

Land Use and Climate Variability Amplify Contaminant Pulses

PAGES 221–222

In 2002, the mid-Atlantic region experienced record drought levels. In September 2003, Tropical Storm Isabel produced large amounts of rainfall in the Chesapeake Bay region, and freshwater flow into the Chesapeake Bay was 400% above the long-term monthly average (<http://chesapeake.usgs.gov/isabelinfo.html>). Record drought conditions followed by a very wet year coincided with pulsed watershed nitrogen exports and one of the most severe zones of hypoxia, or “dead zones,” reported in the Chesapeake Bay.

Large pulses of contaminants such as this event may occur more often given evidence of increased variability of precipitation and hydrologic extremes occurring with climate change [Intergovernmental Panel on Climate Change (IPCC), 2007]. Conversion of land to human-dominated uses has increased contaminant loads in streams and rivers and further transformed hydrologic cycles [Vitousek *et al.*, 1997]. Together, land use and climate change may interact in unexpected ways to alter the amplitude, frequency, and duration of contaminant pulses in streams and rivers (i.e., large contaminant loads that are transported over relatively short time scales).

Contaminant pulses have great implications for watershed management, and research will be critical for detecting long-term changes in variability in contaminant trends, which in some cases could indicate regime shifts in water quality and signify substantial, long-lasting reorganizations of aquatic ecosystems [Carpenter and Brock, 2006]. Accurate contaminant monitoring and forecasting also will be particularly critical for protecting drinking water supplies, preserving aquatic habitat and human health, and promoting coastal water quality.

Land Use and Climate Change Amplify Hydrologic Connectivity

Humans have altered hydrologic connectivity between landscapes, groundwater,

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and streams via engineered flow paths designed to quickly route water through storm drains, tile drains for agricultural land, and ditches. This has led to more efficient delivery of contaminants to receiving waters. In addition, loss of natural headwater streams and floodplain wetlands associated with land use change decreases retention capacity, increases erosion, and may further contribute to pulses of contaminants downstream.

Thus, accelerated transport from landscapes to streams and reduced retention capacity may amplify variability in contaminant pulses produced by climatic extremes. Contaminants can be flushed during storms and other extreme weather events that may increase in frequency and/or magnitude

with future climate change. These flushes can be exacerbated by droughts that lead to accumulation of contaminants in watersheds.

Pulse Events in Streams and Rivers: Magnitudes, Lag Times, and Uncertainties

Several emerging examples highlight the interacting effects of land use and climate change on contaminant pulses. Agriculture and urbanization can increase sediment loads above natural background conditions [Gellis *et al.*, 2009], and sediment transport can respond strongly to increased variability in precipitation and streamflow [Langland *et al.*, 2007]. For instance, the Potomac River, near Washington, D. C., has experienced large annual pulses of sediment in response to brief extreme weather events with a statistically significant linear relationship with annual streamflow (Figure 1). Increased sediment can impair ecological habitat; scour bridges; transport adsorbed

