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Discussion of "Estimation of the water balance using observed soil water in the Nebraska Sandhills" by V. Sridhar and K.G. Hubbard

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The authors employ a modified version of the Thornthwaite-Mather (TM) model to estimate the water balance at four sites in the Nebraska Sandhills. They state that their "approach in this investigation is to first apply the TM model over selected sites using individual weather station data and then to estimate regional averages in comprehending the regional water balance." However, such a generalization, i.e., the computation of regional averages, is ambiguous in the paper. It is not clear whether the authors consider the station-averaged mean annual evapotranspiration (ET) rate of 861 mm a site-specific or a regionally representative value. Only when one compares it with the corresponding annual precipitation rate of 420 mm may one conclude that the specified ET value cannot be a regional average because that would mean ET overall is more than double the precipitation rate the area receives. Since no major groundwater decline was reported in the Sandhills during the study period, one wonders where the additional water came from if not from within the Sandhills, which is widely recognized as a significant recharge region for the groundwater system of the High Plains aquifer (Bleed and Flowerday 1998; Szilagyi et al. 2003, 2005). Consequently, the ET rate the authors publish cannot be a regional average, it can be representative only of the interdunal valleys and areas with shallow groundwater that *locally* can evaporate more water than they receive via precipitation.

Accepting that the ET values are site specific, however, leads one to another problem. Namely, the discrepancy between them and the values obtained by the Robinson-Hubbard model the authors present in Fig. 5 (of the original paper) for the same sites. In the latter model the estimated ET values are nicely constrained by precipitation. Which model is correct then? Or can it be that these latter ET values are regionally representative? But how, if they are derived from the same weather station inputs? This is not explained in the study.

In summary, a mean annual ET rate more than double the corresponding precipitation rate cannot be representative of the regional water balance of the Sandhills in Nebraska. For an alternative description of the long-term mean water balance terms one is kindly referred to the studies by Szilagyi et al. (2003, 2005), which show them not only for the Sandhills but for the entire state of Nebraska.

References

Bleed, A. S., and Flowerday, C. A., eds. (1998). *An atlas of the sandhills*, 3rd Ed., Conservation and Survey Division, Institute of Agriculture and Natural Resources, Lincoln, Neb.

Szilagyi, J., Harvey, E. F., and Ayers, J. (2003). "Regional estimation of base recharge to ground water using water balance and a base-flow index." *Ground Water*, 41(4), 504–513.

Szilagyi, J., Harvey, F. E., and Ayers, J. (2005). "Regional estimation of total recharge to ground water in Nebraska." *Ground Water*, 43(1), 63–69.

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We are thankful to Dr. Szilagyi for providing us an opportunity to discuss the important points of our paper. We demonstrated a seasonal water balance assessment using a modified Thornthwaite-Mather (TM) model in the Nebraska Sandhills. We computed the water budget for a few representative weather monitoring stations located in the Sandhills using high-resolution soil moisture data to assess moisture storage. In our water balance analysis, soil moisture storage is determined based on observed soil moisture, and actual evapotranspiration, ET_{act}, was computed for each month using the change in soil water and precipitation. If the change in storage is positive based on observed soil moisture, we consider two scenarios, and the least of the two is used for computing actual ET. If the change in storage is positive, which is the case in our study area, as shown in Fig. 3 (of the original paper), where soil moisture storage in the root zone is above 100 mm (except for May, June, and July, when it was close to 50 mm), that additional soil water beyond soil column storage is available for ET. In other words, the study sites were only energy constrained and not soil water constrained. We do not believe that overall ET in the Sandhills exceeds the precipitation. However, at the four stations examined, mainly valley and wet meadow locations in the valley floors of the Sandhills, it was found that ET exceeded precipitation almost at the potential rate where there is plenty of soil moisture. As shown on our website (www.hprcc.unl.edu), Gudmundsen is a wet meadow site with dunes in the distance. The same is true of Arapahoe prairie. In Ainsworth and O'Neil the valleys are much wider; however, these sites are in large meadows. In fact, many of the meadows in the Sandhills

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begin the spring wet and cannot be mowed for hay until much later in the summer.

