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Environmental Effects of Sediment Release from Dams: Conceptual Model and Literature Review for the Kansas River Basin

by Darixa D. Hernandez-Abrams[1], Susan E. Bailey[2], and S. Kyle McKay[3]

PURPOSE: Passing sediment from reservoirs to downstream channels is a potential solution to aging infrastructure and reservoir storage capacity loss, which is a pressing challenge nationwide. The US Army Corps of Engineers (USACE) sediment management actions at reservoirs such as flushing may drive ecological changes that may be beneficial or detrimental to downstream ecosystems. However, these potential effects are currently not well understood or documented. An exploratory study of the potential ecological effects of releasing sediment downstream from reservoirs is presented in this technical note (TN). We focus on Tuttle Creek Reservoir in Kansas and use fish species as indicators of ecological change. A literature review of Kansas fishes was conducted and three conceptual models illustrating potential benefits or negative effects of releasing sediment downstream of Tuttle Creek Reservoir was developed. Some fish species may benefit from sediment releases, while others may be negatively affected. Further research and tools are needed to develop a greater understanding of these effects.

BACKGROUND: Sediment transport in riverine systems is interrupted by dams, causing sediment to be trapped in reservoirs and subsequently decreasing storage capacity and reducing sediment supply to downstream reaches. This sediment supply is critical to maintaining river morphology and ecology (Kondolf 1997; Hauer et al. 2018). Other problems related to sediment trapping in reservoirs are impacts to navigation, flooding related to channel aggradation, energy loss, damages to intakes and outlets, and air pollution caused by desiccated fine sediments in empty reservoirs (Morris and Fan 1998). Some sediment management mitigation strategies attempt to extend reservoir life and pass sediment downstream, such as: sediment bypassing, sluicing, drawdown flushing, dredging and hydrosuction (see review in Kondolf et al. 2014).

Riverine sediment regimes drive many aquatic and riparian ecosystem processes. These processes are altered by sediment transported or stored within river channels, banks, and floodplains (Wohl et al. 2015). When dams interrupt a natural sediment regime, sediment-starved water may cause downstream changes to habitat (e.g., channel incision and coarsening of bed material; Kondolf 1997), decreased water turbidity, and changed concentrations of nutrients and other constituents. These abiotic changes from sediment-starved water may in turn affect primary producers (e.g., decrease biodiversity), invertebrates (e.g., decline in burrowing taxa; Wood and Armitage 1997),

1 US Army Engineer Research and Development Center (ERDC), Environmental Laboratory (EL), Vicksburg, MS, Phone: 601-634-3637, Email: Darixa.D.Hernandez-Abrams@erdc.dren.mil
2 ERDC-EL, Vicksburg, MS, Susan.E.Bailey@usace.army.mil
3 ERDC-EL, New York, NY, kyle.mckay@usace.army.mil

and fish species (e.g., increased predation; Utne-Palm 2002). In contrast, excess sediment may contain high concentrations of heavy metals affecting fish physiology (see review in Kjelland 2015), bury fish embryos, or induce loss of invertebrate habitat due to excess deposition which may lead to trophic cascading. Said differently, altered sediment regimes have complex ecological effects extending across many outcomes.

Environmental conditions, behavioral responses, life history traits, and physiological factors also play a critical role in determining a beneficial or detrimental effect of sediment on fish (Utne-Palm 2002; Kjelland 2015). Fish response may also depend on the concentration and duration of exposure to sediment (Newcomb and Macdonald 1991) as well as timing and magnitude of the event (Anderson et al. 1996). Fish traits such as those related to reproduction (e.g., spawning duration, rearing period) or feeding (e.g., herbivore, insectivore) may be used to assess their tolerance to sediment (Nelson et al., 2021) or hydrological effects (Craven et al. 2010).

Sediment management plays an important role in USACE operations. For instance, Tuttle Creek Lake is one of six major Federal reservoirs in the Kansas River, trapping 4,741 acre-ft/year of mainly fine-grained sediment (sand, silt, clay; Shelley et al. 2016). Sediment management actions are being pursued such as hydrosuction (Shelley 2019) or water injection dredging.[1] This study examines the potential ecological benefits or harms of sediment release at Tuttle Creek Lake. Our first objective was to conduct a literature review of primary and secondary sources on the topics of sediment management, effects of sediment on riverine ecosystems, and local fishes. The second objective was to create a conceptual model of potential fish response to key aspects of the sediment regime and proposed sediment management alternatives.

CONCEPTUAL MODEL DEVELOPMENT: Since effects of sediment release on downstream environments are difficult to quantify due to the complexity of the system, a literature review was conducted that focused on key local Kansas fish studies (Cross et al. 1976; Cross and Collins 1995; Rahel and Thel 2004; Haslouer et al. 2005; Gido et al. 2006; Gido et al. 2010) as well as a general assessment of the broader literature on riverine sediment regimes (e.g., Kondolf 1997; Wohl et al. 2015; Hauer et al. 2018). We summarized the literature in an annotated bibliography reviewing key resources. A general conceptual model was subsequently developed following a stepwise approach recommended by Fischenich (2008; Table 1).

