Evaluation of Close-range Remotely-sensed Multispectral Imagery to Quantify the Effects of Particle Size Distribution on Instream Turbidity

FISP Technical Committee
Project Status Report
7 October 2014

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U.S. Department of the Interior
U.S. Geological Survey

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Outline

- Review
  - Objectives
  - Background
  - Methodology
- Progress
- Results
  - Sample lab analysis
  - Vertical profiles
  - Photographs/image processing
  - Regression model exploration
- Challenges & Possible Solutions
- What's next?

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Review

- Objectives
  - Hysteresis in the relationship between turbidity and suspended-sediment concentration has been attributed to changing particle size distribution (PSD).
  - Current methods to measure PSD are time-consuming and/or very expensive.

  - Pilot Project:
    - We are developing methodology to continuously monitor PSD using relatively inexpensive 'off-the-shelf' equipment and software in order to increase the accuracy of turbidity-based suspended-sediment records.

Review

- **Background**
  - **Turbidity-SSC spectral response using satellite remote sensing**
    - Empirical models for large rivers, estuaries, reservoirs
    - Shorter λ (450-590 nm, UV-visible) = lower SSC
    - Longer λ (630-900 nm; visible-NIR) = higher SSC

    - Log-linear below ~600-800 nm, linear ~600-800 to 1,050 nm
    - Linear <500 mg/L, non-linear >500 mg/L
    - R^2 ~0.80-0.92
    - For SSC <2,000 mg/L, many studies <250 mg/L

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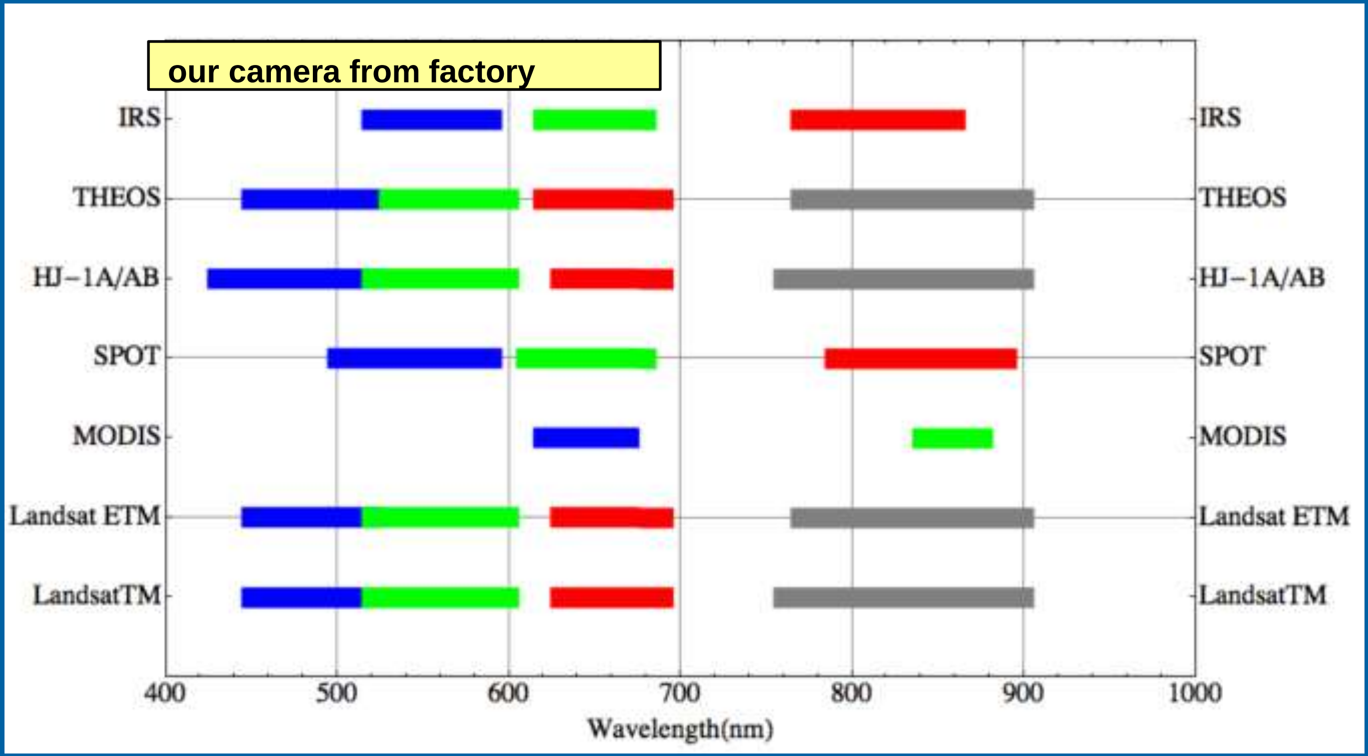
Review

- **Background**
  - **Turbidity-SSC spectral response using satellite remote sensing**



Satellite spectral band range

Liqin, 2014

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Review

- **Methodology - Overview**
  1. **Acquire photographs of river surface**
  2. **Normalize imagery to account for variation in ambient light**
  3. **Collect concurrent suspended sediment samples**
  4. **Analyze samples for PSD (& SSC)**
  5. **Discover and demonstrate a relationship between imagery and particle size = *build an empirical regression model***

