrt{RgD} \frac{0.05}{C_f} \left( \frac{\tau^*_{\text{form}}}{2.5} \right)
\]

\[
\tau^*_{\text{form}} = \frac{HS}{RD}
\]

\[
R = \frac{\rho_s - \rho}{\rho}
\]

\[
C_f \frac{Q_w^2}{B_c^2 H^2} = gHS
\]
UPSTREAM BOUNDARY CONDITIONS
1) Effective morphologically active flood flow, $Q$;
2) Input rate of bed material, $Q_{tf}$;

DOWNSTREAM BOUNDARY CONDITION
The bed elevation at the shoreline is equal to mean sea level
The land-building model: results for a 30 years simulation (1977-2006) on the Wax Lake Delta

Distance of the shoreline from the vertex of the delta, $r_s$

Longitudinal profiles of elevation

Sea level rise, 2 mm/yr;
Subsidence rate, 5 mm/yr.
The present version of the inundation model: the flow of the calculations

- **Initial and boundary conditions**
- **The land building model predicts the coarse structure of the delta**
- **The inundation procedure predicts the downdelta variation of the frequency of inundation**
- **Prediction of the type of vegetation**
The inundation procedure: what we have to consider

To compute the downdelta variation of the mean annual frequency of inundation we need to consider

1) The interannual variability of flow discharge;
2) The interannual variation of sea level due, for example, to cold fronts;
3) The fine structure of the delta: in each transect the bed elevation is not constant!
4) The backwater effect,
   a) the flow is assumed steady and not uniform;
   b) a Chezy formulation is implemented to solve the backwater equation;
   c) the Shields number is not assumed constant.
The inundation procedure: we have to consider

Interannual variability of flow discharge
Mean daily flows recorded at Calumet station

Interannual variability of sea level
Mean sea level recorded at Vermillion Bay station

Flow duration curve

Probability of exceedence
The inundation procedure: we have to consider

Fine structure of the delta, or the variability of bed elevation in each transect

\[ B_f = \theta_f r \]

\( \eta_{av} \) average elevation of the transect

\( \eta \) elevation

\( p_e(\eta, r) \) probability density of bed elevation,

(portion of the transect at distance \( r \) from the vertex with elevation between \( \eta \) and \( \eta + d\eta \)).

\[ \int_{-\infty}^{+\infty} p_e(\eta, r) d\eta = 1 \]
The inundation procedure: definitions

\( \xi \)  
water surface elevation

\( p_e(\eta, r) \)  
probability density of bed elevation,

(portion of the transect at distance \( r \) from the vertex with elevation between \( \eta \) and \( \eta + d\eta \)).

\[ B_r = \theta_f r \]

Inundated fraction of the delta

\[ F_i(\xi, r) = \int_{-\infty}^{\xi} p_e(\eta, r) d\eta \]

Width and depth of inundation, \( B_i \) and \( H_i \)

\[ B_i(\xi, r) = B_f(\xi) F_i(\xi, r) \]

\[ H_i(\xi, r) = \xi(\xi) - \int_{-\infty}^{\infty} \eta p_e(\eta, r) d\eta \]
The inundation procedure: backwater formulation (1)

The cross section is assumed rectangular with width $B_{\text{flow}}$ and water depth $H_{\text{flow}}$

$$B_{\text{f}} = \theta_f \, r$$

$$B_{i1} \quad B_{i2}$$

$$\eta_{\text{av}} \quad \eta \quad \xi$$

$$B_i(\xi, r) = B_f(r) \, f_i(\xi, r)$$

$$H_i(\xi, r) = \xi(r) \cdot \int_{-\infty}^{\eta_p(\eta, r)} d\eta$$

$$H_{\text{flow}}$$

$$\xi$$
The inundation procedure: backwater formulation (2)

What is the relation between $B_{\text{flow}}$ and $B_i$ and between $H_{\text{flow}}$ and $H_i$?

$$B_{\text{r}} = \theta_r r$$

$B_{\text{flow}}$

$H_{\text{flow}}$

$\zeta$

$$B_{\text{flow}} = \Gamma_B B_i \quad H_{\text{flow}} = \Gamma_H H_i$$

Where $\Gamma_B$ and $\Gamma_H$ are user specified parameters that need to be calibrated from the data.

