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Multifunctional agricultural watersheds for climate adaptation in Midwest USA: commentary

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Abstract

Meeting the societal demand for food, bioproducts and water under climate change is likely to greatly challenge the maize-soybean agriculture of the Midwest USA, which is a globally significant resource. New agricultural systems are needed that can meet this challenge. Innovations in water management engineering and cropping system diversification may provide a way forward, enabling transformation to highly multifunctional agricultural watersheds that expand both agricultural production and water-related services to society, and which provide scalable units of climate adaptation in agriculture and water systems. Implementation and refinement of such watersheds require corresponding social innovation to create supportive social systems, in economic, political and cultural terms. A range of emerging social innovations can drive the emergence of highly multifunctional agricultural watersheds, by enabling robust cooperation, resource exchange and coordinated innovation across multiple societal sectors and scales. We highlight relevant innovations and opportunities for their exploratory implementation and refinement in the Midwest.

Context and problem

Globally, humanity faces a truly grand challenge: meeting needs for food, agricultural bioproducts and water, in the face of climate change. In this commentary, we consider how this challenge might be met in the context of the maize-soybean agriculture of the Midwest USA. This regional agriculture of ca. 60 million ha is globally significant: the region's soils, water and climate resources are highly conducive to intensive agricultural production, much of which is exported. However, ongoing and expected changes in regional precipitation and climate (Seeley, 2015; Kim et al., 2017)—particularly the anticipated shift toward fewer, larger rainfall events—strongly highlights the need for improved management of these soil and water resources (Claassen and Ribaudo, 2016) in order to sustain agriculture. For example, additional soil and water conservation measures will be needed to accommodate the larger rainfall events that are anticipated (Walthall et al., 2012). Increases in water storage are needed to support production during summer droughts. In addition, water-related impacts of current agriculture and water management are expected to increase, such as urban flooding and interference with river navigation. In response, additional water management will be needed to provide the wide range of water-related services needed by society (Brauman et al., 2007).

The Midwest needs new agricultural systems that can meet this grand challenge. In our opinion, the prevailing view is the financial costs of these systems will be very high: many suppose that enhancing water-related services to society will cause costly decreases in agricultural production. Moreover, it is unclear how or by whom these anticipated costs can be paid (Hayes et al., 2016), resulting in social tensions such as the ongoing urban-rural conflict over water quality in Iowa, USA. We believe that this pessimistic outlook is unwarranted. We propose that emerging innovations in agricultural diversification and hydrological engineering practices, implemented and optimized at the watershed scale, can enhance production, water and climate adaptation at affordable costs if supported by complementary social innovations. We contend that it is now time for exploratory implementation of such watersheds. Below, we survey emerging innovations that are setting the stage for such implementation efforts, weigh incentives for participation in implementation, and highlight opportunities to move forward.

Emerging Innovations

Advances in hydrology, water engineering and complementary crops

First, understanding and management of the hydrology of Midwestern US agricultural watersheds are in a phase of rapid expansion and innovation. Advancements in spatial mapping and computing enable low-cost identification of critical areas within watersheds that have disproportionate impacts on water resources (Galzki et al., 2011). New approaches to the hydrological engineering of watersheds, such as controlled drainage, are enabling high levels of water storage in ways that can also expand and stabilize total watershed agricultural production in variable rainfall regimes (Drury et al., 2009). Importantly, total agricultural production can be expanded by growing new crops that are adapted to critical sites for water conservation in watersheds (Guo et al., 2018). These sites are typically marginal for production of conventional row crops, but not for certain perennial biomass crops. For example, shrub willows and prairie cordgrass are two novel biomass crops that can produce large yields in wet areas of a field that may result from controlled drainage. Both are receiving intensive development in terms of genetic improvement, production methods and end-use markets (Volk et al., 2016; Boe et al., 2017). In addition, perennial crops such as alfalfa and horticultural crops are increasingly targeted to critical watershed areas (Jordan et al., 2015), providing economically viable production options while efficiently improving water resources (Wilson et al., 2014).

