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Evaluating flood risk and alterations to hydraulic patterns following installation of low-grade weirs in agricultural systems

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ABSTRACT

Because low-grade weirs are designed to impede flow of water there is concern from producers that they will lead to decreased drainage and increased flooding in adjacent fields. The purpose of this study was to determine if weirs increased the risk of flooding and backflow. Analyses were conducted to evaluate the effect of low-grade weirs on hydrology. The first analysis targeted how weir-related modifications affected a single ditch by using pre and post weir-implementation data. Results of Wilcoxon–Mann–Whitney tests were mixed, with no significant differences for ditch W1 and significant differences at ditch W2 for both time to peak ($p = 0.009$) and time to base ($p < 0.001$) following weir installation. Differences in peak height were significant at W1 ($p = 0.004$) and not significant at W2 ($p = 0.875$). The second analysis determined if significant differences existed between ditches modified with weirs in general and ditches which were unmodified in general. Results of a MANOVA indicate no significant difference for time to peak ($p = 0.985$) between ditches with weirs and those without weirs, and a significant increase in time to base in sites with weirs ($p = 0.003$). The estimate of weir effect for time to base indicates that it takes approximately 23 h 13 min (s.e. = 7 h 30 min) longer to return to initial water level when weirs are present. The third analysis considered differences between peak heights for ditches modified with weirs in general and ditches which were unmodified in general. Results of a Wilcoxon–Mann–Whitney test of normalized peak heights indicated that maximum peak heights during storm events were approximately 10% lower in ditches with weirs (18.4 vs. 28.5%, $p = 0.015$). Results suggest weirs do not increase flooding potential but merely hold water in ditches longer by slowing return to pre-storm-event levels.

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1. Introduction

Much of the research focus on agricultural water resources relates to issues of nutrient loading and effectiveness of best management practices to mitigate nutrient-laden runoff from fields. Many areas worldwide are under pressure to preserve water resources, both in quantity and quality. Much attention has been given to this issue by governments and regulatory agencies, resulting in government support to share in the financial costs of conservation. One practice that has been used in Mississippi (USA) and other production areas is low-grade weirs (hereafter “weirs”) (Fig. 1). Weirs fall into the broad class of controlled drainage structures, and their intended function is such. Weirs are small impoundments (like check dams) placed within drainage ditches at strategic intervals, dependent on the fall or grade change of a ditch channel (Kröger et al., 2011). They are non-specific to commodity being grown and do not require specially sourced materials. This allows weirs to be widely utilized across varying ecosystems under a multitude of conditions. The benefits of weirs have been examined in semi-controlled experiments for issues related to increases in hydraulic residence time (Kröger et al., 2008) and decreased nitrate–nitrogen concentrations and loads (Kröger et al., 2011). Field investigations of weirs have also investigated sediment and phosphorus accumulation (Usborne et al., 2013), and nutrient load reductions (Littlejohn et al., 2014).

For obvious reasons, a majority of research on weirs, and other drainage control structures, focuses on the nutrient management effectiveness; this is likely driven by the fact that governments subsidize these practices to achieve their nutrient reduction goals (i.e., water quality standards). However, nutrient reduction is not always the primary concern of the producer. Producers often face a more immediate threat in the form of flooding, and a more pressing need

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Fig. 1. Low-grade weir in a field setting.

for adequate drainage. Like many agricultural areas worldwide, the Mississippi Alluvial Valley has a history shaped by historic floods. Areas of alluvial deposition from meandering rivers are generally fertile agriculture regions. Unfortunately, proximity to the river, flat topography, and shallow, rain-fed water table make these areas prone to periods of small- and large-scale flooding. This problem is compounded by the presence of heavy clay soils, which can seal up quickly and limit infiltration, resulting in large volumes of runoff at times and standing water at other times. The ability to limit flooding and drain water from fields is crucial for sustained farming operations in these and other areas worldwide in flood-prone river basins and/or with similar soil types. Intuitively, producers in these areas frequently focus on the flooding/drainage management, rather than management of nutrient runoff. The purpose of this study was to determine if weirs increased the risk of flooding and backflow. This study differs from previous studies in that the goal is not to quantify the nutrient reduction efficiency of the best management practice, but to examine hydrologic risk. There is concern among producers that by installing impediments to water flowing through agricultural ditches (i.e., away from agricultural fields), risks of flooding and backflow will be exacerbated. In a previous study on producer perceptions regarding agricultural pollution of water, Barnes et al. (2009) noted that producers desired to see scientific validation before adopting best management practices. Thus it is important that this issue by addressed by research to increase the likelihood of adoption for weirs by producers; especially those operating in areas which have high potential to be non-point source polluters due to intensive agriculture coupled with high potential for runoff.

