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2013-2014 PROJECTS

MAGNETIC AND GEOCHEMICAL CHARACTERIZATION OF IN SITU OBSIDIAN, NEW MEXICO*:*
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TECTONIC EVOLUTION OF THE FLYSCH OF THE CHUGACH TERRANE ON BARANOF ISLAND, ALASKA*:*
Faculty: *JOHN GARVER*, Union College, *CAMERON DAVIDSON*, Carleton College
Students: *BRIAN FRETT*, Carleton College, *KATE KAMINSKI*, Union College, *BRIANNA RICK*, Carleton College, *MEGHAN RIEHL*, Union College, *CLAUDIA ROIG*, Univ. of Puerto Rico, Mayagüez Campus, *ADRIAN WACKETT*, Trinity University,

EVALUATING EXTREME WEATHER RESPONSE IN CONNECTICUT RIVER FLOODPLAIN ENVIRONMENT*:*
Faculty: *ROBERT NEWTON*, Smith College, *ANNA MARTINI*, Amherst College, *JON WOODRUFF*, Univ. Massachusetts, Amherst, BRIAN YELLEN, University of Massachusetts
Students: *LUCY ANDREWS*, Macalester College, *AMY DELBECQ*, Beloit College, *SAMANTHA DOW*, Univ. Connecticut, *CATHERINE DUNN*, Oberlin College, *WESLEY JOHNSON*, Univ. Massachusetts, *RACHEL JOHNSON,* Carleton College, *SCOTT KUGEL*, The College of Wooster, *AIDA OROZCO*, Amherst College, *JULIA SEIDENSTEIN,* Lafayette College

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Faculty: *DAVID JONES*, Amherst College, *JASON TOR*, Hampshire College,
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JON WOODRUFF, University of Massachusetts
ANNA MARTINI, Amherst College
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JULIA SEIDENSTEIN, Lafayette College
Research Advisor: Dru Germanoski

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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

INTRODUCTION

On August 28th, 2011, Hurricane Irene passed over western Massachusetts and Vermont and dumped 180 millimeters to 250 millimeters of rain on the Deerfield River Basin within 24 hours. This record-breaking precipitation, paired with high antecedent soil moisture conditions, caused numerous mass wasting events, extensive flooding, and extreme fluvial erosion, resulting in an anomalously high sediment load delivered to the Connecticut River estuary. One estimate has suggested that the Deerfield catchment, a Connecticut River tributary comprising only 5% of the larger watershed, accounted for as much as 40% of the total sediment load exiting the Connecticut (Yellen et al, in review). Additionally, the Deerfield's sediment contribution exceeded at minimum 10 to 40 years of routine average sediment discharge for the basin (Yellen et al, in review). This suggests that extreme events drive the geomorphic evolution of New England's glacially-conditioned upland watersheds and therefore challenges the commonly held belief that annual bankfull floods are the dominant geomorphic agents in fluvial systems (Wolman and Miller, 1960).

In order to understand the sediment production of the Deerfield River watershed during Hurricane Irene, it is necessary to examine both the sources of this sediment and any intrabasin deposition and storage. To this end, during July of 2013, I collected six push cores from Sherman Reservoir, a hydropower reservoir on the Deerfield River on the border of Vermont and Massachusetts in order to search for an Irene event layer. Previous work by Yellen et al (in review) has characterized the Irene layer as distinctly gray in color, low in organic content, unusually fine (D_{90} ranging from 25 to 35 μm; medium silt), enriched in potassium (K), and deficient in zirconium (Zr). This signature bears striking resemblance to the fine-grained matrix of Pleistocene glacial deposits that blanket the watershed in a surficial layer up to 15 meters thick (Koteff and Pessl, Jr., 1981), suggesting that sediment yields were largely sourced from erosion of indurated lodgment tills and upland glaciolacustrine clays. Presence or absence of an event layer in Sherman Reservoir will more precisely indicate the geographic origin of Deerfield River sediment and provide insight into the watershed's sediment production, storage, and transportation dynamics.