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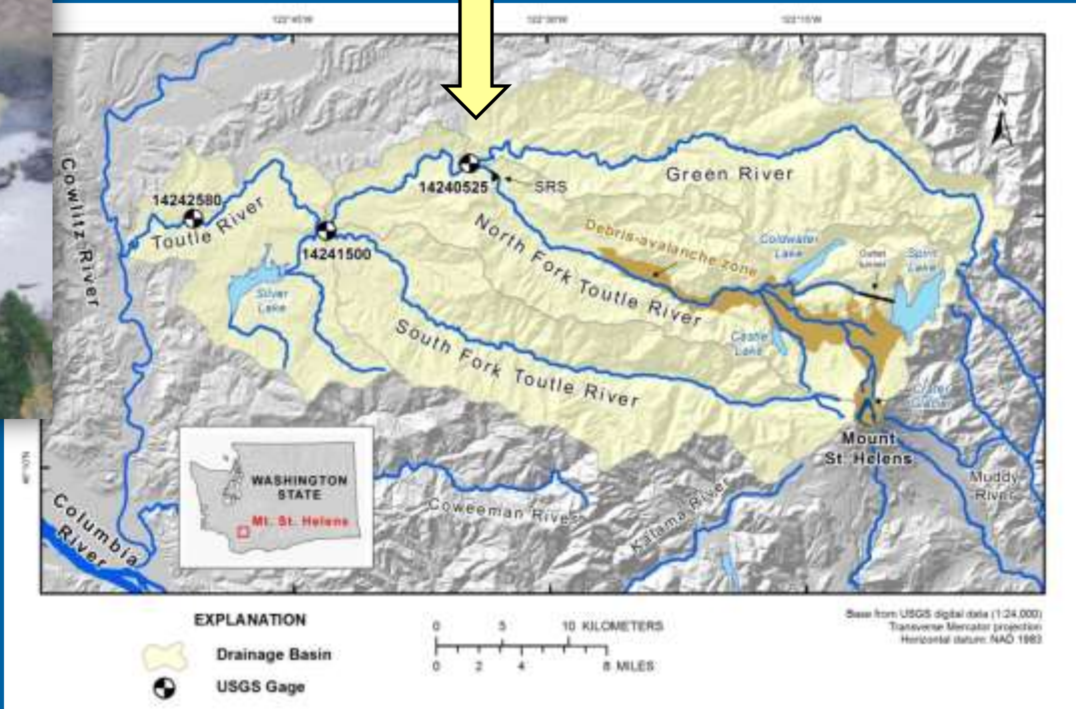
Progress

- **Current status**
  - **Pilot project site selection – DONE**

Mean SSL = 3 M tons
SSC = 31-79,800 mg/L



USGS 14240525 NF Toutle River below SRS near Kid Valley, WA
Cooperator: U.S. Army Corps of Engineers

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Progress

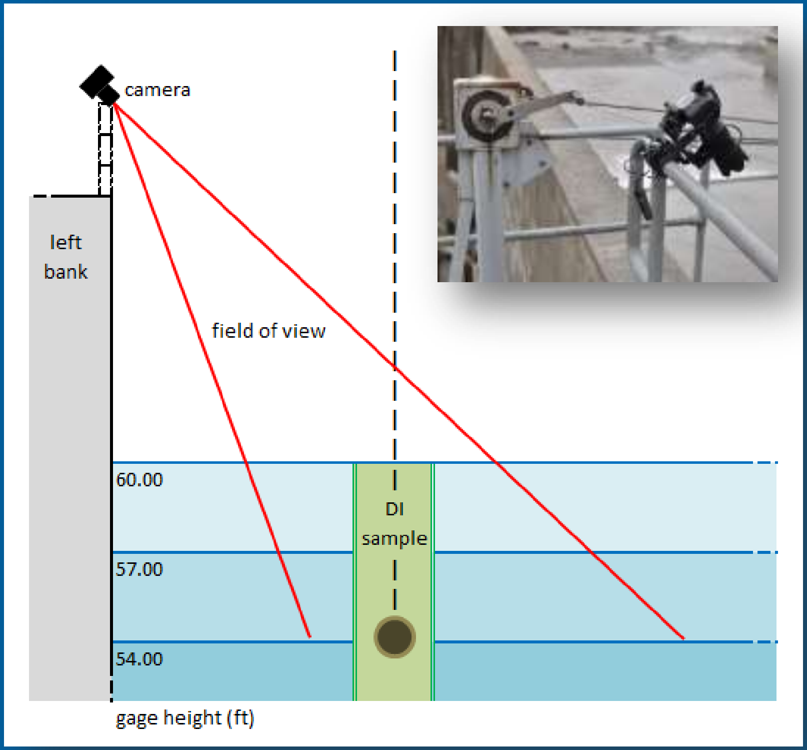
- Current status
  - Pilot project site selection – DONE
  - Camera system selection – DONE

NCSETUP8.BIN	1/3/2014 1:57 PM	BIN File	5 KB


white balance reference card

Progress

- **Current status**
  - **Pilot project site selection – DONE**
  - **Camera system selection – DONE**
  - **Initial field data acquisition methods – DONE**



SOP: Particle Size Image Capture at FTP Using a Nikon DSLR

U.S. Geological Survey, Volcano Hazards Program, Cascades Volcano Observatory Surveillance (Hydrologic Monitoring) Group

Important Contacts:

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✓ **OBJECTIVE:**

Acquire images of river surface for particle size analysis.

NOTE: This workflow was written for the USGS-CVO using a Nikon camera and lens for data collection. The U.S. Geological Survey does not endorse any product or software.