We do not dispute the discusser's claim that higher ET cannot be representative of the regional pattern; however, our study does not go beyond the selected sites within the Sandhills ecosystem. In fact, in another study, Sridhar and Wedin (2009) demonstrated the implementation of a land surface model (LSM) covering both uplands and lowlands at the field scale (< 2 km^2) in the Sandhills and estimated ET close to 600 mm, which is also higher than the amount of precipitation received. The LSM is a robust, physically based model, and its estimates agree with the estimates of our study (i.e., they are energy controlled). While this study is conducted at the local scale and the plant-water dynamic is in agreement for many studies (Sridhar et al. 2006; Gosselin et al. 2006; Radell and Rowe 2008; Sridhar et al. 2008), we state that regional assessment of recharge to groundwater cannot be directly compared with our assessment merely because of the scale artifacts.

Indeed, we substantiate this in our discussion, in which we show the regional groundwater table had a general rise in the fall and spring seasons and subsequently depleted in the growing season owing to root water uptake, before being recharged again. However, there is a strong gradient in the groundwater system across the region, and in an earlier study, Gosselin et al. (2006) demonstrated a strong correlation between groundwater and evapotranspiration. The discusser argues that there is no decline in the groundwater system. There have been recent studies, however, suggesting a general decline in groundwater over the High Plains region, including the Sandhills (Gurdak et al. 2009), and human-induced changes (pumping) in addition to demand owing to natural climate variability may be significant. The scope of our study is limited to the root water extraction and the unlimited supply of water (in meadows) during some times of the growing season and hence the computation of water balance at the seasonal scale. Furthermore, our results should not be taken to mean that there will be a general decline in the groundwater. Whether or not this kind of water budget alters the regional groundwater table is still an open question that needs to be addressed.

Finally, the discusser argues that there is a difference in our model estimates. Clearly, each model represents different physical processes to determine evapotranspiration. In this present study, ET is not constrained but limited by storage, whereas in the Robinson and Hubbard model (Robinson and Hubbard 1990), which uses the Penman method, water use is primarily energy constrained. While it is true that we use the same locations for the study, the inputs used to drive these different schemes are different. In our current study, we use only precipitation and soil moisture, whereas the Robinson and Hubbard model uses precipitation, temperature, humidity, solar radiation, and wind speed.

In conclusion, the water balance behavior of the Sandhills cannot be simplified over short time and spatial scales as stated by us and the discusser. The regional aquifer behavior needs an assessment at the decadal or greater time step that has hydraulic connectivity beyond portions of the Sandhills. Following the facts from Gurdak et al. (2009), we would go further to reiterate that a study that tightly and dynamically couples both surface and groundwater is critical to explain groundwater exchanges, and large-scale behavior must be studied with the same detail as local-scale attributes, although the complexities can be simplified at larger scales.

References

Gosselin, D. C., Sridhar, V., Harvey, F. E., and Goeke, J. W. (2006). "Groundwater fluctuations in interdunal environments and evapotranspiration estimates for a wet meadow in the Nebraska Sand Hills, U.S.A." *Great Plains Res.*, 16(1), 17–28.

Gurdak, J. J., McMahon, P. B., Dennehy, K., and Qi, S. L. (2009). "Water quality in the High Plains aquifer, Colorado, Kansas, Nebraska, New Mexico, Oklahoma, South Dakota, Texas, and Wyoming, 1999–2004." *USGS Circular 1337*, U.S. Department of Interior, USGS, Reston, VA.

Radell, D. B., and Rowe, C. M. (2008). "An observational analysis and evaluation of land surface model accuracy in the Nebraska Sand Hills." *J. Hydrometeor.*, 9, 601–621.

Robinson, J. M., and Hubbard, K. G. (1990). "Soil water assessment model for several crops in the high plains." *Agron J.*, 82, 1141–1148.

