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Trends in nutrient and sediment retention in Great Plains reservoirs (USA)

Davi Gasparini Fernandes Cunha · Maria do Carmo Calijuri · Walter Kennedy Dodds

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Abstract Reservoirs are artificial ecosystems with physical, chemical, and biological transitional characteristics between rivers and lakes. Greater water retention time in reservoirs provides conditions for cycling materials inputs from upstream waters through sedimentation, biological assimilation and other biogeochemical processes. We investigated the effects of reservoirs on the water quantity and quality in the Great Plains (Kansas, USA), an area where little is known about these dominant hydrologic features. We analyzed a 30-year time-series of discharge, total phosphorus (TP), nitrate (NO_3^-), and total suspended solids (TSS) from six reservoirs and estimated overall removal efficiencies from upstream to downstream, testing correlations among retention, discharge, and time. In general, mean removal of TP (42–74 %), TSS (0–93 %), and NO_3^- (11–56 %) from upstream to downstream did not change over 30 years. TP retention was associated with TSS removal, suggesting that nutrient substantial portion of P was adsorbed to solids. Our results indicated that reservoirs had the effect of lowering variance in the water quality parameters and that these reservoirs are not getting more or less nutrient-rich over time. We found no evidence of temporal changes in the yearly mean upstream and downstream discharges. The ratio upstream/downstream discharge was analyzed because it allowed us to assess how much contribution of additional unsampled tributaries may have biased our ability to calculate retention. Nutrient and sediment removal was less affected by hydraulic residence time than expected. Our study demonstrates that reservoirs can play a role in the removal and processing of nutrient and sediments, which has repercussions when valuing their ecological services and designing watershed management plans.

Keywords Eutrophication · Long-term assessment · Multipurpose reservoirs · Nutrient removal · Solids retention

D. G. F. Cunha (✉) · M. do Carmo Calijuri
Departamento de Hidráulica e Saneamento, Escola de Engenharia de São Carlos, Universidade de São Paulo, Avenida Trabalhador São-Carlense, 400, 13560-590 São Carlos, São Paulo, Brazil
e-mail: davig@sc.usp.br

W. K. Dodds
Division of Biology, Kansas State University, 116 Ackert Hall, Manhattan, KS 66506, USA

Introduction

Reservoirs dominate most river networks and generally increase water retention time (Vörösmarty et al. 2003), which is an important parameter controlling biogeochemical processes (Rueda et al. 2006). Reservoir flushing affects downstream river water quality in relation to organic forms of nutrients, biochemical oxygen demand (Chung et al. 2008), and particulate and dissolved metals (Cánovas et al. 2012).

Nutrient pollution is common in freshwaters (Traykov and Boyanovsky 2008; Popovicova 2009). Reservoirs can influence the transport of added nutrients to the oceans and other downstream receiving waters because reservoirs may act as sinks for sediments and pollutants (Bukaveckas et al. 2005; Liu et al. 2012). While modeling reservoir hydrodynamics and water quality is an important tool to help selecting strategies and operational procedures for effective water management through a good command of the ecological processes in the water bodies (Diogo et al. 2008), less empirical information is available on long-term effects of reservoirs on material transport.

By slowing water movement, reservoirs are often able to capture roughly one-half of the river sediments that flows into them (Zahar et al. 2008) and modify their chemistry. Sedimentation in reservoirs can decrease the transport of solids from upstream to downstream (Dang et al. 2010). Often, suspended materials are dominated by inorganic solids in the inflows but by the time water leaves the reservoir, solids are dominated by organic fractions (Whiles and Dodds 2002; Jones and Knowlton 2005; Klaver et al. 2007). Accumulation of sediments can reduce the storage volume and decrease water quality (López-Tarazón et al. 2009). Suspended solids can decrease light penetration, cause release of previously adsorbed metals and pesticides, and have negative effects on aquatic biota (Billota and Brazier 2008).

A wide range of nitrate retention percentages are described in the literature for reservoirs (e.g., Okereke et al. 1988; Jossette et al. 1999; David et al. 2006; Schoch et al. 2009). Denitrification is considered the main route for nitrate loss in lentic water bodies (Harrison et al. 2009) and depends upon the water depth and residence time (Seitzinger et al. 2002). The retention of this nutrient can vary over time within the reservoirs (Cope et al. 2011) and empirical models are available to predict the nitrogen seasonal dynamics (e.g., Tomaszek and Koszelnik 2003). Phytoplankton assimilation, especially ammonium and nitrate (Reynolds 1997), and subsequent sedimentation and burial can also contribute to the depletion of these inorganic nitrogen forms in the water column.

Reservoirs also act as a sink for phosphorus through sedimentation and burial. Nutrient availability and longer residence time stimulate phytoplankton growth in reservoirs as compared to rivers entering them (Neal et al. 2006). The process of phosphorus retention in the reservoirs depends on external loading and factors influencing sedimentation, including hydraulic residence time, area, and depth (Kõiv et al. 2011), as well as uptake for primary production (Jossette et al. 1999).

There is still a lack of data from areas where reservoirs dominate surface water and studies on how retention varies over time. Retention coefficients can predict nutrient retention in lakes, but may underestimate retention in reservoirs (e.g., Hejzlar et al. 2006). Many studies focused on monitoring finer temporal scales (e.g., weekly), with results relying on only a few years (or even a single year) of data (Kann and E. Asarian 2007). However, land use and climate changes occur over several years, and shorter-term studies could miss important aspects of significant temporal variation (Gelbrecht et al. 2005). In addition, as reservoirs age, their nutrient and sediment retention could change.

We aimed to investigate the effects of reservoirs on the water quantity and quality in the Great Plains (Kansas, USA) by analyzing a 30-year time-series of discharge, total phosphorus, nitrate and total suspended solids from six reservoirs. We estimated the removal of nutrients and solids from upstream to downstream in each reservoir and investigated correlations among retention, discharge and time.

Materials and methods

Study area

The State of Kansas (KS), located in Midwestern USA (Fig. 1), has annual precipitation ranges from west to east of between 400 and 1,200 mm. Maximum river flows usually occur in the spring, from March to June. We selected six reservoirs in KS with different areas, depths, and residence times (Table 1). These aquatic systems are located in the Missouri River and the Arkansas River Basins. The reservoirs are used for drinking water supply, flood control, recreation, navigation, irrigation, and pollution abatement. Despite all these different uses, the water quality in KS reservoirs is progressively decreasing due to agriculture (Dzialowski et al. 2005; Wang et al. 2005) and other anthropogenic impacts, mainly from nonpoint sources (Bhuyan et al. 2003). Their current enrichment condition corresponds to the mesotrophic–eutrophic state (Dodds et al. 2006; Carney 2009). Water quantity is also a point of concern as climate change and groundwater overexploitation are leading to streamflow decline and negative annual water budgets (Brikowski 2008).

