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A GEOBIOLOGICAL APPROACH TO UNDERSTANDING DOLOMITE FORMATION AT DEEP SPRINGS LAKE, CA
Faculty: *DAVID JONES*, Amherst College, *JASON TOR*, Hampshire College,
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POTENTIAL EFFECTS OF WATER-LEVEL CHANGES ON ON ISLAND ECOSYSTEMS: A GIS SPATIOTEMPORAL ANALYSIS OF SHORELINE CONFIGURATION
Faculty**:** *KIM DIVER*, Wesleyan Univ.
Students: *RYAN EDGLEY*, California State Polytecnical University-Pomona, *EMILIE SINKLER*, Wesleyan University

PĀHOEHOE LAVA ON MARS AND THE EARTH: A COMPARATIVE STUDY OF INFLATED AND DISRUPTED FLOWS
Faculty: *ANDREW DE WET*, Franklin & Marshall College, *CHRIS HAMILTON*. Univ. Maryland, *JACOB BLEACHER*, NASA, GSFC, *BRENT GARRY*, NASA-GSFC
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THE GEOMORPHIC FOOTPRINT OF MEGATHRUST EARTHQUAKES: A FIELD INVESTIGATION OF CONVERGENT MARGIN MORPHOTECTONICS, NICOYA PENINSULA, COSTA RICA
Faculty*:* *JEFF MARSHALL*, Cal Poly Pomona, *TOM GARDNER*, Trinity University, *MARINO PROTTI, OVSICORI-UNA, SHAWN MORRISH*, Cal Poly Pomona
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HOLOCENE AND MODERN CLIMATE CHANGE IN THE HIGH ARCTIC, SVALBARD NORWAY
Faculty: *AL WERNER*, Mt. Holyoke College, *STEVE ROOF,* Hampshire College, *MIKE RETELLE*, Bates College
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Keck Geology Consortium: Projects 2013-2014
Short Contributions— Fluvial Response to Extreme Weather Project

EVALUATING EXTREME WEATHER RESPONSE IN THE CONNECTICUT RIVER FLOODPLAIN ENVIRONMENT
Faculty: ROBERT NEWTON, Smith College
JON WOODRUFF, University of Massachusetts
ANNA MARTINI, Amherst College
BRIAN YELLEN, University of Massachusetts

EXTREME PRECIPITATION AND EROSION IN UPLAND WATERSHEDS: A CASE STUDY FROM SHERMAN RESERVOIR, MA
LUCY ANDREWS, Macalester College
Research Advisors: Kelly MacGregor and Brian Yellen

IDENTIFYING STORM DEPOSITS IN A DRY FLOOD CONTROL RESERVOIR IN WESTERN MASSACHUSETTS, USA
AMY DELBECQ, Beloit College
Research Advisor: Susan Swanson

SEDIMENTATION BEHIND CONWAY ELECTRIC DAM, SOUTH RIVER, WESTERN MASSACHUSETTS
SAMANTHA DOW, University of Connecticut
Research Advisor: William Ouimet

A CASE STUDY OF STORM DEPOSITION IN LITTLEVILLE LAKE, HUNTINGTON, MA
CATHERINE DUNN, Oberlin College
Research Advisor: Amanda Schmidt

DELTA PROGRADATION IN A FLOOD CONTROL RESERVOIR: A CASE STUDY FROM LITTLEVILLE LAKE, HUNTINGTON, MA
RACHEL JOHNSON, Carleton College
Research Advisor: Mary Savina

IMPACTS OF EXTREME PRECIPITATION ON SEDIMENT YIELDS FOR POST GLACIAL UPLANDS OF THE NORTHEAST
WESLEY JOHNSON, University of Massachusetts Amherst
Research Advisor: Jon Woodruff

DISCERNING EXTREME WEATHER EVENTS IN THE CONNECTICUT RIVER SYSTEM THROUGH THE STUDY OF SEDIMENTS IN UPLAND DAMS AND FLOOD CONTROL RESERVOIRS OF WESTERN MASSACHUSETTS AND SOUTHWESTERN VERMONT
SCOTT KUGEL, The College Of Wooster
Research Advisors: Dr. Mark Wilson and Dr. Meagen Pollock