Should we expect that $\Gamma_B < 1$ and $\Gamma_H > 1$?
The inundation procedure: backwater formulation (3)

Channel sinuosity $\Omega$: downdelta and downchannel coordinates

\[ \Omega = \frac{\Delta r_c}{\Delta r} \]
The inundation procedure: backwater formulation (4)

The backwater equation

\[(1 - F_r^2) \frac{dH}{dx} = S - C_f F_r^2 \]

where

- \( H \) is the water depth;
- \( x \) is a streamwise coordinate;
- \( C_f \) is a non-dimensional friction coefficient;
- \( S \) is the channel slope defined as
  \[ S = -\frac{\partial \eta}{\partial x} \]
  where \( \eta \) denotes the channel bed elevation;
- \( F_r \) is the Froude number defined as
  \[ F_r = \frac{U}{\sqrt{gH}} = \frac{q_w}{\sqrt{gH^3}} = \frac{Q}{\sqrt{gB_c^2H^3}} \]
  Where \( q_w \) is the water discharge per unit channel width,
- \( B_c \) is the channel width,
- \( g \) is the acceleration of gravity;
- \( U \) is the mean flow velocity, \( U = Q/(B_cH) \)
The inundation procedure: backwater formulation (5)

The backwater equation on our fan delta

\[
\left(1 - Fr^2\right) \frac{dH}{dx} = S - C_f Fr^2 = S - S_f
\]

\[
S = -\frac{\partial \eta_t}{\partial r}
\]

in downdelta coordinate

friction slope, energy losses per unit distance in the downchannel direction

\[
S_f = C_f Fr^2
\]

The energy losses between two computational nodes are

\[
S_f \Delta r_c = C_f Fr^2 \Delta r_c
\]

That in downdelta coordinates becomes

\[
S_f = \Omega C_f Fr^2
\]

\[
\left(1 - Fr^2\right) \frac{dH}{dr} = S - \Omega C_f Fr^2
\]
The inundation procedure: backwater formulation (6)

The backwater equation on our fan delta: who are $H$ and $Fr$?

\[
\left(1 - Fr^2\right) \frac{dH}{dr} = S - \Omega C_f Fr^2
\]

$B_f = \theta_f r$

$B_{flow}$

$H_{flow}$

$\zeta$

$B_{flow} = \Gamma B_i$ \hspace{1cm} $H_{flow} = \Gamma H_i$

$H$ is equal to $H_{flow}$

The Froude, $Fr$, number is

$Fr = \frac{Q}{\sqrt{gB_{flow}^2 H_{flow}^3}}$

The backwater equation thus becomes

\[
\left(1 - \frac{Q^2}{gB_{flow}^2 H_{flow}^3}\right) \frac{dH_{flow}}{dr} = S - \Omega C_f \frac{Q^2}{gB_{flow}^2 H_{flow}^3}
\]
The inundation procedure: backwater formulation (7)

Integration of the backwater equation on our fan delta

\[
\left(1 - \frac{Q^2}{gB_{\text{flow}}^2H_{\text{flow}}^3}\right)\frac{dH_{\text{flow}}}{dr} = S - \Omega C_f \frac{Q^2}{gB_{\text{flow}}^2H_{\text{flow}}^3}
\]

where

\[B_{\text{flow}} = \Gamma_B B_i, \quad H_{\text{flow}} = \Gamma_H H_i\]

and

\[B_i(\xi, r) = B_f(r) f(\xi, r)\]

\[H_i(\xi, r) = \xi(r) - \int_{-\infty}^{\xi} p_e(\eta, r) d\eta\]

\[F_i(\xi, r) = \int_{-\infty}^{\xi} p_e(\eta, r) d\eta\]

The backwater equation is integrated starting from downstream because the flow will most likely be Froude-subcritical.

Downstream boundary condition

\[H_{\text{flow}} \Big|_{r=r_s} = \xi_d - \eta_t \Big|_{r=r_s}\]

The calculation of the fraction of inundated delta, of the width and depth of inundation is not easy. We thus integrate the backwater equation in the form

\[
\left(1 - \frac{Q^2}{gB_{\text{flow}}^2H_{\text{flow}}^3}\right)\frac{d\xi}{dr} = -\Omega C_f \frac{Q^2}{gB_{\text{flow}}^2H_{\text{flow}}^3}
\]

with \(\xi = \eta_t + H_{\text{flow}}\)
The inundation procedure

What happens once we have computed the inundated fraction of the delta, the width and the depth of inundation?
The inundation procedure

What happens once we have computed the inundated fraction of the delta, the width and the depth of inundation?