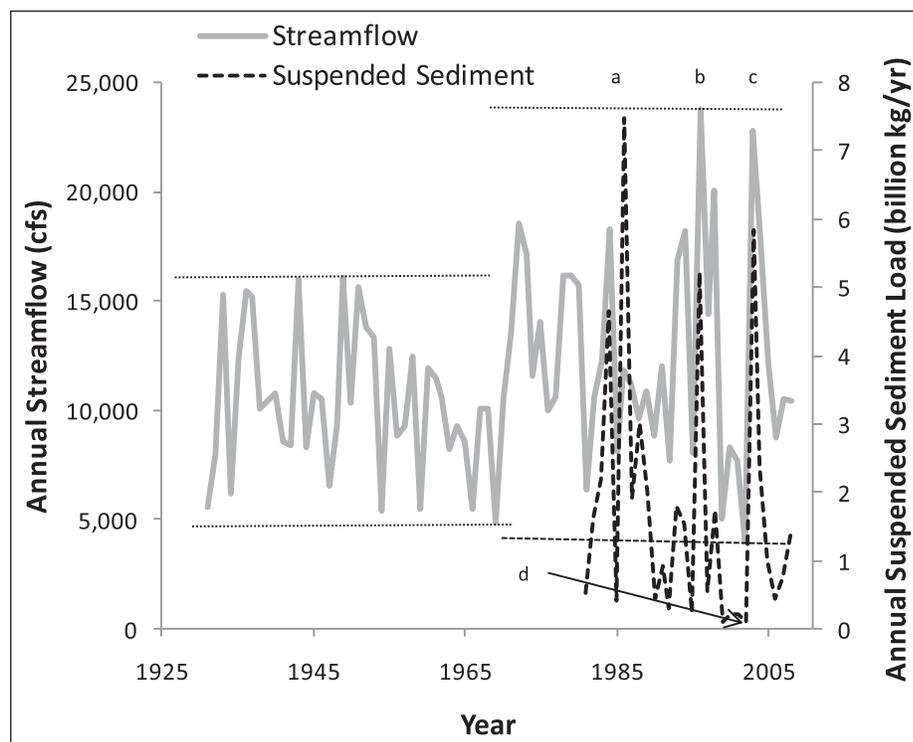


Fig. 1. Annual streamflow (in cubic feet per second (cfs); $35.31 \text{ cfs} = 1 \text{ m}^3/\text{s}$) and sediment loads (in billions of kilograms per year) in the Potomac River, near Washington, D. C. Information and data can be found at <http://va.water.usgs.gov/chesbay/RIMP/>. Dashed curve represents ranges in streamflow variability from 1931–1971 and 1972–2008. Letters a, b, c, and d represent tropical storms Gloria and Juan, the 1996 flood, Tropical Storm Isabel, and a record drought, respectively.

nutrients, metals, and organic contaminants; increase the need for dredging; and affect reservoirs and drinking water supplies. Moreover, each different land use practice influences sources, storage, and transport of sediment [Gellis *et al.*, 2009]. Loads in the Potomac River may be further altered by increased variability in streamflow from drought to flood conditions since the 1970s [Langland *et al.*, 2007].

In addition, land use and climate can interact to amplify watershed nitrogen exports, which contribute to coastal eutrophication and decreased water quality. Transport of nitrate may respond to shifting patterns in climate variability, further complicating the ability to forecast nitrate exports across changing human-dominated landscapes. In the Chesapeake Bay region, climate variability produced substantially different levels of amplification of nitrate exports from agricultural, urbanized, and forested watersheds [Kaushal *et al.*, 2008]. Nitrate exports declined during record drought in 2002, increased during the wet year of 2003, and unexpectedly continued to increase in 2004 as runoff declined (Figure 2). This pattern may have been driven by flushing of nitrate stored during dry years, mineralization of organic matter washed into valleys, decreased nitrate removal via denitrification in groundwater and streams, or increased biotic nitrate production in soils due to drying and rewetting events [Borken and Matzner, 2009]. Different land uses therefore increase vulnerability to climate-driven nitrate pulses with downstream effects on coastal water quality.

The interaction of land use and climate change has also substantially affected contaminant loads of fresh water throughout North America [Hall *et al.*, 1999; Schindler, 2001; Howarth *et al.*, 2006] and throughout other regions around the world (see supporting information in the online supplement to this *Eos* issue (http://www.agu.org/eos_elec)), and there is a growing need to develop strategies to increase the adaptive capacity and resilience of watershed management. Data regarding changes in magnitude and variability of contaminant pulses can be used in improving risk assessment; prioritizing sediment, nutrient, and contaminant reductions in watersheds [Oleson and Carr, 1990; Boesch *et al.*, 2001]; designing adequate stormwater management and bioremediation to keep pace with changing environmental conditions [National Research Council, 2008]; and guiding river floodplain and wetland restoration strategies. Empirical data on contaminant pulses will also be necessary for improving predictive models forecasting effects on water quality and development of future decision-making tools regarding water resources [Murtugudde, 2009].

Monitoring the Pulse in a Changing Climate and Landscape

Altered variability in frequency and magnitude of contaminant pulses presents

challenges to existing monitoring networks. Adaptive monitoring focused on specific questions and management objectives that can be modified to keep pace with environmental change are becoming increasingly necessary [Lindenmayer and Likens, 2009].

Ecological and hydrological observatories are developing new approaches for continuous high-resolution data in streams and rivers. High-resolution data capture pulses and important seasonal dynamics not previously appreciated. For example, recent studies using acoustic Doppler profiling on the Hudson River provide continuous measurements of suspended sediment dynamics and show that high-flow events provide large inputs of sediments over relatively short intervals [Wall *et al.*, 2008]. In addition, conductivity sensors can be used to detect pulses in road salt in streams and rivers originating from deicer use [Pellerin *et al.*, 2008]. For example, in the northeastern United States, pulses in chloride concentrations follow regular seasonal patterns and can increase in winter to 5 grams per liter (25% of the concentration of seawater; see the online supplement to this *Eos* issue). Future patterns in urbanization and climate (winter temperatures and ice storms) may therefore be expected to influence magnitude and frequency of salt pulses. These salt pulses may have impacts on toxicity to freshwater life and drinking water supplies [Kaushal *et al.*, 2005].