Sridhar, V., Hubbard, K. G., You, J., and Hunt, E. (2008). "Development of soil moisture index to quantify agricultural drought and its 'user-friendliness' in severity-area-duration assessment." *J. Hydrometeorology*, 9(4), 660–676.

Sridhar, V., Hubbard, K. G., and Wedin, D. A. (2006). "Assessment of soil moisture dynamics of the Nebraska Sandhills using long-term measurements and a hydrology model." *J. Irrig. Drain. Eng.*, 132(5), 463–473.

Sridhar, V., and Wedin, D. A. (2009). "Hydrological behaviour of grasslands of the Sandhills: Water and energy balance assessment from measurements, treatments, and modelling." *Ecohydrology*, 2(2), 195–212.

Discussion of "Natural Hydrograph of the Missouri River near Sioux City and the Least Tern and Piping Plover" by Donald G. Jorgensen

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The author analyzed stream-flow data from a single gauging station to predict preengineering flooding frequency for "sandbar islands adjacent to stream gauge on the Missouri River at Sioux City." He predicted dates that sandbars would be exposed and discussed his results relative to reproduction by least terns (*Ster-*

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nula antillarum) and piping plovers (*Charadrius melodus*). His analysis predicted sandbar inundation during nesting and concluded that "successful migrations of age-zero juveniles leading to recruitment would not have resulted from the use of the sandbar islands for attempted reproduction most years in the Sioux City area." We argue that the author (1) overlooked published historical records of breeding terns and plovers on the Missouri River and nearby systems, (2) inaccurately portrayed inundation for Missouri River sandbars and the importance of high flows for forming sandbars, and (3) underestimated these species' ability to withstand periodic reproductive failures. We conclude that the data do not support the author's contention that the preengineered Missouri River was "unfriendly" to terns and plovers.

Historical Record

The author expressed doubt about historical abundance and recruitment of terns and plovers on the Missouri River, implying that breeding grounds "expanded" northward after river modification. However, he overlooked abundant historical evidence that both species commonly nested in the Dakotas, Nebraska, and Iowa, including in river sandbars and the Missouri bottoms (Aughey 1878; Bruner et al. 1904; Abbott 1916; Wood 1923; Youngworth 1930, 1931, 1932, 1935; Stephens 1937; Stiles 1939; Haecker et al. 1945; Over and Thomas 1946). The author also overlooked key evidence that nesting least terns were common on the preengineered Missouri River near Sioux City. Youngworth (1931) documented sandbar-nesting terns and at least 150 post-breeding adults and juveniles in this area.

Morphological and Hydrological Issues

Lack of historical sandbar distribution and elevation data constrains assessment of these habitats. The author's inferences about tern and plover reproduction are based on sandbar exposure dates derived from a flow-exceedance hydrograph (Fig. 7 in the original paper) and a stage-discharge relationship (rating curve) constructed from observations during a single year at a single cross section at the Sioux City gauge (Table 2 in the original paper). The author acknowledged spatial variability in sandbar development, but he did not consider spatial bias in his results. We believe that the sandbar elevations inferred by the author are substantially lower than expected based on the theory of channel-forming events and observations on other rivers.

Rating curves from streamflow gauges provide useful historical information on channel morphology, but they sample a single cross section and are typically sited where geomorphic complexity is minimal (Carter and Davidian 1968). Thus, data from such stations may not represent geomorphic variability along a river (Juracek and Fitzpatrick 2009). The Sioux City station is in a relatively narrow, simple reach and cannot provide a rating curve representative of much of the adjacent Missouri River, particularly not for more geomorphologically complex areas of channel where terns and plovers typically breed. Channel width at the gauging station was approximately 580 m during the late 1930s, whereas mean width of the relatively nonengineered channel upstream of Sioux City was 1,132 m (Elliott and Jacobson 2006). Currently in the minimally engineered river 30 km upstream of Sioux City, sandbars are lacking in narrow areas and increase in abundance and complexity in flow-expansion zones (Elliott and Jacobson 2006). Youngworth (1932) observed that least terns vacated the Sioux City area owing to "work on the channel of the Missouri River" such that "most sandbars were gone" and predicted they would "move up the river where construction will not be carried on and where dozens of sandbars still exist." These observations confirm the birds' preference for complex unaltered river reaches and suggest that substantial anthropogenic changes, which the author concluded "were minimal," preceded 1938–1939.