STUDY AREA

The Deerfield River, the second-longest tributary to the Connecticut River, runs 113 kilometers from southern Vermont into northwestern Massachusetts before joining the Connecticut at Greenfield, Massachusetts (Fig. 1). Along its path, the Deerfield drains 1,722 square kilometers, drops approximately 607 meters, and passes through 10 hydroelectric developments (Table 1). Nine major tributaries feed the river's controlled median annual flow of 30.8 cubic meters per second (16.9 cubic meters per second estimated natural) (Herzfelder, 2004). Glacial clays and tills underlain by micaceous schistose bedrock constitute the primary geology of the basin (Melvin et al, 1992).

Table 1: Hydroelectric facilities on the Deerfield River (Gomez and Sullivan Engineers, P.C.); note the three reservoirs upstream of Sherman Reservoir that affect the Deerfield's discharge entering Sherman Reservoir.

Station Name	**In Service**	**River Kilometer**	**Gross Storage (m^3)**	**Hydropower Capacity (MW)**	**Drainage Area (km^2)**
Somerset	1911	106.2	7.073×10^7	-	77.7
Searsburg	1922	97.0	5.082×10^5	4.2	233.1
Harriman	1925	78.1	1.447×10^8	33.6	476.6
Sherman	1927	67.6	1.676×10^6	7.2	606.1
Station No. 5	1974	66.3	1.456×10^5	17.6	613.8
Bear Swamp	1974	62.8	5.760×10^5	600	657.9
Fife Brook	1974	59.5	2.726×10^5	11.3	657.9
Station No. 4	1913	32.2		4.8	1046.4
Station No. 3	1912	27.4	6.784×10^5	4.8	1295.0
Gardners Falls	1904	25.3		3.6	1300.2
Station No. 2	1913	21.2		4.8	1307.9

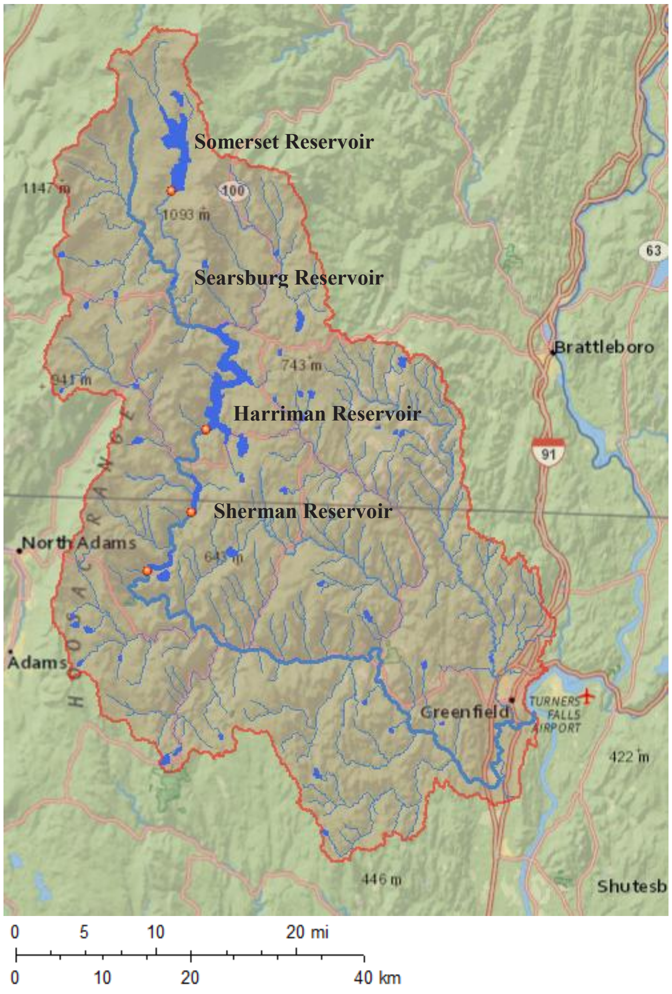


Figure 1: Map of the Deerfield River watershed (Deerfield River Watershed Association). Major dams are marked with orange circles, and Sherman Reservoir and the reservoirs upstream of it are labeled.