The emerging sustainable bioeconomy

Development of these highly-multifunctional watersheds depends on crops that can thrive under the hydrological regimes created by water storage, as we have noted. Crucially, demand for such crops (e.g., prairie cordgrass and willow) may well expand considerably in the coming decade, as a new, more diversified agricultural bioeconomy emerges, based on new crops and new bio-based food, nutrition, health, and industrial products, propelled by entrepreneurship and technological innovation in biomass and bioproduct processing and manufacturing (Chen and Zhang, 2015). Broadly concerted efforts to expand this bioeconomy across supply and value chains are needed to realize its large potential for sustainable economic development (Rogers et al., 2017) and thereby create demand for crops that thrive in new hydrological regimes. Importantly, the emerging bioeconomy also includes food and bioproducts containing sustainably-produced raw materials from conventional crops. If produced in highly-multifunctional watersheds, food and bioproducts from these crops can acquire highly-marketable sustainability attributes (Bonner et al., 2014)

Collaborative governance of large watersheds

Collaborative governance at large watershed scales is now recognized as highly advantageous, in recognition of the complexity and interdependency of resource management in watersheds, widely dispersed power and responsibility for such management and the potential for mutual gain through coordinated actions (Head et al., 2016). Effective and adaptive collaborative governance regimes require shared norms of inclusion, communication, fairness and power-sharing. A supportive resource base is needed at technical, political, legal, economic, cultural and financial levels, including collaboratively-oriented leaders in organizations across sectors and scales who can build trusting working relationships. A shared understanding of watershed goals, and a strong focus on ongoing monitoring, learning and experimentation are critical. Large-watershed management initiatives are being actively piloted by state agencies in the Midwest, e.g., by Minnesota's 'One Watershed, One Plan' Initiative (http://bwsr.state.mn.us/planning/1W1P/1W1P_Factsheet.pdf) and the 'Iowa Watershed Approach' (http://iowawatershedapproach.iowa.gov/). Both initiatives aim to create adaptive planning and coordinating institutions for all major watersheds in each state, by focusing resources from many sectors. Both emphasize the integration of local watershed planning with state-level strategies and resources to advance state-level goals for water-related services, e.g., the Iowa Nutrient Reduction Plan. Both recognize the importance of locally-controlled actions, and the need to link local watershed institutions into a state-level network that ensures that local action is prioritized, targeted and comprehensively monitored so that both local and state-level goals are efficiently advanced. Such watershed governance arrangements could aggregate sufficient economic and political power to drive land-use change for climate adaptation by activating cycles of adaptation in response to expanding need for adaptation.

Small watershed-scale cooperative organizations

These have arisen as a key means for organizing and implementing cooperative production of water-related services. Cooperatives promote spatial coordination of management that helps meet water conservation goals more efficiently (Pennington et al., 2017). Essentially, cooperatives efficiently coordinate and aggregate actions by individual landowners to enhance conservation outcomes of these efforts, enhance negotiating power of these landowners and minimize costs and risks for individual landowners. For the cooperative production of water-related services by small watersheds, legal cooperative structures would design and execute land-use change across the watershed to achieve conservation goals, receive and distribute payments from beneficiaries and investors, and work with independent agencies certifying performance in relation to conservation goals. Such cooperative watershed management has been championed by influential agricultural groups (Duncanson et al., 2014). In Western Europe, such cooperatives have had many successes (Franks, 2010). Supported by significant subsidies to groups of farmers that contract to carry out coordinated management, these groups have taken collective action to enhance water-related services, such as improving water infrastructure and making broad changes in fertilization practices. Importantly, the groups have successfully negotiated with regional and national governments, winning increased autonomy to take action by local innovation rather than prescribed solutions. These examples show that such cooperatives can help farmers negotiate mutually acceptable terms for the provision of water-related services to large-watershed governance organizations. Similar incentives are largely absent in the USA, but experiments in small-watershed cooperatives are starting to appear, e.g., agricultural nutrient management cooperatives in California, begun in 2016 (https://www.rcdmonterey.org/nutrient-management-cooperatives-development).

Cooperative production of water-related services could be facilitated by new methods for coordinating collective action. These methods assure individuals that if they contribute to a collective effort, their actions will not be futile, thus addressing the 'assurance problem', i.e., the fact that individuals have little incentive to contribute to a collective effort unless they have the assurance that others will also contribute. Such conditional contributions can be formalized by the use of assurance contracts (Tabarrok 1998), which require participants to take action only if other actors also agree to act, in sufficient numbers to solve a common problem. These methods can help watershed-based cooperatives organize to meet a goal for water-related services (e.g., a certain quantity of water storage). Using this approach, no landowner need take costly measures to meet the goal unless others in the watershed are also willing to do so, in sufficient numbers to meet the goal.

