Residual herbicide concentrations in on-farm water storage–tailwater recovery systems: Preliminary assessment

Erin M. Grantz | Deborah Leslie | Michele Reba | Cammy Willett

1 Dep. of Crop, Soil, and Environmental Sciences, Univ. of Arkansas, 1366 W. Altheimer Dr., Fayetteville, AR 72704, USA
2 Dep. of Earth Sciences, Univ. of Memphis, 109 Johnson Hall, Memphis, TN 38152, USA
3 USDA-ARS, Delta Water Management Research Unit, 504 University Loop, Jonesboro, AR 72401, USA

Correspondence
Erin M. Grantz, Dep. of Crop, Soil, and Environmental Sciences, Univ. of Arkansas, 1366 W. Altheimer Dr., Fayetteville, AR 72704, USA.
Email: egrantz@uark.edu

Funding information
U.S. Geological Survey 104b; Arkansas Soybean Promotion Board

Abstract
On-farm water storage–tailwater recovery systems reduce groundwater usage and intercept agrochemical loads, but pesticide residue dynamics in these systems are not well understood. This study monitored concentrations of seven herbicides in seven northeast Arkansas tailwater recovery systems (April 2017–March 2018). Clomazone, glyphosate, metolachlor, and quinclorac were frequently detected, with minimal detections of 2,4-D, dicamba, and propanil. Concentrations peaked during the growing season (1 Apr.–15 Sept.), reflecting an interaction of application and precipitation. Clomazone, glyphosate, and quinclorac concentrations were greater in ditches (<0.80–67, <0.50–6.2, and <0.40–62 μg L⁻¹, respectively) than in the associated reservoir (<0.80–6.0, <0.50–4.1, and <0.40–6.0 μg L⁻¹, respectively), but metolachlor concentrations were not different between structure types (maximum 22–32 μg L⁻¹). Off-season concentrations were mostly below detection, except for quinclorac. Cycling recovered tailwater through the system and irrigating from reservoirs may minimize risk of cross-crop contaminations with residual herbicides. Managed groundwater recharge should use reservoir water during winter to protect groundwater quality.

1 INTRODUCTION

Producers in the U.S. mid-South facing groundwater decline have incorporated on-farm water storage–tailwater recovery (OFWS–TWR) systems into their irrigation practices (Fugitt et al., 2011; Yaeger, Massey, Reba, & Adviento-Borbe, 2018; Yaeger, Reba, Massey, & Adviento-Borbe, 2017). These networks of ditches paired with a storage reservoir replace 25–50% of a production system’s groundwater irrigation on average (Sullivan & Delp, 2012). Reservoirs also have the potential to supply managed groundwater recharge (MAR) (Reba et al., 2017). Other benefits of OFWS–TWR systems include reduction of solids and agrochemical loads that contribute to impaired water quality downstream (USDA-NRCS, 2011; USEPA, 2009). Studies of spatial and temporal dynamics of solids and nutrients suggest that OFWS–TWR systems can reduce loads and watershed yields substantially (Omer & Baker, 2019, Omer, Dyer, Czarnecki, Kröger, & Allen, 2018a) by retaining flow during periods of high precipitation (Czarnecki, Omer, & Dyer, 2017; Omer et al., 2018b).

Pesticide residue concentrations and loads may also be reduced by OFWS–TWR systems. Some pesticides may degrade within the extended hydraulic residence time in an
OFWS–TWR system (Lewis, Tzilibakis, Warner, & Green, 2016). For others, removal may be promoted by increased spatial and temporal interaction with sediment or aquatic vegetation. For these reasons, models identify ponds as a best management practice (BMP) to reduce chlorpyrifos and diazinon export from agricultural lands (Luo & Zhang, 2009). Longitudinal studies of pesticide dissipation in drainage ditches suggest rapid sorption and/or uptake (Bennett et al., 2005; Moore et al., 2001). But pesticide monitoring in OFWS–TWR systems is rare. The most extensive study to date detected a number of rice (Oryza sativa L.) production herbicides throughout the OFWS–TWR flow system during the growing season (Dewell & Lavy, 1996). In addition, pesticide residue accumulation was observed in sediments of eight Mississippi drainage ditches (Kröger, Moore, & Brandt, 2012), suggesting some “removed” pesticides are stored long-term, with the potential to build up and reenter the water column through sediment desorption or resuspension.