The inundated fraction of the delta $F_i$ is a function of the sea level, $\xi_{sd}$, of the water discharge, $Q$, and of the downdelta coordinate $r$

$$F_i(\xi, r) = \int_{-\infty}^{\xi(r)} p_e(\eta, r) d\eta$$

but

$$\xi = \xi(Q, \xi_{sd}, r)$$

thus

$$F_i(Q, \xi_{sd}, r) = \int_{-\infty}^{\xi(Q, \xi_{sd}, r)} p_e(\eta, r) d\eta$$

Flow discharge and mean sea level have their own probability densities, $p_Q$ and $p_{\xi_{sd}}$, and a joint probability density $p_{Q, \xi_{sd}}$.

If

$$F_i(Q, \xi_{sd}, r) = \int_{-\infty}^{\xi(Q, \xi_{sd}, r)} p_e(\eta, r) d\eta$$

represents the inundated fraction of the delta for the discharge $Q$ and the sea level $\xi_{sd}$

$$F(r) = \iint F_i(Q, \xi_{sd}, r) p_{Q, \xi_{sd}}(Q, \xi_{sd}) dQ d\xi_{sd}$$

Should represent the mean annual frequency of inundation.
The inundation procedure

The mean annual frequency of inundation

\[ F(r) = \int \int f_i(Q, \xi_d, r) p_{Q, \xi_d} (Q, \xi_d) dQ d\xi_d \]

If water discharge and sea level turn out to be uncorrelated

\[ F(r) = \int \int f_i(Q, \xi_d, r) p_Q (Q) p_{\xi_d} (\xi_d) dQ d\xi_d \]

Where \( p_Q \) and \( p_{\xi_d} \) can be interpreted as the fractions of time that water discharge and sea level are equal to \( Q \) and \( \xi_d \).

Otherwise things are a bit more complicated
The present version of the inundation model

Once we have computed the mean annual frequency of inundation in each transect

We need a criterion (usually site-specific) to predict the type of vegetation on the delta

<table>
<thead>
<tr>
<th>Vegetation Community Type (dominant species)</th>
<th>Annual frequency of inundation</th>
</tr>
</thead>
<tbody>
<tr>
<td>High Woody (Salix nigra)</td>
<td>&lt; 44%</td>
</tr>
<tr>
<td>High Emergent (Eleocharis quenneli, Polygonum punctatum, Vigna luteola)</td>
<td>13 to 62%</td>
</tr>
<tr>
<td>Intermediate Emergent (Schoenoplectus americanus, Alternanthera philoxeroides, Leersia o zliboides)</td>
<td>27 to 86%</td>
</tr>
<tr>
<td>Low Emergent (Sagittaria platyphylla, Nelumbo lutea)</td>
<td>68 to 97%</td>
</tr>
<tr>
<td>Submerged Aquatic (Potamogeton nodosus)</td>
<td>86 to 100%</td>
</tr>
</tbody>
</table>

Example for the Wax Lake Delta (a freshwater system)
The inundation model

One more problem

The inundation model should predict the ecological succession on a prograding delta

We hardly have detailed measurements of bed elevation each year to derive the probability densities of bed elevation

Do the probability densities of bed elevation change as the delta progrades?

If so, how?
The inundation model

One more assumption

We assume similarity relationships: functions expressed in terms of dimensionless downdelta coordinate $r/r_s$, are time-invariant, even as $r_s$ increases in time due to delta progradation.
The present version of the inundation model: Application to the Wax Lake Delta

Chenier plain

Wax Lake Delta

Atchafalaya Delta

Chenier au tigre

Atchafalaya

Bay

Bird-foot Delta

Water discharge data at Calumet station

Sea level data at Vermillion Bay
The present version of the inundation model: Application to the Wax Lake Delta

Probability functions of bed elevation

The data

PROBLEM 1: no LIDAR data under water

LIDAR 2006

Datum NAVD88

Images courtesy of John Shaw (UT Austin)

PROBLEM 2: transects in the inundation model are not linear.
They are arcs with center in the vertex of the delta

USACE 1999

Datum NGDV29
The present version of the inundation model: Application to the Wax Lake Delta

Cumulative probability functions of bed elevation: a first brutal approximation

**LIDAR 2006**
37 radial transects, one every 250m from $r = 1000$ m to $r = 10000$ m $\approx r_s$

**Radial transect $r = 5000$ m**

**USACE 1999**
9 straight transects, one every 800 m, from $x \approx 1700$ m to $x \approx 8000$ m

**Straight transect $r = 4950$ m**

Elevation of the submerged fraction of the delta equal to the average elevation of the channels at distance $r$ from the vertex.
The present version of the inundation model: Application to the Wax Lake Delta

Is this reasonable?