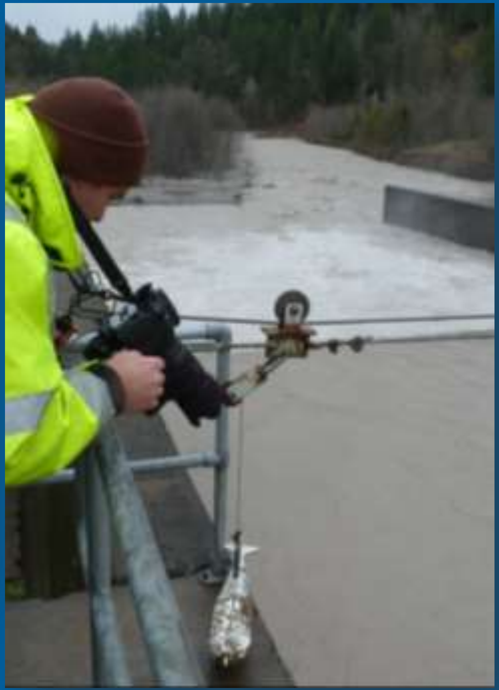
✓ **EQUIPMENT LIST:**

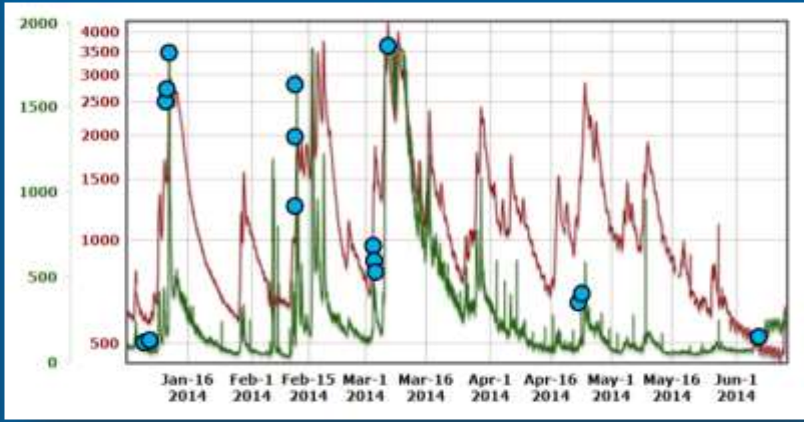
	REQUIRED:
	Nikon D800E (or D7000) DSLR
	Nikon EN-EL15 Li-Ion batteries, charged, at least 2
	Tamrac quick-release strap
	Nikkor 70-300 mm f/4.5-5.6 G AF-S lens with hood and cover
	CF & SD memory cards with sufficient storage (~2GB per set)
	67mm clear filter
	67mm UV filter
	67mm circular polarizing filter
	WhiBal reference card
	Camera mount, consisting of:
	Manfrotto 293 lens rail w/234RC
	Manfrotto 808RC4 pan/tilt head
	Manfrotto 635 super clamp
	Clear plastic rain covers (at least 2)
	Lens cleaning cloth and solution

	OPTIONAL:
	Spare battery and charger
	Spare SD and/or CF memory cards
	Additional cleaning supplies
	Nikon MB-D12 battery pack with 8x AA
	Nikon USB cable (mini-USB to USB)
	Field laptop with Control My Nikon software (Panasonic Toughbook LT165 has it loaded) with sufficient battery power and/or inverter

Progress

- **Current status**
  - **Pilot project site selection** – **DONE**
  - **Camera system selection** – **DONE**
  - **Initial field data acquisition methods** – **DONE**
  - **Data acquisition** – **DONE**





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Progress

- **Current status**
  - **Pilot project site selection** – **DONE**
  - **Camera system selection** – **DONE**
  - **Initial field data acquisition methods** – **DONE**
  - **Data acquisition** – **DONE**
  - **Sample lab analysis** – **DONE**

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Progress

- **Current status**
  - **Pilot project site selection** – DONE
  - **Camera system selection** – DONE
  - **Initial field data acquisition methods** – DONE
  - **Data acquisition** – DONE
  - **Sample lab analysis** – DONE
  - **Image processing/regression work** – IN PROGRESS

STATISTICS of INDIVIDUAL LAYERS

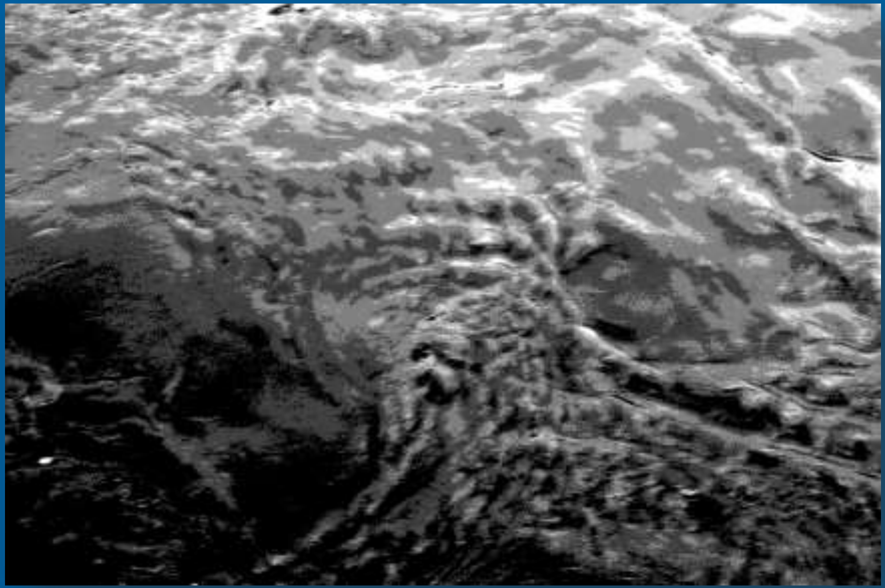
Layer	MIN	MAX	MEAN	STD
1	68.0000	155.0000	140.3416	4.9301
2	57.0000	145.0000	129.9683	4.8840
3	37.0000	127.0000	110.4950	4.6638

COVARIANCE MATRIX

Layer	1	2	3
1	24.30563	23.18829	21.18488
2	23.18829	23.85346	21.79662
3	21.18488	21.79662	21.75117

CORRELATION MATRIX

Layer	1	2	3
1	1.00000	0.96303	0.92136
2	0.96303	1.00000	0.95691
3	0.92136	0.95691	1.00000



Progress

- **Current status**
  - **Pilot project site selection** – DONE
  - **Camera system selection** – DONE
  - **Initial field data acquisition methods** – DONE
  - **Data acquisition** – DONE
  - **Sample lab analysis** – DONE
  - **Image processing/regression work** – IN PROGRESS
  - **Manuscript writing** – IN PROGRESS

EVALUATION OF CLOSE-RANGE REMOTELY-SENSED MULTISPECTRAL IMAGERY TO QUANTIFY THE EFFECTS OF PARTICLE SIZE DISTRIBUTION ON INSTREAM TURBIDITY

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INTRODUCTION

Quantifying suspended-sediment concentration (SSC) using continuous instream turbidity is rapidly becoming common practice within sediment monitoring programs. Sediment-surrogate technologies such as turbidity promise increased accuracy and reduced cost compared to traditional physical sample-based methods (Gray and Gartner, 2009; Landers et al., 2012; Landers and Sturm, 2013). However, hysteresis in the relationship between turbidity and SSC has been attributed to changing particle size distribution (PSD) (Landers and Sturm, 2013; Uhrich et al., 2014). Temporal variation of PSD causes increased uncertainty in simple linear turbidity-SSC regression equations, due to the changes in nephelometric reflectance off the varying grain sizes in suspension (Uhrich et al., 2014). This discrepancy decreases the accuracy of real-time SSC computations. To overcome this, we show how concurrent and independent measurements of PSD (presently only obtainable using relatively expensive LISST technology) can increase the accuracy of turbidity-based SSC records.