As sources for irrigation and MAR, OFWS–TWR systems pose potential agronomic and environmental challenges due to pesticide persistence and recirculation. Agronomically, OFWS–TWR may result in low-level application of herbicides to nontarget crops, potentially reducing yields. Environmentally, OFWS–TWR systems may be sources of pesticide contamination via discharge to streams or as a water supply for MAR. Thus, integrated monitoring across seasons and system locations is needed for thorough assessment of the effectiveness of OFWS–TWR as a BMP for reducing or removing pesticide residues. The objectives of this study were (a) to monitor target herbicide concentrations in seven northeast Arkansas OFWS–TWR systems (Supplemental Figures S1–S2) over a full year (Apr. 2017–Mar. 2018) and (b) to analyze concentrations for differences between seasons and structure types (ditch or reservoir), with the goal of facilitating management of OFWS–TWR systems to reduce risk of cross-crop and groundwater contamination.

2 | MATERIALS AND METHODS

Site selection targeted OFWS–TWR systems of comparable size (reservoir surface area ~13–34 ha; ditch width ~6.6–16 m; Supplemental Table S1). Adjacent fields were predominantly planted in conventional rice and Roundup Ready (Bayer) soybean [Glycine max (L.) Merr.]. Based on herbicide application records collected from producers, as well as regional frequency and anticipated future use (ditches drain from other production systems), we targeted seven herbicides (Supplemental Table S2): 2,4-dichlorophenoxyacetic acid (2,4-D), dimethazone 2-(2-chlorobenzyl)-4,4-dimethylisoxazolidin-3-one (clomazone), 3,6-dichloro-2-methoxybenzoic acid (dicamba), N-(phosphonomethyl)glycine (glyphosate), 2-chloro-N-(2-ethyl-6- methylphenyl)-N-(2-methoxy-1-methylethyl) acetamide (metolachlor), N-(3,4-dichlorophenyl)propanamide (propanil), and 3,7-dichloroquinoline-8-carboxylic acid (quinclorac). Ditches and reservoirs were sampled at accessible locations in proximity to the pumps that transport water between structures. Grab samples were collected weekly (Apr.–Aug. 2017) to monthly (Sept. 2017–Mar. 2018) in high density polyethylene bottles from ~0.5 m depth using a pole sampler and were shipped overnight on ice to the University of Arkansas Residue Laboratory.

Samples were stored at 4 °C until filtration through a 0.45-μm nylon membrane within 48 h of receipt. Filtered samples were preserved by freezing until analysis by enzyme-linked immunosorbent assay with photometric detection (glyphosate) or by high performance liquid chromatography with photodiode array detection following solid phase extraction (SPE). During SPE, acidified samples (0.5% v/v phosphoric acid), were concentrated from 200 to 8 ml 50:50 acetonitrile/methanol using Strata-X reverse-phase polymer columns. Columns were conditioned with 100% methanol, equilibrated with 0.5% v/v phosphoric acid in ultrapure water, and rinsed with 20% v/v methanol and 0.5% v/v phosphoric acid in ultrapure water. Eluates were analyzed using a mobile phase gradient (34–64% v/v acetonitrile in 0.1% v/v phosphoric acid over 20 min). For all analytes, SPE recovery was 100% ± 5%, confirmed with fortified samples for each new Strata-X lot. Bulk water sample concentrations were calculated by multiplying the measured eluate concentration by the ratio of eluate and sample volumes. Nondetections or concentrations below reporting limits (i.e., 10 times the detection limit; 2,4-D, propanil, and quinclorac = 0.40 μg L⁻¹; dicamba and clomazone = 0.80 μg L⁻¹; glyphosate = 0.50 μg L⁻¹; metolachlor = 2.0 μg L⁻¹) were censored in subsequent analysis.

Summary statistics were calculated by season (spring = 16 Mar.–15 June, summer = 16 June–15 Sept., fall = 16 Sept.–15 Dec., and winter = 16 Dec.–15 Mar.), and for ditches and reservoirs across seasons and during the growing season (16 Mar.–15 Sept.) and off-season (16 Sept.–15 Mar.). Kaplan Meier survival analysis or robust regression order statistics
were used when censoring frequency was <50% or ≥50–80%, respectively (Helsel, 2012). Summary statistics were not calculated when censoring frequency was >80%. Herbicide concentrations were compared for differences between seasons using generalized Wilcoxon tests and between adjacent ditches and reservoirs using paired Prentice–Wilcoxon tests. Summary statistic calculations and generalized Wilcoxon tests were conducted in R, version 3.1.6 (R Core Team, 2019) using the NADA (Lee, 2017) and interval (Fay & Shaw, 2010) packages. Paired Prentice-Wilcoxon tests were conducted in Minitab 19 (Minitab, 1998) using the PPW macro (Helsel, 2012).

