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ANNA MARTINI, Amherst College
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JULIA SEIDENSTEIN, Lafayette College
Research Advisor: Dru Germanoski

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IDENTIFYING STORM DEPOSITS IN A DRY FLOOD CONTROL RESERVOIR IN WESTERN MASSACHUSETTS, USA

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Research Advisor: Susan Swanson

INTRODUCTION

In August 2011, Hurricane Irene struck the east coast of the United States. In a single day, more than 20 cm of rain fell over western Massachusetts resulting in record-breaking floods (Kinney, 2011). Flood control reservoirs along tributary streams protected the Connecticut River from severe flooding. Reservoirs act as sediment traps and preserve storm event deposits (Ambers, 2001; Snyder et al., 2006). Knightville Reservoir was one of the reservoirs that held back Irene's floodwaters. Knightville is distinct in that it is a dry reservoir and only fills during flood events. It is likely that the event layers preserved at Knightville will be thinner than typical reservoir event layers because there is a shorter residence time of floodwater within dry reservoirs (Heinemarm, 1981). By identifying the sediment signature of the Irene storm event within Knightville, the potential of dry reservoirs to preserve past storm events can be better understood. This has wider applications for understanding recent climate history and flood frequency.

Knightville Reservoir is located on the East Branch of the Westfield River in the Berkshire Hills of western Massachusetts (Fig. 1). The reservoir's watershed is 415 km^2 and is heavily forested with surficial glacial till deposits. Major flood events in 1936 and 1938 spurred the construction of the 48 m high Knightville Dam in 1941 (U.S. Army Corps of Engineers, 2011). Knightville usually functions as a recreational facility, but during storm events the area becomes an active reservoir, reducing flooding downstream. Release of floodwater begins in the days following a major storm event (U.S. Geological Survey, 2013).

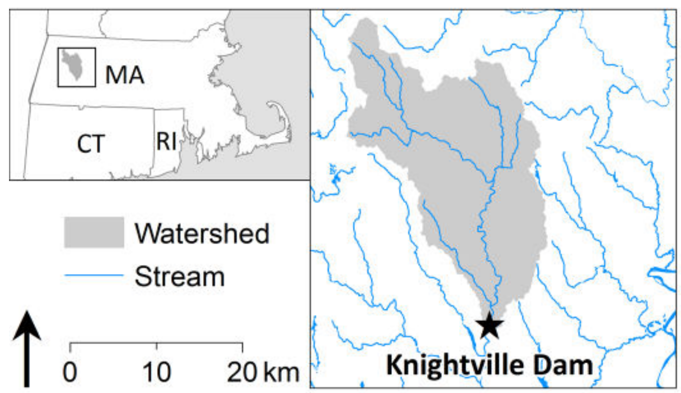

Figure 1. Location of Knightville Dam on the East Branch of the Westfield River along with the dam's watershed.

Grain size analysis, water content, and organic matter may be used to identify event deposits. Coarse-grained layers that fine upwards characterize event deposits within reservoirs. Event layers can be identified and quantified using grain size analysis, and dips in water content and organic matter may occur (Ambers, 2001). Water content decreases because less water is retained by sand than by clay (Davis, 1992). During high-flow events, a rapid influx of inorganic sediment results in a layer with low organic matter (Ambers, 2001).

The most severe storm events for western Massachusetts in the past century occurred in 1936, 1938, 1955, 1987, and 2011 (Wandle, 1991). Relative dating of reservoir sediments using cesium-137 (Cs-137) and mercury (Hg) may help identify particular storm event layers. Onset of Cs-137 correlates to 1954 when nuclear testing began, and a peak in

Cs-137 occurred in 1964 (Walling, 1992). Hg can be used to date sediment cores because there are well-documented Hg fluctuations in the region that correspond to industrial changes. Frazier et al. (2000) found reservoir sediments near Boston, Massachusetts show a peak in sedimentation of Hg around 1980, but are dependent on proximity to industrial complexes. Cs-137 and Hg can be used to identifying the timing associated with specific event layers and also inform on sedimentation rates.