The average elevation of the modified LIDAR transects is not too different from the average elevation of the USACE transects.

We need probability density functions that can be implemented in the model.

We assume similarity relationships: the probability functions expressed in terms of dimensionless downdelta coordinate $r/r_s$, are time-invariant, even as $r_s$ increases in time due to delta progradation.

1) Can we make the elevation non-dimensional so that the probability functions collapse in a single curve?
2) Can we express the parameters of the distributions with non-dimensional relations that describe their variability in the downdelta direction?
3) What sort of probability functions will fit the data?
The present version of the inundation model: Application to the Wax Lake Delta

Cumulative probability functions of bed elevation

Two parameter gamma distribution (dimensioned)

\[ G(x;k,\theta) = \int_{0}^{x} y^{k-1} e^{-y/\theta} \frac{1}{\theta^k \Gamma(k)} dy \] defined for \( y \geq 0, k > 0 \) and \( \theta > 0 \)

\( k \) is a shape parameter and \( \theta \) is a scale parameter;

The mean of the distribution is \( \theta k \) and the variance is \( k \theta^2 \)

LIDAR 2006 above 0

Radial transect \( r = 5000 \) m

USACE 1999 below 0

Straight transect \( r = 4950 \) m

The parameters of the distribution can be estimated from the data.

\[ \theta = \frac{\sigma^2}{\eta_{av}} \]
\[ k = \frac{\eta_{av}}{\theta} \]
The present version of the inundation model: Application to the Wax Lake Delta

Cumulative probability functions of bed elevation: regression functions to predict the parameters of the distribution

We could use this in the model but we have to make $\theta$ non-dimensional and we need to somehow link it to the elevation of the delta top predicted with the land building model.

We probably need something better than this.
The present version of the inundation model: Application to the Wax Lake Delta

Cumulative probability functions of bed elevation (non-dimensional)

Two parameter gamma distribution: collapse of the curve if we make the bed elevation non-dimensional with the average bed elevation above 0 or below 0

LIDAR 2006 above 0

\[
P_e \left( \frac{\eta}{\eta_{av,ab}} \right) = G \left( \frac{\eta}{\eta_{av,ab}}, k = 3.8, \theta = 0.27 \right)
\]

USACE 1999 below 0

\[
P_e \left( \frac{\eta}{\eta_{av,be}} \right) = 1 - G \left( \frac{\eta}{\eta_{av,be}}, k = 0.75, \theta = 1.27 \right)
\]
The present version of the inundation model: Application to the Wax Lake Delta

Cumulative probability functions of bed elevation (non-dimensional)

Two parameter gamma distribution: functions to compute the average elevation of the transect above, \( \eta_{av,ab} \), and below, \( \eta_{av,be} \), 0.

\[
\frac{\eta_{av,ab} - \eta_{av}}{(\eta_{av,ab} - \eta_{av})^1} = 1.25 \left( \frac{r}{r_s} \right)^{-0.98}, \frac{r}{r_s} \geq 0.2
\]

\[
\frac{\eta_{av,ab} - \eta_{av}}{(\eta_{av,ab} - \eta_{av})^1} = 0.29 \left( \frac{r}{r_s} \right)^{-1.93}, \frac{r}{r_s} < 0.2
\]

where

\( \eta_{av} \) denotes the average elevation of the transect

\( r_s \) is the downdelta coordinate of the shoreline, computed with the land building model.