GEOCHEMICAL AND MICROFOSSIL RECORD OF MASS HEMLOCK DECLINES IN THE SEDIMENT OF BARTON'S COVE, WESTERN MASSACHUSSETS: IMPLICATIONS OF HEMLOCK DIEOFF TODAY
AIDA OROZCO, Amherst College
Research Advisor: Anna M. Martini

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CLAY MINERALOGY FINGERPRINTING OF SEDIMENTS DEPOSITED FROM TROPICAL STORM IRENE IN THE CONNECTICUT RIVER WATERSHED

JULIA SEIDENSTEIN, Lafayette College
Research Advisor: Dru Germanoski

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SEDIMENTATION BEHIND CONWAY ELECTRIC DAM, SOUTH RIVER, WESTERN MASSACHUSETTS

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INTRODUCTION

Sedimentation behind man-made dams can be seen along streams and rivers throughout New England. Many of these rivers, such as the South River in Conway, Massachusetts, have a long history of damming and impoundment for various types of mill operations, beginning in the 17th and 18th centuries and continuing into the 20th century for flood control, recreation, and power generation. Sediment derived from the landscape and transported by rivers accumulates in the deep, low velocity reservoirs formed behind dams, building a record that can be used to interpret depositional histories, past storm events, and erosion rates of the upstream landscape.

New England has seen significant anthropogenic modification and land use changes over the past few centuries. Deforestation and agricultural practices in the 18th and 19th centuries resulted in reduced hillslope cohesion, enhanced erosion, and increased sedimentation in New England rivers, continuing until reforestation began in the early 20th century (Francis and Foster, 2000). This is supported by the work of Wilkinson and McElroy (2007), who attribute continental erosion related to agriculture to sharp increases in rates of rapid erosion inferred in the stratigraphic record. Furthermore, they find that modern sedimentation rates are much higher compared to past sedimentation rates due to the impact of humans as geomorphic agents affecting the availability and flow of sediment within upland watersheds.

Mill dams play an important role in regulating the storage and release of sediment transported along a fluvial network. Dam construction on the South River began in 1744, and a total of 30 dam structures (predominantly mill dams) existed at one time or another (Field, 2013). Presently, only three of these original dams remain intact (Field, 2013). Breaching of these mill dams has likely led to an increase of impounded sediment in the watershed. Studies on the role of mill dams and modern sediment budgets throughout the mid-Atlantic have attributed an increase of sediment in the fluvial system due to mill dam breaching, as well as long term sediment release due to processes such as freeze thaw cycles on the exposed banks of incised reservoir sediment (Pizzuto et al., 2010; Walter and Merritts, 2008; Merritts et. al., 2011).

The focus of this study is to understand sedimentation behind the Conway Electric dam on the South River in Western Massachusetts based on cores taken at the site, historical documents, aerial photography, and GIS analysis. Sediment from the cores can be analyzed to develop an age model and sediment accumulation rates based on geochemical signatures, as well as to examine variations in grainsize and composition to understand sediment deposition.

STUDY AREA

Conway Electric Reservoir (CER) lies behind a nonfunctional dam located on the South River in Conway, Massachusetts. The South River originates out of the Ashfield Pond in Ashfield, MA, and flows for 15.8 mi (25.4 km) prior to its confluence with the Deerfield River (Field, 2013). At the dam, the South River watershed has a drainage area of 26.3 mi^2 (68.1 km^2).

The Conway Electric dam lies 1 km upstream of the South River's confluence with the Deerfield River within the deep narrow river valley that defines the lower portion of the watershed. It was originally built out of logs in 1899, in order to provide electricity for a trolley in Conway; it was replaced in 1906 by a concrete structure that is the remaining relic structure along the river. The damming structure presently stands 17m high, and the former reservoir originally extended upstream for ~1.5 km. Today, the dam is silted up, and the sediment preserved records a century of fluvial deposition along the South River.

Complete siltation results in zero trap efficiency for any sediment at CER, except for deposition on floodplains during flood events. The original reservoir would have had a trap efficiency of sediment close to 100 percent, decreasing as siltation increased (Brune, 1953; Verstaeten and Poesen, 2000).

Geologic Setting

The bedrock geology along the South River consists of Devonian calcareous schist. A bedrock constriction of the valley is seen immediately downstream of the dam, and it is possible that the dam may have been built on a natural knickpoint in the longitudinal profile of the South River that exists through this section. Hillslopes in this section of the South River are steep, and large, angular boulders of schist are evident in the channel downstream of the dam. These boulders appear to be derived locally from hillslope erosion processes.

