Using Remote Sensing to Analyze River Geomorphology

Seeing Water from Space Workshop
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Rivers impact:
- Geology
- Ecology
- Humans
- The atmosphere

Rivers GRWL Surface area Google Earth Engine
A river’s form reflects the conditions and processes present in its watershed.

Remote sensing gives us:
- Elevation
- Slope
- Planform morphology
  - Length
  - Width
  - Surface area
  - Braiding

Useful knowledge:
- Discharge
- Flood hazards
- Transport capacity
- Groundwater processes
- Human impact
- Water quality
- Gaseous emissions

Rivers          GRWL           Surface area          Google Earth Engine
Topographic data

Remote sensing of terrain

Photogrammetry

Synthetic Aperture Radar (SAR)

Light detection and ranging (LiDAR)

ncdot.gov

Rivers          GRWL           Surface area          Google Earth Engine
Digital elevation models (DEM)

Biences:
1. Location
2. Elevation
3. Flow accumulation
4. Planform morphology

Problems:
1. Errors in DEM
2. Threshold flow accumulation
3. Incomplete global coverage
4. Planform morphology

No high quality DEMs above 60° N

Threshold flow accumulation $\rightarrow$ rivers!

Rivers
GRWL
Surface area
Google Earth Engine
Conventional river width datasets are based on a series of necessary assumptions

\[ \text{Width} = a \times \text{Discharge}^b \]

\[ \text{Discharge} = c \times \text{Basin Area}^k \]

Rivers

GRWL

Surface area

Google Earth Engine
Conventional DEM width datasets are inadequate

Andreadis et al. (2013) *Water Resources Research*

“Hydraulic and hydrologic modeling has been moving to larger spatial scales with increased spatial resolution, and **such models require a global database of river widths** and depths to facilitate accurate river flow routing.”

Raymond et al. (2013) *Nature*

“Unfortunately the data sets we currently use to model **global stream and river hydraulics (width and velocity)** are biased to temperate systems that generally have modest rainfall.”

Wehrli (2013) *Nature*

“…[T]he heavy modifications that have been made to surface water systems… result in **an artificial river morphology that cannot be predicted by geographical scaling laws.**”

Pavelsky et al. (2014) *Journal of Hydrology*

“No **globally consistent and continuous map of river widths exists** for rivers as narrow as 50–100 m… to provide a preliminary estimate for the extent of rivers wider than a 50 m or 100 m threshold.
Is there an alternative method?

Advantages:

1) Directly observable:
   - Inundation extent
   - Centerline
   - Width
   - Braiding

2) Global coverage

3) 30 m resolution

4) Multitemporal

Rivers  |  GRWL  |  Surface area  |  Google Earth Engine
1. Determine optimal time of year to measure rivers

Dataset development

- **Rivers**
  - GRWL
  - Surface area
  - Google Earth Engine
1. Determine optimal time of year to measure rivers
2. Acquire >8,000 Landsat scenes
3. Remove clouds
4. Delineate water with MNDWI (Xu, 2006)

Dataset development

Rivers  GRWL  Surface area  Google Earth Engine
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6. Mask and subset
7. Touchup & ID rivers
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8. RivWidth
Global River Widths from Landsat (GRWL)
Global River Widths from Landsat (GRWL)

- 58 million measurements of rivers
- 30 meter resolution
- River width at mean flow
- Improved location accuracy
- Includes braiding index
- Includes rivers above 60° N (20%)
- Freely available upon publication
North America River Width dataset is freely available (search NARWidth)
GRWL vs. conventional DEM width data sets

GRWL Widths > 100 m

DEM Widths > 100 m

Pavelsky et al. (2014)
Science question: How much greenhouse gas do rivers emit?

According to Raymond et al., 2013 Nature: 1.8 Pg C/yr

Rate of carbon emissions per area

CO₂ partial pressure

Stream gas transfer velocity

Rivers

GRWL

Surface area

Google Earth Engine

Rivers

GRWL

Surface area

Google Earth Engine
How do Raymond et al. estimate river surface area?

Surface Area = \( \sum \text{Length} \times \text{Width} \)

1. DEM-derived data
2. Stream gauge data
3. Climatic data

Rivers          GRWL           Surface area          Google Earth Engine
Surface area of rivers (& streams)

**GRWL Surface Area** = \( \sum \text{Length} \times \text{Width} \)

…but what about narrow streams?