3 | RESULTS AND DISCUSSION

3.1 | Seasonal patterns in herbicide concentrations

Clomazone, glyphosate, metolachlor, and quinclorac were frequently detected (17, 35, 15, and 80% of samples, respectively) in the OFWS–TWR systems (Figure 1a–d). Dicamba, 2,4-D, and propanil were rarely detected (0.4, 1.1, and 5.7%, respectively). No producers reported 2,4-D or dicamba use. One producer reported propanil use, but propanil was not detected in that system, and sampling intensity may have been insufficient to track propanil dynamics due to rapid degradation (Kanawi, Van Scoy, Budd, & Tjeerdema, 2016; Supplemental Table S2).

Detected herbicide concentrations peaked during the growing season, with temporal variability most directly influenced by interaction of application and precipitation timing (Figure 1; Table 1). Concentrations of clomazone (median <0.80 μg L⁻¹) and quinclorac (median 0.90–2.0 μg L⁻¹) were highest in spring and summer (p = .001) after applications by most producers in mid-April 2017. Metolachlor concentrations (median 1.1 μg L⁻¹) were higher in summer only (p = .001), coinciding with reported applications in mid-June through early July and reflecting common seasonal patterns in the Mississippi River Delta (Coupe, Thurman, & Zimmerman, 1998). Glyphosate concentrations (median 0.57 μg L⁻¹) peaked in summer but were also higher in spring (median 0.50 μg L⁻¹) and fall (median 0.20 μg L⁻¹) relative to winter (median <0.50 μg L⁻¹; p = .001), reflecting frequent, broad use (Barber et al., 2019). Herbicide concentrations were lowest (p = .001) in fall and winter, with concentrations either below detection (clomazone median <0.80 μg L⁻¹) or at low levels relative to the growing season (glyphosate median <0.50–0.20 μg L⁻¹; quinclorac median 0.50–0.60 μg L⁻¹).

Seasonal dynamics in OFWS–TWR residual herbicide concentrations are congruent with previous studies of agricultural watersheds, especially the trend of a “spring flush”
FIGURE 1 Frequency of (a) clomazone, (b) glyphosate, (c) metolachlor, and (d) quinclorac detections greater than the reporting limit, >1.0 μg L⁻¹ (except metolachlor, which had a reporting limit of 2.0 μg L⁻¹), and >10 μg L⁻¹ by month during the study period April 2017–March 2018. (e) Craighead County, AR, monthly precipitation totals and 1981–2010 climate normals (Arguez, Durre, Applequist, Squires, & Vose, 2010) by month. Shaded areas (a–d) approximate common application timing for the detected herbicides in the region (Barber et al., 2019).

(Thurman, Goolsby, Meyer, & Kolpin, 1991). For 62 lake and river sites in four Arkansas counties, spring and summer samples comprised 73% of pesticide detections (Senseman, Lavy, Mattice, Gbur, & Skulman, 1997). However, unexplained spikes in concentrations occurred, including elevated clomazone (2.9 μg L⁻¹) and quinclorac (20 μg L⁻¹) concentrations in a November ditch sample. Recurrence of spring-applied herbicides could indicate re-entrainment of sediments...
and/or desorption from sediment. Further inquiry, including mass spectrometric identification of compounds, is required to interpret such events.

### 3.2 Differences between OFWS–TWR structure types

During the growing season, clomazone (median ditch, 0.29 μg L\(^{-1}\); median reservoir, <0.80 μg L\(^{-1}\)), glyphosate (median ditch, 0.71 μg L\(^{-1}\); median reservoir, 0.28 μg L\(^{-1}\)), and quinclorac (median ditch, 2.0 μg L\(^{-1}\); median reservoir, 0.90 μg L\(^{-1}\)) were greater and more frequently detected in ditches than in the adjacent reservoir (Table 2; \(p < .001\)). These findings differ from comparisons of nutrients and solids between system structures (Moore, Pierce, & Farris, 2015) but are congruent with the concept that residues are diluted along the flow path by mixing with increasingly large water volumes at lower concentrations, in tandem with sedimentation and degradation over time. Mattice, Skulman, Norman, and Gbur (2010) observed this pattern in four regional river networks, with pesticide concentrations decreasing with increasing discharge. Further, 62% of pesticide detections occurred in rivers and streams relative to lakes and reservoirs in the survey by Senseman et al. (1997).