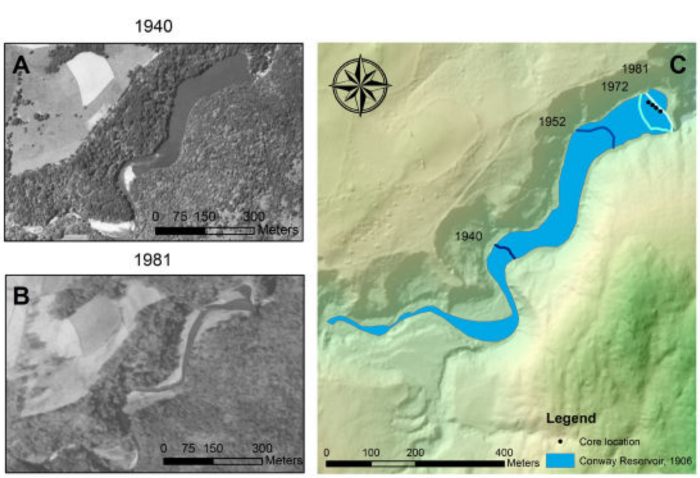

Figure 1. (A-B) Aerial photography showing Conway Electric Reservoir in 1940 and 1981. (C) Map displaying the original extent of the reservoir in 1906, and the progradation of the sediment delta front for the years 1940, 1952, 1972, and 1981, as well as neighboring LiDAR topography.

Surficial deposits from previous glaciations mantle much of the landscape of New England, and till is the primary glacial deposit in the South River watershed. This glacial material is a primary source of sediment for the South River, particularly in the steeper, upstream tributaries of the watershed (Field, 2013). Evidence of Late Pleistocene and Holocene terraces adjacent to the modern river channel in the LiDAR indicates that the South River has been reworking and incising into glacial material for the last ~16,000 years, after ice had completely retreated from the watershed (Ridge et al., 2001).

METHODS

Field

Field observations, photos, and data collection was completed in summer and fall 2013. Four 3" diameter sediment cores were collected at four separate sites in the floodplain adjacent to the South River directly upstream of the dam using a vibracore (see Fig. 1c).

Ground Penetrating Radar (GPR) data taken using the Mala Ex unit with a 200MHz antenna was obtained along 2 transects of the river. The data was processed in RadExplorer 1.4. One transect was taken starting at the dam and moving upstream along the river. A second transect was taken from north to south across the river at the transect perpendicular to the location of core VC1.

Laboratory

All cores were run through a GeoTek MSCL-S gamma counter to obtain bulk density measurements. The cores were then opened and prepared for analyses on porosity, percent organics based on Loss on Ignition (LOI), grain size, Cesium-137, and mercury. Subsampling was done on all four cores in roughly 10 cm intervals in preparation for porosity, LOI and grain size analyses. Samples were dried for all of these analyses in a 100˚ C drying oven. LOI was performed on the samples using a 550˚C oven, following methods mentioned in Yellen et al. (2014) and Dean et al.

(1974). Samples were prepared for grain size analyses by sieving at <63 µm fraction. Percent fines were obtained based on weight percentages after sieving. Samples 63 µm and greater were then run through the particle analyzer CAMSIZER to obtain grainsize distributions for D10, D50, and D90. Gamma spectrometry of Cesium-137 (^{137}Cs) was counted on the Canberra GL2020R Low Energy Germanium Detector Gamma counter to obtain a constraint on age of the cores taken from VC3 at depths of 213 and 473 cm. Mercury was sampled on the bottom half of VC3 from a depth of 215 to 473 cm, using roughly 10 cm intervals, and samples were run on the Teledyne Leeman Labs Hydra-C.