Novel social and economic coordination mechanisms

Rapid innovation is underway in coordination mechanisms that can support the emergence and operation of highly-multifunctional watersheds. Relevant mechanisms include the emerging practice of transdisciplinary landscape design; applied to watersheds, this practice engages a wide range of societal sectors in a multi-stage process (Opdam et al., 2015) that begins with the development of a shared, systemic understanding of the watershed in social and biophysical terms. Deployed in a collaborative context that engages multiple stakeholders, this understanding supports co-design of targeted land-use change to address current and anticipated problems. Co-design is supported by emerging 'geodesign' technologies that integrate geographical information systems, spatial computing and simulation, to provide visualization of landscape designs and rapid model-based feedback on design performance (Slotterback et al., 2016). These computational methods and decision support tools are critical to enhance efficiency and reveal the complexity of watershed-scale systems, including unanticipated dynamics and feedbacks.

Second, a range of new economic mechanisms enables public and private investors to obtain attractive returns on investments and thus provide flows of capital to support efficient production of hydrological services within watersheds. For example, areas within large watersheds that are exposed to major water-related risks (e.g., of water scarcity, poor water quality, or flooding) are increasingly cooperating with other areas within these watersheds to reduce their risks. In essence, certain sites in watersheds can provide comparatively low-cost 'green infrastructure' that can be of high value to climate-vulnerable in these watershed areas. For example, in Iowa, the city of Cedar Rapids is paying to farms to install conservation measures that store water and protect drinking water (http://www.cedarrapids.org/residents/utilities/middle_cedar_partnership_project.php). Such cooperation can be mediated by environmental credit trading schemes for managing stormwater flows and nutrient emissions in watersheds that create flooding and pollution risks, such as the Washington DC stormwater retention credit program (https://doee.dc.gov/src). Environmental credit trading is complemented by other emerging economic coordinating mechanisms, e.g., outcome-based and avoided-cost markets (Reed et al., 2014; Whelpton and Ferri, 2017); all of these enable public and private investors to reduce risks and obtain attractive returns on investments and thus provide flows of capital to support efficient production of hydrological services within watersheds.

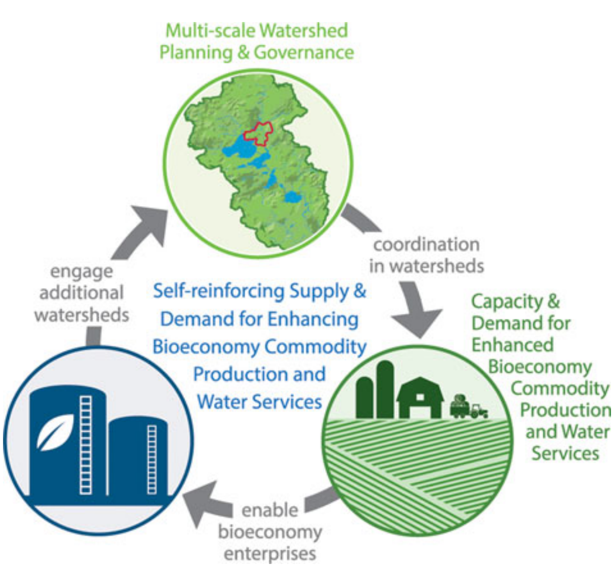

Figure 1. Potential virtuous cycle, driven by collaborative governance in large watersheds, that stimulates coupled land-use change, bioeconomic development and enrollment of further watersheds in response to demand for agricultural commodities and climate adaptation.

Exploratory implementation

We suggest that the time is ripe for concerted implementation efforts that integrate the emerging innovations described above because substantial incentives now exist for potential participants in the development of multifunctional agricultural watersheds. In the case of small-watershed cooperatives, farmer advocates (Duncanson et al., 2014) have proposed that these cooperatives will enhance their bargaining power and reduce the costs of transactions with clients for products and services produced in multifunctional watersheds, e.g., regulatory agencies, commodity markets and markets for ecosystem services such as nutrient and stormwater credits. For example, these cooperatives might obtain watershed-level certification of compliance with government water management agencies, greatly reducing individual transaction costs with these agencies.