Figure 1 presents the preliminary conceptual model of the ecological effects of sediment release on fishes in the Tuttle Creek Lake system. The model shows how different management actions (grey boxes) alter elements of the sediment regime (grain size, magnitude, and timing; blue boxes), which subsequently influence biotic and abiotic drivers and intermediate processes (white boxes) that ultimately affect fish species (yellow ovals). The black arrows indicate potential relationships between components. All these changes may induce other broad-scale ecological outcomes (green ovals), which are not explicitly addressed. Notably, other possible drivers of change are not included such as flow regime, connectivity, macroinvertebrates, and water temperature (examples in orange box).

[1] Personal communication. John Shelley, Ph.D., P.E., River Engineering and Restoration, Kansas City District, US Army Corps of Engineers. April 21, 2022.

Table 1. Stepwise process for developing a conceptual model of ecological effects of sediment release from Tuttle Creek Lake.

Step	Tuttle Creek Application
1. State the model objectives.	Objectives were to: (1) Help structure thinking about this complex system and its ecological processes, (2) Depict key components, processes and relationships that may be affected by sediment releases in Tuttle Creek Lake and (3) Communicate important stressors and drivers of change linked to potential outcomes in fish populations.
2. Bound the system of interest.	We focused on Tuttle Creek Lake in Kansas and chose fish species as indicators of change.
3. Identify critical model components.	We identified components of the sediment regime as main drivers of change to abiotic and biotic system constituents.
4. Articulate relationships among model components.	Management actions alter the sediment regime in the system. The sediment regime is a critical part of the system that affects biotic and abiotic intermediate stressors, components or drivers. The intermediate stressors or drivers of change may affect fish population outcomes and changes to fish communities cause broad-scale ecological outcomes.
5. Represent the conceptual model.	We used a box-and-arrows diagram to illustrate relationships between system components.
6. Describe the expected pattern of behavior.	Depending on properties of the sediment release, intermediate components may affect fish populations. For example, grain size considered as washload may increase turbidity, potentially causing gill abrasion that would affect survival, growth and development.
7. Test, review, and revise.	We received initial feedback from colleagues at the University of Georgia's River Basin Center working on adjacent issues. The model was then presented at a USACE Kansas City District virtual workshop where participants also provided feedback.

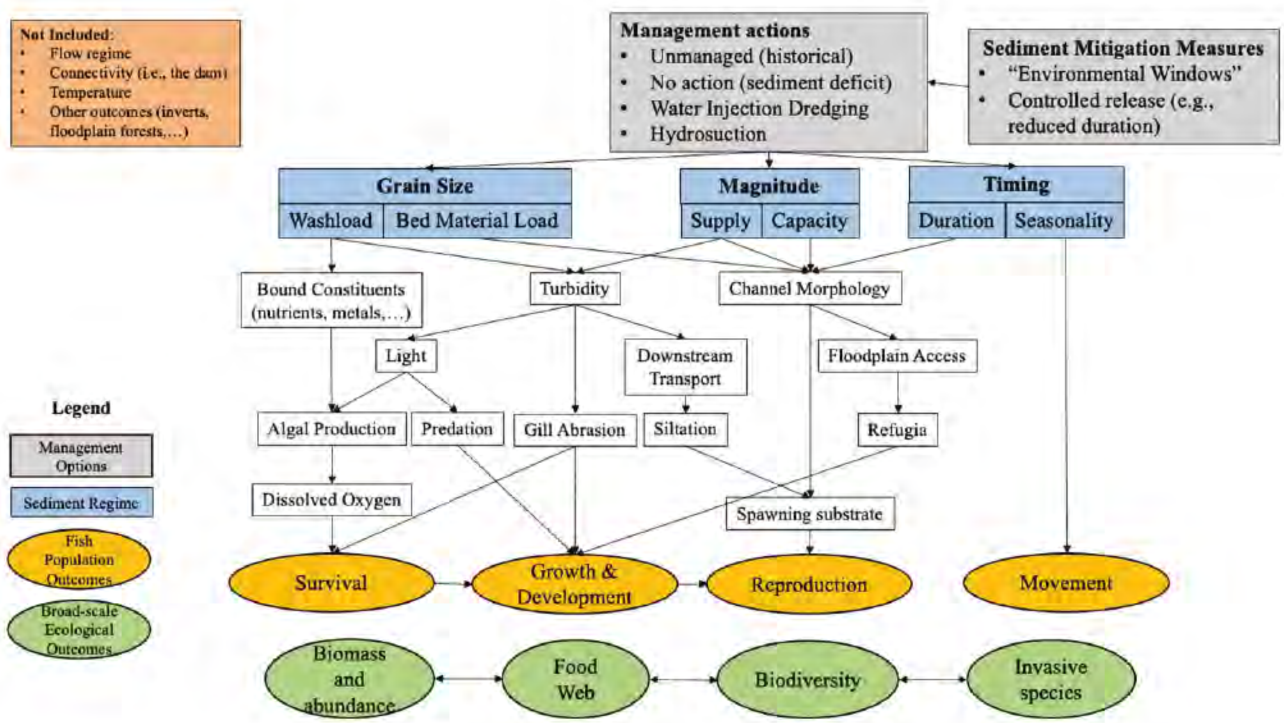

Figure 1. General conceptual model of ecological effects of sediment release from Tuttle Creek.