GIS and USGS Stream Gages

Geographic Information Systems (GIS) was used to quantify the volume of sediment stored in CER. A longitudinal profile of the river was created based off of a LiDAR (light detection and ranging) 1m Digital Elevation Model (DEM) to illustrate the wedge of sediment and calculate an average depth to the original (pre-dam) longitudinal river profile (Fig. 2a). The uppermost extent of the reservoir was determined based on the intersection of the sediment wedge and the interpreted pre-dam river profile. Average depth of the sediment wedge was calculated as the difference between the modern LiDAR based river profile and the pre-dam river profile (Fig. 3c). Aerial photography dating from the years 1940, 1952, 1972, 1981, 1990, and 2013 was obtained to quantify a change in the areal extent of the reservoir and location of the river delta front prograding into the reservoir (Fig. 1c). The imagery was georeferenced and digitized into shapefiles outlining the extent of the sediment having filled in the reservoir, and location of the sediment-reservoir interface at the delta front. The volume of the sediment wedge was calculated using the area of the sediment polygons created in GIS, along with the average depth of the sediment wedge from the longitudinal profile analysis. Calculations were based on the assumption that the valley bottom is v-shaped, as a rectangular shaped bottom is less realistic and would overestimate the volume of sediment stored.

United States Geological Survey (USGS) stream gage data for peak annual flow was obtained for the South

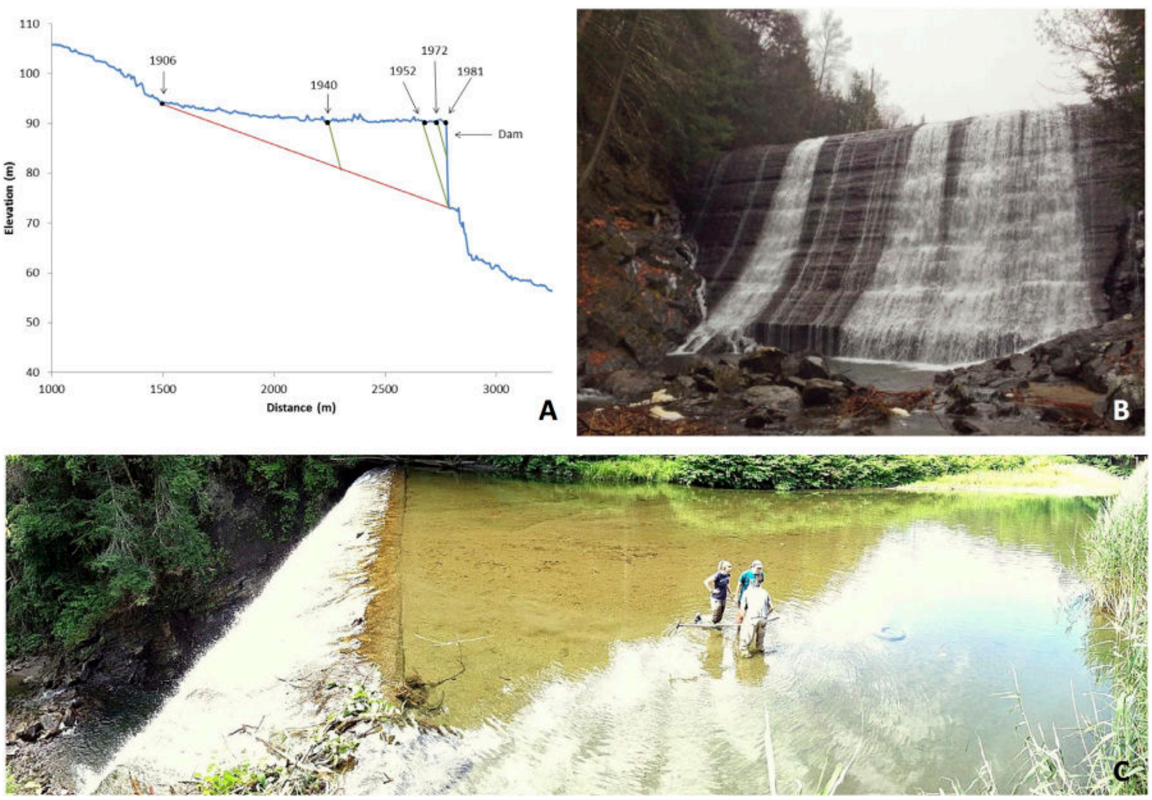

Figure 2. (A) LiDAR based longitudinal profile of the South River at the Conway Electric Reservoir (blue). The solid red line is an interpreted profile of the river prior to impoundment. The green solid lines show the progradation of a Gilbert delta during sediment infilling for the years 1940, 1952, 1972, and 1981 based on the sediment-reservoir contact seen in the aerial photographs (see Fig. 1). (B) Photograph of the 17m high dam taken downstream looking upstream. (C) Photograph of complete CER siltation and modern South River flowing directly over the dam.