METHODS

Data Collection. In order to identify event deposits, cores were collected at three different locations along the reservoir during June 2013. The north site is the farthest upstream from the dam, the middle site is located in the central region of the reservoir, and the south site is located in a small basin just upstream from the dam (Fig. 2).

At the north and middle sites, bucket augering and hammer coring were used on sandy sediments. Bucket auger samples were collected at 10 to 30 cm intervals and have sample IDs beginning with KAS. Three hammer cores were collected by driving a 4 cm aluminum pipe into the ground with a sledge and were removed using a hydraulic jack. These cores have sample IDs beginning with KHC and were subsampled at 10 cm intervals, or wherever a visible change in grain size occurred.

At the south site, Russian peat coring and push coring were used to collect soft, fine-grained sediments. Four viable Russian peat cores were and have sample IDs beginning with KDRC (Fig. 2). The core barrel was 3 cm wide and 50 cm long. Multiple drives were performed to create a longer core. A sampling interval of 5 cm was used, with the first few centimeters divided into 1 or 2 cm intervals to gain higher resolution data where the Irene event layer was expected. Push coring was performed from a canoe in a pond near the dam with a method similar to hammer coring. The two push cores (KDC1 and KDC2) were collected at the same site, with the first having a smaller sampling interval of 1 cm. Only KDC1 was analyzed.