In contrast, growing season metolachlor concentrations (median 0.48–0.78 μg L\(^{-1}\)) were not different between ditches and reservoirs (\(p = .83\)). Elevated metolachlor concentrations in reservoirs at the end of the flow system, compared with the other detected herbicides, may reflect low metolachlor sorption to soil/sediment and transport mainly in the dissolved phase (Lerch, Lin, Goyne, Kremer, & Anderson, 2017), as well as slow degradation in environmental waters (Liu, Maguire, & Pacepavicius, 1995). Indeed, metolachlor and its metabolites are frequently detected in surface waters (Liu, Maguire, & Pacepavicius, 1995). Indeed, metolachlor and its metabolites are frequently detected in surface waters (Liu, Maguire, & Pacepavicius, 1995).

### 3.3 Preliminary examination of OFWS–TWR herbicide residues for potential risks

Maximum detected herbicide concentrations did not exceed national drinking water standards (glyphosate <0.7 mg L\(^{-1}\); USEPA, 2018) or human health advisories (metolachlor <0.7–2 mg L\(^{-1}\)) and benchmarks (clomazone <5.4–30 mg L\(^{-1}\); quinclorac <2.4–60 mg L\(^{-1}\); USEPA, 2018).

---

**Table 2** Summary statistics of the four herbicides frequently detected in the on-farm water storage-tailwater recovery systems by structure type, calculated across seasons and for the growing season (1 Apr.–15 Sept. 2017) and off-season (16 Sept. 2017–15 Mar. 2018)

| Herbicide   | Dataset | Median | Mean | SD | Maximum | Prentice–Wilcoxon test |
|-------------|---------|--------|------|----|---------|------------------------|
|             |         |        |      |    |         |                        |
|             |         | Ditch  | Rsvr |    | Ditch  | Rsvr                 |                        |
| Clomazone   | All     | 0.13   | <0.80 |   | 1.2    | –                     | –                      |
|             | GS      | 0.29   | <0.80 |   | 1.9    | –                     | –                      |
|             | OS      | <0.80  | <0.80 |   | –      | –                     | –                      |
| Glyphosate  | All     | 0.55   | 0.18 | 0.36 | 6.1     | 0.52                  | 95                     | 4.1                     |
|             | GS      | 0.71   | 0.28 | 0.47 | 1.2     | 0.56                  | 6.2                    | 4.1                     |
|             | OS      | 0.28   | <0.50 |   | 1.6    | 9.8                   | 95                     | 3.0                     |
| Metolachlor | All     | <2.0   | <2.0 |   | –      | –                     | –                      |
|             | GS      | 0.48   | 0.78 | 2.4 | 2.4     | 1.8                   | 32                     | 2.0                     |
|             | OS      | <2.0   | <2.0 |   | –      | –                     | –                      |
| Quinclorac  | All     | 0.80   | 0.90 | 3.2 | 7.3     | 0.74                  | 62                     | 6.0                     |
|             | GS      | 2.0    | 0.90 | 4.6 | 8.8     | 0.89                  | 62                     | 6.0                     |
|             | OS      | 0.40   | 0.70 | 0.77| 2.0     | 0.3                   | 20                     | 2.0                     |

Note: GS, growing season; OS, off-season; Rsvr, reservoir.