For the clients of small-watershed cooperatives (e.g., regulatory agencies, commodity markets and markets for ecosystem services), participating in these networks provides important practical and reputational benefits. Large firms that are undertaking sustainability sourcing initiatives may substantially increase their ability to engage with farmers, as well as reduce their transaction costs, by working with cooperatives rather than individual producers (Freidberg, 2017). Finally, pursuing environmental and social goals by collective action at watershed scales can offer meaningful measurement and assurance mechanisms for investors in these systems (e.g., providers of private and public capital via environmental improvement bonds).

Given the inherent complexity of the watershed-based approach to climate adaptation that we propose, and the immature nature of most of the key innovations, learning-by-doing efforts and patience will be essential. Implementation will likely need a regional-scale cross-sector collaborative group that is able to address regional environmental, economic and social goals in relation to the nexus of agriculture, water and climate adaptation. The group should plan and execute pilot projects at modest scales, and use these to drive cycles of learning, refinement and expansion of scale. For example, such projects might be designed and organized to meet demands for sustainably sourced bioproducts (Fig. 1). If properly designed and coordinated on farm and watershed scales, production of such bioproducts can efficiently enhance farm profit, bioproduct feedstock supply and water-related services (Bonner et al., 2016; Chaubey et al., 2016). Such coupled creation of value can drive the development of further watershed-scale coordination needed to organize further value creation, potential creating a positive feedback 'virtuous cycle' process of regional climate adaptation. To activate such cycles, collaborative groups must refine critical innovations that are not yet fully viable (e.g., supply/value chains for biomass crops). For example, biofuel production from cellulosic biomass might support diversification in many watersheds but has major supply-chain problems (Dale, 2017). Only future-focused cross-sector collaborations focused on the multiple benefits of highly-multifunctional watersheds can muster the patient (long-term) capital investments and other resources needed to refine key technical and social innovations to the point of viability.

There are immediate opportunities to take this approach in certain Midwestern watersheds, such as the Cedar River in Iowa, or the Upper Sangamon in Illinois. Both watersheds have notable concentrations of assets—i.e., social, human, organizational and financial capital—focused on the agriculture-water-climate nexus. For example, in the Iowa portions of the Cedar River watershed, there are three Regional Conservation Partnership Projects, all focused on agricultural effects on water resources, and supported in total by US$13.2 million USD in Federal grant funds. Additionally, The Iowa Watershed Approach project (supported by US$92 million US Federal grant) has selected the middle section of the Cedar watershed as one of nine focal watersheds in Iowa for flood risk mitigation, and the Midwest Row Crop Collaborative (MRCC) has selected that same section as one of three focal watersheds for its work to enhance sustainability of annual crop production in the Midwest. The MRCC (http://midwestrowcrop.org/) is a project of major environmental NGOs and food and agricultural firms active in input supply, commodity trading, manufacturing and retailing; collectively, these groups have enormous market and policy power.

In these large watersheds, a cross-sector collaborative group should form to link smaller watersheds with key downstream sites (Fig. 1), and include interested parties active at regional or national scales. To begin, regional collaborative groups should engage in future-focused dialogue, aided by scenario-based foresight methods and transdisciplinary landscape design tools (Slotterback et al., 2016), to explore the notion of highly-multifunctional watersheds and consider regional opportunities for exploratory implementation.

Conclusion

In the Midwest USA, transformative changes in agricultural production and water management are likely to be necessary. We argue that highly-multifunctional watersheds, organized as we envision, can serve as vehicles for such transformation and as biophysical and social units of climate adaptation. Creating such watersheds can align strong interests of a wide range of communities, organizations, firms and institutions, acting at local, regional and national scales. However, a concerted effort of coordinated innovation is now required, through well-resourced exploratory implementation. Crucially, the implementation should focus on refinement of emerging, potentially transformative innovations such as perennial crops that tolerate periodic flooding, and social innovative coordinating methods such as trading programs and assurance contracts. Implementation must be measured and experimental, given that most such innovations are still immature and not fully viable. The ultimate goal is to activate and sustain adaptive flexibility at spatial and social scales. Ultimately, that flexibility looks to be our best hope for meeting societal demand for food, bioproducts and water under climate change.

