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Establishing the linkages among watershed threats, in-stream alterations and biological responses remains a challenge: Fayetteville Shale as a case study

Sally A. Entrekin[1], Bradley J. Austin[2], Michelle A. Evans-White[3] and Brian E. Haggard[2]

Abstract

Hydraulic fracturing for oil and gas can alter the biological integrity of small streams. Persistent and stable community composition and ecological function define integrity that can change in response to alterations. An inherent challenge is identifying ecological indicators supported by adequate data prior to ecosystem alterations, unknown interactions among alterations, and the appropriate scale to measure indicators. Oil and gas extraction has increased in the last decade in density and geographic expanse across the U.S. in regions without a history of extraction. Disturbances associated with extraction are land clearing for supporting infrastructure, freshwater withdrawals, and possible chemical and wastewater water spills during drilling/fracturing, reuse, transport, and treatment. The well and pipeline density along with violations in a watershed are often used as indicators of biological risk at the reach (100 m) and small (<130 km^2) watershed scale. The risk for measurable and biologically significant ecological alterations is probably increased by more wells placed close to stream channels, surface water withdrawal volumes that are not scaled to stream discharge seasonal and daily volumes and more frequent transport of wastewater and spills. Yet, the linkage between physical alterations to watersheds and the proposed ecological responses that may serve as endpoints associated with these changes remain largely unquantified. Ecological indicators that can be linked to watershed alterations (e.g. oil and gas pad density) and associated in-stream stressors (i.e. sedimentation) are needed to address rapid species loss and altered ecological functions.

Addresses

[1] Biology Department, University of Central Arkansas, Conway, AR, United States

[2] Arkansas Water Resources Center and Biological and Agricultural Engineering Department, University of Arkansas, Fayetteville AR 72701, United States

[3] Department of Biological Sciences, University of Arkansas, Fayetteville AR 72701, United States

Corresponding author: Entrekin, Sally A (sentrekin@uca.edu)

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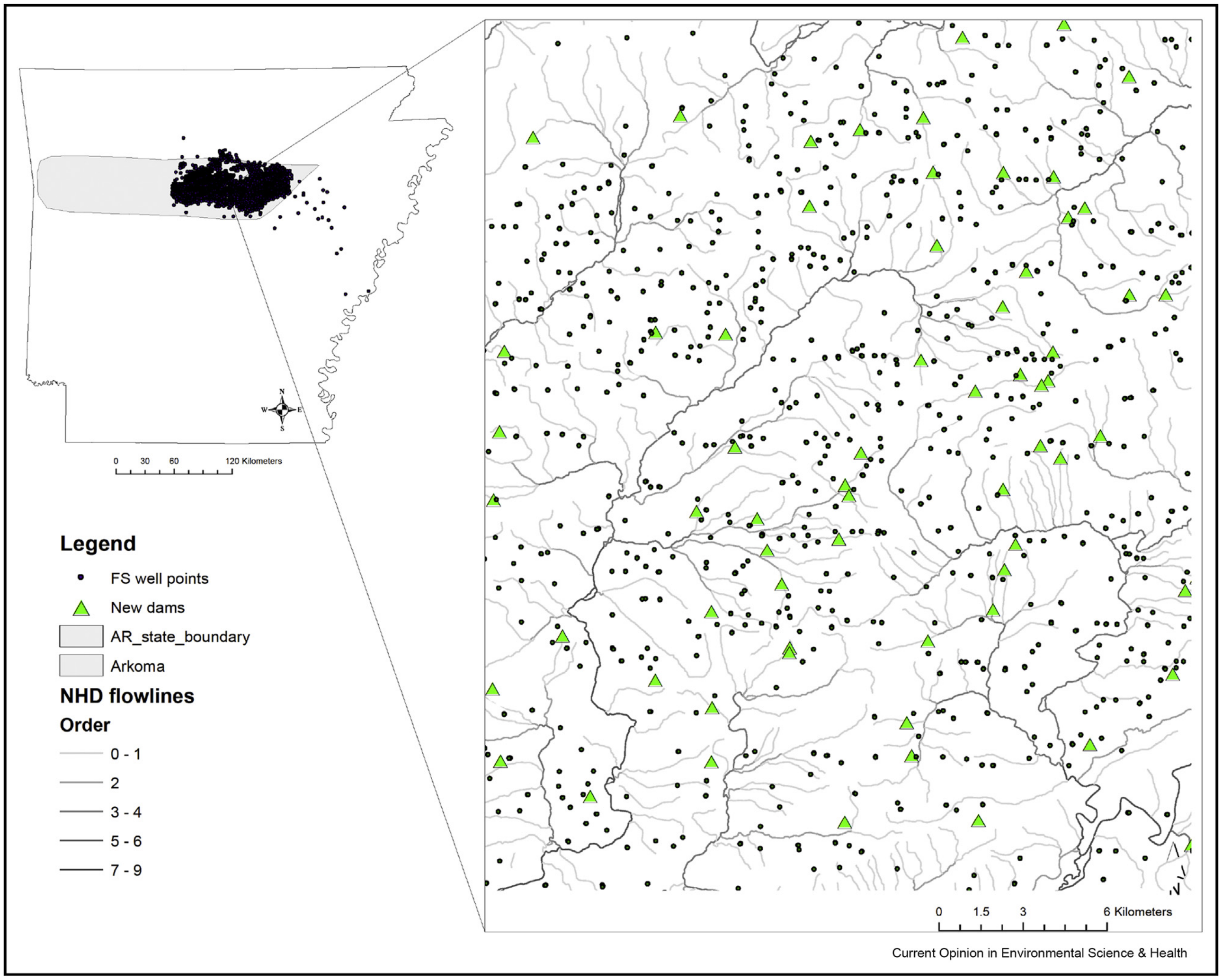
Introduction