Point- and mid-channel bar elevations scale with water depth and generally extend to near bank-full elevation (Bridge 1993). Bars can grow upward to within a centimeter of the water surface if stage is held for a sufficient duration (Andrews and Nelson 1989; Schmidt and Rubin 1995; Andrews et al. 1999). Flood peaks of 3,500–4,500 m^3/s in 1938–1939 (see Figs. 5 and 6 in the original paper) would be expected to construct sandbars up to the 4.2 m stage, compared to the 1.5–2.4 m stage the author identified for sandbar overtopping. Two-year recurrence floods (approximately bank-full, 3,650 m^3/s) would be expected to create sandbars with elevations extending to about the 3.5 m stage. Given the planform and hydraulic complexity of the preengineered Missouri River, abundant bare sandbar area likely existed in the preengineered river at elevations up to bank-full stages. Although lack of historical data prevents us from proving this assumption, we argue that the author's analysis of a morphologically simple, single cross section probably underestimated the amount of high-elevation sandbars elsewhere.

The natural flow regime consists of intra- and interannual flow variation that can be split into components with differing ecological functions, such as bar-building floods, recessional flows (nesting flows), and low flows (Mathews and Richter 2007). The interaction of temporal variability in large (bar-building) flow events and episodic low-water years and the considerable spatial variability of the preengineered Missouri River would have produced a mosaic with bare sandbars of a range of sizes and elevations such that suitable nesting habitat would have been available in some amount in most years. For example, in 29 of 100 years of modeled natural flow regime, the March flood pulse was equal to or larger than the May flood pulse (U.S. Army Corps of Engineers 1998; Jacobson and Galat 2008) and could have deposited bare sandbar surfaces that would remain exposed throughout the May pulse. Moreover, in 12 out of 100 years, both peaks were below the conservative 1,590 m^3/s peak cited by the author.

Tern and Plover Population Ecology

Piping plovers and least terns have periodically high reproductive rates, long life spans, and high dispersal capabilities. Therefore, they can maintain viable populations without breeding at all possible locations each year. Both species readily colonize newly deposited sand habitats, such as river sandbars and coastal barrier island beaches (Thompson et al. 1997; Elliot-Smith and Haig 2004). Colonizing birds typically experience several years of high reproduction followed by reproductive and population declines (Sidle et al. 1992; Leslie et al. 2000; Catlin 2009; Cohen et al. 2009). This pattern repeats in time and space creating a "metapopulation," i.e., a group of populations that persists, while the component populations come and go (Hanski 1998; Catlin 2009; Cohen et al. 2009). The spatially and temporally variable habitat on the preengineered Missouri River and adjacent prairie potholes no doubt supported plover and tern metapopulations.

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Conclusion

A complete understanding of tern and plover populations on the preengineered Missouri River is unattainable. Nonetheless, these species clearly nested in the region and on Missouri River sandbars, and exposed sandbars were probably more common than the author concluded. We credit the author for suggesting that hindcasting habitat availability may provide inferences about historic tern and plover populations. However, we believe predictions will be most useful when they reflect the spatial and temporal variability of the historic river, and the life-history strategies of the species.

Acknowledgments

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References

Abbott, G. A. (1916). "North Dakota." *Wilson Bull.*, 28, 1–4.

Andrews, E. D., Johnston, C. E., Schmidt, J. C., and Gonzales, M. (1999). "Topographic evolution of sand bars." *The Controlled Flood in Grand Canyon*, R. H. Webb, J. C. Schmidt, G. R. Marzolf, and R. A. Valdez, eds. American Geophysical Union, Washington, D.C., 117–130.

Andrews, E. D., and Nelson, J. M. (1989). "Topographic response of a bar in the Green River, Utah to variation in discharge." *River Meandering, AGU Water Resources Monograph*, S. Ikeda and G. Parker, eds. American Geophysical Union, Washington, D.C., 463–485.