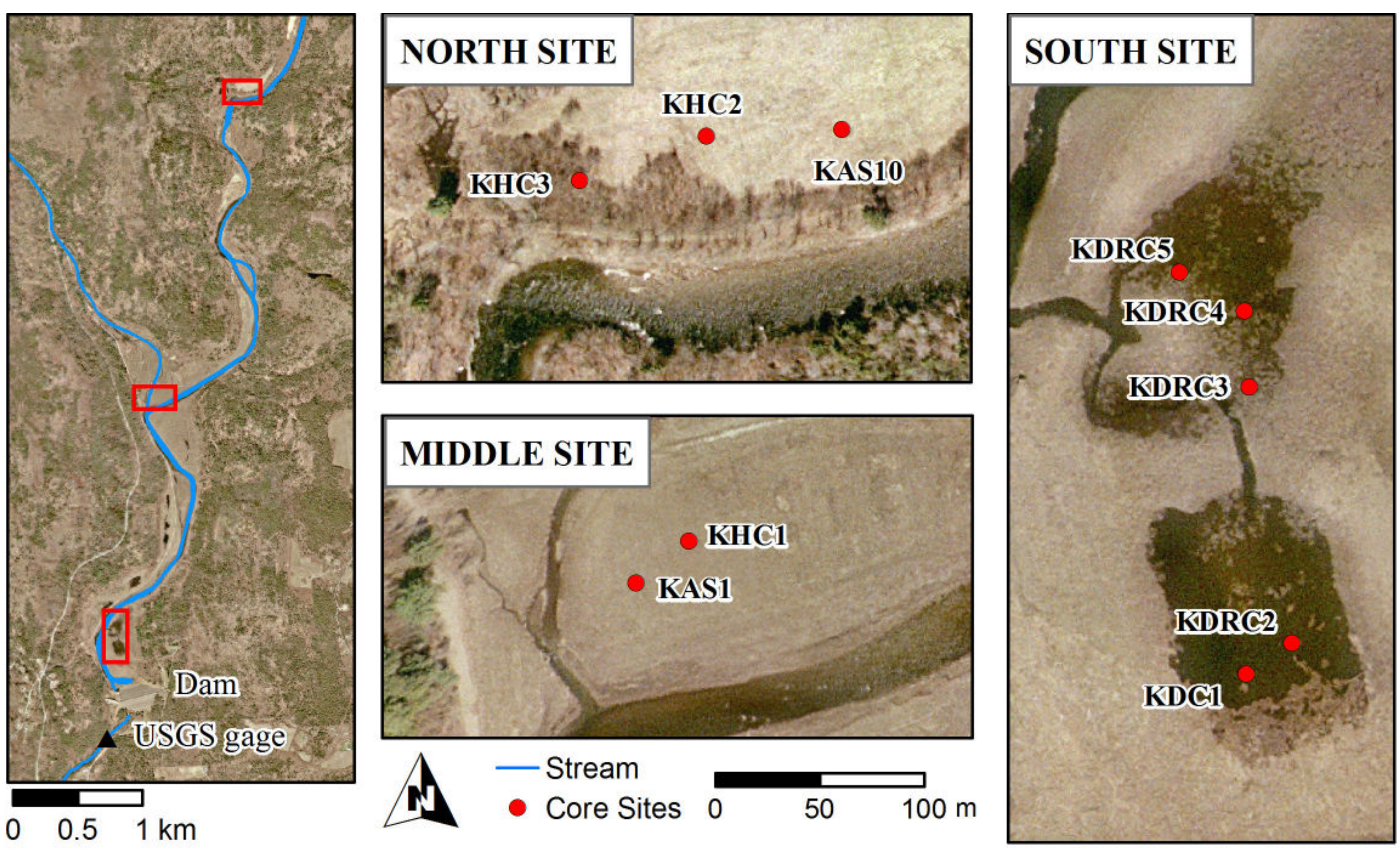

Figure 2. Core locations in Knightville Reservoir.

Gaging data for the East Branch of the Westfield River was obtained from the USGS gaging station at Knightville, located 300 m downstream of the Knightville Dam (Fig. 2). Historic records of peak annual discharge were plotted relative to peak annual precipitation gathered from NOAA National Climatic Data Center.

Analyses. Grain size distribution was used to identify and quantitatively analyze coarse layers in reservoir sediments. The sediments were dried, burned, and lightly broken apart using a mortar and pestle. A subsample between 0.1 g and 1 g was thieved and soaked in 10 mL of 50g/L sodium hexametaphosphate (NaPO3) for over an hour before being sonicated for 60 seconds. Three 10-second measurements were collected and averaged using a Malvern Mastersizer 200 laser particle size analyzer with a Hydro 2000 MU wet dispersion accessory at the University of Wisconsin – Platteville. The system was rinsed at least three times between samples.

The water content of the sediments was measured as the weight percent difference between the wet and dry sediments. The samples were dried at 100°C. The calculation of the weight percent water was $(W_{wet} – W_{dry}) / W_{wet} * 100$, where *W* is the weight of the wet and dry sediments. Water content for some cores was not measured because several months had passed since collection.

The percent organic matter was measured for all cores using loss on ignition. Dry samples were burned in a muffle furnace at 550°C for two hours. The weight percent organics was calculated using $(W_{dry} - W_{burned}) / W_{dry} * 100$, where *W* is the weight of the dry and burned sediments.

Eight samples from mud-rich cores were measured for Cs-137 using a Canberra GL2020R Low Energy Germanium Detector at the University of Massachusetts – Amherst. About 5 g of sediment were dried, powdered, weighed, and then placed in the isotope analyzer. If Cs-137 was not detected after several days, the sample was assumed to have no Cs-137. These results were normalized for the sample weight and measurement time.

Dried sediments were analyzed for Hg using a Hydra-C mercury analyzer with a cold vapor atomic absorption configuration (CVAAS) at Smith College. Calibration was performed using National Institute of Standards and Technology standard 2702 for inorganics in marine sediment. The results were normalized by dividing by the percent of organic matter.

RESULTS

Grain size analysis, water content, organic matter, Cs-137, and Hg data were plotted to help identify storm event layers (Fig. 3). The D^{90}, or 90th percentile of sediment size was used to emphasize coarse layers. The first 50 cm of all cores show little variation and an average D^{90} around 100 µm. There is a small positive spike in grain size in the first 5 cm on most cores, which is most visible in KHC1. All of the cores with grain size measurements below 60 cm show an abrupt increase in grain size from 100 µm to >800 µm. The depth of this grain size increase varies, occurring between 50 and 200 cm. Below this abrupt increase, grain size varies, but is much coarser than the top 50 cm.