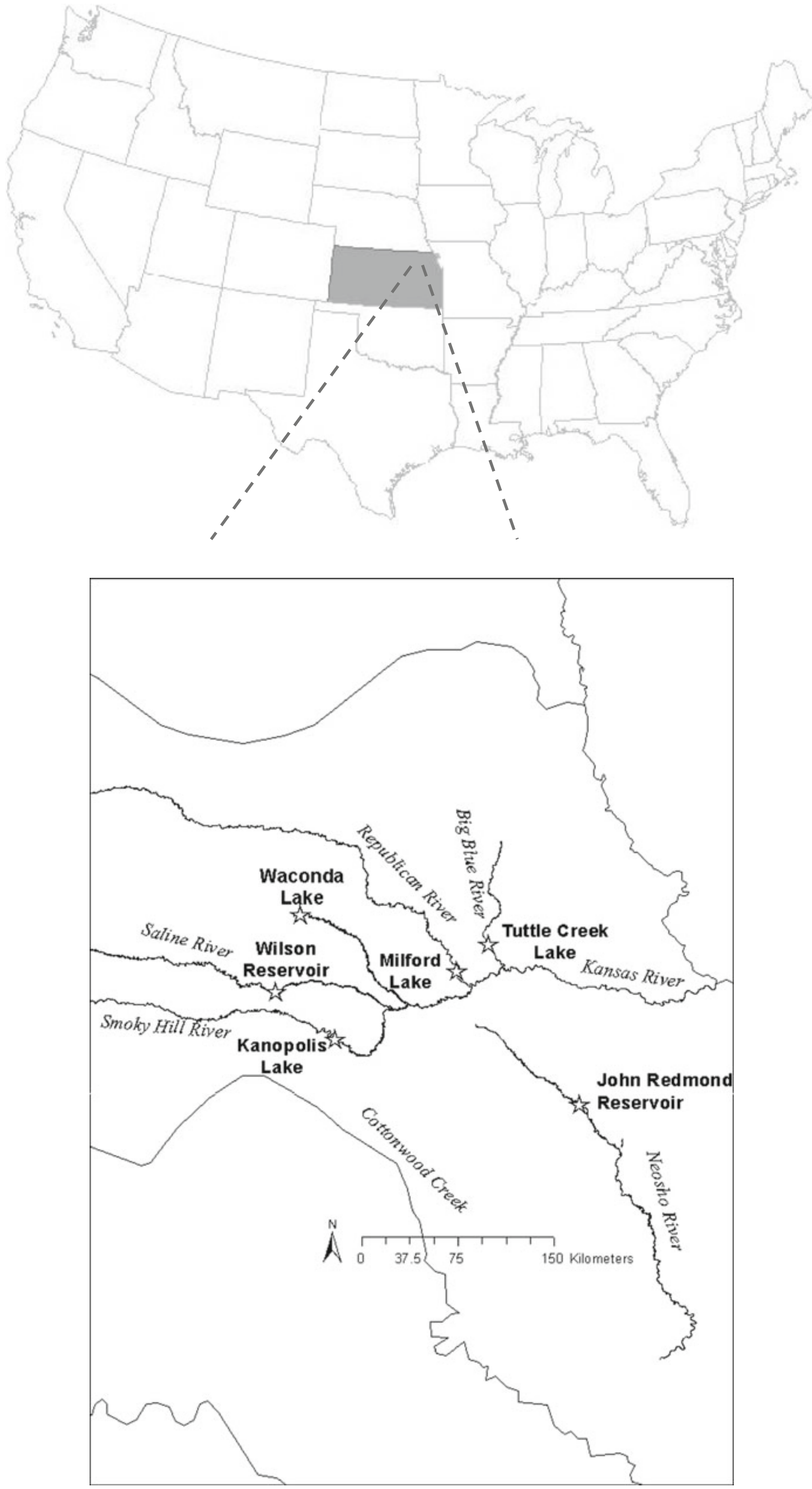

Fig. 1 Studied reservoirs in Kansas (USA): Kanopolis, John Redmond, Wilson, Tuttle Creek, Milford and Waconda Reservoirs

Table 1 Main characteristics of the studied Great Plains reservoirs in the USA, including their geographic coordinates (latitude and longitude), major tributary river, surface area, average and maximum depths, water volume, residence time and main water uses

Parameter	Reservoir					
	Kanopolis	John Redmond	Wilson	Tuttle Creek	Milford	Waconda
Latitude	38º37′34″ N	38º34′17″ N	38º56′33″ N	39º20′31″ N	39º06′23″ N	39º30′15″ N
Longitude	98º00′17″ W	94º45′57″ W	98º30′42″ W	96º40′08″ W	96º55′53″ W	98º23′08″ W
Major tributary river	Smoky Hill	Grand Neosho	Saline	Big Blue	Republican	Solomon
Surface area (km^2)	13.8	32.7	36.5	50.6	63.6	50.9
Average depth (m)	4.6	1.8	7.3	7.6	7.6	7.3
Maximum depth (m)	10.7	3.7	19.8	15.2	19.8	13.7
Water volume (km^3)	0.062	0.060	0.290	0.312	0.434	0.298
Residence time (months)	3	1	28	5	12	18
Main water uses	S, F, R	S, F, R	F, R, N, P	F, R, N, P	S, F, R, N, P	S, F, R, I, P

S drinking water supply, *F* flood control, *R* recreation, *N* navigation, *I* irrigation, *P* pollution abatement

Table 2 Number of sample collections and source of available data on discharge, total phosphorus (TP), total suspended solids (TSS) and nitrate (NO_3^-) in the Kanopolis, John Redmond, Wilson, Tuttle Creek, Milford and Waconda Reservoirs

Variable	Information	Reservoir													
		Kanopolis		John Redmond		Wilson		Tuttle Creek		Milford		Waconda		Total	
		Up	Down	Up	Down	Up	Down	Up	Down	Up	Down	Up	Down	Up	Down
Discharge	Number of samples	32	40	40	40	59	47	52	62	93	43	64	46	340	278
	Source	USGS	USGS	USGS	USGS	USGS	USGS	USGS	USGS	USGS	USGS	USGS	USGS		
TP	Number of samples	274	150	300	176	279	163	194	306	293	251	124	154	1,464	1,200
	Source	KDHE	KDHE	KDHE	KDHE	KDHE	KDHE	KDHE	KDHE	KDHE	KDHE	KDHE	KDHE		
TSS	Number of samples	282	152	285	156	270	153	189	282	301	265	124	163	1,451	1,171
	Source	KDHE	KDHE	KDHE	KDHE	KDHE	KDHE	KDHE	KDHE	KDHE	KDHE	KDHE	KDHE		
NO_3^-	Number of samples	264	148	263	142	262	147	177	265	293	251	124	144	1,383	1,097
	Source	KDHE	KDHE	KDHE	KDHE	KDHE	KDHE	KDHE	KDHE	KDHE	KDHE	KDHE	KDHE		

Up upstream, *Down* downstream, *KDHE* Kansas Department of Health and Environment, *USGS* United States Geological Survey

Data analysis

We collected data on upstream and downstream discharge, total phosphorus (TP), total suspended solids (TSS), and nitrate (NO_3^-) from the assessed reservoirs. TP, TSS, and NO_3^- were quantified in a bimonthly basis from 1972 to 2010 by the Kansas Department of Health and Environment (KDHE) as part of its stream monitoring network. Samples were collected between 9 a.m. and 5 p.m. at each site and analyzed through standard methods (KDHE 1972–2010, USEPA 1983). Discharge was monitored by the United States Geological Survey (USGS) (see details on Table 2). We calculated yearly arithmetic mean values for each variable and multiway analysis of variance (MANOVA) was used to verify the significance of the following effects: (1) retention over time (years) and (2) spatial position (upstream and downstream).