Aughey, S. (1878). *Notes on the nature of the food of the birds of Nebraska*, U.S. Entomological Commission, Washington, D.C.

Bridge, J. (1993). "The interaction between channel geometry, water flow, sediment transport and deposition in braided rivers." *Geological Society (London)*, 75, 13–71.

Bruner, L. R., Wolcott, H., and Swenk, M. H. (1904). *A preliminary review of the birds of Nebraska*, Klopp and Barlett, Omaha, Neb.

Carter, R. W., and Davidian, J. (1968). "General procedure for gaging streams." *U.S. Geological Survey Techniques of Water-Resources Investigations*, Book 3, Chap. A6.

Catlin, D. H. (2009). "Population dynamics of piping plovers (Charadrius melodus) on the Missouri River." Dissertation, Virginia Polytechnic Institute and State Univ., Blacksburg, Va.

Cohen, J. B., Houghton, L. M., and Fraser, J. D. (2009). "Piping plover nesting density and reproductive success in response to storm and human-created habitat changes." *Wildl. Monogr.*, 173, 1–24.

Elliott, C. M., and Jacobson, R. B. (2006). "Geomorphic classification and assessment of channel dynamics in the Missouri National Recreational River, South Dakota and Nebraska." *USGS Scientific Investigations Rep. 2006-5313*, USGS, Reston, Va.

Elliot-Smith, E., and Haig, S. M. (2004). "Piping plover (Charadrius melodus)." *Birds of North America*, A. Poole, ed. Cornell Lab of Ornithology, Ithaca, N.Y.

Haecker, W. R., Moser, R. A., and Swenk, J. B. (1945). "Checklist of birds of Nebraska." *Nebraska Bird Review*, 13:12.

Hanski, I. (1998). "Metapopulation dynamics." *Nature*, 396(6706), 41–49.

Jacobson, R. B., and Galat, D. L. (2008). "Design of a naturalized flow regime—An example from the Lower Missouri River, USA." *Ecohydrology*, 1(2), 81–104.

Juracek, K. E., and Fitzpatrick, F. A. (2009). "Geomorphic applications of stream-gage information." *River. Res. Appl.*, 25, 392–347.

Leslie, D. M., Wood, G. K., and Carter, T. S. (2000). "Productivity of endangered least terns (Sterna antillarum athalassos) below a hydropower and flood-control facility on the Arkansas River." *Southwest. Nat.*, 45(4), 483–489.

Mathews, R., and Richter, B. D. (2007). "Application of the indicators of hydrologic alteration software in environmental flow setting." *J. Am. Water Resour. Assoc.*, 43(6), 1400–1413.

Over, W. H., and Thomas, C. S., eds. (1946). *Birds of South Dakota*, Rev. Ed., Univ. of South Dakota, Vermillion, S.D.

Schmidt, J. C., and Rubin, D. M. (1995). "Regulated streamflow, fine-grained deposits, and effective discharge in Canyons with abundant debris fans." *Natural and Anthropogenic Influences in Fluvial Geomorphology, AGU Geophysical Monograph 89, The Wolman Volume*, J. E. Costa, A. J. Miller, K. W. Potter, and P. R. Wilcock, eds., American Geophysical Union, Washington, D.C., 177–196.

Sidle, J. G., Carlson, D. E., Kirsch, E. M., and Dinan, J. J. (1992). "Flooding: Mortality and habitat renewal for least terns and piping plovers." *Colon. Waterbirds*, 15, 132–136.

Stephens, T. C. (1937). "Birds of Dakota County Nebraska." *Am. Midl. Nat.*, 18, 373–397.

Stiles, B. F. (1939). "The least tern in Iowa." *Iowa Bird Life*, 9, 18–21.

Thompson, B. C., et al. (1997). "Least tern (Sterna antillarum)." *Birds of North America*, A. Poole, ed. Cornell Lab of Ornithology, Ithaca, N.Y.