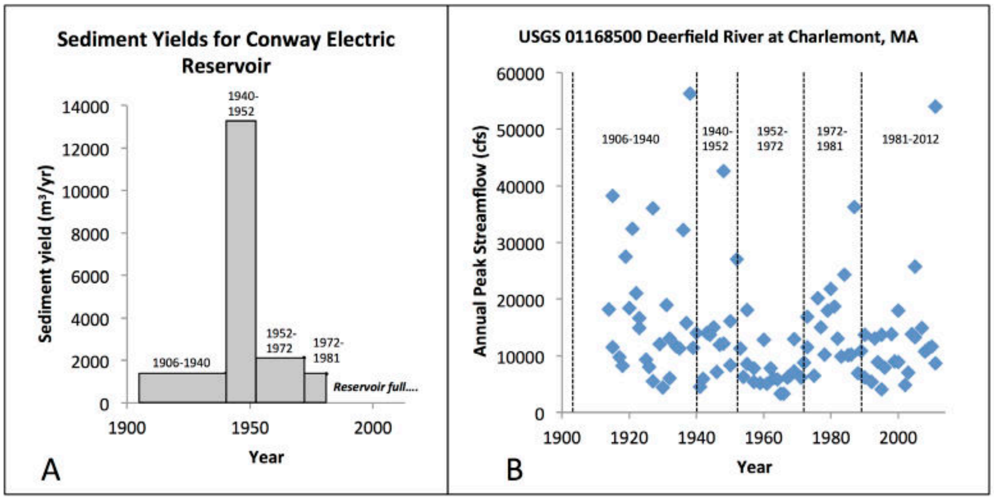

Figure 3. (A) Sediment yields for the South River watershed calculated at the Conway Electric Reservoir. (B) Peak annual discharge data for the Deerfield River measured 25 km upstream of the confluence with the South River. (C) Table showing changes in sediment area, average depth, volume, and sediment yield rate calculations for the different time frames between progradations of the sediment delta front. Sediment yields were converted from m^3 to tonnes/km^2 using an average rock density of 2000kg/m^3.

C

Time period	Sediment Area (m^2)	Avg. Depth (m)	Volume (m^3)	Infilling rate (m^3/yr)	Sediment Yield (tonnes/km^2)
Photo Intervals					
1906-1940	20519	4.6	46784	1376	40
1940-1952	26168	12.2	159231	13269	390
1952-1972	10176	8.3	42381	2119	62
1972-1981	3604	6	10812	1351	40
Average					
1906-1981	60467	8.1	243983	3253	96

River gage 01169900 near Conway, MA. Collection of data at this gage began in 1966. Data from the Deerfield River gage 01168500 at Charlemont, MA was also obtained because it contains a longer record of data, starting in 1913.

RESULTS AND DISCUSSION

Field and GPR analyses

Four cores were successfully extracted at VC1, VC2, VC3, and VC4 measuring 333 cm, 290 cm, 486 cm, and 160 cm respectively. GPR was not very successful at the site in identifying bedrock or the bottom of the reservoir fill. This was due to issues with reflection caused by steep sided valley walls and abundant vegetation. The antenna used was also too weak to penetrate the thick reservoir fill, and was unsuccessful at imaging below shallow depths.

Core analyses

Cesium-137 (^{137}Cs), a radioisotope that is a byproduct of nuclear weapons testing, was detected at 42 Bq/kg for a depth of 213 cm and 6 Bq/kg at 473 cm in VC3. The onset of ^{137}Cs began in 1953, with the peak concentration occurring in 1963 (Holmes, 2001). This provides a rough age of the core at this depth, the sediment not exceeding an age older than 1953.

Mercury is assumed to bind to organic material, and was normalized to organics in order to try to provide an age record. The metal could also bind to clays, but virtually none is found in the >63 µm (silt and sand) fraction. In western MA, the peaks of mercury in the record are associated with industry during World War II and through the 1950-1960's, before levels decline post 1970 (Woodruff et al., 2013). The mercury record in the cores did not show any clear trends identifying peaks or decline, which should have been picked up based on the age of the cores provided by ^{137}Cs. This could be due to the core being too shallow to obtain the pre-WWII traces, and because the deposits above 200 cm are too coarse and low in organics to provide a complete mercury record.