CONCEPTUAL MODEL APPLICATION: Fish species native to Kansas and found in the Tuttle Creek watershed were evaluated as indicator organisms for their better-documented direct and indirect response to sediment and environmental conditions in Kansas (Gido et al. 2010; Gido et al. 2006; Haslauer et al. 2005; Rahel and Thel 2004; Cross and Collins 1995; Collins and Jeane 1976). Kansas fishes may be generally categorized as sensitive or sediment tolerant depending on their habitat preference, feeding, typical movement patterns, life history, reproduction and predator-prey relationships, and based on literature-reported information. Two species were chosen to represent these categories in two hypothetical conceptual models (Figure 2 and Figure 3). We also referred to population statuses for Kansas fishes (Natureserve 2020) to identify species that might be of special interest because of their low population numbers. The models relative to sediment sensitive and tolerant fishes of conservation interest are demonstrated below.

Sediment sensitive fish example. Figure 2 conceptualizes a hypothetical example of how changes in sediment regime can trigger drivers that may affect local fishes classified as sediment sensitive taxa. In this example, the Johnny Darter (*Etheostoma nigrum*; listed as vulnerable; NatureServe 2020) was used as a possible sediment sensitive species in the Kansas River. The Johnny Darter lives in clear water streams and nests beneath stones in the stream bed (Cross and Collins 1995). Under the current conditions downstream of Tuttle Creek Lake (No action sediment deficit), the amount of fine sediment is low; therefore, the Johnny Darter should be able to reach its nesting habitat without obstacle. However, if the sediment regime were changed to a water injection dredging management action, this could change the magnitude, timing, and grain size of the current sediment regime and channel morphology by filling available nesting substrate with fine sediment (Figure 2). This change in the quality and availability of spawning substrate could lower the Johnny Darter's reproductive success causing a potential population decline.

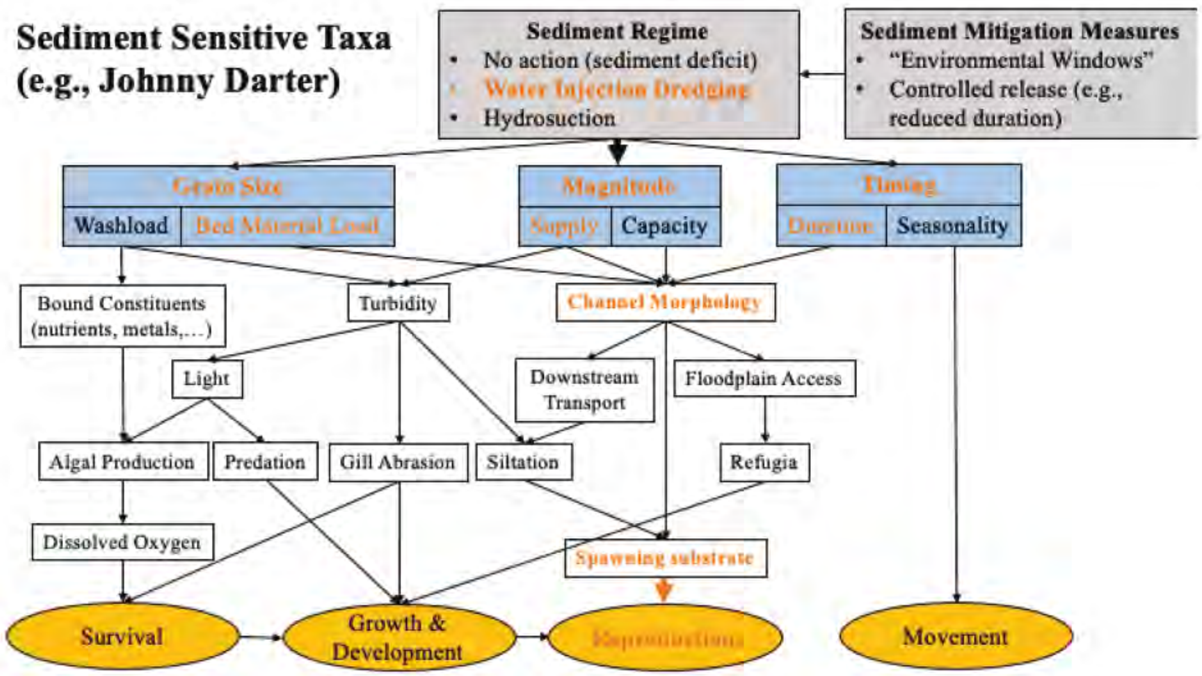

Figure 2. Example conceptual model for potential ecological effects of sediment release from Tuttle Creek represented with the Johnny Darter as a sediment sensitive taxon.