U.S. Army Corps of Engineers. (1998). *Reservoir regulation studies—Daily routing model studies, master water control manual Missouri River review and update study*, Vol. 2A, U.S. Army Corps of Engineers, Northwest Division, Omaha, Neb.

Wood, N. A. (1923). *A preliminary survey of the bird life of North Dakota*, Univ. of Michigan, Ann Arbor, Mich.

Youngworth, W. (1930). "Breeding of the least tern in Iowa." *Wilson Bull.*, 42, 102–103.

Youngworth, W. (1931). "The American egret and tern in South Dakota." *Wilson Bull.*, 43, 309–310.

Youngworth, W. (1932). "Field notes from Sioux City, Iowa." *Auk*, 49, 494.

Youngworth, W. (1935). "The birds of Fort Session, South Dakota, a sixty year comparison." *Wilson Bull.*, 47, 209–235.

Closure to "Natural Hydrograph of the Missouri River near Sioux City and the Least Tern and Piping Plover" by Donald G. Jorgensen

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The writer evaluated historic data at the gauge at Sioux City, Iowa, to determine, if possible, whether the historic natural hydrograph of the Missouri River at Sioux City, Iowa, was "friendly" (i.e., would allow long-term recruitment) for the least tern and piping plover on the Missouri River sandbar islands near Sioux City. The primary background data was the flow data from USGS at the gauge, which included periodic cross-sectional measurements as well as daily flow data. Critical supporting biological data included information and observations by Stiles (1938, 1955) on the Missouri River. Accurate information on the timing of breeding, nesting, rearing, fledging, and migrating of terns and plover on the Missouri River specifically is available from the U.S. Army Corps of Engineers (USACE) and was used as criteria

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for the evaluation. Ancillary information was found, in general, to support the conclusions of the original paper.

Major Critiques

The discussers critiqued the writer's treatment of three major areas:

1. The writer overlooked published historical records of breeding terns and plovers on the Missouri River and nearby systems.

The discussers critique is inaccurate as the historical record was beyond the scope of the original paper. Further, they have recharacterized the information in the original paper. The paper is specific to the sandbar islands of the Missouri River at Sioux City and is largely based on the analysis at the gauge site at Sioux City. Notwithstanding the errors in the discussers' analysis, their concerns will be addressed to some degree.

The writer used information from Stiles (1938, 1955) in depth. The Stiles articles include observations of tern nesting on the Missouri River with reference to the gauge height. Stiles's observations were made in the same general time frame as the hydrological data the writer obtained from USGS. Further, the writer discusses historically relevant information, including observations from the Lewis and Clark expedition, Beacom (2003), Ducey (1981), Hardy (1957), Jorgensen (2003a), Jorgensen (2003b), Kirsch (1996), Mitchell (1998), Ryan et al. (1993), Schwalbach (1988), and the U.S. Fish and Wildlife Service (2000). Beacom (2003) includes reviews of much of the original historical data available. To state that the writer overlooked historical data is unjustified.

2. The writer inaccurately portrayed inundation for Missouri River sandbars and the importance of high flows for forming sandbars.

Again the discussers have recharacterized what was reported in the original paper. They inaccurately extended the scope of the paper.

The writer was aware of bar-forming processes as pointed out on page 1369. However, he did not make any statements about the formation of island sandbars in relation to the analysis of the hydrological conditions at the Sioux City gauge for 1938 and 1939. The writer used measurements of the cross section at the gauge, which included the island sandbars, along with the actual daily flow as reported by USGS. The original analysis did not require speculation on the degree of sandbar formation because the sandbars were defined by the available data.

3. The writer underestimated the least terns' and piping plover's ability to withstand periodic reproductive failures.

The discussers have again recharacterized what is in the original paper. This topic is not within the scope of the paper. What the writer did show, based on measured data, including the flooding of the Missouri River sandbar islands, is that successful migration of age-zero juvenile piping plover would have been very unlikely at best for 1938 and 1939. This statement is based on data collected at the USGS gauge on the Missouri River at Sioux City. Additional analyses suggest that this condition might exist 85% of the time or more. This analysis is conservative as it does not consider other factors that would likely reduce recruitment, such as predation; unfavorable cold, wet weather; and illness.