Sherman Reservoir, the subject of this study, is located at river kilometer 67.6 and measures 3.2 kilometers long by 0.4 kilometers wide at its widest point. Sherman Reservoir's catchment totals 606.1 square kilometers, 129.5 square kilometers of which fall between Sherman Reservoir and Harriman Reservoir located 10.5 kilometers upstream. The reservoir has a surface area of 0.88 square kilometers and 4.432×10^6 cubic meters of gross storage, 1.676×10^6 cubic meters of which are considered usable for hydroelectric purposes. Sherman Dam, built in 1927 and located at the southern end of the reservoir, is an earth-fill structure 33.5 meters high and 247 meters long. The hydroelectric facility adjacent to the dam is managed by TransCanada Hydro Northeast Inc. on a peaking, weekly storage basis and can generate up to 7.2 megawatts (TransCanada Hydro Northeast Inc.).

Three dams control the Deerfield's discharge above Sherman Reservoir. Somerset Dam (river kilometer 106.2, surface area 6.1 square kilometers) serves purely to store water and does not produce any hydropower. Searsburg Dam (river kilometer 97.0, surface area 0.1 square kilometers) and Harriman Dam (river kilometer 78.1, surface area 8.3 square kilometers) both have hydroelectric facilities, and Harriman also retains high spring flows. Searsburg Reservoir is operated on a peaking, daily storage basis, and the much-larger Harriman Reservoir is managed on a peaking, seasonal storage basis (Deerfield River Watershed Assessment).

In addition to the water discharge that exits Harriman Reservoir, Sherman Reservoir is fed directly by the West Branch of the Deerfield River, which drains an

Figure 2: Aerial view of Sherman Reservoir with core locations; cores were collected in the northern half of the reservoir, as the southern half was inaccessible due to dam and hydropower operations. Note the South Branch of the Deerfield River entering the reservoir from the west.

area of 82.4 square kilometers before entering the main Deerfield at Readsboro, VT (Herzfelder, 2004). Three additional tributaries also enter the Deerfield below Harriman Dam, including the South Branch of the Deerfield River, which enters the reservoir directly just north of the state border. Therefore, much of the sediment entering Sherman Reservoir is probably transported by the West Branch, the South Branch, and minor tributaries, as water residence time behind Harriman Dam is likely to remove most bedload and suspended sediment from the water column. As a result, any event signatures likely reflect erosion and transport in this 129.5-square kilometer subwatershed.

METHODS

Core Collection

Over the course of two days in late July of 2013, a series of six push cores were collected from various points in Sherman Reservoir (Fig. 2). The cores were sampled with polycarbonate tubes and the assistance of a piston and slide hammer. The piston was set 20 centimeters above the sediment-water interface to preserve surface strigraphy. Each core was driven until resistance, at which point the core was brought up and capped. Cores were returned to the lab, split, and described (Table 2).

Sonar data were collected from a canoe using a StrataBox operating at 10 kHz. Paired depth and latitude-longitude values were used to construct a coarse bathymetry map of Sherman Reservoir.

Table 2: Sherman Reservoir cores and analyses performed; loss-on-ignition (LOI) provides a proxy for organic content; mercury (Hg) levels aid in building an age model and distinguishing event deposits; x-ray fluorescence (XRF) is used to examine the K/Zr ratio; grain size (GS) analysis is useful in delineating event deposits; and cesium-137 (^{137}Cs) counting provides age horizons for discussing accumulation rates and event layers.

Core name	Water depth (m)	Sediment collected (m)	Analyses performed
SR1	2.73	1.22	LOI; Hg; XRF
SR2	1.25	0.72	LOI; Hg; ^{137}Cs
SR3	7.90	1.38	LOI; Hg; XRF; GS; ^{137}Cs
SR4	2.59	1.96	LOI; Hg
SR5	9.60	1.58	LOI; Hg; GS
SR7	12.60	1.20	LOI; Hg

LABORATORY ANALYSES

Loss-on-ignition (LOI) measurements were performed on each core to provide a proxy for organic content. Cores were subsampled at a constant interval of 5 centimeters within each core. Additional samples were taken at stratigraphically interesting transitions. Subsamples, each weighing approximately 10 to 15 grams when wet, were weighed and dried overnight at 105° C. The next morning, subsamples were reweighed to determine the weight of water lost, then baked at 550° C for four hours. The final weight after burning determined percent lost on ignition, a suitable proxy for organic content.