Sediment tolerant fish example. Figure 3 is a conceptual model of how changes to the sediment regime in Tuttle Creek may affect local sediment tolerant taxa. We chose the Flathead Chub (*Platygobio gracilis*) as the sediment tolerant representative species, which is listed as critically imperiled in Kansas (NatureServe 2020). Reduction of turbidity in rivers of Kansas is thought to be one of the major threats to this species. The current sediment supply downstream of Tuttle Creek has led to conditions of low turbidity and increased light penetration. Unnaturally clear water caused by impoundments allows for predators of the Flathead Chub to be more effective and for the other sight-feeding fishes to compete for food resources with the chub (Rahel and Thel 2004). These conditions may be allowing Flathead Chub predators to be more effective; therefore, affecting the chub's survival and potentially leading to a population decrease (Figure 3). This taxon could potentially benefit from an increase in turbidity through sediment releases.

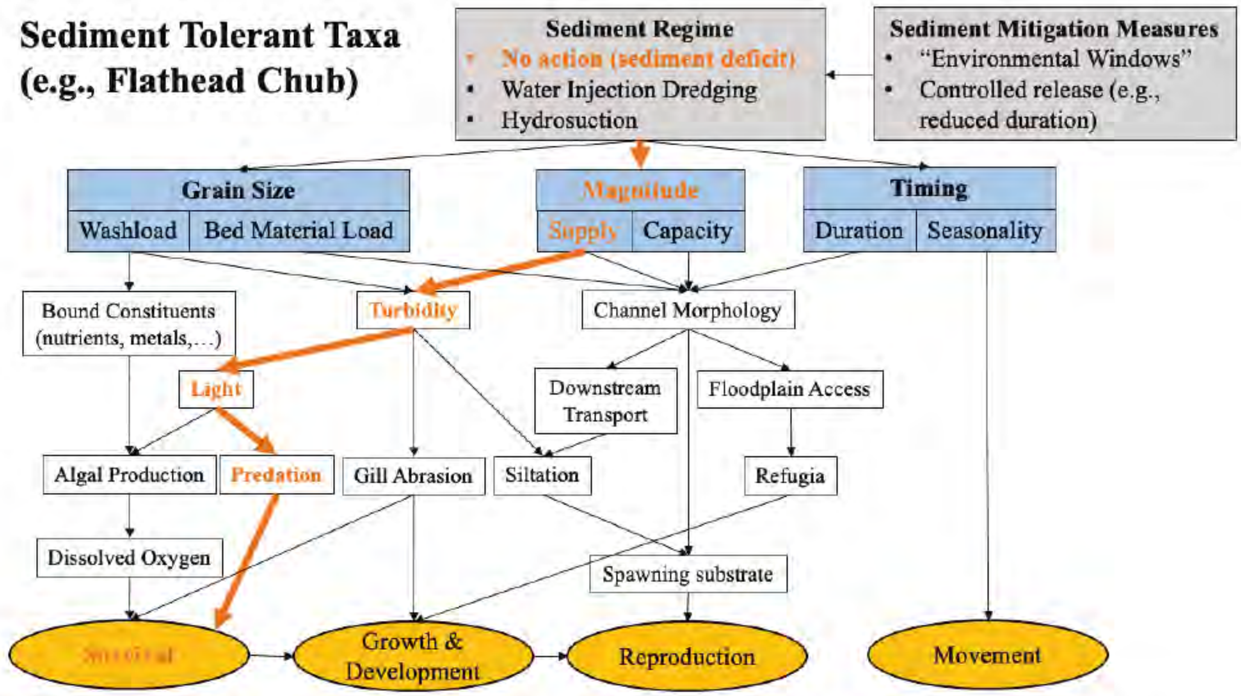

Figure 3. Example conceptual model for potential ecological effects of sediment release from Tuttle Creek in sediment tolerant taxon.

PRELIMINARY FINDINGS: Tuttle Creek is a system with predominantly fine grain sediment that may have presence of sediment sensitive and tolerant fish species. System dynamics may vary greatly depending on the magnitude and timing of releases as well as the fish species present. An environmental assessment may help understand current water quality conditions and the community structures of fish populations. A broader assessment of potential drivers of change will be conducted in future study phases. More information and tools are needed to help inform decision-makers, such as:

- Additional detail regarding the effects of proposed management actions on the grain size, magnitude, and timing of potential sediment releases.
- Compilation of additional fish response thresholds (e.g., sediment toxicity).
- Additional investigation of other potentially relevant environmental outcomes (e.g., invertebrates, aquatic vegetation, riparian areas, water quality, etc.).
- Monitoring protocols, models or other tools are needed to quantitatively evaluate the potential effects of suspended sediment release in sediment starved streams.

ADDITIONAL INFORMATION: The authors are grateful for thoughtful input from Drs. John Shelley, Trudy Estes, Rollin Hotchkiss, Matt Kondolf, and Keith Gido as well as interagency attendees at a USACE Kansas City (virtual) workshop in August 2020. The study was conducted with support from the Sustainable Rivers Program and the Ecosystem Management and Restoration Research Program (EMRRP).