* A positive or negative median of differences between paired observations in Prentice–Wilcoxon tests indicates higher or lower concentrations, respectively, in ditches when \(p < .05\). *For censoring frequency >80%, median is known only to be below the reporting limit. *For censoring frequency >80%, mean and standard deviation cannot be estimated.
2014b). Observed clomazone, glyphosate, and quinclorac concentrations are not expected to be lethal to fish, invertebrates, or nonvascular plants after acute or chronic exposures (USEPA, 2014a). This is congruent with a previous ecotoxicological assessment of OFWS–TWR system water and sediment (Moore et al., 2015). Maximum metolachlor concentrations, however, were within ranges known to be toxic to fish, invertebrates, and nonvascular plants. Assessments of crop sensitivities to residual herbicides in irrigation are limited. Soybean is sensitive to dicamba doses in irrigation exceeding \(30–160 \text{ g ha}^{-1}\) equivalent to 0.05–0.14 mg L\(^{-1}\) in 3 ac-in of irrigation (Grantz, Lee, Willett, & Norsworthy, 2020; Willett, Grantz, Lee, Thompson, & Norsworthy, 2019). This study detected 2,4-D, quinclorac, clomazone, glyphosate, and propanil concentration maxima of similar magnitude to the dicamba concentration range reported to injure soybean. However, the detected herbicides in irrigation may be less likely to damage crops, as soybean and dicamba are a known high-sensitivity pairing (Egan, Barlow, & Mortensen, 2014).

## 4 | CONCLUSIONS

Herbicides applied to fields adjacent to OFWS–TWR systems were frequently detected in ditches and reservoirs, with peak concentrations during the growing season in ditches. While it is not known if residual herbicides at detected concentrations can lead to cross-crop injury, risk may be minimized by cycling tailwater through the reservoir for treatment and for sourcing irrigation. This strategy may be effective for clomazone, glyphosate, and quinclorac, but managing metolachlor residues may be more complex due to its persistence in reservoirs during the growing season. Residual herbicide concentrations were lowest in the OFWS–TWR systems in winter, although evidence of off-season quinclorac persistence in reservoirs was observed. Targeting winter months for MAR using OFWS–TWR reservoirs should best protect groundwater quality.

## ACKNOWLEDGMENTS

We thank our producer cooperators: Lindy Alexander, Roger Bradley, Jerry Don Clark, Bryan Huber, Mickey Seeman, Gary Sitzer, and Tom Wimpy. Funding was provided by the Arkansas Water Resources Center through the U.S. Geological Survey 104b National Institute of Water program and the Arkansas Soybean Promotion Board. The research was supported by the University of Arkansas System Division of Agriculture and the U.S. Department of Agriculture, Agricultural Research Service (USDA-ARS). The authors acknowledge the technical assistance of Ian Godwin and Klariissa Kahill of the USDA-ARS Delta Water Management Research Unit. Mention of trade names or commercial products in this publication is solely for the purpose of providing specific information and does not imply recommendation or endorsement by the U.S. Department of Agriculture, which is an equal opportunity provider and employer.

## CONFLICT OF INTEREST

The authors have no conflicts of interest to disclose.

## ORCID

Erin M. Grantz https://orcid.org/0000-0002-0823-0842

## REFERENCES

Arguez, A., Durre, I., Applequist, S., Squires, M., Vose, R., Yin, X., & Bilotta, R. (2010). NOAA's U.S. climate normals (1981–2010). Washington D.C.: NOAA National Centers for Environmental Information. https://doi.org/10.7289/V5PN93JP

Barber, L. T., Boyd, J. W., Selden, G., Norsworthy, J. K., Burgos, N., & Bertucci, M. (2019). MP44 Arkansas: Recommended chemicals for weed and brush control. Little Rock: University of Arkansas System Division of Agriculture Cooperative Extension Service.

 Battaglin, W. A., Furlong, E. T., Burkhardt, M. R., & Peter, C. J. (2000). Occurrence of sulfonyleurea, sulfonamide, imidazolinone, and other herbicides in rivers, reservoirs, and ground water in the midwestern United States, 1998. Science of the Total Environment, 248, 123–133.

 Bennett, E. R., Moore, M. T., Cooper, C. M., Smith, S., Jr., Shields, F. D., Jr., Drouillard, K. G., & Schulz, R. (2005). Vegetated agricultural drainage ditches for the mitigation of pyrethroid-associated runoff. Environmental Toxicology and Chemistry, 24, 2121–2127.

 Coupe, R. H., Thurman, E. M., & Zimmerman, L. R. (1998). Relation of usage to the occurrence of cotton and rice herbicides in three streams of the Mississippi Delta. Environmental Science & Technology, 32, 3673–3680.