The probability functions above and below 0 are then renormalized to express the fraction of delta that is above and below 0.
Another problem: we cannot predict the average bed elevation in each transect with our land-building model.

\[
\eta_t - \eta_{av} = -1.45 \frac{r}{r_s} + 2.45
\]

How can we relate the elevation of the delta top predicted with the land building model to the average elevation of the transect, \( \eta_{av} \)?
We are finally ready to run the model: geometric results

Average bed elevation, water surface elevation and inundated fraction of the delta predicted for the last two characteristic values of water discharge and sea level.
The present version of the inundation model: Application to the Wax Lake Delta

The last backwater curve

- computed mean bed elevation
- computed water surface elevation
- data, average bed elevation
- USACE average bed elevation
- submerged fraction of the delta
The present version of the inundation model: Application to the Wax Lake Delta

Prediction of the average bed elevation above and below 0

![Graph showing prediction of average bed elevation above and below 0](image-url)
The present version of the inundation model: Application to the Wax Lake Delta

Prediction of the ecological succession based on mean annual frequency of inundation: criterion

<table>
<thead>
<tr>
<th>Vegetation Community Type (dominant species)</th>
<th>Annual frequency of inundation</th>
</tr>
</thead>
<tbody>
<tr>
<td>High Woody (Salix nigra)</td>
<td>&lt; 44%</td>
</tr>
<tr>
<td>High Emergent (Glossa salentula, Polygonum punctatum, Vigna luteola)</td>
<td>13 to 62%</td>
</tr>
<tr>
<td>Intermediate Emergent (Scenophyllum americanus, Alternanthera philoxeroides, Leersia oryzoides)</td>
<td>27 to 86%</td>
</tr>
<tr>
<td>Low Emergent (Sagittaria platyphylla, Nelumbo lutea)</td>
<td>68 to 97%</td>
</tr>
<tr>
<td>Submerged Aquatic (Potamogeton nodosus)</td>
<td>86 to 100%</td>
</tr>
</tbody>
</table>
The present version of the inundation model: Application to the Wax Lake Delta

Prediction of the ecological succession based on mean annual frequency of inundation: non-dimensional results

Submerged aquatic

Inundation (% of the year)

6 yrs 12 yrs 18 yrs 24 yrs 30 yrs

high woody

high emergent

intermediate emergent

low emergent

Submerged aquatic

0 0.2 0.4 0.6 0.8 1

r/r

6 yrs 12 yrs 18 yrs 24 yrs 30 yrs

low emergent

Submerged aquatic
The present version of the inundation model: Application to the Wax Lake Delta

Prediction of the ecological succession based on mean annual frequency of inundation: dimensional results

Submerged aquatic

<table>
<thead>
<tr>
<th>$r_s$ (m)</th>
<th>Inundation (% of the year)</th>
</tr>
</thead>
<tbody>
<tr>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td>2000</td>
<td>10</td>
</tr>
<tr>
<td>4000</td>
<td>20</td>
</tr>
<tr>
<td>6000</td>
<td>30</td>
</tr>
<tr>
<td>8000</td>
<td>40</td>
</tr>
<tr>
<td>10000</td>
<td>50</td>
</tr>
<tr>
<td>12000</td>
<td>60</td>
</tr>
</tbody>
</table>

6 yrs  12 yrs  18 yrs  24 yrs  30 yrs

high woody  high emergent  intermediate emergent  low emergent
The present version of the inundation model: Application to the Wax Lake Delta

Another criterion: prediction of the vegetation cover based on delta elevation

<table>
<thead>
<tr>
<th>High woody</th>
<th>High Emergent</th>
<th>Intermediate Emergent</th>
<th>Low Emergent</th>
<th>Submerged Aquatic</th>
</tr>
</thead>
<tbody>
<tr>
<td>$\eta_{\text{veg}}$</td>
<td>PC</td>
<td>$\eta_{\text{veg}}$</td>
<td>PC</td>
<td>$\eta_{\text{veg}}$</td>
</tr>
<tr>
<td>10</td>
<td>20</td>
<td>0</td>
<td>20</td>
<td>-20</td>
</tr>
<tr>
<td>15</td>
<td>30</td>
<td>7</td>
<td>35</td>
<td>-10</td>
</tr>
<tr>
<td>20</td>
<td>40</td>
<td>15</td>
<td>60</td>
<td>0</td>
</tr>
<tr>
<td>25</td>
<td>50</td>
<td>22</td>
<td>35</td>
<td>10</td>
</tr>
<tr>
<td>30</td>
<td>60</td>
<td>30</td>
<td>20</td>
<td>20</td>
</tr>
<tr>
<td>35</td>
<td>70</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>40</td>
<td>80</td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

$\eta_{\text{veg}}$ elevation of the delta above mean sea level in centimeters

PC percent of transect covered by a certain vegetation type
Another criterion: prediction of the vegetation cover based on delta elevation
Some references


Some references (2)