Each core was also subsampled sampled for mercury (Hg) analysis, again at varying intervals, in order to help constrain core age models and accumulation rates. Subsamples for Hg analysis were dried overnight at 105° C before analysis was performed with a Teledyne Leeman Labs Hydra-C mercury analyzer. Results were reported in units of parts per billion (ppb).

Cores SR2 and SR3 underwent cesium-137 (^{137}Cs) counting on a Canberra GL2020R Low Energy Germanium Detector to identify the 1954 ^{137}Cs onset and 1964 ^{137}Cs peak. Knowing these date horizons in the cores helps to constrain age models and sediment accumulation rates (Ambers, 2001).

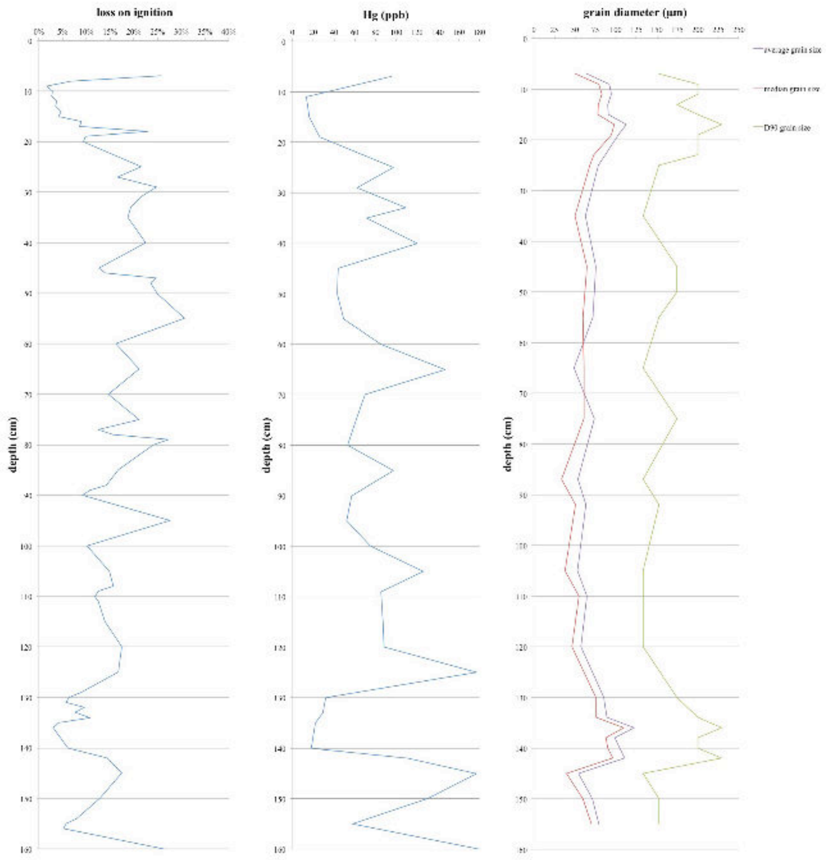
Cores SR1 and SR3 were scanned on an ITRAX x-ray fluorescence (XRF) core scanner to examine bulk density and elemental abundances. Of particular interest is the K/Zr ratio. Enrichment in K indicates that the sample material is derived from K-rich illite and muscovite clays that are abundant in the matrix of glacial till in the watershed. Alternatively, high Zr values signal that the sediment is sourced from more weathered material that has likely been extensively reworked within the stream network that is enriched in erosion-resistant zircon (Yellen et al, in review).