Water content and organics are closely related (Fig. 3). Cores at the north and middle sites display similar patterns in water and organics. Water and organics begin around 15% and 10% respectively, dropping to 10% and < 2% after 30 cm. The south site cores display peaks in water and organics around 20 cm depth, with the exception of KDRC5 that shows minimal fluctuations.

The normalized Cs-137 measurements display a range of values with depth, depending on the core (Fig. 3). In KDRC2 and KDRC3, there is no Cs-137 found below 110 cm, but Cs-137 was found at 80 cm in KDRC3. This indicates that 1954 sedimentation is located between these two depths, indicating there was an average sedimentation rate of around 1.7 cm/yr. Cs-137 is present in all 4 KDRC5 samples and shows a peak at 130 cm depth. If this peak indicates sedimentation from 1964 when Cs-137 was at its peak, there has been an average sedimentation rate of 2.8 cm/yr.

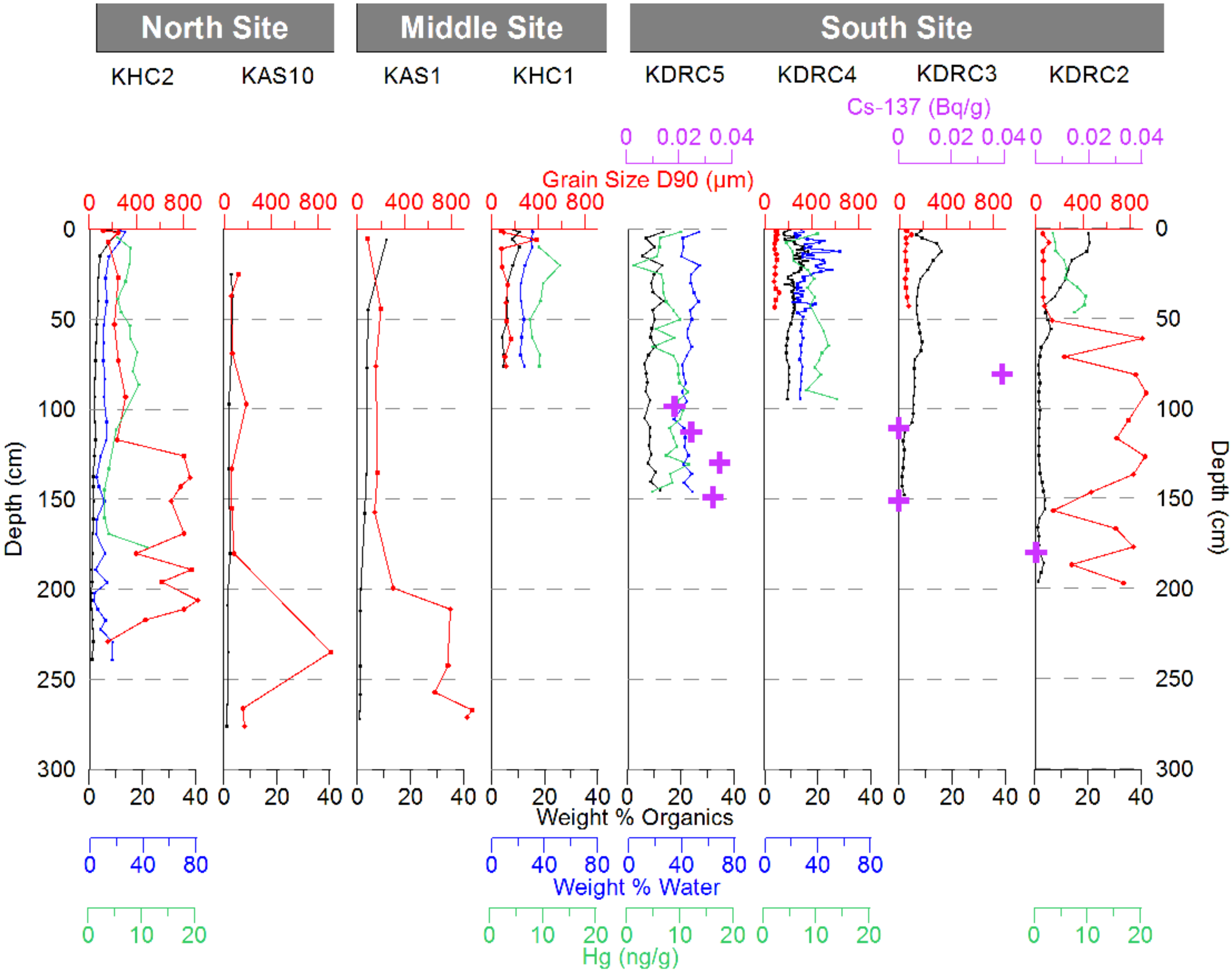

Figure 3. Grain size, water content, organic matter, Hg, and Cs-137 data for Knightville cores.

The normalized Hg levels in the north site cores do not show much variation with depth (Fig. 3). KHC2 is the exception, showing a rise in Hg where there is a fine-grained layer at 180 cm. Overall, Hg levels did not show strong patterns, but a dip in Hg occurs at 15 cm in most south site cores and may be followed by a peak around 50 cm shown in KDC1 and KDRC2.