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References

Boe A, Johnson PJ, Owens V, Lee D, Guo J and Gonzalez-Hernandez JL (2017) Genetics and partitioning for biomass of prairie cordgrass compared to switchgrass on marginal cropland. *BioEnergy Research* **10**, 864–875.

Bonner IJ, Muth DJ, Koch JB and Karlen DL (2014) Modeled impacts of cover crops and vegetative barriers on corn stover availability and soil quality. *BioEnergy Research* **7**, 576–589.

Bonner I, McNunn G, Muth D, Tyner W, Leirer J and Dakins M (2016) Development of integrated bioenergy production systems using precision conservation and multicriteria decision analysis techniques. *Journal of Soil and Water Conservation* **71**, 182–193.

Brauman KA, Daily GC, Duarte TKE and Mooney HA (2007) The nature and value of ecosystem services: An overview highlighting hydrologic services. *Annual Review of Environment and Resources* **32**, 67–98. doi: 10.1146/annurev.energy.32.031306.102758.

Chaubey I, Cibin R and Feng Q (2016) *Precision Conservation for Biofuel Production. Precision Conservation: Geospatial Techniques for Agricultural and Natural Resources Conservation*. Madison, WI: ASA-CSSA. doi: 10.2134/agronmonogr59.2013.0030.

Chen HG and Zhang YHP (2015) New biorefineries and sustainable agriculture: increased food, biofuels, and ecosystem security. *Renewable and Sustainable Energy Reviews* **47**, 117–132, doi: 10.1016/j.rser.2015.02.048.

Claassen R and Ribaudo M (2016) Cost-effective conservation programs for sustaining environmental quality. *Choices* **31**, 1–12. http://www.jstor.org/stable/choices.31.3.04.

Dale B (2017) A sober view of the difficulties in scaling cellulosic biofuels. *Biofuels, Bioproducts and Biorefining* **11**, 5–7, doi: 10.1002/bbb.1745.

Drury CF, Tan CS, Reynolds WD, Welacky TW, Oloya TO and Gaynor JD (2009) Managing tile drainage, subirrigation, and nitrogen fertilization to enhance crop yields and reduce nitrate loss. *Journal of Environmental Quality* **38**, 1193–1204. doi: 10.2134/jeq2008.0036.

Duncanson K, Moseley J and Yoder F (2014) Cooperative conservation: A producer-Led approach to achieving healthy agricultural landscapes. http://www.foodandagpolicy.org/content/1-cooperative-conservation-producer-led-approach-achieving-healthy-agricultural-landscapes.

Franks J (2010) Boundary organizations for sustainable land management: the example of Dutch environmental co-operatives. *Ecological Economics* **70**, 283–295, 10.1016/j.ecolecon.2010.08.011.

Freidberg S (2017) Big food and little data: the slow harvest of corporate food supply chain sustainability initiatives. *Annals of the American Association of Geographers* **107**, 1–18. doi: 10.1080/24694452.2017.1309967.

Galzki J, Birr AS and Mulla DJ (2011) Identifying critical agricultural areas with 3-meter LiDAR elevation data for precision conservation. *Journal of Soil and Water Conservation* **66**, 423–430, 10.2489/jswc.66.6.423.

Guo T, Cibin R, Chaubey I, Gitau M, Arnold JG, Srinivasan R, Kiniry JR and Engel BA (2018) Evaluation of bioenergy crop growth and the impacts of bioenergy crops on streamflow, tile drain flow and nutrient losses in an extensively tile-drained watershed using SWAT. *Science of the Total Environment* **613**, 724–735. doi: 10.1016/j.scitotenv.2017.09.148.

Hayes D, Kling C and Lawrence J (2016) *Economic evaluation of Governor Branstad's Water Quality Initiative*. Ames, Iowa: Center for Agricultural and Rural Development. Available at: http://www.card.iastate.edu/products/publications/synopsis/?p=1245 (Accessed 12 July 2017).