Finally, cores SR3 and SR5 underwent detailed grain size analysis using a Horiba LA-920 Particle Size Analyzer at the National Lacustrine Core Repository. To prepare samples for analysis, cores were subsampled into centrifuge tubes at consistent intervals and where stratigraphically interesting, then digested in a warm bath of 30% H_2O_2. To control the rate of the reaction, 95% ethyl alcohol and cool air were added as necessary, and temperature was adjusted to fall somewhere between 21° C and 85° C throughout the reaction, depending on the vigor of the reaction. The tubes of sediment, H_2O_2, and water were centrifuged regularly, and water was removed from the top of the tubes using a sipping Erlenmeyer flask-vacuum apparatus. Additional was H_2O_2 added each time the reaction visibly ceased in order to continue to encourage organic digestion. The reaction was determined complete when the sediment did not react to the introduction of additional H_2O_2. This process of organic digestion lasted approximately a week for each sample. Samples were then shaken overnight in a solution of 0.5% sodium hexametaphosphate (SHMP) and analyzed suspended in SHMP with the Horiba LA-920 and an autosampling device.

RESULTS

Loss-on-ignition (LOI) values range from 1% to 36%, with the majority of values falling between 5% and 15%. There is no apparent drop in LOI near the surface of any of the cores, which suggests a lack of an Irene event layer. Hg values are similarly variable, with a high concentration of 278 parts per billion (ppb) at the surface of core SR7, a low concentration 10 ppb at the bottom of core SR2, and most values ranging from 50 ppb to 125 ppb in all six cores. None of the cores displays a zone of marked K/Zr enrichment.

The D_{90} value for grain size represents the grain diameter below which 90% of clast diameters fall. Yellen et al (in review) determined the D_{90} of the Irene layer in bays off the Connecticut River estuary to range from 25 to 35 µm, indicating a size classification of medium silt. Contrastingly, the uppermost 20 centimeters of SR3 and SR5 display a D_{90} value consist with fine to very fine sand (62.5 to 250 µm) (Fig. 3). Grain diameter does not change noticeably with depth in these two cores. D_{90} in core SR5 falls between 133 µm and 229 µm, while in SR3 grain size varies within a range from 101 µm to 175 µm. Therefore, the upper portions of cores SR3 and SR5 that could contain an Irene layer are in fact too coarse to match Irene's depositional signature in other proximal water bodies.