REMOTE SENSING

Remote sensing is a rapidly growing subdiscipline in river science due to its ability to answer complex spatial and temporal questions; cost-effective data acquisition, processing and analysis; and the increasing participation of hydrologists in geospatial technology (Marcus and Fonstad, 2010). River remote sensing has become a broad field. While active remote sensing is used to map and assess geomorphic characteristics of river environments for decades, passive optical remote sensing using reflected electromagnetic radiation in the visible and near-infrared spectrum has been successfully used to estimate water discharge (Bjerklie et al., 2004; Xu et al.,

Schedule	FY2014
Instrumentation design and installation	December-January
Field data collection	January-June
Particle size analysis – CVO sed. Lab	February-August
Digital image analysis and regression	February-September
Prepare peer-reviewed report	September-October
~~Submit final draft to USGS publishing center~~	November

*** SEDHYD 2015 paper, Nov. 23rd deadline**

Results

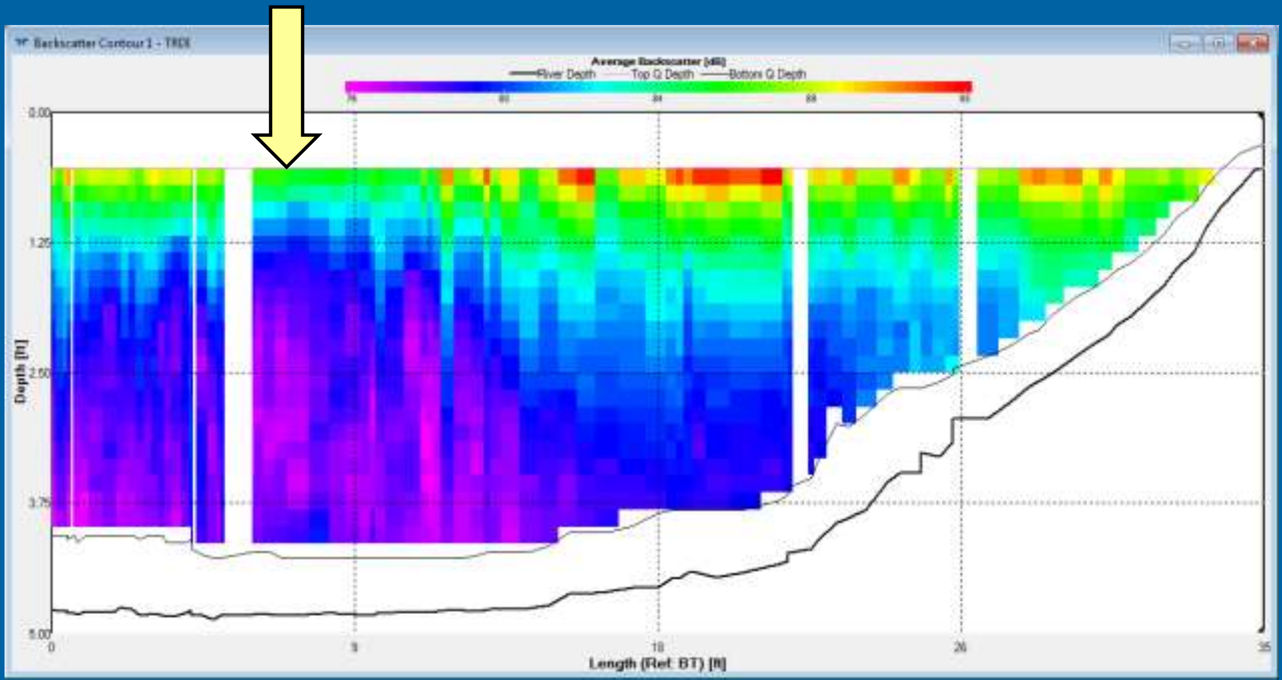
- **Sample lab analysis, >100 total including EDI's**
  - **SSC for 26, full-size analysis for 9 samples**
    - 262 – 7,339 mg/L
    - 98.2 – 100.0% < 0.5 mm (med. sand - clay)
    - 27.8 – 94.3% < 0.063 mm (silt - clay)
    - 9.5 – 32.5% < 0.004 mm (clay)
    - 4.4 – 24.3% < 0.002 mm (mineral clay)
  - **Turbidity range = 79-4,170 FBRU**
  - **Trends = rise, peak, recession, trough**

Results

- Vertical profiles
  - Full-depth DI vs. surface (20-30s, 3/16” nozzle)
  - Turbidity (most sensitive to fines, DTS-12)