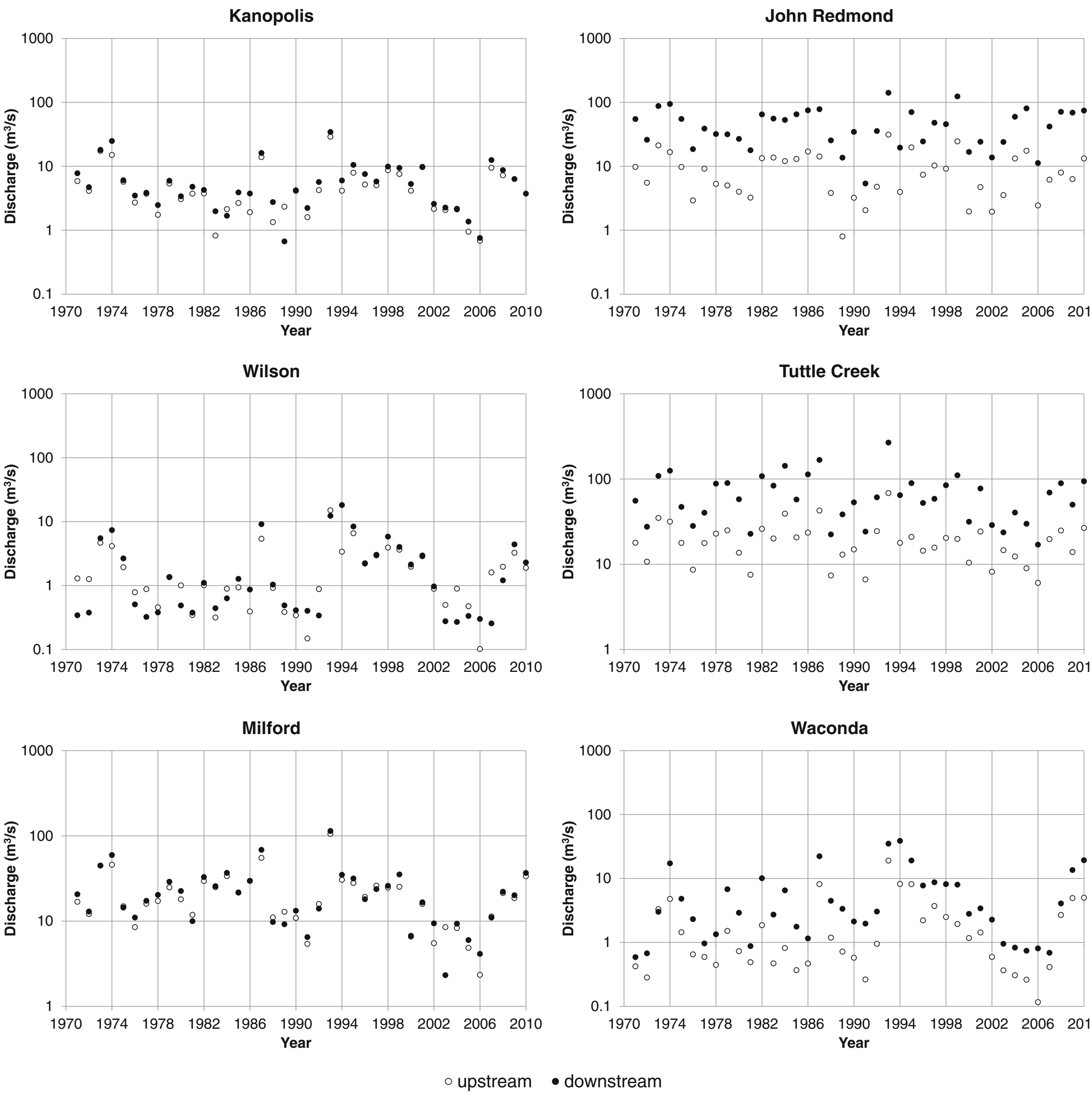

Fig. 2 Discharge (cubic meter per second) in a log scale over time (1972–2010) in the Kanopolis, John Redmond, Wilson, Tuttle Creek, Milford, and Waconda Reservoirs (upstream and downstream)

We considered a confidence level of 95 % ($p<0.05$) indicative of statistical significance. We used linear regression to analyze the relationships between (1) the difference in discharge (ratios of discharge upstream/downstream) and retention and (2) paired nitrate and total nitrogen (when available) to verify if the former would be a good indicator of the latter in our dataset.

Results

We accounted for approximately 88 % of discharge in the Kanopolis Reservoir (i.e., only 12 % of the discharge was made up of other streams and tributaries we did not account for), 19 % in John Redmond, 100 % in Wilson, 30 % in Tuttle Creek, 100 % in Milford, and 36 % in Waconda (Fig. 2). The lower discharges were