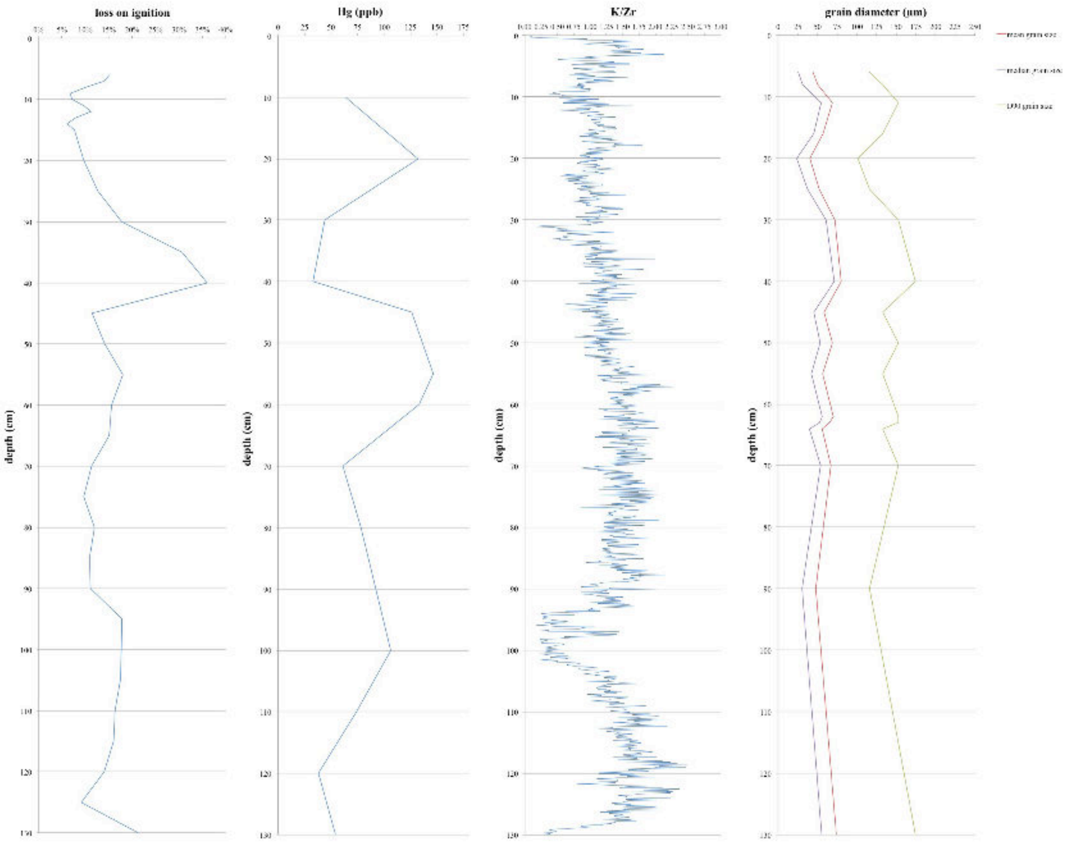


Figure 3: Analytic results for cores SR3 and SR5; note the absence of an Irene event deposit that is fine-grained (25 – 35 µm), enriched in K/Zr, and highly inorganic (low %LOI).

DISCUSSION

None of the six cores displays a definitive Irene layer, as evidenced by the lack of an event deposit near the top of each core that is gray in color, enriched in the K/Zr ratio, unusually fine-grained, and low in organics as observed elsewhere following Irene (Yellen et al, in review). This is surprising given that Sherman Reservoir intercepted all of the Deerfield's flood discharge from the upper 35% of its watershed. Considering this reservoir's location in the headwaters of a steep watershed and observations that sediment yield and relief are often correlated (e.g. Milliman and Farnsworth, 2013), we expected a very prominent Irene layer here. Absence of an event deposit prompts two possible interpretations. First, Harriman reservoir did not export any sediment to Sherman Reservoir, and the subwatershed between Harriman Reservoir and Sherman Reservoir that includes the West Branch of the Deerfield did not produce a significant sediment contribution as a result of Hurricane Irene. Alternatively, Sherman Reservoir has low trapping efficiency, so sediment was routed past it without settling out of suspension. The first interpretation, insignificant sediment production, is more likely, because even if most of the sediment was exported from the reservoir, it is probable that a small event layer would still deposit behind the dam.

If minimal Hurricane Irene-related sediment was produced above Sherman Reservoir, this makes the fact that the Deerfield contributed 40% of the Connecticut's total sediment yield during Irene even more astounding, considering that the majority of this sediment must have sourced from below Sherman Reservoir. Estimates indicate that the entire Deerfield watershed produced ~350 tonnes/km^2 of fine-grained sediment immediately following Hurricane Irene (Yellen et al, in review). Assuming the basin above Sherman Reservoir did not produce any sediment, the lower watershed must have produced up to 532 tonnes/km^2. The pattern of erosion in the lower watershed merits further study, as evidence from Sherman Reservoir indicates that sediment production in the Deerfield basin is highly heterogeneous.

CONCLUSION

The Deerfield River produced approximately 40% of the entire Connecticut River watershed's sediment yield during Hurricane Irene in August 2011. Given this information, it is surprising that evidence from a coring study of Sherman Reservoir indicates that the upper 35% of the Deerfield basin above Sherman Reservoir did not produce a significant sediment contribution. The reservoir, located on the Deerfield and managed for hydropower production, does not contain an Irene event layer that is fine-grained, enriched in K and depleted in Zr, low in organics, and distinctly gray in color. This result suggests that the lower 65% of the Deerfield basin produced sediment an average rate of 532 tonnes/ km^2, begging the question of why the lower basin was so productive while the upper basin was not. More study on the effects of extreme weather events on the geomorphic evolution of post-glacial upland watersheds is necessary to address this question. It is possible that in this system, the major geomorphic agent driving basin erosion and sedimentation is in fact infrequent, high-magnitude events rather than annual bankfull flows. Further research related to this topic may aid in the development of soil conservation and erosion prevention programs in upland watersheds, and identification of patterns of erosion during and after extreme weather events may contribute to infrastructure protection and expansion.

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