Surface = 9 – 30% less fines, *n* = 11

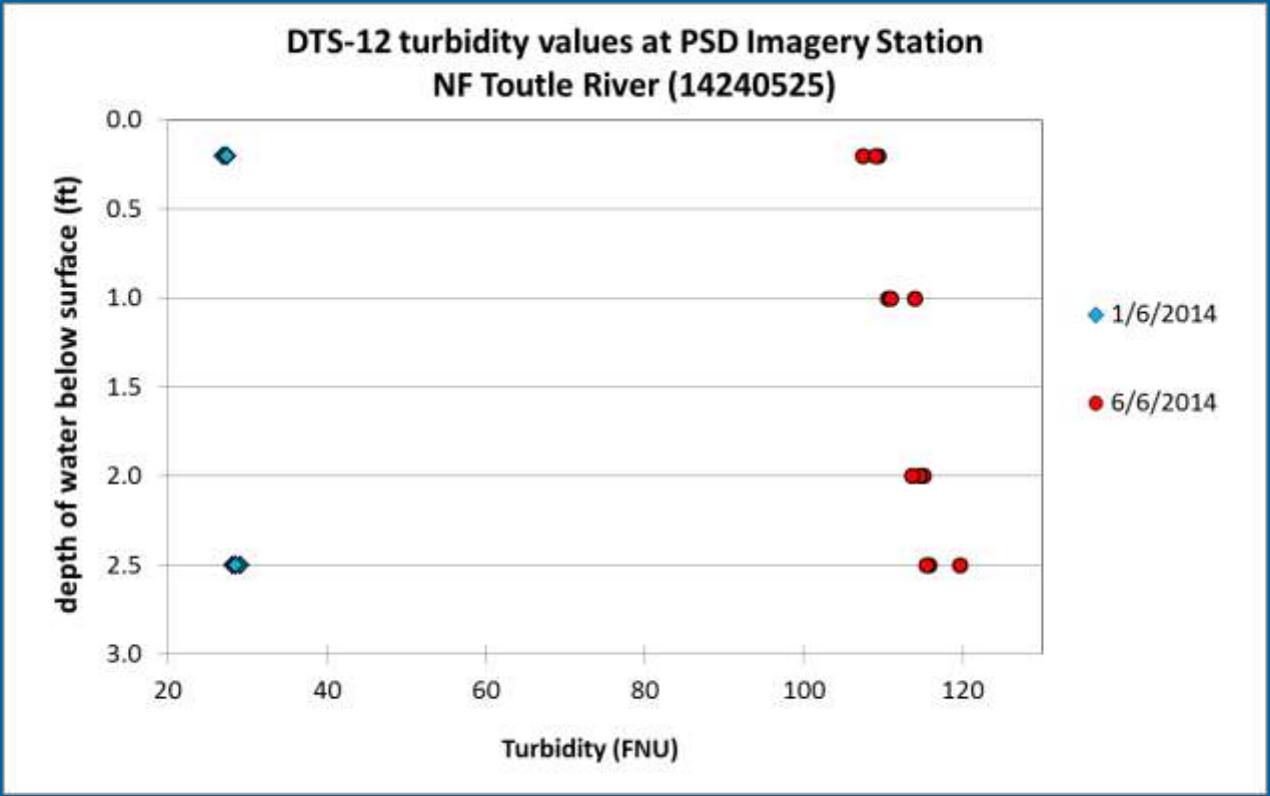
PSD sample vertical



Uncorrected backscatter, StreamPro, 5 cm cell, left channel

Results

- Vertical profiles
  - Full-depth DI vs. surface (20-30s, 3/16” nozzle)
  - Turbidity (most sensitive to fines, DTS-12)



Results

- **Photographs, >700 frames**
  - **Exposure bracketing sequences (EV) – prevent data clipping**
  - **Filters (clear, ultraviolet, polarizer) – clip UV, change geometric effects at water-air boundary**
  - **File type (RAW, NEF, TIF, JPEG) – degree of signal processing**
  - **Bit-depth (8, 16, 32) – data precision, range**
  - **Color space (sRGB, Adobe RGB, ProPhoto) – data precision, range**

RED					GREEN					BLUE					RGB COMP					
MIN	MAX	MEAN	STD	COV	MIN	MAX	MEAN	STD	COV	MIN	MAX	MEAN	STD	COV	MIN	MAX	MEAN	STD	COV	FILTER
79.0000	255.0000	126.6464	23.7313	563.1745	76.0000	255.0000	117.3192	20.0542	402.1702	70.0000	255.0000	102.7455	12.3067	151.4555	75.0000	255.0000	115.5704	18.6974	372.2667	CP
83.0000	218.0000	130.6795	21.8246	476.3149	81.0000	209.0000	122.8326	18.5657	344.6856	69.0000	181.0000	112.1829	11.7223	137.4123	77.6667	202.6667	121.8983	17.3709	319.4709	UV
62.0000	188.0000	105.1208	17.3851	302.2407	56.0000	169.0000	98.4528	15.0575	226.7296	53.0000	138.0000	89.5306	10.2675	105.4218	57.0000	165.0000	97.7014	14.2367	211.4640	CL

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Results

- **Image analysis matrix is enormous**
  - Exposure: 9 EV values + HDR combination 10
  - Filters (field): clear, UV, polarizer 03
  - File type: RAW, NEF, TIF, JPEG 04
  - Bit-depth: 8, 16, 32 03

  - Sample result: SSC, %course, sand, silt, clay 05
  - Sample depth: full, surface 02
  - Sample trend: rise, peak, recession, trough 04
  - Filter (PP): low-pass, histogram equalization 02
  - Band combinations/ratios (i.e., indices) many

  - **This gets BIG, FAST = >160,000 unique analysis possibilities**

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Results

- **Initial pairing of photographs & samples**
  - Matched using clock time; set max Δ_{time} = ~30 min
  - Focused on samples with more complete lab analysis
  - Chose three particle size classes: <0.063%, <0.004%, and <0.002%
  - Started with EV0, 8-bit JPEG files, AdobeRGB color space
  - Used ArcGIS *Band Collection Statistics tool* to compute min, max, mean, std, cov for each of three bands
  - Used a correlation matrix in Excel to initially explore relationships
  - Continued exploring relationships by simple linear regression plots

  - **12 datasets, 83 pairs, 14 withheld for bootstrapping accuracy assessment**

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Results

- **Initial simple OLS regression models tell us…**
  - For the clear filter, full-depth samples are generally more strongly correlated than surface or all samples
  - UV filter improves silt-size grains a little; better resolution in R-band
  - G-band is most useful for silt-clays, but **strongest correlations come from R- and B-bands**
  - Low pass filter improves relation to clay-size grains
  - 32-bit ProPhotoRGB didn’t perform as well as expected
  - 16-bit NEF-TIF conversions may prove useful