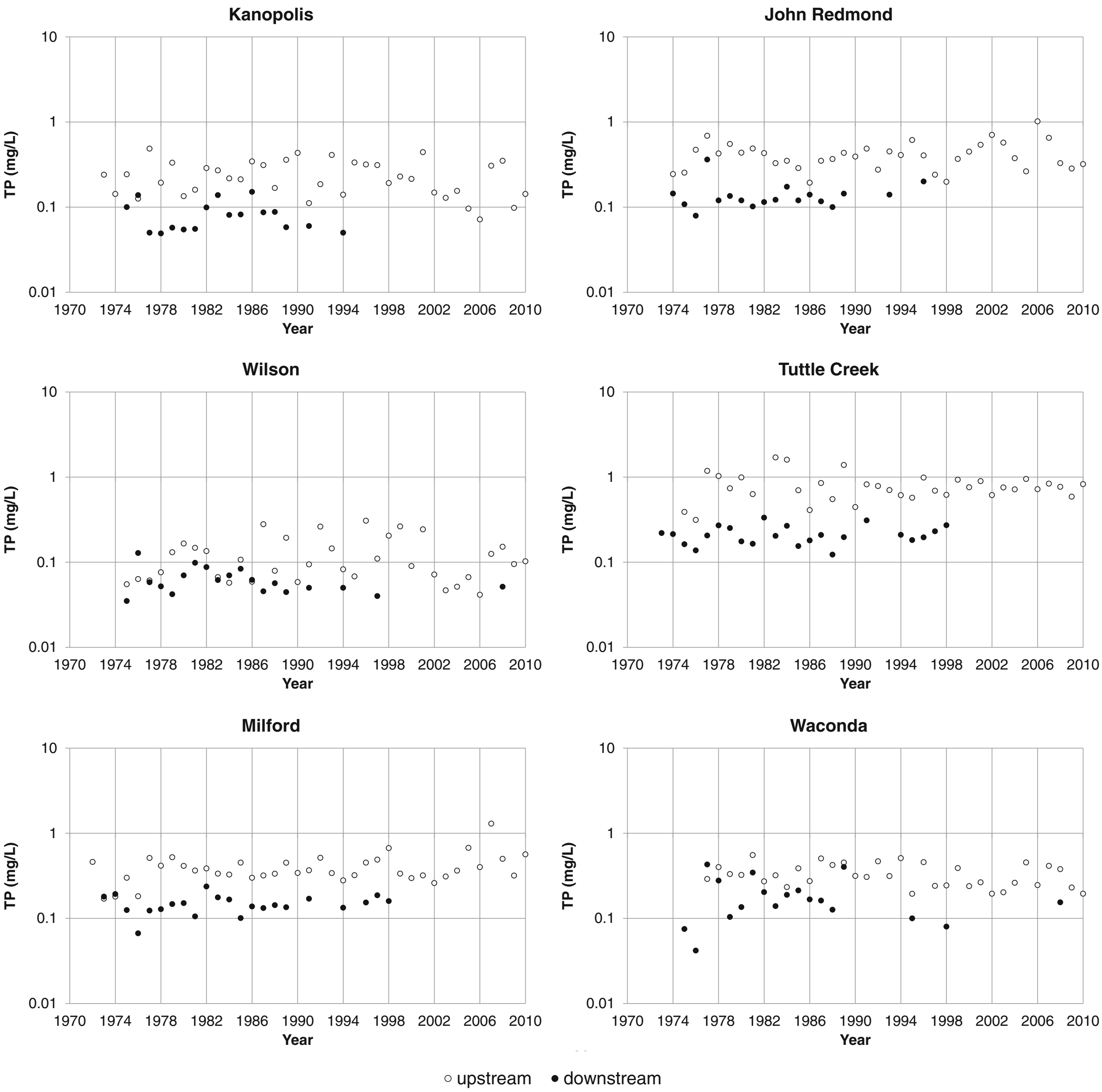

Fig. 3 Total phosphorus (milligram per liter) in a log scale over time (1972–2010) in the Kanopolis, John Redmond, Wilson, Tuttle Creek, Milford and Waconda Reservoirs (upstream and downstream)

found in the Wilson and Waconda Reservoirs (frequently below 10 m^3/s), whereas the greatest ones were observed in the Tuttle Creek (maximum of 268 m^3/s downstream the reservoir in 1993).

The TP, TSS, and NO_3^- concentrations were generally greater upstream when compared to downstream, indicating a net retention (Figs. 3, 4, and 5). In the Wilson Reservoir, yearly mean TP concentrations varied between 0.04 and 0.31 mg/L (upstream) and 0.04 and 0.13 mg/L (downstream); TSS concentrations varied between 22 and 388 mg/L (upstream) and 13 and 107 mg/L (downstream); NO_3^- varied between 0.02 and 0.94 mg NO_3^-N/L (upstream) and 0.02 and 0.58 (downstream). The highest nutrient and solids

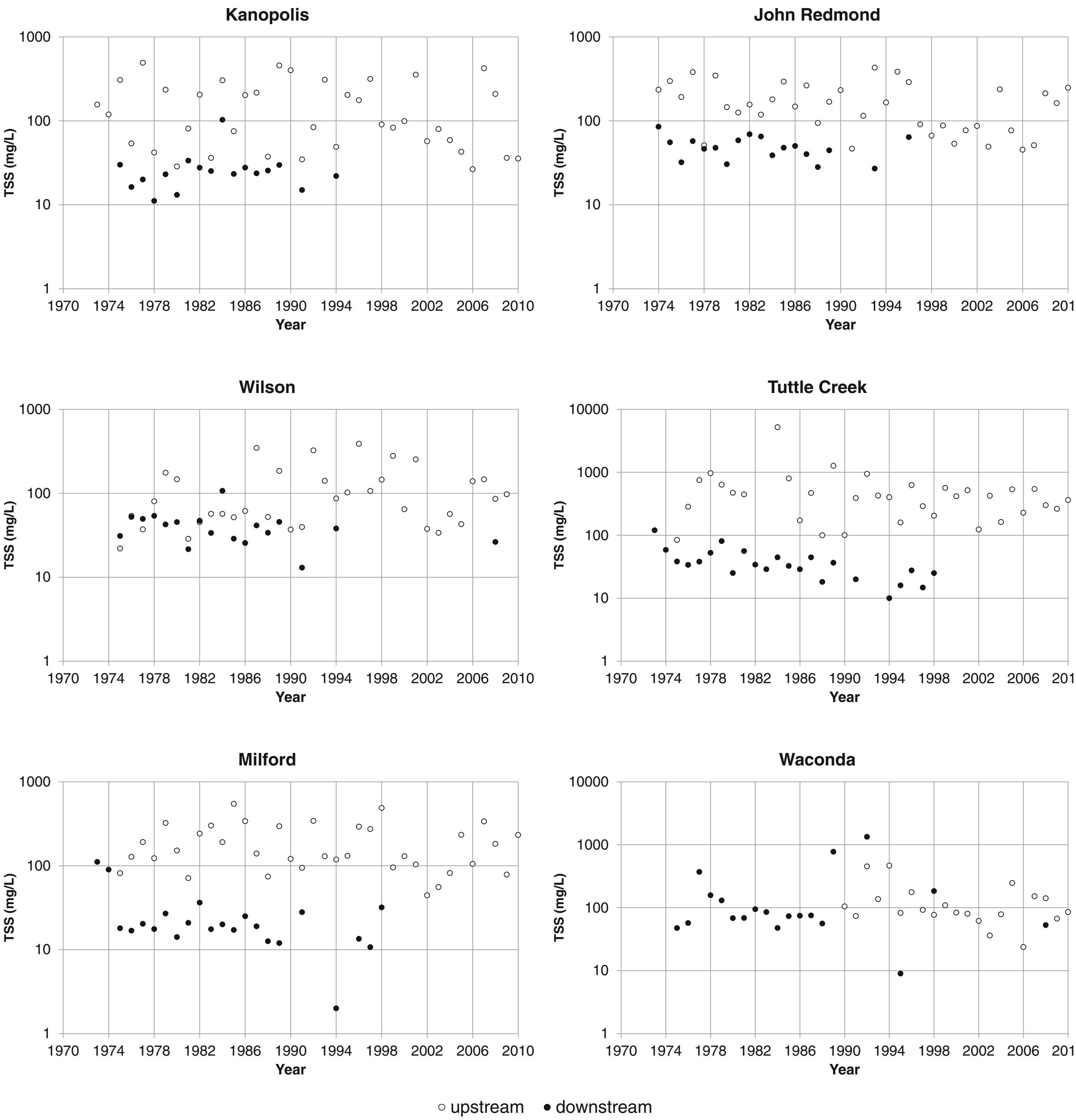

Fig. 4 Total suspended solids (milligram per liter) in a log scale over time (1972–2010) in the Kanopolis, John Redmond, Wilson, Tuttle Creek, Milford and Waconda Elder Reservoirs (upstream and downstream)