 Czarnecki, J. M. P., Omer, A. R., & Dyer, J. L. (2017). Quantifying capture and use of tailwater recovery systems. Journal of Irrigation and Drainage Engineering, 143, 05016010. https://doi.org/10.1061/(ASCE)IR.1943-4774.0001124

 Dewell, R. A., & Lavy, T. L. (1996). Influence of rice production on the quality of water in tailwater collection reservoirs (Pub 178.26). Fayetteville: Arkansas Water Resources Center.

 Egan, J. F., Barlow, K. M., & Mortensen, D. A. (2014). A meta-analysis on the effects of 2,4-D and dicamba drift on soybean and cotton. Weed Science, 62, 193–206.

 Fay, M. P., & Shaw, P. A. (2010). Exact and asymptotic weighted logrank tests for interval censored data: The interval R package. Journal of Statistical Software, 36, 1–34.

 Fugitt, D. T., Battreal, J. L., Johnston, J., Kelley, C., Ritches, M., Dotson, P. et al. (2011). Arkansas groundwater protection and management report for 2010. Little Rock: Arkansas Natural Resources Commission.

 Grantz, E. M., Lee, J. A., Willett, C. D., & Norsworthy, J. K. (2020). Soybean response to dicamba in furrow irrigation. Agrosystems, Geosciences & Environment. https://doi.org/10.1002/agg2.20039

 Helsel, D. R. (2012). Statistics for censored environmental data using Minitab® and R (2nd ed.). Hoboken, NJ: John Wiley & Sons.

 Kanavi, E., Van Scoy, A. R., Budd, R., & Tjeerdema, R. S. (2016). Environmental fate and ecotoxicology of propanil: A review. Toxicological and Environmental Chemistry, 98, 689–704.
Kröger, R., Moore, M. T., & Brandt, J. R. (2012). Current and past-use pesticide prevalence in drainage ditches in the Lower Mississippi alluvial valley. *Pest Management Science*, 68, 303–312.

Lee, L. (2017). NADA: Nondetects and Data Analysis for Environmental Data. R package version 1.6-1. Retrieved from https://CRAN.R-project.org/package=NADA

Lerch, R. N., Lin, C. H., Goyne, K. W., Kremer, R. J., & Anderson, S. H. (2017). Vegetative buffer strips for reducing herbicide transport in runoff: Effects of buffer width, vegetation, and season. *Journal of the American Water Resources Association*, 53, 667–683. https://doi.org/10.1111/1752-1688.12526.

Lewis, K. A., Tzilivakis, J., Warner, D., & Green, A. (2016). An international database for pesticide risk assessments and management. *Human and Ecological Risk Assessment: An International Journal*, 22(4), 1050–1064. https://doi.org/10.1080/10807039.2015.1133242

Liu, D., Maguire, R. J., & Pacepavicius, G. J. (1995). Microbial transformation of metolachlor. *Environmental Toxicology and Water Quality: An International Journal*, 10, 249–258.

Luo, Y., & Zhang, M. (2009). Management-oriented sensitivity analysis for pesticide transport in water-scale water quality modeling using SWAT. *Environmental Pollution*, 157, 3370–3378.

Mattice, J. D., Skulman, B. W., Norman, R. J., & Gbur, E. E., Jr. (2010). Analysis of river water for rice pesticides in eastern Arkansas from 2002 to 2008. *Journal of Soil and Water Conservation*, 65, 130–140.

Minitab. (1998). MINITAB 19 [Software]. State College, PA: Minitab.

Minitab. (1998). MINITAB 19 [Software]. State College, PA: Minitab.

Moore, M. T., Bennett, E. R., Cooper, C. M., Smith, S., Jr., Shields, F. D., Jr., Milam, C. D., & Farris, J. L. (2001). Transport and fate of atrazine and lambda-cyhalothrin in an agricultural drainage ditch in the Mississippi Delta, USA. *Agriculture, Ecosystems and Environment*, 87, 309–314.

Moore, M. T., Pierce, J. R., & Farris, J. L. (2015). Water-quality analysis of an intensively used on-farm storage reservoir in the northeast Arkansas Delta. *Archives of Environmental Contamination and Toxicology*, 69, 89–94.

Omer, A. R., & Baker, B. H. (2019). Water quality improvements from implementation of tailwater recovery systems. *Sustainable Water Resources Management*, 5, 703–713.