Miscellaneous Comments on the Discussion

1. The discussers stated that the writer "overlooked key evidence that nesting terns were common on the preengineered Missouri River near Sioux City."

The writer never questioned that the least tern (or the piping plover) might attempt to reproduce on the Missouri River near Sioux City. Nor that during some years the birds might successfully raise juveniles to fledgings. The writer's effort was to assess whether tern and plover efforts to reproduce on the Missouri River sandbar islands were successful to the extent that zero-age birds would reach fledging, a prerequisite for recruitment. (Successful fledging would be expected to be somewhat more likely during the severe drought years of the 1930s, including 1938 and 1939.)

2. The discussers write, "Youngworth (1931) documented sandbar-nesting terns and at least 150 postbreeding adults and juveniles in this area." This comment was intended to support their claim that "key evidence" showing nesting was common in the preengineered Missouri River near Sioux City had been overlooked.

The discussers missed the point. The important question is not, were the birds were common but would juveniles reach fledging. Further, the statement is a misleading recharacterization of Youngworth (1931). Youngworth actually wrote, "On August 3, the writer counted not less than 150 Least Tern, many immature birds at the above lake, where the birds were no doubt gathering for the fall migration." First, the birds were not on the Missouri River. Further, no one knows if any of the mature birds were postbreeding. If they did breed, it is not known where they bred. Also, if they were postbreeding, it is not known whether their effort resulted in zero-age juveniles reaching fledging.

3. The discussers suggest that channel modifications in the "Sioux City area" were other than minimal. They reported observations by Youngworth (1932) on channel modification at Sioux City. Based on these observations, they then suggested that the writer's statement that anthropogenic changes "were minimal" was not accurate.

The writer analyzed the hydrological data available at the USGS gauge. This is stated accurately in the original paper. Youngworth (1932) reported extensive channel modifications. Specifically he stated, "The government has been doing extensive work on the channel of the Missouri River, in the way of revetments, dikes, and pilings, and as a result many sandbars are gone, being cut out by the narrowing channel. The birds will no doubt move upstream, above Sioux City, where construction will not be carried on and where dozens of sand bars still exist." The referenced channel modifications were downstream of the gauge. Modification above the gauge was minimal. USGS field investigators made numerous measurements at the gauge site. In general, no significant control or change of control at the gauge site was noted. In 1938–1939 both the streambed beneath the Combination Bridge and the streambed upstream of the gauge continued to be a braided stream with exposed sandbar islands, except when it was flooded. Fig. 3 on page 1368 (in the original paper) clearly shows complex streambed geometry with no fewer than five sandbar islands and the river as a braided stream. The writer's analysis was clearly reported to be at the Sioux City gauge. Accordingly, his statement that anthropogenic changes had minimal effects is accurate and is consistent with Youngworth (1932).

The discussers state that the March flood pulse, if its maximum flow rate was equal to or exceeded the May flood pulse, could have created sandbars of such a height that the May pulse

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would not submerge them. Further, they specifically state, "For example, in 29 of 100 years of modeled natural flow regime, the March flood pulse was equal to or larger than the May flood pulse…and could have deposited bare sandbar surfaces that would remain exposed throughout the May pulse."

The writer analyzed 1938 and 1939 specifically (see Figs. 5 and 6 in the original paper). Both years had March flows that exceeded the May–July flows. In both cases the sandbar islands were completely submerged.

4. The discussers state that bars can grow to within a centimeter of the water surface. They correctly note that the March flood pulse was in the range of 3,500 to 4,500 m^3/s in 1938 and 1939. They then conclude, without any metrics, that the expected sandbar heights would be on the order of 4.2 m. Several references, such as Andrews et al. (1999) were cited as examples of bar growth, inferring that the writer had not adequately considered bar growth.