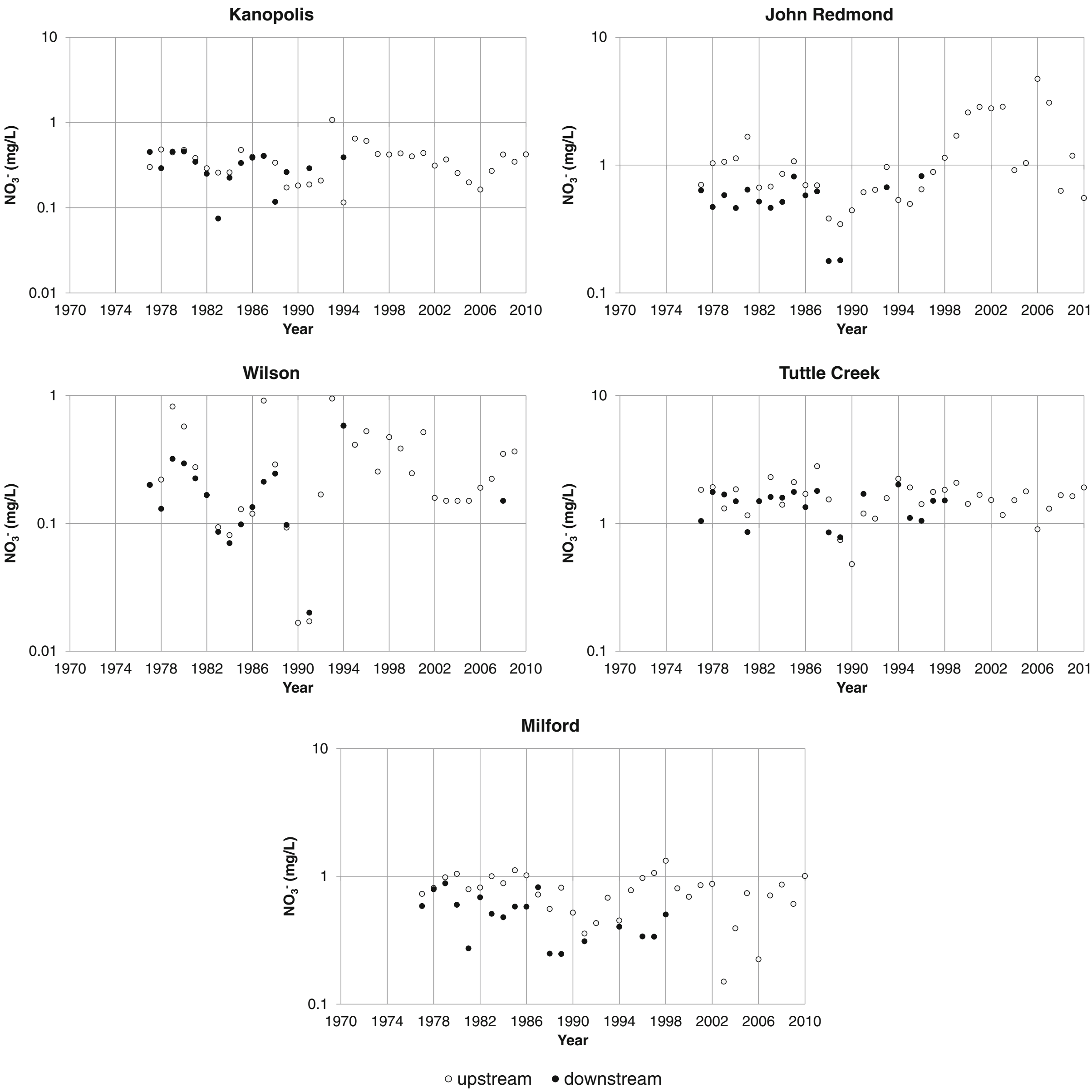

Fig. 5 Nitrate (milligram per liter) in a log scale over time (1972–2010) in the Kanopolis, John Redmond, Wilson, Tuttle Creek, Milford and Waconda Reservoirs (upstream and downstream)

concentrations were observed in the Tuttle Creek Reservoir (maximum of 1.7 mg TP/L, 5,200 mg TSS/L, and 2.8 mg NO_3^-N/L) and the lowest were observed in the Kanopolis Reservoir (maximum of 0.5 mg TP/L, 490 mg TSS/L, and 1.1 mg NO_3^-N/L). Nitrate was considered a good estimator of total nitrogen as a significant relationship (R^2=0.78) was found between available paired data on these variables (Fig. 6).

All reservoirs significantly removed nutrients and solids (p<0.05, MANOVA) from the upstream to the downstream waters. The percentages of mean reduction (Table 3) varied between 42 and 74 % (TP), 0 and 93 % (TSS), and 11 and 56 % (NO_3^-) over time across all reservoirs. The ability for removing these materials, however, did not vary over time (p=0.214 for TP; p=0.847 for TSS, and p=0.159 for NO_3^-, MANOVA), suggesting that the retention capacity did not change

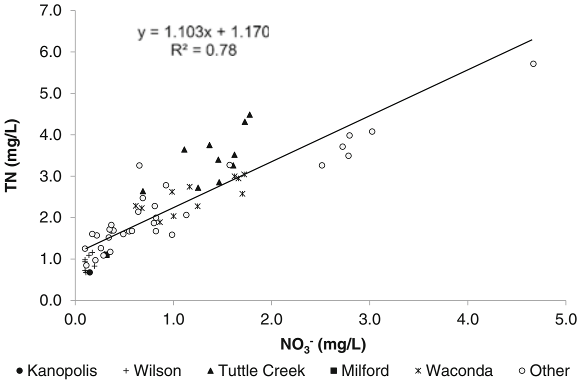

Fig. 6 Relationships between nitrate (NO_3^-) and total nitrogen (TN) in the Kanopolis, Wilson, Tuttle Creek, Milford, Waconda, and other Great Plains Reservoirs (Cheney and Perry)

within the last 30 years, although some recent data is missing in our dataset, especially on TP.

The difference in discharge (ratios of discharge upstream/downstream) significantly influenced the retention of TP, TSS, and NO_3^- ($p<0.05$, MANOVA) when data for all reservoirs were considered (Table 4). Conversely, when considered separately, the relationship between the ratios and the retention capacity was significant only for TSS in the Kanopolis Reservoir and NO_3^- in the John Redmond and Milford Reservoirs. In the case of the John Redmond Reservoir, the ratios upstream/downstream discharge were always below 0.3 because we were accounting for only 20 % of the water overall (Fig. 2). The retention may thus be underestimated as other streams may contribute to increasing nutrients and solids concentrations in the water.