Future Needs for Effective Monitoring

A growing volume of high-resolution sensor data will be challenging to analyze, interpret, and disseminate. Maintaining and expanding existing federal long-term programs monitoring streamflow and contaminants will be critical. Long-term data from local and state natural resource agencies present valuable insights into temporal and baseline conditions. Additional sensor data may further affect the way contaminant loads and discharges are regulated in the future. With new technology and new time series data, researchers may find that ecosystems are more or less resilient than expected based on previous monitoring approaches. Thus, developing effective partnerships among academia; federal, state, and local agencies; and nonprofit organizations will be useful for designing and implementing effective monitoring strategies in response to future contaminant pulses.

The synergistic, interactive effects of climate and land use are likely to greatly complicate efforts to forecast long-term trends of contaminant loads in human-dominated watersheds. High-resolution monitoring, event sampling, improved data analysis/synthesis, and forecasting models will be needed to adequately protect drinking water, human health, and ecosystem functions affected by increased magnitude and frequency of contaminant pulse events.

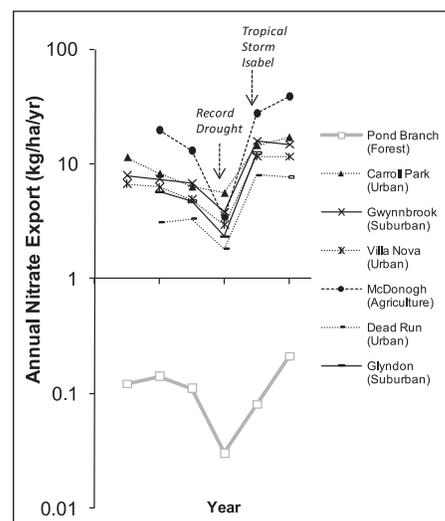


Fig. 2. Pulses in annual nitrate export (in kilograms per hectare per year) in streams in Maryland during record drought and wet years. Adapted with permission from Kaushal *et al.* [2008]. Copyright 2008 American Chemical Society.

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NEWS

New Gulf Oil Leak Estimates Dwarf Original Figures

PAGE 222

New estimates of the amount of oil flowing from BP's leaking oil well in the Gulf of Mexico are dramatically higher than initial numbers, according to figures released by U.S. Secretary of Energy Steven Chu, Secretary of the Interior Ken Salazar, and U.S. Geological Survey Director Marcia McNutt on 15 June. "The most likely flow rate of oil today is between 35,000 and 60,000 barrels per day," based on estimates by U.S. government and independent scientists, they indicated.

"This estimate brings together several scientific methodologies and the latest information from the seafloor and represents a significant step forward in our effort to put a number on the oil that is escaping from BP's well," Chu indicated. He noted the numbers could change with the collection of additional data, and he added that the administration has been focusing on responding to the upper end of the flow estimate.

The revised estimates are based on analyses of video taken by remotely operated vehicles, acoustic technologies, measurements of oil collected, and pressure measurements taken inside a cap placed over the riser pipe.

At an earlier news briefing, on 10 June, McNutt, who leads the National Incident Command's Flow Rate Technical Group (FRTG), said estimates calculated prior to BP's 3 June riser cut and cap installation indicated that between 20,000 and 40,000 barrels of oil had been leaking daily. Earlier government estimates placed the flow at 5000 barrels per day; on 27 May, more than a month after the spill began, FRTG estimated that between 12,000 and 19,000 barrels were leaking each day.

Oil flow estimates have been based on methodologies by several groups of scientists, including the FRTG Plume Modeling Team, which is observing video of the damaged well and estimating fluid velocity and flow volume with the use of particle image velocimetry analysis; the FRTG

Mass Balance Team, which is calculating the amount of oil on the ocean surface with the use of remote sensing data from the Airborne Visible/Infrared Imaging Spectrometer (AVIRIS) and satellite imagery; FRTG Reservoir Modeling and Nodal Analysis teams; and a team of university researchers—led by Woods Hole Oceanographic Institution with assistance from researchers from Johns Hopkins University, University of Georgia, and Massachusetts Institute of Technology—using acoustic technologies and working in coordination with the Unified Command.

McNutt said each methodology "has its advantages and shortcomings, which is why it is so important that we take several scientific approaches to solving this problem, that the teams continue working to refine their analyses and assessments, and that those many data points inform the updated best estimate that we are developing."

She added it will be possible to get a precise number of the flow rate. "BP has been instructed to capture 100% of the flow. When they do, we will go back to all of the groups, take a look at their estimates, and find out the systematic biases. And we will learn so much more about measuring oil in the ocean that we will do a better job next time about how we go about measuring."

—RANDY SHOWSTACK, Staff Writer