Head BW, Ross H and Bellamy J (2016) Managing wicked natural resource problems: the collaborative challenge at regional scales in Australia. *Landscape and Urban Planning* **154**, 81-92. doi: 10.1016/j.landurbplan.2016.03.019.

Jordan NR, Clower KM, Manson SM, Bonsal DB and Immich JL (2015) Land use and land cover in critical source areas on small dairy farms in the eastern United States. *Journal of Soil and Water Conservation* **70**, 257–266.

Kim J, Kug J, Jeong S, Huntzinger D, Michalak A, Schwalm R, Wei Y and Schaefer K (2017) Reduced North American terrestrial primary productivity linked to anomalous Arctic warming. *Nature GeoScience* **10**, 572–576. doi: 10.1038/ngeo2986.

Opdam P, Westerink J, Vos C and de Vries B (2015) The role and evolution of boundary concepts in transdisciplinary landscape planning. *Planning Theory & Practice* **16**, 63–78. doi: 10.1080/14649357.2014.997786.

Pennington DN, Dalzell B, Nelson E, Mulla D, Taff S, Hawthorne P and Polasky S. (2017) Cost-effective land use planning: optimizing land use and land management patterns to maximize social benefits. *Ecological Economics* **139**, 75-90. doi: 10.1016/j.ecolecon.2017.04.024.

Reed MS, Moxey A, Prager K, Hanley N, Skates J, Bonn A, Evans CD, Glenk K and Thomson K (2014) Improving the link between payments and the provision of ecosystem services in agri-environment schemes. *Ecosystem Services* **9**, 44–53, org/10.1016/j.ecoser.2014.06.008.

Rogers JN, Stokes B, Dunn J, Cai H, Wu M, Haq Z and Baumes H (2017) An assessment of the potential products and economic and environmental impacts resulting from a billion ton bioeconomy. *Biofuels, Bioproducts and Biorefining* **11**, 110–128, 10.1002/bbb.1728.

Seeley MW (2015) *Minnesota Weather Almanac: Completely Updated for the New Normals*. St. Paul: Minnesota Historical Society Press.

Slotterback CS, Runck B, Pitt DG, Kne L, Jordan NR, Mulla DJ, Zerger C and Reichenbach M (2016) Collaborative Geodesign to advance multifunctional landscapes. *Landscape and Urban Planning* **156**, 71–80, 10.1016/j.landurbplan.2016.05.011.

Tabarrok A (1998) The private provision of public goods via dominant assurance contracts. *Public Choice* **96**, 345–362, 10.1023/A:1004957109535.

Volk TA, Heavey JP and Eisenbies MH (2016) Advances in shrub-willow crops for bioenergy, renewable products, and environmental benefits. *Food and Energy Security* **5**, 97–106, 10.1002/fes3.82.

Walthall CL, Hatfield J, Backlund P, Lengnick L, Marshall E, Walsh M, Adkins S, Aillery M, Ainsworth EA, Ammann C, Anderson CJ, Bartomeus I, Baumgard LH, Booker F, Bradley B, Blumenthal DM, Bunce J, Burkey K, Dabney SM, Delgado JA, Dukes J, Funk A, Garrett K, Glenn M, Grantz DA, Goodrich D, Hu S, Izaurralde RC, Jones RAC, Kim S-H, Leaky ADB, Lewers K, Mader TL, McClung A, Morgan J, Muth DJ, Nearing M, Oosterhuis DM, Ort D, Parmesan C, Pettigrew WT, Polley W, Rader R, Rice C, Rivington M, Rosskopf E, Salas WA, Sollenberger LE, Srygley R, Stöckle C, Takle ES, Timlin D, White JW, Winfree R, Wright-Morton L and Ziska LH (2012) *Climate Change and Agriculture in the United States: Effects and Adaptation*. USDA Technical Bulletin 1935. Washington, DC: USDA.

Whelpton L and Ferri A (2017) Private capital for working lands conservation – a market development framework. The Conservation Finance Network. http://cbey.yale.edu/sites/default/files/Private_Capital_for_Working_Lands_Conservation.pdf.

Wilson GL, Dalzell BJ, Mulla DJ, Dogwiler T and Porter PM (2014) Estimating water quality effects of conservation practices and grazing land use scenarios. *Journal of Soil and Water Conservation* **69**, 330–342.