Table 3 Mean reduction (%) for total phosphorus (TP), total suspended solids (TSS), and nitrate (NO_3^-) from upstream to downstream each of the studied reservoirs: Kanopolis, John Redmond, Wilson, Tuttle Creek, Milford and Waconda

Variable reservoir	TP (%)	TSS (%)	NO_3^- (%)
Kanopolis	67	83	14
John Redmond	67	72	56
Wilson	50	64	39
Tuttle Creek	74	93	11
Milford	63	86	33
Waconda	42	–	48

All shown percentages of reduction were considered statistically greater than zero ($p<0.05$, MANOVA)

– no reduction

Table 4 Statistical analysis of the relationships between the difference in discharge (ratios of discharge upstream/downstream) and retention of total phosphorus (TP), total suspended solids (TSS) and nitrate (NO_3^-) from upstream to downstream each of the studied reservoirs: Kanopolis, John Redmond, Wilson, Tuttle Creek, Milford and Waconda

Reservoir	Upstream/downstream discharge (ratio) versus retention of:		
	TP	TSS	NO_3^-
Kanopolis	p=0.057	**p<0.05**	p=0.092
John Redmond	p=0.057	p=0.754	**p<0.05**
Wilson	p=0.469	p=0.262	p=0.085
Tuttle Creek	p=0.377	p=0.468	p=0.612
Milford	p=0.275	p=0.760	**p<0.05**
Waconda	p=0.405	–	–
All reservoirs	**p<0.05**	**p<0.05**	**p<0.05**

The MANOVA considered a confidence level of 95 % (statistically significant if $p<0.05$)

However, in the Milford Reservoir, we were accounting for most of the water and the ratios presented a greater variation (from 0.8 to 1.4). Figure 7 further illustrates that when downstream exceeded upstream discharge (ratios <1), NO_3^- retention was smaller, reflecting the possible impact of other streams and tributaries we did not account for. On the other hand, NO_3^- removal was greater with ratios higher than one (maximum of 70 % of retention, with a respective discharge ratio of 1.4).

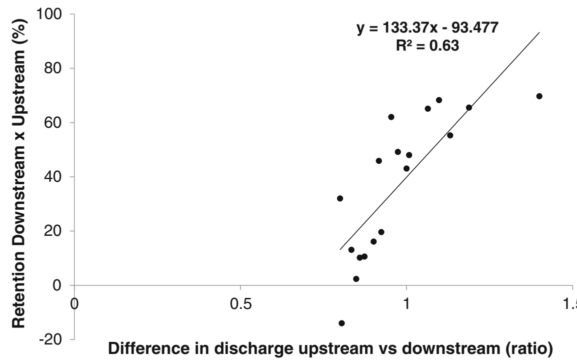

Fig. 7 Nitrate (NO_3^-) retention in the Milford Reservoir (upstream versus downstream) plotted against the ratios of discharge upstream/downstream

Discussion

Upland streams significantly affect downstream water quality (Dodds and Oakes 2008) and land use shifts have potential influences on water chemistry through nonpoint pollution sources in Kansas. Protection of both headwaters and downstream riparian zones may contribute to attenuating pollutant loads entering the water bodies (Banner et al. 2009). Besides such control zones, artificial reservoirs are also an important component for removing and processing nutrient and sediment entering them and the watersheds.

However, it is difficult to establish a general rule on how reservoirs influence nutrient and sediments given the complexity and individuality of the aquatic systems (Friedl and Wüest 2002). Considering the assessed Great Plain reservoirs, the mean reduction percentages of TP and TSS were relatively high in comparison to similar studies in Europe (12 % for TP and 55 % for TSS reported by Teodoru and Wehrli 2005) and the USA (13 % for TP and 80 % for TSS presented by James and Barko 2004).

As a consequence of smaller upstream discharges and longer hydraulic residence times, retention is normally greater in extremely dry years. We expected more TP and TSS removal in the Wilson and Waconda Reservoirs because these water bodies have the longest mean residence times (28 and 18 months, respectively, Table 1), favoring sedimentation and biogeochemical processing. However, the opposite was found: the lowest reduction percentages were found in such reservoirs, ≤50 % for TP and ≤64 % for TSS. In the case of the Waconda Reservoir, we were accounting for only 36 % of the discharge and the contribution of other tributaries may have increased nutrient concentrations in the water, compromising our ability to calculate retention rates. Therefore, in practical terms, the ratio for upstream/downstream accounted discharge is an important parameter to be considered when analyzing nutrient and sediment retention. Despite its short residence time (5 months), Tuttle Creek Reservoir presented the highest removal percentages among all reservoirs (74 % for TP and 93 % for TSS).

The removal efficiency depends upon the configuration of the aquatic systems, (e.g., one single reservoir or a series of reservoirs along a river, Kummu and Varis 2007). Depth and surface area are also important parameters controlling reservoir retention capacity. Shallower reservoirs and those with a longer fetch are more prone to suspension of sediments. John Redmond Reservoir, the shallowest (1.8-m average depth) and one of the smallest analyzed reservoirs (32.7 km^2), had the second lowest TSS removal percentage (72 %). Considering lakes larger than 25 km^2 and with hydraulic residence times smaller than 4 months, phosphorus retention coefficients are expected to increase with increasing relative depths (Kõiv et al. 2011).

Particle trapping by lakes and reservoirs is commonly correlated with the relative low phosphorus concentrations downstream (Houser et al. 2010). TP removal was coupled with TSS retention within the studied reservoirs in Kansas (R^2=0.51), indicating that a significant part of this nutrient was adsorbed to solids. High inputs of sediments during the periods of maximum river flows may result in more significant phosphorus retention as phosphorus combines with suspended solids and is removed from the water column by sedimentation (Bolin et al. 1987). During periods of drought and water level drawdown, outflow concentrations of TP and TSS normally increase due to different factors like sediment resuspension (Shantz et al. 2004), especially in shallow ecosystems. Since we focused on a broader time scale and calculated yearly means for the studied variables, such seasonal effects were not seen in our study.

Reservoirs retain more than 30 % of the total nitrogen removed by lentic systems globally (Harrison et al. 2009). Nitrate removal presented relatively high variation among the studied reservoirs (minimum of 11 % and maximum of 56 %). A similar 30-year study (Schoch et al. 2009) reported a reduction of 22±6 % in NO_3^- concentrations as an effect of the Saylorville Reservoir (USA). Residence time is normally considered an important parameter for modeling nitrate in reservoirs and lakes (Whitehead and Toms 1993). However, despite having the lowest hydraulic residence time, the John Redmond Reservoir presented the highest NO_3^- retention percentage, suggesting that the mechanism of removal was not affected by the water retention time in this aquatic system. The concentration ratios of NO_3^-/TP from the upstream sampling points of the analyzed reservoirs were about two times higher than the same ratios downstream, indicating that NO_3^- retention was smaller than TP in percentage terms across all reservoirs.

Inflow water quality and quantity varies in both seasonal and interannual scales and affects reservoirs influence on biogeochemical cycles (Cooper and Knight 1990). Great Plains Rivers' regimes are altered by impoundments and hydrologic records have shown increase in minimum discharge events and decrease in floods (Costigan and Daniels 2012). Land use shifts and ongoing climate change in one of the world's most important agricultural regions (Drummond et al. 2012) is also a point of concern in the Great Plains as such alterations might affect water quality over time. However, we have not found evidence of changes in the yearly mean upstream and downstream discharges in our study. Retention capacity of TSS, TP, and NO_3^- has not changed within the 30 years of the analysis either.