ACKNOWLEDGMENTS: This study was conducted for and funded by the U.S. Army Corps of Engineers (USACE) Engineering Research and Development Center (ERDC) Ecosystem Management and Restoration Research Program (EMRRP) and by the USACE and The Nature Conservancy's Sustainable Rivers Project. Initial feedback for the conceptual model was provided by members of the University of Georgia's River Basin Center. The technical note was reviewed and improved by John Shelley, Burton Suedel, and Todd Slack. For information on EMRRP, please contact the Program Manager, Dr. Brook Herman, at Brook.D.Herman@erdc.dren.mil. This technical note should be cited as follows:

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ANNOTATED BIBLIOGRAPHY

<u>Peer-reviewed journal papers</u>

Craven, S. W., J. T. Peterson, M. C. Freeman, T. J. Kwak, and E. Irwin. 2010. "Modeling the relations between flow regime components, species traits, and spawning success of fishes in warmwater streams." *Environmental Management 46*(2): 181-194.

> Craven et al. studied relationships between flow regime, fish species traits, and young-of-year fish density by using hierarchical linear models and looking at short-term high and low flows, short-term flow stability, and long-term mean flows and flow stability effects on fish reproductive success. The metanalysis included data on fish species from Illinois, Alabama, and Georgia from 1977-2005. Reproductive success was organized into spawning (e.g., duration, complex or broadcast species) and rearing (e.g., hugger, cruiser, slackwater, pool habitat uses, herbivore, insectivore) fish traits. The authors found that short-term high flows most affected spawning success during spawning periods and that species traits affected recruitment success. Overall, reproductive success was positively related to short-term high discharges during the spawning season. Some fish species analyzed overlap with local Kansas fishes (e.g, Green Sunfish, Orangespotted Sunfish, White Crappie, Johnny Darter and Hornyhead Chub). Though this paper looks at effects of hydrologic alterations on fish, methods used to categorize fishes into reproductive guilds may be adapted to study effects of changes in sediment regime and its interactions with changes in hydrologic regime.

Cross, W. F., C. V. Baxter, K. C. Donner, and R. S. Rogers. 2011. "Ecosystem ecology meets adaptive management: food web response to a controlled flood on the Colorado River, Glen Canyon." *Ecological Applications* 21(6): 2016-2033.

> Cross et al. conducted a three-year analysis of secondary production and flow foodwebs in Glen Canyon to test the effects of a controlled flood on invertebrate and predatory rainbow trout food-web dynamics. The study area had no tributaries and therefore, the water was clear for the majority of the year. They found in general that invertebrate secondary production declined following the flood, while trout production increased significantly. However, when they looked at the invertebrate taxa commonly consumed by the rainbow trout, this showed an increase in taxa abundance that may explain the increase in rainbow trout abundance. Authors suggested that controlled floods may create favorable conditions for invasive invertebrates and rainbow trout but that there is still a lot of uncertainty regarding effects of controlled flood on food-web dynamics. This article helps Tuttle Creek by potentially providing information of predator-prey dynamics after controlled floods used to pass sediment downstream. It also provides possible experimental design ideas to monitor for adaptive management actions.

Gido, K. B., W. K. Dodds, and M. E. Eberle. 2010. "Retrospective analysis of fish community change during a half-century of landuse and streamflow changes." *Journal of the North American Benthological Society* 29(3): 970-987.

Gido et. al used retrospective analysis to evaluate the effects of anthropogenic activity on fish species richness and community structure in three major Kansas river basins between 1947 and 2003. The upper Arkansas River basin was affected by water withdrawals, the Smokey Hill River basin was affected by impoundments and the lower Kansas River basin mostly by impoundments as well. In general, occurrence of several prairie-river species has declined overtime in all basins and some have disappeared (e.g., Flathead and Silver Chub). Fish assemblages in western Kansas showed more changes overtime than ones in the lower Kansas basin. Percent occurrence of invasive species has increased since 1991. The authors mention that fish species likely to persist in Great Plains rivers are non-broadcast fishes cued by temperature or daylight and not dependent on flow conditions. Changes to connectivity and channel morphology due to placement of impoundments are some of the major drivers of decline in fish species. This article helps inform on the historical effects of dams on Kansas fish species due to changes in the sediment and hydrological regimes.

Gido, K. B., J. A. Falke, R. M. Oakes, and K. J. Hase. 2006. "Fish-habitat relations across spatial scales in prairie streams." *American Fisheries Society Symposium* (Vol. 48, p. 265). American Fisheries Society.

Gido et al. compare data used to study fish species-environmental relations at three different scales (catchments, reaches, and sites) in the Kansas River in order to understand how much variability of assemblages could be explained by adding broad to fine scale habitat variables. They used predictive modeling from data collected at 150 sites on the lower Kansas River basin and provide a table of the species occurrence and habitat variables with their percent variance. The authors found that variation in fish assemblage structure and individual species occurrence can be explained by using GIS to quantify habitat measurements at reach and catchment scales while site-scale habitat measurements did not improve predictive ability. Stream size and soil variables were important predictors of fish assemblage structures. This article is useful to the Kansas City District because it provides information on local fish assemblages and potentially cost-effective methods to predict fish-assemblages in the Kansas River.

Gido, K. B., C. W. Hargrave, W. J. Matthews, G. D. Schnell, D. W. Pogue, and G. W. Sewell. 2002. "Structure of littoral-zone fish communities in relation to habitat, physical, and chemical gradients in a southern reservoir." *Environmental Biology of Fishes* 63(3): 253-263.