2. Materials and methods

2.1. Study area

Four study sites were located in Humphreys County, Mississippi (Fig. 2). This area is considered part of the Mississippi Alluvial Valley. Common features of this region include (1) alluvial soils which are inherently variable in texture; (2) temperate winters with hot summers (frequently reaching highs in excess of 35 °C), with high humidity common May through September; and (3) average annual rainfall of approximately 147 cm. Major crops include corn (*Zea mays*), soybean (*Glycine max*), and cotton (*Gossypium hirsutum*), as well as rice (*Oryza sativa*), with many acres requiring irrigation water. Study sites were located within agricultural fields, representative of Mississippi Alluvial Valley farms as just described.

At each site, existing agricultural drainage ditches were modified to increase drainage potential in these fields. These ditches drain into an oxbow lake, which in turn, drains into the Yazoo River, before flowing into the Mississippi River and finally to the Gulf of Mexico. Previously, Strock et al. (2010) acknowledged flooding concerns associated with water-level control structures. However, in contrast to this study, flooding concerns were focused downstream, rather than upstream. Their recommendation to remedy this situation was a “series of low-level retention structures along long ditch reaches” (i.e., weirs). Modifications to ditches in this study included increasing the channel bed and tailing the slopes back, in addition to installing a series of weirs. Weirs were constructed by placing an earthen berm within the ditch. The berm was covered first with engineered woven fabric for stabilization and then with a layer of rip-rap (Fig. 1). Weir placement and height was a function of the grade change for the individual research site. The target goal for weir placement at the study site (and elsewhere in the region) was to maintain one-tenth of a foot of grade fall per 100 feet of ditch length. The number of weirs per ditch is presented in Table 1.

2.2. Data collection

All ditches were monitored from January 2011 to December 2012. In September 2011, ditches W1 and W2 were modified and multiple weirs were installed. Ditches C1 and C2 were unmodified and contained no weirs for the duration of the study. Data obtained from ditches W1 and W2 prior to weir installation were classified as “pre-weir” water level data for the purposes of pre-versus-post analyses. Data were taken from the same locations along the ditch for both pre- and post-weir collections.

Level loggers (In Situ, Inc., Fort Collins, Colorado) were placed throughout the length of each drainage ditch at multiple sampling sites within the ditch to record water level (Fig. 3). For ditches W1 and W2, level loggers were attached to metal stakes via clips and positioned in ditches approximately 0.3 m upstream from where each weir would eventually be placed. For ditches C1 and C2, level loggers were placed in the same manner at intervals throughout the ditch. Level loggers were mounted approximately 5 cm above the sediment. A reference level logger was also placed on the bank of each ditch above the reach of water flow. Water level data were continuously recorded over the period of study at each sampling site in intervals no greater than 15 min. Data from the reference level logger were used to calibrate data collected from the in-ditch loggers.

Precipitation data for the study were obtained from a United States Geological Survey gage, approximately 8.6 km from the study area (Station: 330304090210100, Bee Lake Tributary No. 1 NR, Thornton, Mississippi). Sites were visited within 48 h of a storm event. Precipitation data was not used to define hydrologic events within ditch channels as precipitation intensity and infiltration affect runoff volumes. To ensure accurate and observable hydrologic changes in ditch channels, storm events were defined by an increase of more than 10 cm in recorded water level which was not due to irrigation.

The day on which these sites were visited serves as the initial starting point for the three precipitation intervals considered for data analyses. The precipitation intervals considered were (1) day of sampling (hereafter “day of”), (2) two days prior to day of sampling through day of sampling (hereafter “two day”), and (3) seven days prior to day of sampling through day of sampling (hereafter “seven day”). Total precipitation values were calculated for each of these three intervals. For the purposes of analysis, days were considered to begin at local time 00:00 and end at 23:59, without regard for the actual start time of the storm event. The intervals were selected to help present a fuller picture of saturation levels within the soil and the ditch than could be given by a single day.

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