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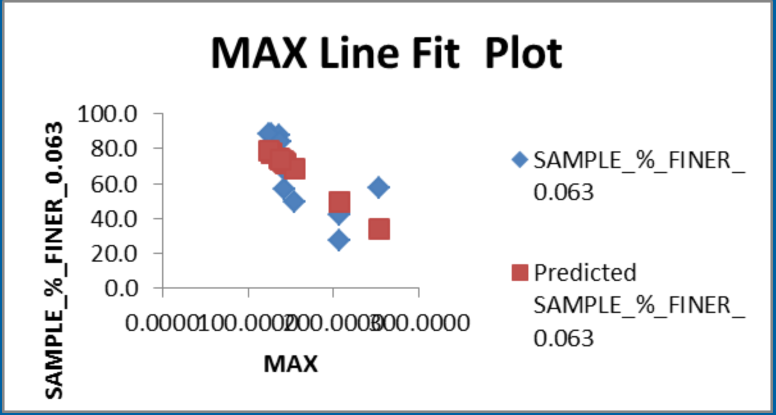
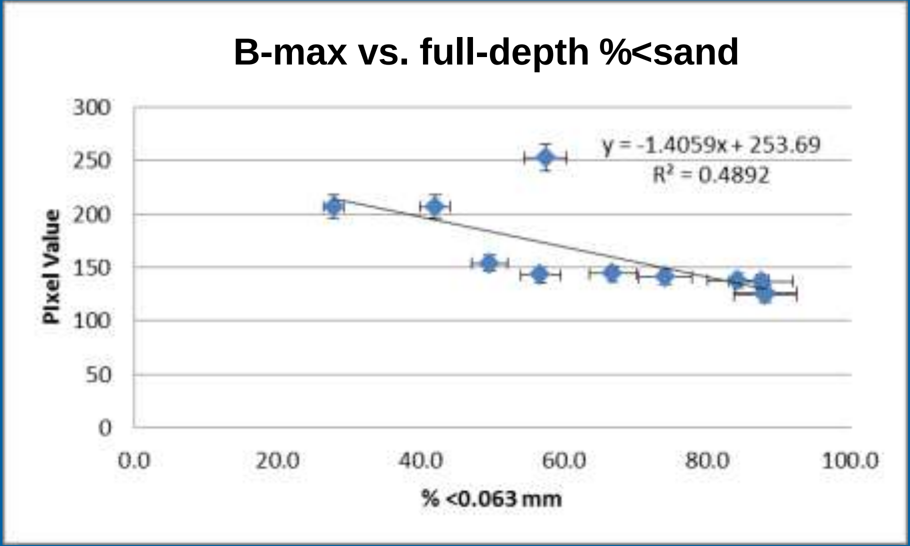
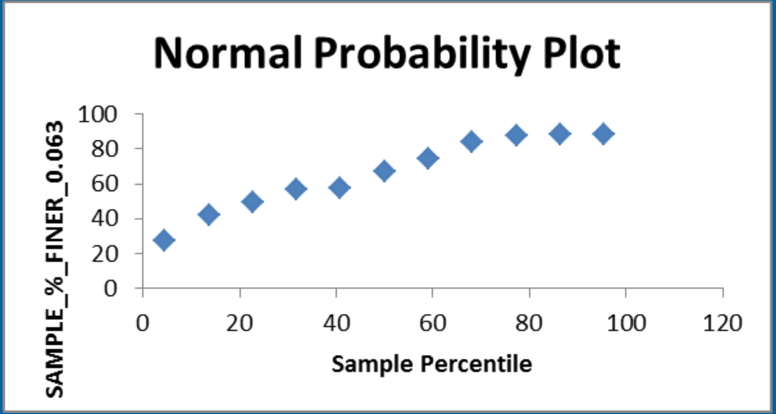
Results

- Best models so far…
  - B-max from EV0, clear filter, 8-bit JPEG vs. full-depth %<0.063 mm
    - n = 11
    - $R^2 = 0.489$
    - Significance F = 0.017
    - P-value = 0.0166

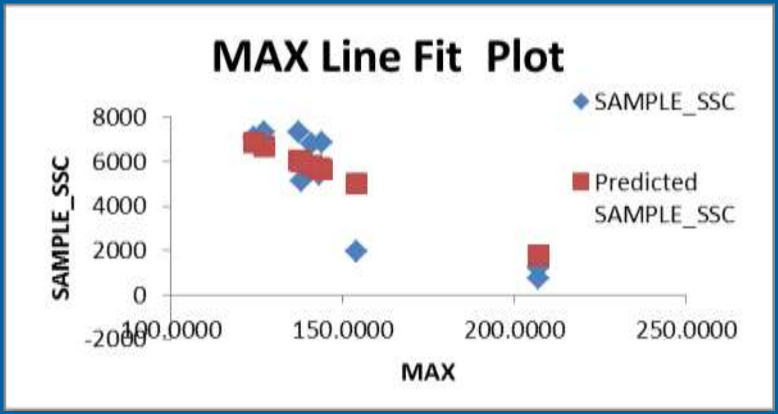


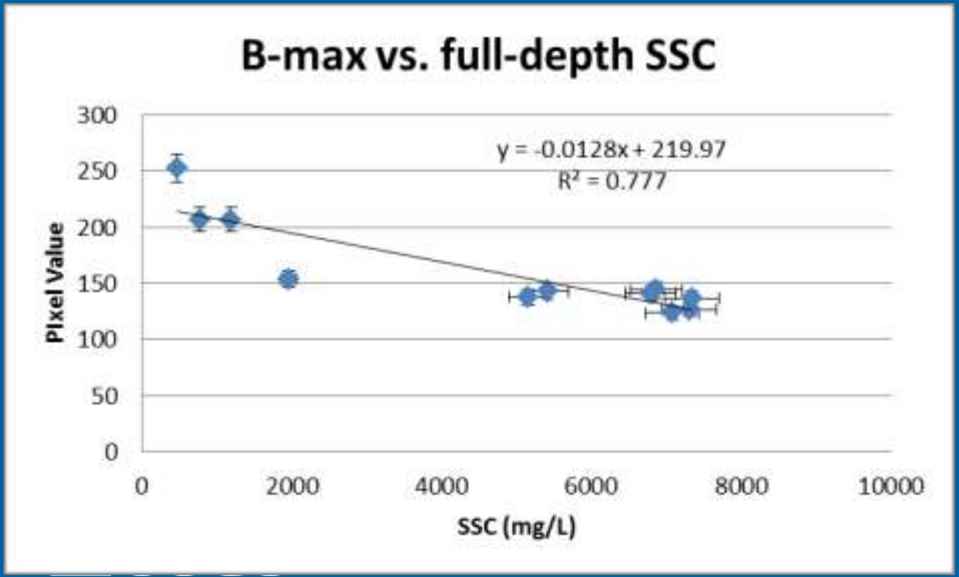


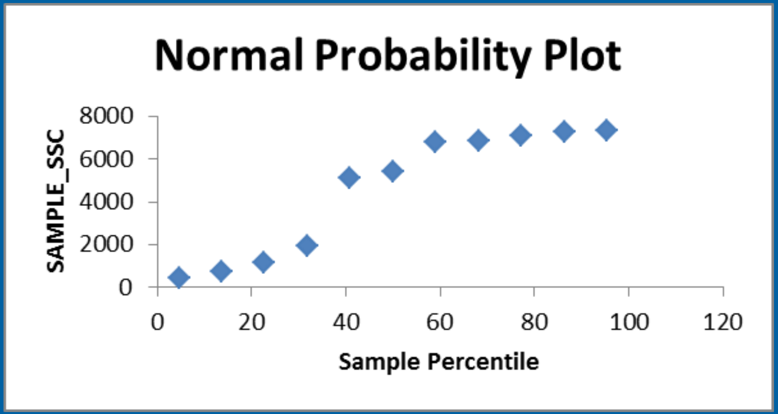


Results

- **Best models so far…**
  - **B-max from EV0, clear filter, 8-bit JPEG vs. full-depth SSC**
    - **n = 11**
    - **R^2 = 0.777**
    - **Significance F = 0.000**
    - **P-value = 0.0003**