LOI, porosity, and grainsize display fairly consistent trends at similar depths between the four cores and within the same core. Fine grained sediment has a higher organic content and lower water content (Fig. 4). At ~200 cm in all four cores there is a transition to finer grained sediment deeper in the core. An anomaly in grainsize for VC4 compared to the other cores occurs within the top 50-100 cm, which display coarse grained sediment compared to finer sediment at the same depth in the other cores, then finer grained sediment compared to coarser grained below that at 100-150 cm (Fig. 5). The coarser material near the top of each core demonstrates the progradation of the delta over previously deposited fine grained material when these sites sat in the reservoir in away from the delta front. The anomaly for VC4 indicates a slightly later arrival of the delta front for this location, and follows the pattern of delta stratigraphy discussed in Snyder et al. (2006), where sand dominated foreset layers overlie finer grained bottomset deposits.

GIS analyses

Changes in the area for the size of the reservoir sediment and location of the delta front can be seen in Figure 1. Overtime, the size of the reservoir decreases as sediment storage increases. Sediment accumulation occurred based on the progradation of a delta into the reservoir. The 1906 extent of the reservoir was interpreted to extend about 1350 meters upstream from the dam. The reservoir was filled with sediment by 1981. The total volume of sediment trapped and stored in CER was calculated to be ~244,000 m^3, based on the assumption of a v-shaped valley bottom. The average sediment yield based on this volume and the time period 1906 to 1981 is 3250 m^3/yr (following the methods of McCusker and Daniels, 2008).

Sediment yields were also calculated for each of the time periods that saw significant progradations of the delta into the reservoir based on aerial photography (Figure 1c, Figure 2a, and Figure 3). Rates are similar between 1906-1940, 1952-1972, and 1972-1981. However, 1940-1952 saw an increase of ~10x in the rate of sediment infilling. These calculations using the delta do not account for fine-grained sediment that would have been deposited in the bottomset bed. Therefore, sediment yields for 1940 onwards may be overestimates. In particular, correcting this error is likely to increase 1906-1940 and decrease 1940-1952.

Sediment yields were compared to discharge data for the Deerfield River to analyze the potential for a relationship between flood events and sedimentation rates. Snyder et al. (2006) examine the progradation of the delta into Englebright Lake, where high peak flows during certain time intervals increase sediment loads that become trapped in the reservoir. However, at CER, flood events do not appear to correlate strongly with sedimentation. There are only two significant flood events that occur between 1940 and 1952 that could account for the increase in sedimentation observed. More frequent flooding, including the record flood of 1938, occurred prior to 1940, but these events do not produce an increase in the amount of sedimentation from 1906-1940 when compared to 1940-1952 rates. A lower than average number of flood events occurred between 1952 and

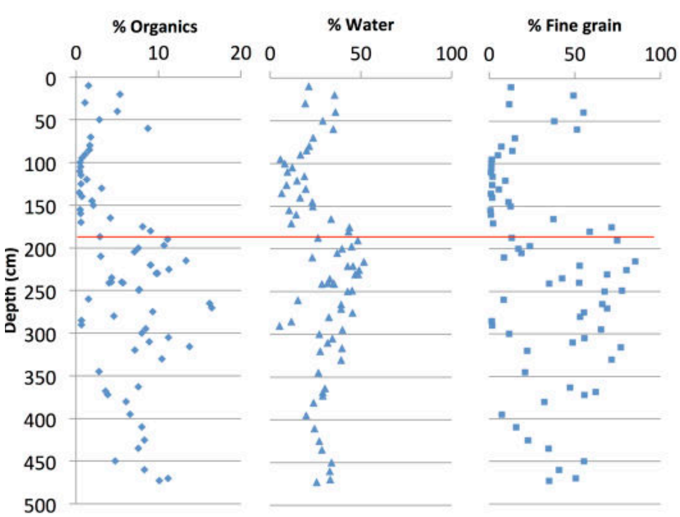

Figure 4. Depth profiles for VC3 showing percent organics, porosity, and percent fines. Fine grained sediment displays higher organic content, but lower water content. The red line displays the 200 cm transition in all three sediment characteristics.