The usefulness of the examples, such as Andrews et al. (1999), who discussed results of the controlled flood of the Colorado River in the Grand Canyon, is questionable. Shear, availability of movable sediment, velocity distribution, and flow duration are all controlling factors in movement of sediment. It is unlikely that the shear, availability of moveable sediment, and duration of flow associated with the man-made flood of the Colorado River in the Grand Canyon and the March flow of the Missouri River at Sioux City are comparable. The discussers present no data to support their hypothesis. Accordingly, the contention that sandbars at Sioux City would likely be higher than what was measured is unsupported and problematic.

Finally, and most importantly, the writer used actual measurements of cross sections to define the heights of the sandbar islands. Speculation by the discussers is not germane.

Conclusions

The discussion predominantly dealt with items that were not part of the original study. Further, the discussers' recharacterization of information from the references and their extensive and repeated recharacterization of the material presented by the writer is a disservice.

The original study was carefully scoped, and the results were presented accurately. The study used actual hydrological measurements of the conditions in conjunction with the most recent and complete information on the timing of terns and plover reproductive efforts. Further, historical observations of the occurrence of tern and plover, including the flooding of the sandbar islands, are consistent with the writer's analysis.

References

Andrews, E. D., Johnston, C. E., Schmidt, J. C., and Gonzales, M. (1999). "Topographic evolution of sand bars." *The Controlled Flood in Grand Canyon*, R. H. Webb, J. C. Schmidt, G. R. Marzolf, and R. A. Valdez, eds., American Geophysical Union, Washington, DC, 117–130.

Beacom, W. M. (2003). *A review of* 200 years *of information about the least tern and piping plover relative to the Missouri River*, Missouri River Technical Committee of the Siouxland Chamber of Commerce, Sioux City, IA.

Ducey, J. A. (1981). *Interior least tern*, U.S. Fish and Wildlife Service, Pierre, SD.

Hardy, J. W. (1957). "Least tern of the Mississippi Valley." *Museum of Michigan State Univ. Biological Series*, Vol. 1, Michigan State Univ., Lansing, MI.

Jorgensen, D. G. (2003a). *Evaluation of a spring rise for the Missouri River*, Missouri River Technical Committee of the Siouxland Chamber of Commerce, Sioux City, IA.

Jorgensen, D. G. (2003b). *The Missouri River below Gavins Point—The least terns, piping plovers, sandbars, and the natural hydrograph*, Missouri River Technical Committee of the Siouxland Chamber of Commerce, Sioux City, IA.

Kirsch, E. (1996). "Habitat selection and productivity of least tern (*Sterna antillarum*) on the Lower Platte River, Nebraska." *Wildlife Monographs 132*, Wildlife Society, Bethesda, MD.

Mitchell, W. A. (1998). "Species profile (*Sterna antillarum*), interior population, on military installations in the southeastern United States." *Technical Rep. No. SERDP-98–1*, U.S. Army Engineers Waterway Experiment Station, Vicksburg, MS, 26.

Ryan, M. R., Root, B. G., and Mayer, P. M. (1993). "Status of piping plovers in the Great Plains of North America: A demographic simulation model." *Conserv. Biol.*, 7, 581–585.

Schwalbach, M. J. (1988). "Conservation of least terns and piping plovers along the Missouri River and its major western tributaries in South Dakota." MS thesis, South Dakota State Univ., Brookings, SD.

Stiles, B. F. (1938). "Nesting of least tern in Iowa." *Wilson Bulletin*, 50, 19–21.

Stiles, B. F. (1955). "The least tern in Iowa." *Iowa Bird Life*, 25, 19–21.

U.S. Fish and Wildlife Service. (2000). *Biological opinion of the operation of the Missouri River main stem reservoir system, operation and maintenance of the Missouri River bank stabilization and navigation project, and operation of the Kansas River reservoir system*, U.S. Fish and Wildlife Service, Bethesda, MD.

Youngworth, W. (1931). "The American egret and tern in South Dakota." *Wilson Bull.*, 43, 309–310.

Youngworth, W. (1932). "Field notes from Sioux City, Iowa." *Auk*, 49, 494.

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