Our investigation has also shown that the evaluated reservoirs are not getting more nutrient rich. TP, for example, was relatively stable within the 30-year period. Reservoirs have the tendency to decrease variance in nutrient loads. In terms of the 30-year standard deviation upstream/downstream (milligram per liter): 0.11–0.03 (Kanopolis), 0.17–0.06 (John Redmond), 0.07–0.02 (Wilson), 0.30–0.05 (Tuttle Creek), 0.19–0.04 (Milford), and 0.10–0.11 (Waconda). The respective values for upstream–downstream NO_3^- standard deviation were (milligram per liter): 0.18–0.12, 0.99–0.19, 0.24–0.13, 0.47–0.37, 0.26–0.20, and 0.47–0.42. The standard deviation values were frequently higher for the upstream dataset in comparison to the downstream, indicating that reservoirs had the effect of lowering variance in the studied water quality parameters

Humans are increasing nutrient export worldwide (Caraco and Cole 1999; Mayorga et al. 2010; Qu and Kroeze 2010). If people want to control the associated eutrophication, management actions are necessary to control the loads reaching freshwaters and oceans. The studied Great Plains reservoirs provide important ecosystem services, including reduction in nutrient and solids concentrations and overall benefits to the downstream water quality. However, none of the reservoirs completely removes nutrient or sediment pollution. Although their removal capacity has not changed in the last 30 years, it is advisable to perform continuous monitoring of their retention ability and, if necessary, set upper limits for admissible inflow loads in order to avoid reservoir siltation and further undesirable enrichment.

Conclusions

Our study indicated that the assessed Great Plains reservoirs are not only able to remove (on average) 61, 66, and 34 % of the upstream TP, TSS, and NO_3^- concentrations, respectively, but also have been maintaining this ability for 30 years, despite all anthropogenic impacts they are submitted to. This has important implications when valuing the environmental services performed by the reservoirs and when designing watershed management plans to alleviate eutrophication and other forms of water pollution.

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References

Banner, E., Stahl, A., & Dodds, W. (2009). Stream discharge and Riparian land use influence in-stream concentrations and loads of phosphorus from Central Plains Watersheds. *Environmental Management, 44*(3), 552–565.

Bhuyan, S. J., Koelliker, J. K., Marzen, L. J., & Harrington, J. A., Jr. (2003). An integrated approach for water quality assessment of a Kansas watershed. *Environmental Modelling & Software, 18*(5), 473–484.

Billota, G. S., & Brazier, R. E. (2008). Understanding the influence of suspended solids on water quality and aquatic biota. *Water Research, 42*(12), 2849–2861.

Bolin, S. B., Ward, T., & Cole, R. A. (1987). Phosphorus models applied to New Mexico reservoirs. *Journal of Water Resources Planning and Management, 113*(3), 323–335.

Brikowski, T. H. (2008). Doomed reservoirs in Kansas, USA? Climate change and groundwater mining on the great plains lead to unsustainable surface water storage. *Journal of Hydrology, 354*(1–4), 90–101.

Bukaveckas, P. A., Guelda, D. L., Jack, J., Koch, R., Sellers, T., & Shostell, J. (2005). Effects of point source loadings, subbasin inputs and longitudinal variation in material retention on C, N and P delivery from the Ohio River Basin. *Ecosystems, 8*, 825–840.

Cánovas, C. R., Olias, M., Vazquez-Suñé, E., Ayora, C., & Miguel Nieto, J. (2012). Influence of releases from a fresh water reservoir on the hydrochemistry of the Tinto River (SW Spain). *Science of the Total Environment, 416*(1), 418–428.

Caraco, N. F., & Cole, J. J. (1999). Human impact on nitrate export: an analysis using major world rivers. *Ambio, 28*(2), 167–170.

Carney, E. (2009). Relative influence of lake age and watershed land use on trophic state and water quality of artificial lakes in Kansas. *Lake and Reservoir Management, 25*(2), 199–207.

Chung, S. W., Ko, I. H., & Kim, Y. K. (2008). Effect of reservoir flushing on downstream river water quality. *Journal of Environmental Management, 86*(1), 139–147.

Cooper, C. M., & Knight, S. S. (1990). Nutrient trapping efficiency of a small sediment detention reservoir. *Agricultural Water Management, 18*, 149–158.

Cope, V., Mercante, C. T. J., Carmo, C. F., Sendacz, S., & Monteiro Júnior, A. J. (2011). Mass balance of nutrients during the filling phase of two reservoirs of Sistema Produto Alto Tietê (SPAT). *Acta Scientiarum Biological Sciences, 33*(1), 49–57.

Costigan, K. H., & Daniels, M. D. (2012). Damming the prairie: human alteration of great plains river regimes. *Journal of Hydrology, 444–445*, 90–99.

Dang, T. H., Coynel, A., Orange, D., Blanc, G., Etcheber, H., & Le, L. A. (2010). Long-term monitoring (1960–2008) of the river-sediment transport in the Red River Watershed (Vietnam): temporal variability and dam-reservoir impact. *Science of The Total Environment, 408*(20), 4654–4664.

David, M. B., Wall, L. G., Royer, T. V., & Tank, J. L. (2006). Denitrification and the nitrogen budget of a reservoir in an agricultural watershed. *Ecological Applications, 16*(6), 2177–2190.

Diogo, P. A., Fonseca, M., Coelho, P. S., Mateus, N. S., Almeida, M. C., & Rodrigues, A. C. (2008). Reservoir phosphorous sources evaluation and water quality modeling in a transboundary watershed. *Desalination, 226*(1–3), 200–214.

Dodds, W. K., & Oakes, R. M. (2008). Headwater influences on downstream water quality. *Environmental Management, 41*(3), 367–377.

Dodds, W. K., Carney, E., & Angelo, R. T. (2006). Determining ecoregional reference conditions for nutrients, secchi depth and chlorophyll a in Kansas Lakes and reservoirs. *Lake and Reservoir Management, 22*(2), 151–159.

Drummond, M. A., Auch, R. F., Karstensen, K. A., Sayler, K. L., Taylor, J. L., & Loveland, T. R. (2012). Land change variability and human–environment dynamics in the United States Great Plains. *Land Use Policy, 29*, 710–723.

Dzialowski, A. R., Wang, S. H., Lim, N. C., Spotts, W. W., & Huggins, D. G. (2005). Nutrient limitation of phytoplankton growth in central plains reservoirs, USA. *Journal of Plankton Research, 27*(6), 587–595.

Friedl, G., & Wüest, A. (2002). Disrupting biogeochemical cycles—consequences of damming. *Aquatic Sciences, 64*, 55–65.

Gelbrecht, J., Lengsfeld, H., Pöthig, R., & Opitz, D. (2005). Temporal and spatial variation of phosphorus input, retention and loss in a small catchment of NE Germany. *Journal of Hydrology, 304*, 151–165.

