Continued Development of a Non-contact Sediment Surrogate Technique Based on Multispectral Imagery

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Extended Abstract

The adaptation of suspended-sediment surrogate technologies continues to rapidly expand across fluvial sediment and geomorphology monitoring efforts. Over a decade of research and development shows increased reliability and accuracy with reduced program cost as compared to traditional sample-based methods.

To investigate relationships between multispectral imagery and river suspended-sediment concentration (SSC), we acquire concurrent pairs of water-surface photographs and suspended-sediment samples over a range of hydrologic conditions. Cameras are bank-mounted, with field-of-view perpendicular to flow at a 45-degree angle of incidence to maximize water surface penetration. Lens focal length adjustment provides a consistent nominal pixel size of 0.5 mm on the water surface at various distances. Depth-integrating and automatic samplers are co-located and time synced with the camera systems. Image analyses include spectral normalization, file conversion, and statistical calculations. Calibration datasets compile these image statistics and associated sample lab results for linear regression model development.

Development of the 'SedCam' technique began with a small research grant from the Federal Interagency Sediment Project (FISP) in 2013 (SedCam v1.0; Mosbrucker et al., 2015). The USGS Next Generation Water Observing System (NGWOS) project funded a subsequent study in 2019 (SedCam v2.0; Mosbrucker et al., 2022), and continues to support research and development of the technique in several states (SedCam v2.1-2.3).

SedCam v1.0

A feasibility study was conducted at a USGS gage on the North Fork Toutle River in Washington State (Figure 1; Mosbrucker et al., 2015). Downstream of Mount St. Helens volcano, the exceptionally high sediment yield (mean annual suspended-sediment discharge of 3 million tons from a 150-mi^2 basin) provided an excellent threshold test; SSC in calibration dataset samples ranged from 305 to 7,339 mg/L (n=39). More than 700 images were acquired during a 6-month period from a mobile digital single-lens reflex (DSLR) camera system. SedCam v1.0 recorded three-band imagery (380–680 nm; 470 nm peak wavelength) only during sampling. A wide variety of lens filters and camera configurations were evaluated to investigate optimal settings.

Figure 1. Natural color aerial photograph of North Fork Toutle River and Green River confluence showing water with high suspended-sediment concentration (light brown) mixing with clear tributary water.

Two regression models evaluated the ability to predict SSC from image spectral information. Results show that normalized (by white balance calibration card) pixel values extracted from river surface imagery can predict SSC (Table 1; SSC_{point}, R^2=0.90, ±35.8 model standard percent error (MSPE)). Additionally, the same spectra (maximum value of the blue band, B_{max}) can predict concentration of suspended fines (clay to silt) in the same samples (Table 1; SSC_{fines}, R^2=0.90, ±45.5 MSPE). The authors note that these negative correlations are less sensitive at concentrations above ~4,000 mg/L, with the greatest error occurring below 2,000 mg/L.

Table 1. Regression model summary with statistical diagnostics for [1]SedCam v1.0 and [2]SedCam v2.0.

Response (y)	Explanatory (x)	Model	R^2	RMSE	MSPE
SSC_{point}[1]	B_{max}	$SSC_{point} = (5.3281 \times 10^{12})(B_{max}^{-4.225})$	0.90	0.133	±35.8
SSC_{fines}[1]	B_{max}	$SSC_{fines} = (3.2540 \times 10^{14})(B_{max}^{-5.111})$	0.90	0.163	±45.5
SSC_{point}[2]	R_{max}	$SSC_{point} = 44.201(R_{max}^{2.207})$	0.93	0.139	±37.8
SSC_{mean}[2]	R_{max}	$SSC_{mean} = 82.776(R_{max}^{1.962})$	0.69	0.295	±97.5

SedCam v2.0

As with most sediment surrogates, relationships are site specific, so the feasibility project was expanded to a basin with different sediment characteristics. With a 40% smaller drainage area, 400 times less suspended-sediment discharge, and up to 80% lower fines concentration, the USGS gage at East Branch Brandywine Creek in Pennsylvania was selected for the first long-term SedCam deployment.

SedCam v2.0 acquired 15-minute imagery over a continuous 20-month period. This second iteration used two DSLR camera systems simultaneously (in one waterproof housing) to investigate additional spectra (Figure 2). One camera (similar to v1.0) recorded the visible spectrum (400–700 nm; ~540 nm peak wavelength) while the second was modified to record the sensor's full spectral range (340–1,100 nm; ~1,000 nm peak wavelength). Together, more than 90,000 images were acquired during a 20-month period. Due to exposure metering issues and low spectral precision, the second camera was not used for further analysis.

Figure 2. Field data collection panel showing (*A*) the 'SedCam v2.0' camera system mounted on a handrail on the gage house roof (view looking downstream toward bridge), (*B*) camera housing with white balance calibration card mounted underneath and pump sample intake on left bank, (*C*) interior of camera housing looking toward river surface, and (*D*) depth-integrated sampler deployed from the bridge.

A calibration dataset of paired imagery from the first camera was used in regression model development (Mosbrucker et al., 2022). One model used only left-bank samples while the other used cross-sectional mean SSC. The maximum pixel value of the red band (R_{max}) was found to be the best explanatory variable for both response variables (Table 1; SSC_{point} and SSC_{mean}, respectively). Results show left-bank samples are superior to cross-sectional mean (expected as they are co-located with imagery) with similar error as SedCam v1.0 (Table 1; R^2=0.93, ±37.8 MSPE) at lower SSC values (34–1329 mg/L).

This deployment provided insight into optimal camera selection, configuration, white balance normalization, power supply reliability, and other operational factors. Lessons learned from SedCam v1.0 and v2.0 are currently being used at four additional locations.

SedCam v2.1-2.3

The latest iteration of SedCam development continues to use two camera systems in one housing. One camera remains unmodified (DSLR, 400–700 nm visible spectrum). However, the second camera (full spectrum DSLR in v2.0) has been replaced with a near-infrared mirrorless conversion. This allows (1) proper exposure of the expanded spectral signature and (2) greater precision of the 3-band imagery from 720 to 1,100 nm.

While B_{max} from a visual spectra sensor worked best from 2,000 to 4,000 mg/L, and R_{max} worked best below 1,300 mg/L, we hypothesize that the efficacy of 720-1,100 nm spectra will allow a single camera to be used at a wide range of sediment conditions. Before the end of 2023, we anticipate having enough data to determine whether the SedCam is a suitable non-contact suspended-sediment surrogate at monitoring sites shown to foul and/or destroy in-stream optical backscatter sensors.

References

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