Omer, A. R., Dyer, J. L., Czarnecki, J. M. P., Kröger, R., & Allen, P. J. (2018a). Development of water budget for tailwater recovery systems in the lower Mississippi alluvial valley. *Journal of Irrigation and Drainage Engineering*, 144, 05018001. https://doi.org/10.1061/(ASCE)IR.1943-4774.0001302

Omer, A. R., Miranda, L. E., Moore, M. T., Krutz, L. J., Czarnecki, J. M. P., Kröger, R., … Allen, P. J. (2018b). Reduction of solids and nutrient loss from agricultural land by tailwater recovery systems. *Journal of Soil and Water Conservation*, 73, 284–297.

R Core Team. (2019). *R: A language and environment for statistical computing*. Vienna: R Foundation for Statistical Computing. Retrieved from https://www.R-project.org/

Reba, M. L., Massey, J. H., Adviento-Borbe, M. A., Leslie, D., Yaeger, M. A., Anders, M., & Farris, J. (2017). Aquifer depletion in the Lower Mississippi River basin: Challenges and solutions. *Journal of Contemporary Water Research and Education*, 162, 128–139.

Rebich, R. A., Coupe, R. H., & Thurman, E. M. (2004). Herbicide concentration in the Mississippi River basin: The importance of chloroacetanilide herbicide degradates. *Science of the Total Environment*, 321, 189–199.

Senseman, S. A., Lavy, T. L., Mattice, J. D., Gbur, E. E., & Skulman, B. W. (1997). Trace level pesticide detections in Arkansas surface waters. *Environmental Science & Technology*, 31, 395–401.

Sullivan, M. E., & Delp, W. M. (2012). Water conservation planning: How a systems approach to irrigation promotes sustainable water use. In *NABC Report 24: Water Sustainability in Agriculture* (pp. 145–159). Retrieved from https://ecommons.cornell.edu/handle/1813/51384

Tagert, M. L. M., Massey, J. H., & Shaw, D. R. (2014). Water quality survey of Mississippi’s Upper Pearl River. *Science of the Total Environment*, 481, 564–573.

Thurman, E. M., Goolsby, D. A., Meyer, M. T., & Kolpin, D. W. (1991). Herbicides in surface waters of the midwestern United States: The effect of spring flush. *Environmental Science & Technology*, 25, 1794–1796.

USDA-NRCS. (2011). *Irrigation systems, tailwater recovery*. Washington, DC: USDA-NRCS. Retrieved from http://www.nrcs.usda.gov/Internet/FSE_DOCUMENTS/stelprdb1046887.pdf

USEPA. (2009). *National water quality inventory: 2004 report*. Washington, DC: USEPA.

USEPA. (2014a). *Aquatic life benchmarks*. Washington, DC: USEPA Office of Chemical Safety and Pollution Prevention. Retrieved from https://www.epa.gov/pesticide-science-and-assessing-pesticide-risks/aquatic-life-benchmarks-pesticide-registration

USEPA. (2014b). *Human health benchmarks for pesticides*. Washington, DC: USEPA. Retrieved from http://www.epa.gov/dwstandardsregulations/drinking-water-contaminant-human-health-effects-information#benchmarks

USEPA. (2018). 2018 edition of the drinking water standards and health advisories tables (822-F-18-001). Washington, DC: USEPA.

Willett, C. D., Grantz, E. M., Lee, J. A., Thompson, M. N., & Norsworthy, J. K. (2019). Soybean response to dicamba in irrigation water under controlled environmental conditions. *Weed Science*, 67, 354–360.

Yaeger, M. A., Reba, M. L., Massey, J. H., & Adviento-Borbe, M. A. A. (2017). On-farm irrigation reservoirs in two Arkansas critical groundwater regions: A comparative inventory. *Applied Engineering in Agriculture*, 6, 869–878.

Yaeger, M. A., Massey, J. H., Reba, M. L., & Adviento-Borbe, M. A. A. (2018). Trends in the construction of on-farm irrigation reservoirs in response to aquifer decline in eastern Arkansas: Implications for conjunctive water resource management. *Agricultural Water Management*, 208, 373–383.

**SUPPORTING INFORMATION**

Additional supporting information may be found online in the Supporting Information section at the end of the article.

**How to cite this article:** Grantz EM, Leslie D, Reba M, Willett C. Residual herbicide concentrations in on-farm water storage–tailwater recovery systems: Preliminary assessment. *Agric Environ Lett*. 2020;5:e20009. [https://doi.org/10.1002/ael2.20009](https://doi.org/10.1002/ael2.20009)