Ecological indicators in U.S. freshwaters are used to identify environmental conditions that reflect the possibility of compromised surface water designated uses (i.e. the publics determined use of the water). Indicator assessment requires routine sampling; therefore, measurable with minimal effort and cost [1]. A suite of potential ecological indicators for surface waters have been proposed to assess high volume hydraulic fracturing (HVHF) to access oil and gas [2–5]. Because activities associated with HVHF can result in multiple point and nonpoint source pathways that could alter physical, chemical, and biological conditions, identifying an appropriate suite of indicators and their linkages to watershed characteristics is a challenge (Fig. 1, [6]). For example, the probability that a spill will occur and reach a nearby stream is greatest when within the first 3 years of installation and when the rate of drilling and stream density in the landscape are high [7,8]. Still, significant uncertainty that a spill will occur is introduced from varying environmental conditions and operator best management practices. In contrast, landscape conversions from well pad area and density can be forecast through build-out scenarios based on past production and market projections [9], but the link between watershed alterations, surface water quality, and biological responses are currently largely unpredictable. Here, we summarize the existing surface water physical, chemical, and biological responses to HVHF that are drawn from our experience in the Fayetteville Shale (FS) and associated indicators of environmental changes to help guide future research.

In Arkansas's Fayetteville Shale, recovery of natural gas using hydraulic fracturing began in 2004.

- Since then, over 6000 wells were installed across approximately 22,900 km^2 representing about one third of the entire play (Fig. 1).
  - Current well density is 0.22 wells/km^2 across the gas field.

Fig. 1



Arkansas's Arkoma basin and associated high volume hydraulically fractured wells. Well point locations and dams for source water are shown in relation to streams color coded by Strahler order. FS = Fayetteville Shale.

- Total infrastructure associated with hydraulic fracturing has resulted in a 2% decrease in natural habitat and an additional 1067 linear km of edge habitat from added roads, pipelines, and gas well pads [10].
- All of the freshwater for hydraulic fracturing was sourced from nearby streams and ponds (total $\sim 2.8 \times 10^7$ m^3 from 2004 to 2014 [11]).
  - Fifty-two percent of permit sites for water withdrawal were on 1st - 3rd order streams. The Army Corp of Engineers permitted 153 new dams to hold water for hydraulic fracturing (FOIA # 15-030399); >50% of impoundments were on 1st-3rd order and intermittent streams.
  - Seventy percent of hydraulically-fractured wells used recycled-produced (i.e. waste from wells) waters that resulted in $\sim$25% lower demand for freshwater [12].

Over a decade later, ecological studies have been conducted to assess how watershed alterations from hydraulic fracturing have altered stream water quality, quantity and associated aquatic organisms.

Fragmentation, water withdrawals, and material spills threaten surface water quality

Infrastructure (i.e. well pads, paved and unpaved roads, ponds, and pipelines) that result in a decline in natural vegetation cover and increased impervious or unvegetated land increases sedimentation and mobilized nutrients (e.g. nitrogen (N) and phosphorus (P)), sheet flow, and modified flow paths to receiving streams [13,14]. What is not well understood is how much landscape alteration can occur in watersheds before

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