[Image: Photo: Andrew Cooper]

Rivers  | GRWL  | Surface area | Google Earth Engine
Surface area estimate for North America

Extrapolated width-area relationship from wide to narrow rivers and streams

1.6±1.1 m (Downing et al., 2012)

Total surface area of North American rivers and streams:

\[ 124,000^{+39,000\,}_{-15,000} \text{ km}^2 \]

\( \rightarrow 0.55^{+0.17\,-0.07} \text{ % of land surface} \)
- Estimated SA: 124,000 km²
  - % land cover: 0.55%

- Estimated SA: 97,000 km²
  - % land cover: 0.32%

- Estimated SA: 160,000 km²
  - % land cover: 0.88%
Current surface area estimates: Raymond et al. (2013) - Nature

GRWL (Raymond et al., 2013 - Nature)

Africa
• $SA = 10^{4.2} \ W^{-1.1}$
• $SA_{\text{tot}} = 96,787 \ km^2 \ (83,056 \ km^2)$
• Land Cover = 0.32% (0.28%)

North America
• $SA = 10^{4.7} \ W^{-1.13}$
• $SA_{\text{tot}} = 123,940 \ km^2 \ (103,655 \ km^2)$
• Land Cover = 0.55% (0.46%)

South America
• $SA = 10^{4.5} \ W^{-0.97}$
• $SA_{\text{tot}} = 160,119 \ km^2 \ (130,125 \ km^2)$
• Land Cover = 0.88% (0.73%)
Why the difference?

Stream gauges are located at narrow, single channel sites, often near bridges or other fixed structures.
Consequence: Gaseous efflux estimates should likely be revised upwards for rivers and streams.
Future work: Quantifying the distribution of surface area in small watersheds

DHG status quo: power-law distribution with an abrupt lower threshold

hypothesis: log-normal distribution in low-order streams

observed surface area from NARWidth

Rivers  GRWL  Surface area  Google Earth Engine
In situ vs remote sensing data sets:

In situ measurements:
Local coverage
Accurate

Remote sensing measurements:
Global coverage,
Spatially continuous
Systematic

Optimal for global studies
Future work: Quantifying the distribution of surface area in small watersheds

Hill Forest, Durham County

Rivers          GRWL           Surface area          Google Earth Engine

1. Sagehen
2. Elder
3. Kings
4. Coweeta
The distribution of widths in small watersheds follows a log-normal spectrum.
The most common size stream is in the narrow range of 23-39 cm.
• Estimated SA: 124,000 km²
• % land cover: 0.55%

• Estimated SA: 97,000 km²
• % land cover: 0.32%

• Estimated SA: 160,000 km²
• % land cover: 0.88%
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Google Earth Engine

- GIS and remote sensing analysis platform
  - Remote sensing data storage
  - Cloud computing
- User interface
  - [https://earthengine.google.org/#workspace](https://earthengine.google.org/#workspace)
- Time-lapse videos
  - [https://earthengine.google.org/#intro/Amazon](https://earthengine.google.org/#intro/Amazon)
- Trusted tester sign up
  - [https://docs.google.com/forms/d/17-LSoJQcBvUGlwfJRLv0ULYhOahMJs2MwRF2XkrcM/viewform](https://docs.google.com/forms/d/17-LSoJQcBvUGlwfJRLv0ULYhOahMJs2MwRF2XkrcM/viewform)
- Google Earth Engine API
  - [https://ee-api.appspot.com/](https://ee-api.appspot.com/)

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Rivers          GRWL           Surface area          Google Earth Engine
NARWidth was validated with 1,049 USGS and WSC in situ width measurements of rivers at mean annual discharge.
Why is our estimate greater than Raymond et al.?

Methodology

Surface Area = Length * Width

Data from:
1. DEMs
2. Stream gauge data
3. Horton ratios
4. Climatic data

Assumptions:
- Global critical drainage area of 0.1 km²
- ~0.75 m lower width threshold
- In situ width and measurements are accurate
- Q-A relationships
- DHG simplifications
- Horton ratios
- Climate-%SA extrapolation to high latitudes

Raymond et al. DEM coverage:
Incorporating topographic data into GRWL
At many station hydraulic geometry (AMSHG)