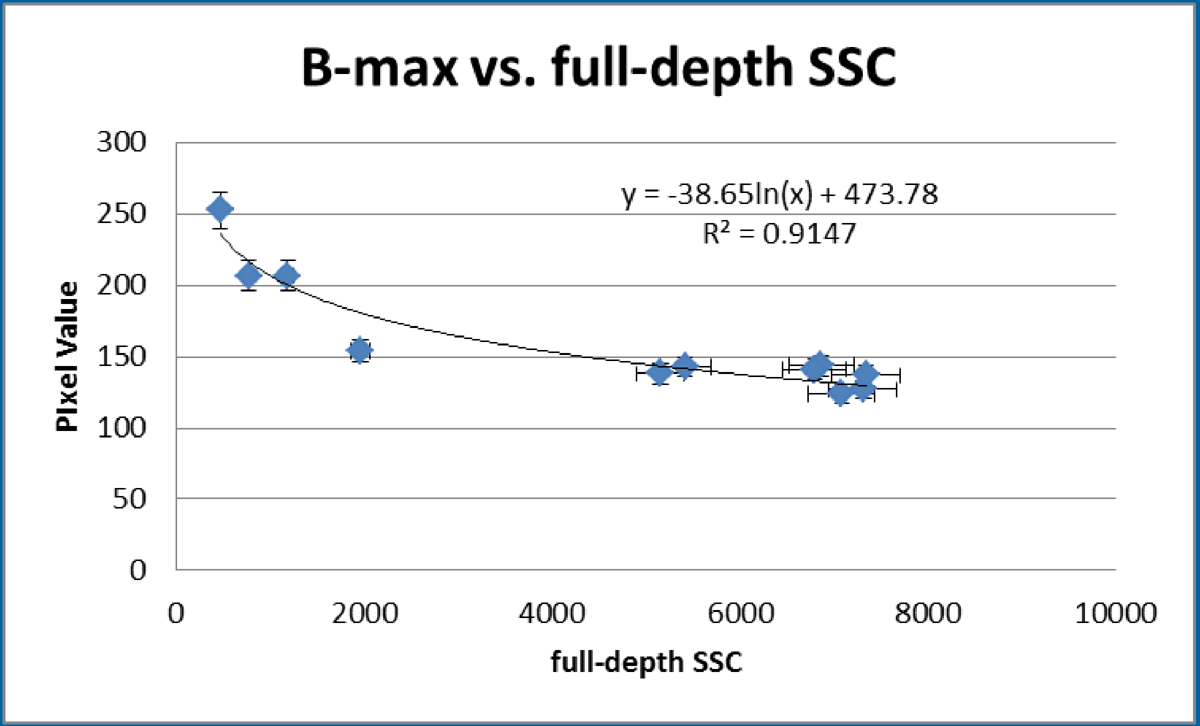




(NFT gage turbidity-SSC multivariate regression is R^2=0.81)

Results

- **Best models so far…**
  - **B-max from EV0, clear filter, 8-bit JPEG vs. full-depth SSC**
    - **n = 11**
    - **R^2 = 0.915**



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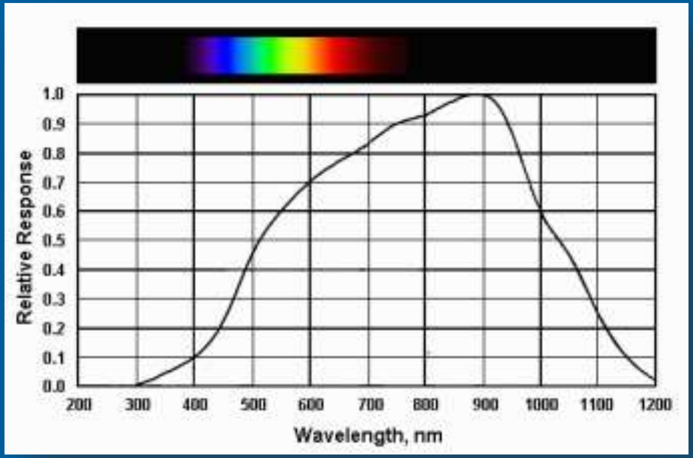
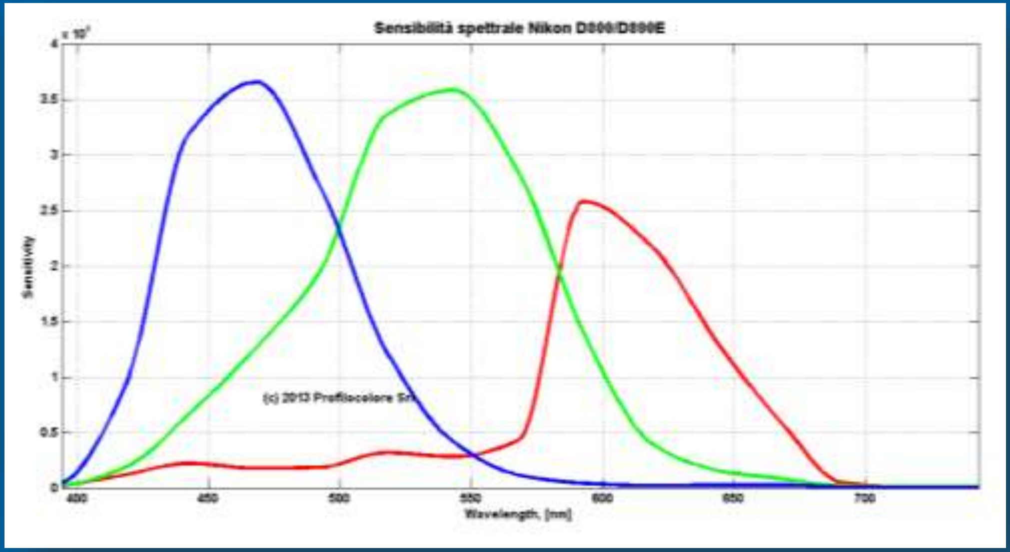
Challenges