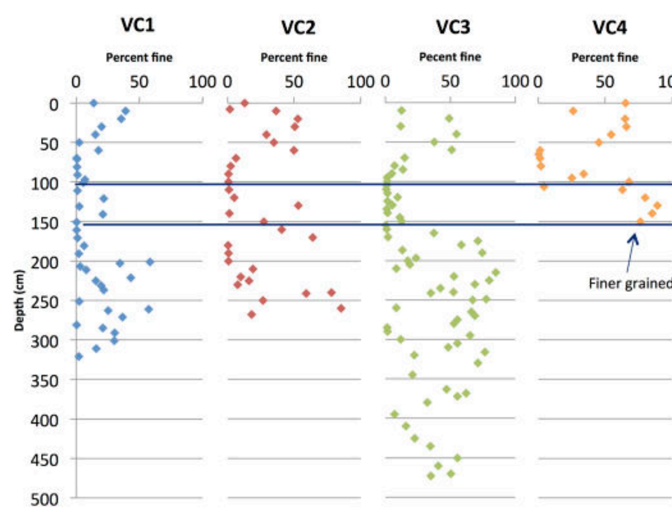

Figure 5. Depth profiles comparing percent fines for VC1, VC2, VC3, and VC4. VC4 is anomalous to the other cores, displaying coarser sediment from 50-100 cm depth, and finer sediment at 100-150 cm in comparison to the other cores.

1972, but rates for this time interval were still greater than comparative rates between 1906-1940 and 1972-1981, even though on average peak annual floods had much lower discharges (Fig. 3b). Hurricane Irene, the second highest peak discharge in the record, occurred in 2011 and is therefore not preserved in the sediments behind the dam.

Imagery using the aerial photography confirms the timing inferred from ^{137}Cs data that the area where the cores were taken infilled after nuclear weapons testing began in the mid-1950s. The progradation of the delta front at the core sites occurs between 1972 and 1981 (Fig. 1). Concentrations of ^{137}Cs were found at 4.73 m deep in these cores, consistent with young sediment and age of the delta front progradations in the reservoir.

CONCLUSIONS

The age of the record at this site was limited by the depth of the cores taken. ^{137}Cs analyses indicate that the upper 4m of sediment at core sites near the dam is younger than 1953-1960. This is consistent with aerial imagery showing the arrival of the sediment accumulation at these sites between 1960 and 1980. In order to get a more accurate age model for the core, a more complete radioisotope profile should be completed. The depth of the core was also too shallow to take advantage of a mercury profile as a proxy for the age of the sediment. A more thorough age analysis on the cores, pinpointing specific dates at specific depths, could provide a more accurate identification of storm deposits within the cores, and would help to better understand rates of deposition.

Historical air photos and GIS analysis provide a solid constraint on the total amount of sediment trapped and stored by the reservoir between 1906 and 1981. While rates are more consistent for 1906-1940, 1952-1972, and 1972-1981, there is a large spike from 1940-1952. This could be due to channel geometry, or the omission of the bottomset bed of the delta. Sediment yields from 1976-1996 in watersheds near the Deerfield range from 8 to 30 tonnes/km^2 (Yellen et al., 2014). Sediment yields in the South River average ~96 tonnes/km^2, higher than nearby watersheds. The yields for 1906-1940 and 1972-1981 are ~40 tonnes/km^2, and ~62 tonnes/km^2 from 1952-1972 (all closer to nearby yields), in contrast to ~390 tonnes/km^2 from 1940-1952. These nearby yields represent modern rates; the South River yields incorporate more historic time periods, which could account for higher rates. The frequency or size of large floods alone do not appear adequate to explain the variations in sediment yields, and it might be worthwhile to consider other factors such as land use or mill pond bank erosion occurring upstream leading to increased sediment yields.

Estimations of sediment volumes and yields are limited by the quality of the aerial photography and georeferencing. For example, the 1940 delta front in the 1940's photograph could be further out, as the photograph is unclear. Error could also result from the estimation of the shape of the valley bottom. Attempting to obtain improved GPR transects of the river in order to determine the depth to bedrock could further be used to better constrain the GIS interpretations, and to identify the true pre-dam river profile under the impounded sediment.

The sedimentation in CER does not appear to be influenced solely by large storm events in the region. Due to the anthropogenic impacts on the South River, other factors should be taken into account in the area, such as land use and mill ponds in understanding the sources of sediment. Grainsize and mineralogical analyses of upstream mill pond sediment and glacial till in comparison to CER could give more insight to the source of the sediment and natural versus anthropogenic erosion in the watershed.

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