Discharge data from the USGS Knightville gaging station and precipitation data from NOAA were assembled and plotted together (Fig. 4). Before the construction of the dam in 1941, there was large variability in peak discharge events, ranging from 2,000 cfs to almost 30,000 cfs. The annual peak discharge has become much more uniform since 1941, only exhibiting annual fluctuations of 1,000 cfs to 5,000 cfs. Overall, peak annual rainfall and peak annual discharge show some correlation before 1941, but after they only show correlation for the largest precipitation events.

DISCUSSION

Identification of Hurricane Irene's sediment signature will provide valuable information on the potential of dry reservoirs to preserve flood deposits. Extreme event deposits were identified through grain size increases and dips in water content and/or organic matter. The small grain size increase present in the first 5 cm of most cores is interpreted to be the

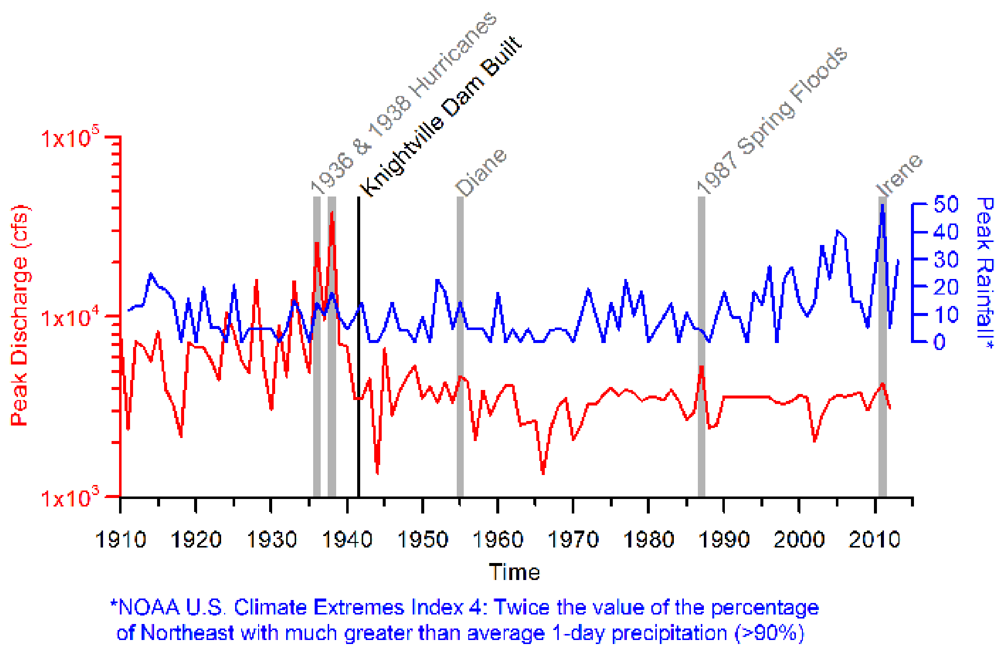

Figure 4. Annual peak discharge at Knightville plotted alongside peak annual rainfall.