Gido et al. analyze the predictability of littoral-zone fish community structure based on biotic and abiotic environmental factors using canonical correspondence analysis and a multiple regression model. Results found that the littoral zone fish community structure was highly predictable. The strongest of the environmental factors that predict littoral zone community structure were Secchi disk (turbidity in lake, including plankton) and conductivity. Authors mention in discussion that small-bodied riverine fishes may live in upper reaches of tributaries to avoid predation due to higher turbidity. Some of the fishes in the community overlap with Kansas River species. The white crappie (*Pomoxis annularis*), ghost shiners (*Notropis buchanani*), orangespotted sunfish (*Lepomis humilis*) and smallmouth buffalo (*Ictiobus bubalus*) are characteristic of turbid, silt, and sand bottomed main-stem rivers.

Haslouer, S. G., M. E. Eberle, D. R. Edds, K. B. Gido, C. S. Mammoliti, J. R. Triplett, and W. J. Stark. 2005. "Current status of native fish species in Kansas." *Transactions of the Kansas Academy of Science* 108(1): 32-46.

Authors re-evaluated the status of native fish species in Kansas and provided a summary of 44 species at risk of extirpation or have declined substantially. Haslouer et al. cite multiple sources of information on the native fishes and possible reasons for their decline. Some of these sources mention turbidity-related potential causes of species decline. For example, scouring of sediments in rearing habitat and dewatering might have caused loss of Chestnut Lamprey from Kansas basins (Cross and Collins 1995). The Brassy Minnow, Common Shiner, and Hornyhead Chub may have declined in the system due to water reductions and increased turbidity (Cross and Moss 1987; Cross and Collins 1995). The Highfin Carpsucker, is less tolerant to high turbidity (Pflieger 1997), and the Brindled Madtom, intolerant to high turbidity and siltation (Cross 1967). The authors also mention that increased turbidity may be the cause of Johnny Darter reduction in range. This assessment helps us determine possible species in Kansas that may be affected by a change in the current sediment regime below Tuttle Creek Lake.

Kjelland, M. E., C. M. Woodley, T. M. Swannack, and D. L. Smith. 2015. "A review of the potential effects of suspended sediment on fishes: potential dredging-related physiological, behavioral, and transgenerational implications." *Environment Systems and Decisions* 35(3): 334-350.

Kjelland et al. conducted an extensive literature review on the effects of suspended sediments on fishes and developed a conceptual model of key components and dynamics that may affect fish species. They identified that future study efforts should focus on effects of dredging that could cause epigentic changes in fishes.

Kondolf, G. M. 1997. "PROFILE: hungry water: effects of dams and gravel mining on river channels." *Environmental management* 21(4): 533-551.

Kondolf discusses the response of river channels to reduction in sediment supply because of dams and gravel mining. He reviews river processes such as energy dissipation, sediment transport, deposition and erosion, channel incision, and explains how dams interrupt these processes.

Kondolf, G. M., Y. Gao, G. W. Annandale, G. L. Morris, E. Jiang, J. Zhang, and R. Hotchkiss. 2014. "Sustainable sediment management in reservoirs and regulated rivers: Experiences from five continents." *Earth's Future* 2(5): 256-280.

Kondolf et al. discuss methods for sediment management in reservoirs and downstream to restore sediment in streams by bypassing sediment, sluicing or drawdown flushing. They discuss these methods through known techniques from across the world. The authors also mention the importance of sediment regime and ecological effects. Sediment release time and quantity have an important role in maintaining and ecologically favorable environment. If too much sediment is released during periods of low flow, ecologically important pools and riffles can have an excess of course and fine sediment. This excess could clog the streambed interfering with surface-groundwater exchange, burying fish, invertebrate eggs, and microhabitat between stones that are used as habitat by aquatic invertebrates and larval fish. The authors also explain differences between sediment bypass (off-channel reservoirs, flood bypass) and sediment pass-through (turbid density currents, drawdown routing/sluicing).

- Sediment bypass- diverts part of sediment water before reaching reservoir through a bypass channel or tunnel or an off-channel reservoir.
- Drawdown routing/sluicing- water discharge is operated during high flows upstream of the reservoir to flush sediment out in the most "natural" way.
- Drawdown flushing- aims to scour and re-suspend sediment that has deposited in the reservoir and sending it downstream.
- Venting of turbidity currents- allowing natural turbidity currents to pass through outlets in a dam.

Newcombe, C. P., and D. D. MacDonald. 1991. Effects of suspended sediments on aquatic ecosystems. North American Journal of Fisheries Manag*ement 11*(1): 72-82.

Newcombe and MacDonald reviewed literature on effects of suspended sediments on aquatic biota and analyze if a concentration-response model or a concentration-duration model provides better predictive power on the indirect or direct effects on salmonid fishes. The assessment was grouped into lethal effects (i.e., mortality), sublethal effects (i.e., injury), or behavioral effects (i.e., changes in activity pattern) on salmonid fishes. Results suggest that a model that includes concentration of suspended sediment and duration of exposure is a better predictor of the effects of suspended sediment on salmonid fishes.

