The need for water surface slopes and channel width-depth relationships; an example from the Amazon hydrologic-hydraulic modeling

September 16, 2008

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• Overview of Hydrologic-Hydraulic Model

• Model parameterization in Amazon Basin
  – Channel hydraulic geometry and slope

• Model results
  – Hydrographs
  – Total water storage changes

• Links to SWOT mission
  – Channel/floodplain geometry and slope
Hydrologic-Hydraulic Model

Large scale Hydrologic-Hydraulic model based on physics

- 1-D vertical water/energy balance
- 1-D lateral surface and subsurface kinematic wave routing
- 1-D Muskingum-Cunge channel and floodplain routing with lateral split of flow to/from channel and floodplain
- Irregular computational grid based on Pfafstetter units
- Model tracks soil water, surface runoff, subsurface runoff, channel and floodplain storage

Hydrologic-Hydraulic Model

1-D vertical water/energy balance model

\[ \Delta S_c + \Delta S_u = P - E_s - E_c - E_T - Q_s - D \]

Model tracks soil storage in root zone and Canopy storage (minimal); passes excess surface (qs) and root zone (D) waters to routing model.
Hydrologic-Hydraulic Model

- 1-D lateral surface and subsurface kinematic wave routing
  - Surface runoff
  - Subsurface runoff
  - Re-surfacing of subsurface runoff
- Subsurface separated into two zones (upper and lower) to capture depth profile of horizontal conductivity
Hydrologic-Hydraulic Model

- 1-D Muskingum-Cunge channel and floodplain routing
  - with exchange between channel and floodplain
- Each model unit approximated as "Open Book"
  - Contains 2 planes, 1 channel, 1 floodplain
  - Channel and floodplain receive lateral inflow flow from planes 1,2 plus any upstream inflows
Hydrologic-Hydraulic Model

- Computational grid based on Pfafstetter basins; self-replicating system of 9 units
- Units can be small for high drainage density or large to minimize computing resources
- Amazon Basin-Level 4 (5,189 units) at hourly time-step for period 2001 into 2008

(Max No. of Units = $9^{\text{Level}}$)
Hydrologic Modeling Performed at Plane Scale - Split PFAF units

Model parameters spatially average on split PFAF units
Routing models approximate split PFAF units as rectangles

5,189 channels: Channel length = 26 km (0.1 to 890 km)
Channel width = 83 m (6 to 3,630 m)
Floodplain width = 25 m (0.1 m to 55 km)

10,378 planes: Plane area = 110 km² (<1 to 28,000 km²)
Model requires a representative channel cross-section for each model unit (e.g., 5,189 needed for Amazon-L4)

Floodplain Width (>30 km)

Channel Width (~1 km)
Need method for determining channel and floodplain widths and depths throughout basin

Can obtain widths from remote sensing, BUT what do channels look like below surface: triangular, rectangular or some other shape?

What is bankfull depth & width (i.e., separate channel from floodplain)?

Used 82 Streamflow Stations in Amazon Basin
1,000 to 4.7M km²
Hydraulic Geometry
(from in-situ and remotely sensed data)

• Based on Leopold and Maddock (1953) Hydraulic Geometry relations
  \[ w = aQ^b \quad d = cQ^f \quad v = kQ^m \]

• Determined bankfull discharge and hydraulic geometry: \((a,c,k)\) and \((b,f,m)\)

• Developed relations for channel/floodplain characteristics & drainage area

\[
\begin{align*}
Q_b &= 0.096A^{0.95} \\
W_b &= 2.36A^{0.47} \\
D_b &= 0.25A^{0.34} \\
W_f &= 0.017A^{0.96}
\end{align*}
\]
Floodplain width vs. upstream drainage area (does not capture local features)

Current approach, does not fully capture local variations NOT governed by drainage area alone

Reduced floodplain widths impact model results by increasing flow depths and velocity to handle discharge
Model Results - based on 34 gauges 2001-2005

- TRMM 3B42, roughness: channel = 0.04; floodplain = 0.07
- Mean annual mass error = 6.2%; peak error = 5.7%
30 day windows of discharge

- 1,000 to 100,000 km² (discharges variability - 1 to 5 days)
- >100,000 km² (discharge variability - 5 to 10 days)
- 0.001 to 0.0001 m³/s/km²/day

Qx10 m³/s  5K km²
Qx100 m³/s  41K km²
Qx1,000 m³/s  460K km²
Qx1,000 m³/s  1.1M km²
Qx10,000 m³/s  2.1M km²
Qx10,000 m³/s  4.7M km²
Monthly storage changes based on mean storage from Apr 2002 to Dec 2003

Basin-wide monthly $\Delta S$ ranges from +/- 5 cm

Storage changes account for:
- root zone moisture
- sub-surface/surface runoff
- channels and floodplains

Results show importance of both landscape and channel/floodplain stores
Water Storage Components
- Rooting zone soils - 20%
- Subsurface routing - 40%
- Channel/floodplains - 40%

Monthly $\Delta S \pm 5$ cm

Yr-Yr monthly variability 2.5 cm
(due to timing of seasonal precip)
Repeat measurements from SWOT will provide hydraulic geometry!
  – Will provide critical data at ungauged locations (or improve in-situ data)

Need SWOT slopes: slopes from SRTM must be adjusted based on assumed range in bankfull channel velocity and in-situ data
  – Slopes adjusted based on Manning's velocity (0.3-2.3 m/s)
  – Median reach length = 25 km
    0.1 to 900 km
  – Median Slopes
    SRTM - 113 cm/km (1-9,000)
    Adjusted - 26 cm/km (1-750)