Harrison, J. A., Maranger, R. J., Alexander, R. B., Giblin, A. E., Jacinthe, P. A., Mayorga, E., et al. (2009). The regional and global significance of nitrogen removal in lakes and reservoirs. *Biogeochemistry, 93*, 143–157.

Hejzlar, J., Sámalová, K., Boers, P., & Kronvang, B. (2006). Modelling phosphorus retention in lakes and reservoirs. *Water, Soil and Air Pollution: Focus, 6*(2), 123–130.

Houser, J. N., Bierman, D. W., Burdis, R. M., & Soeken-Gittinger, L. A. (2010). Longitudinal trends and discontinuities in nutrients, chlorophyll, and suspended solids in the Upper Mississippi River: implications for transport, processing, and export by large rivers. *Hydrobiologia, 651*, 127–144.

James, W. F., & Barko, J. W. (2004). Diffusive fluxes and equilibrium processes in relation to phosphorus dynamics in the Upper Mississippi River. *River Research and Applications, 20*, 473–484.

Jones, J. R., & Knowlton, M. F. (2005). Suspended solids in Missouri reservoirs in relation to catchment features and internal processes. *Water Research, 39*(15), 3629–3635.

Jossette, G., Leporcq, B., Sanchez, N., & Philippon. (1999). Biogeochemical mass-balances (C, N, P, Si) in three large reservoirs of the Seine basin (France). *Biogeochemistry, 47*(2), 119–146.

Kann, J and E. Asarian. 2007. *Nutrient budgets and Phytoplankton trends in Iron Gate and Copco Reservoirs, California, May 2005 - May 2006*. Final Technical Report to the State Water Resources Control Board, Sacramento, California. 81pp+appendices.

KDHE (1972–2010). *Stream chemistry monitoring program quality assurance management plan*. Division of Environment, Kansas Department of Health and Environment, Topeka, KS.

Klaver, G., van Os, B., Negrel, P., & Petelet-Giraud, E. (2007). Influence of hydropower dams on the composition of the suspended and riverbank sediments in the Danube. *Environmental Pollution, 148*(3), 718–728.

Kõiv, T., Nõges, T., & Laas, A. (2011). Phosphorus retention as a function of external loading, hydraulic turnover time, area and relative depth in 54 lakes and reservoirs. *Hydrobiologia, 660*(1), 105–115.

Kummu, M., & Varis, O. (2007). Sediment-related impacts due to upstream reservoir trapping, the lower Mekong River. *Geomorphology, 85*(3–4), 275–293.

Liu, S. M., Li, L. W., Zhang, G. L., Liu, Z., Yu, Z., & Ren, J. L. (2012). Impacts of human activities on nutrient transports in the Huanghe (Yellow River) estuary. *Journal of Hydrology, 430–431*(2), 103–110.

López-Tarazón, J. A., Batalla, R. J., Vericat, D., & Francke, T. (2009). Suspended sediment transport in a highly erodible catchment: the River Isábena (Southern Pyrenees). *Geomorphology, 109*(3–4), 210–221.

Mayorga, E., Seitzinger, S. P., Harrison, J. A., Dumont, E., Beusen, A. H. W., Bouwman, A. F., et al. (2010). Global nutrient export from water sheds 2 (NEWS 2): Model development and implementation. *Environmental Modelling & Software, 25*(7), 837–853.

Neal, C., Hilton, J., Wade, A. J., Neal, M., & Wickham, H. (2006). Chlorophyll-a in the rivers of eastern England. *Science of the Total Environment, 365*, 84–104.

Okereke, V. I., Bauman, E. R., Austin, T. A., & Schulze Lutz, D. (1988). Midwest (USA) reservoir water quality modification. III. Soluble nutrients. *Water, Air, & Soil Pollution, 37*(3–4), 343–354.

Popovicova, J. (2009). Water quality assessment and ecoregional comparison of a reservoir in east-central Indiana. *Lake and Reservoir Management, 25*(2), 155–166.

Qu, H. J., & Kroeze, C. (2010). Past and future trends in nutrients export by rivers to the coastal waters of China. *Science of the Total Environment, 408*(9), 2075–2086.

Reynolds, C. S. (1997). *Vegetation processes in the pelagic*. ECI, Oldendorf: A model for Ecosystem Theory.

Rueda, F., Moreno-Ostos, E., & Armengol, J. (2006). The residence time of river water in reservoirs. *Ecological Modelling, 191*(2), 260–274.

Schoch, A. L., Schilling, K. E., & Chan, K. S. (2009). Time-series modeling of reservoir effects on river nitrate concentrations. *Advances in Water Resources, 32*(8), 1197–1205.

Seitzinger, S. P., Styles, R. V., Boyer, E. W., Alexander, R. B., Billen, G., Howarth, R. W., et al. (2002). Nitrogen retention in rivers: model development and application to watershed in the northeastern USA. *Biogeochemistry, 57–58*(1), 199–237.

Shantz, M., Dowsett, E., Canham, E., Tavernier, G., Stone, M., & Price, J. (2004). The effect of drawdown on suspended solids and phosphorus export from Columbia Lake, Waterloo, Canada. *Hydrological Processses, 18*(5), 865–878.

Teodoru, C., & Wehrli, B. (2005). Retention of sediments and nutrients in the Iron Gate I reservoir on the Danube River. *Biogeochemistry, 76*(3), 539–565.

Tomaszek, J. A., & Koszelnik, P. (2003). A simple model of nitrogen retention in reservoirs. *Hydrobiologia, 504*(1–3), 51–58.

Traykov, I.T., Boyanovsky, B.B. (2008). Assessment of the nutrient load in the Upper Arda River catchment - Prediction of the trophic state of the Madan Reservoir. *Acta Zoologica Bulgarica*, 225–232.

USEPA. (1983). *Methods for chemical analysis of water and waste* (EPA 600/4-79-020). Cincinnati: U.S. Environmental Protection Agency.

Vörösmarty, C. J., Meybeck, M., Fekete, B., Sharma, K., Green, P., & Syvitski, J. P. (2003). Anthropogenic sediment retention: major global impact from registered river impoundments. *Global and Planetary Change, 39*(1–2), 169–190.

Wang, S. H., Huggins, D. G., Frees, L., Volkman, C. G., Lim, N. C., Baker, D. S., et al. (2005). An integrated modeling approach to total watershed management: water quality and watershed assessment of Cheney reservoir, Kansas, USA. *Water, Air, & Soil Pollution, 164*(1–4), 1–19.

Whiles, M. R., & Dodds, W. K. (2002). Relationships between stream size, suspended particles, and filter-feeding macroinvertebrates in a Great Plains drainage network. *Journal of Environmental Quality, 31*(5), 1589–1600.

Whitehead, P. G., & Toms, I. P. (1993). Dynamic modelling of nitrate in reservoirs and lakes. *Water Research, 27*(8), 1377–1384.

Zahar, Y., Ghorbel, A., & Albergel, J. (2008). Impacts of large dams on downstream flow conditions of rivers: aggradation and reduction of the Medjerda channel capacity downstream of the Sidi Salem dam (Tunisia). *Journal of Hydrology, 351*(3–4), 318–330.