Ock, G., G. M. Kondolf, Y. Takemon, and T. Sumi. 2013. "Missing link of coarse sediment augmentation to ecological functions in regulated rivers below dams: Comparative approach in Nunome River, Japan and Trinity River, California, US." *Advances in River Sediment Research* 1531-1538.

Ock et al. studied the ecological effects of gravel augmentation on ecosystem function downstream of reservoirs in Nunome River, Japan (effects in riffles) and Trinity River, California (effects in gravel bars). The ecological functions evaluated were particulate organic matter (POM) retention and hyporheic exchange in the regulated channel. In Nunome River, POM from reservoir plankton decreased in riffles, indicating retention capacity in the downstream channel for removing plankton from reservoir water. In the Trinity River POM downstream from gravel bars decreased, indicating retention capacity and gravel bars being possible sinks of POM. Gravel bars in Trinity River also played a role in inducing hyporheic flows which would help increase temperature and hydrological heterogeneity in a system.

Wohl, E., B. P. Bledsoe, R. B. Jacobson, N. L. Poff, S. L. Rathburn, D. M. Walters, and A. C. Wilcox. 2015. "The natural sediment regime in rivers: broadening the foundation for ecosystem management." *BioScience 65*(4): 358-371.

Wohl et al. discuss the physical processes of the sediment regime (e.g., sediment inputs, transport, and storage) in terms of river management and their interactions with the water regime. The authors expand on the natural flow regime concept by emphasizing that river restoration management should consider the interconnectedness of the flow and sediment regimes. They illustrate the interactions between the water and sediment through a conceptual model showing how altered (managed) discharge may drive changes in river and valley vegetation, substrate and geometry. They also present a sediment regime conceptual model with hypothetical scenarios of how changes in sediment inputs (an increase or decrease) may affect different river geomorphology and floodplain components that influence habitat, thermal regime and disturbance regime processes. Other useful information includes challenges in integrating sediment regime, things to consider when working with the sediment regime in river management and suggestions for metrics for assessing sediment regimes.

Utne-Palm, A. C. 2002. "Visual feeding of fish in a turbid environment: Physical and behavioural aspects." *Marine and Freshwater Behaviour and Physiology* 35(1-2): 111-128.

Untne-Palm reviews studies on relationship between predator-prey interactions and turbidity. He discusses that turbidity may have a positive effect on some fishes and a negative effect on others. This may depend on prey traits such prey color, lifestage, size, and mobility.

Wood, P. J., and P. D. Armitage. 1997. "Biological effects of fine sediment in the lotic environment." *Environmental Management* 21(2): 203-217.

Wood and Armitage developed a framework on the effects of fine sediment in aquatic ecosystems to give a holistic overview that would benefit river restoration management. The authors discuss origins of sediment, suspension and deposition processes, and give a literature review on the effects on primary producers, invertebrates, and fishes. General ways in which macroinvertebrates and fish species are affected by sediment suspension and deposition are discussed.

Book, guides, database, and government reports

Anderson, P. G., B. R. Taylor, and G. C. Balch. 1996. *Quantifying the effects of sediment release on fish and their habitats*. Canadian manuscript report of fisheries and aquatic sciences/Rapport manuscrit canadien des sciences halieutiques et aquatiques.

Anderson et al. conducted a literature review of primary and secondary literature to evaluate the effects of suspended sediment of aquatic ecosystems. Chapter 2 focuses on sediment impacts on fish and covers effects on behavior, growth, resistance to disease and pollutants, egg mortality, and effects in juvenile and adult fish. They emphasize the severity of the effects of suspended sediment on fishes will be determined by duration and concentration to the exposure as well as, the fish species lifestage.

Cross, F. B., and J. T. Collins. 1995. *Fishes in Kansas*. Natural History Museum, University of Kansas.

Cross and Collins describe native Kansas fish characteristics such as size, habitat, and reproduction. Fish species descriptions also include an illustration of the fishes and maps of occurrence locations in Kansas. This guide helps inform on potential sediment sensitive and tolerant fishes of Kansas. It also provides possible reasons for level of tolerance to sediment in fishes.

Cross, F. B., J. T. Collins, and J. L. Robertson. 1976. *Illustrated guide to fishes in Kansas*. Natural History Museum, University of Kansas.

Cross et al. provide an illustrated guide and list of Kansas fishes. Illustrations show dichotomous keys with different components of the species morphology to help users in identifying species.

Fischenich, C. 2008. *The application of conceptual models to ecosystem restoration*. ERDC/EBA TN-08-1. Vicksburg, MS: US Engineer Research and Development Center.

Fischenich describes what conceptual models are, how they are useful for ecosystem restoration projects, and steps for conceptual model construction.

Hauer, C., P. Leitner, G. Unfer, U. Pulg, H. Habersack, and W. Graf. 2018. The role of sediment and sediment dynamics in the aquatic environment. In *Riverine Ecosystem Management* (pp. 151-169). Springer, Cham.