- **Spectral response curve of our camera**



D800E native sensor
λ = ~300-1,250 nm



D800E UV-IR cut filter
λ = ~380-680 nm

B = 380-620, peak 470 nm
G = 380-680, peak 540 nm
R = 380-680, peak 590 nm (most leakage)

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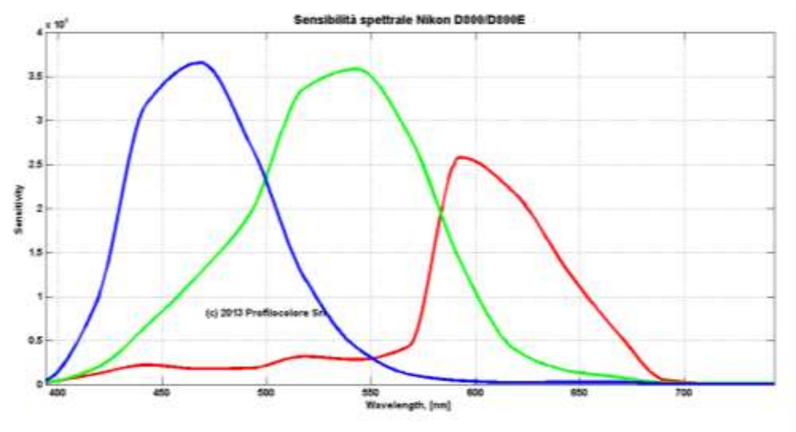
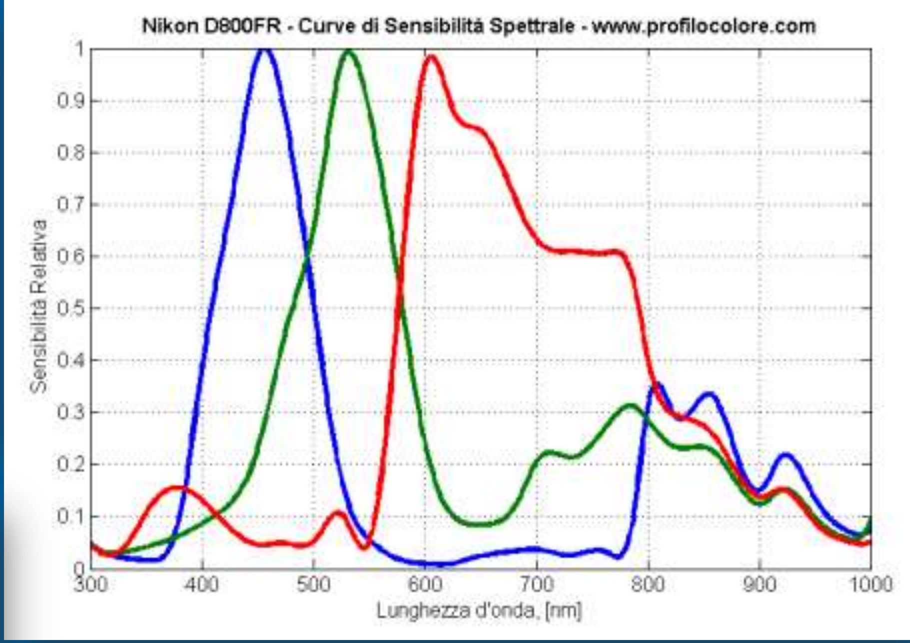
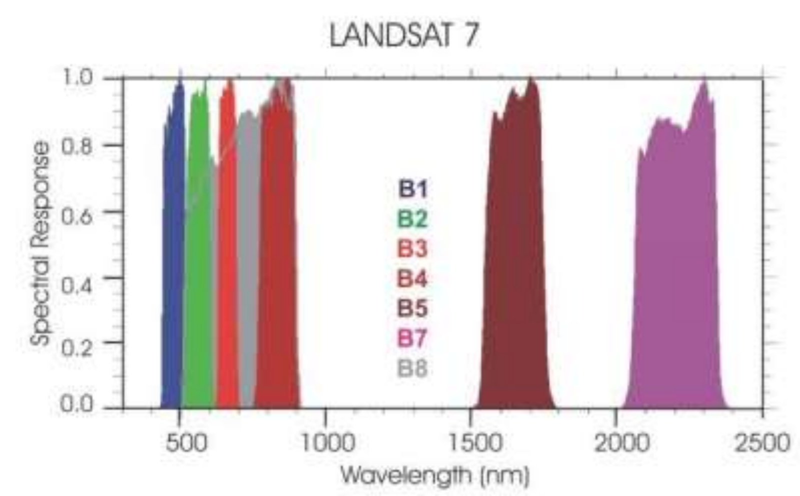
Profilocolore Sri, 2013

Possible Solutions

- **Spectral response curve of our camera**







D800FR + filters

λ = ~320-1,000 nm

λ = 450-2,350 nm

NASA, Profilocolore Sri, 2013

Challenges

- Other
  - How to mine these data more effectively?
  - Site/sensor specific?
  - Need more pairs, especially with full-size analysis
  - Give up on PSD and shoot for SSC?

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What's next?

- **Where do we take this from here?**
  - Continue to explore processing – polarizer, filters,
  - Try a semi-empirical approach using optical and radiative transfer theory (e.g., Volpe et al., 2011; Kilham et al., 2012)
  - Band ratios – may reduce effects of sky reflection, refractive index, etc. in highly turbid waters
  - NIR filter and/or longer exposures – low energy level of upper-end of spectra
  - Modify camera (remove OLPF/UV-IR cut filter)

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What's next?

- **Where do we take this from here?**
  - Install camera at station to continuously take photographs
  - Write batch processing scripts for automation of image analysis (most likely on-site)
  - Develop a piecewise defined function to select the most accurate equation in real-time, based on these data