Irene deposit (Fig 3). This peak is mirrored by a dip in water content in KHC1 and KDRC3 and dips in organic matter in KHC2, KHC3, and KDRC4. Because the Irene event was undoubtedly the largest event in the past several decades, this layer, which is only about 1 cm deep, is probably the sediment deposited as a result of Irene. This layer is 1-2 cm thick, and was probably deposited during the six days following Irene when stormwater was retained in the reservoir.

While some reservoirs contain storm deposits that are much coarser than surrounding sediments (Ambers, 2001; Snyder et al., 2006), Knightville does not. The different patterns of sediment deposition within a dry flood control reservoir may explain the changes in event signatures. Because all the sediments deposited in Knightville are a result of event deposits, the fact that the Irene layer is identifiable as a coarse layer is probably a result of the extreme magnitude of this event compared to annual flood events. Past extreme flood events such as Hurricane Diane in 1955 and the 1987 Spring Floods were not identified in the sedimentary sequence. These may have been overlooked due to larger sampling intervals taken at depth or the event layers may have been destroyed through bioturbation.

The abrupt grain size increase present at depth probably reflects the sedimentation change caused by dam construction. The Cs-137 information is inconclusive, as no samples were measured near the top of the coarse sediments. KDRC2 and KDRC3 show that 1954 is located near the onset of this grain size increase (Fig. 3). In KDRC5 there is a peak in Cs-137 at 135 cm, indicating that this sediment was deposited around 1964. However, the trends in water, organics, and Hg are not similar to the other south site cores, making it difficult to correlate these ages to depths within the other cores. The grain size increase may also represent changes in flow regulation on the dam or changes in land use. The historic flow in Knightville (Fig. 4) does show much more variable peak stream discharges up until the 1970's when peak discharge became less variable except when there are extreme flood events. While this change in flow regulation may have influenced sedimentation, the abrupt increase in grain size is most likely a result of the construction of the dam.

Dam construction may explain these changes in sedimentation patterns if new reservoir sediments were deposited on Quaternary alluvium. The reservoir sediments are much more homogeneous and fine-grained than the sediments below. As opposed to typical reservoirs that have constant deposition, dry reservoirs only accumulate sediment periodically during high flow events, similar to floodplains. One key difference between reservoir sedimentation and floodplain sedimentation is that floodplains preserve moderate events more effectively than extreme events. Floodplains do show a coarse layer corresponding to extreme events, however moderate events often produce more sedimentation than extreme events (Asselman, 1999).

A different story is recorded within Knightville. Here, extreme events may result in high sedimentation. During extreme flow conditions, larger volumes of water are retained for longer periods, which produces more sedimentation. The average rate of sedimentation within the reservoir was estimated by dividing the depth to the grain size (averaged between three sites) with the number of years since the construction of the dam. The average annual sedimentation rate varied by location, but was around 1.5 cm/yr, which is similar the sedimentation rate of 1.7 cm/year obtained from the Cs-137 data from KDRC3. While the Irene event deposit is only 1-2 cm, the deposit from this single storm is comparable to the average annual sedimentation. Extreme events seem to produce much more than average sedimentation. This pattern differs from the sedimentation patterns present in floodplains where extreme events are more poorly preserved (Asselman, 1999).

CONCLUSIONS

Overall, the Irene layer was identified in Knightville reservoir, but only showed a slight increase in grain size. Dips in water and organic matter within the same interval were present for some, but not all cores. Compared to the average annual accumulation rate of 1.5 cm/yr, the Irene layer (1-2 cm thick) represents greater than average sediment accumulation. The sedimentation of extreme events within this dry reservoir more closely reflects the sedimentation patterns of other reservoirs, not the sedimentation patterns in floodplains. While extreme events can be identified in dry reservoirs, the sediment signature is difficult to distinguish from annual flood deposits.

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