Hauer et al. present an overview of the role of sediment in aquatic systems in terms of shaping river morphology, creating habitat, effects of sediment disturbances, and the sediment dynamics with aquatic biota (e.g., macroinvertebrates, fishes, producers). The authors also discuss sediment management options that are structural (installment of habitat features like gravel beds) and nonstructural (operations related to dams like sediment bypass). This chapter in the book, Riverine Ecosystem Management, also presents a conceptual model after Wood and Armitage (1997) where dynamics of sediment processes, chemical effects, biotic effects, and restoration presented for lotic ecosystems.

Juracek, K. E., and D. P. Mau. 2002. Sediment deposition and occurrence of selected nutrients and other chemical constituents in bottom sediment, Tuttle Creek Lake, northeast Kansas, 1962-99 (Vol. 2, No. 4048). US Department of the Interior, US Geological Survey.

Juracek & Mau used bathymetric and core sampling to study nutrients (nitrogen and phosphorus), metals and trace elements, organochorine compounds, and a radionuclide in the bottom of Tuttle Creek Lake. "The estimated mean annual net loads of total ammonia plus organic nitrogen and total phosphorus deposited in the bottom sediment of Tuttle Creek Lake were 6,350,000 lbs per year (2,880,000 kg per year) and 3,330,000 lbs per year (1,510,000 kg per year), respectively." Results detected a negative depositional trend of DDE related to history of DDT use. Concentrations of trace elements and metals were consistent overtime and EPA threshold-effects levels for arsenic, chromium copper, nickel, silver, and zinc were exceeded.

Morris, G. L., and J. Fan. 1998. *Reservoir sedimentation handbook: Design and management of dams, reservoirs, and watersheds for sustainable use*. McGraw Hill Professional.

Morris and Fan outline sedimentation problems in reservoirs and strategies for identifying, analyzing, and managing such problems through sustainable sediment management practices. After discussing principles of sediment, hydrology, limnology, and reservoir engineering, Morris and Fan demonstrate these concepts with 7 detailed case-studies of reservoirs with varying geographic and hydrologic qualities that lead to distinct sediment management problems and solution strategies. The authors offer lessons learned from sediment management at reservoirs and introduce the concept of sustainable sediment management in order to contribute to solving the world's growing challenges in sediment related to impoundments.

Nelson, J. M., T. Stephens, B. P. Bledsoe, R. B. Bringolf, J. Calabria, B. J. Freeman, K. S. Hill, and S. J. Wenger. 2020. *Review of Special Provisions and Other Conditions Placed on GDOT Projects for Imperiled Species Protection, Volume IV*. Georgia Department of Transportation SP&R.

Nelson et al. developed the Total Effect Score which is a system for evaluating the potential effects of road construction over imperiled aquatic species using project and site characteristics and species sensitivity. The authors used available literature and historical data on 111 species to evaluate traits for analyzing sensitivity to road construction effects. Chapter 6 includes an extensive literature review on the effects of sediment on fish, mussels, crayfish, amphibians, turtles, and dragonflies. A system like the Total Effect Score could aid in assessing the impacts of sedimentation release from Tuttle Creek.

Rahel, F. J., and L. A. Thel. 2004. Flathead Chub (*Platygobio graci*lis): a technical conservation assessment. US Department of Agriculture, Forest Service, Rocky Mountain Region, Species Conservation Project, Golden, Colorado. Available: www. fs. fed. us/r2/projects/scp/assessments/flatheadchub. pdf. (May 2011).

The authors conducted a literature review on the biology, ecology, conservation status, and management of the Flathead Chub, *Platygobio gracilis*. One major threat to the Flathead Chub, listed as a state threatened species in Kansas, is an unnatural reduction in turbidity due to the presence of impoundments. Habitat favored by these species are turbid, fast-flowing and warm water with sand and gravel substrate. Flathead Chubs are adapted to turbid habitat by use of chemosensory barbels and buds which enhance their feeding ability. The prairie streams in Kansas are naturally turbid but reservoirs trap sediment behind dam installments. The unnaturally clear water allows for predators to become more effective, while simultaneously favoring sight-feeding species that compete with Flathead Chubs for resources. Restoring natural flow and sediment regimes in this river system may aid in the recovery of this fish species

population. This assessment on the Flathead Chub informs on a species that may be sediment tolerant and may benefit from sediment releases.

Randle, T., G. Morris, M. Whelan, B. Baker, G. Annandale, R. Hotchkiss, and D. Tullos. 2019. *Reservoir sediment management: building a legacy of sustainable water storage reservoirs*. National Reservoir Sedimentation and Sustainability Team White Paper; SEDHYD, Inc.: Denver, CO, USA, 57.

Randle et al. discuss the need for long term sustainable sediment management practices at reservoirs. Authors discuss the importance of storage capacity at reservoirs, safety, and environmental implications of lack of sustainable sediment management practices. The authors describe the steps to developing a sustainable sediment management plan as: monitoring and screening, problem diagnosis and formulation and implementation. They give an overview of cost-benefit analyses as a tool for assessing different sediment management actions and discuss policy development needed.

NatureServe. 2020. NatureServe Explorer: An online encyclopedia of life [web application]. Version4.0. NatureServe, Arlington, Virginia. URL [http://www.natureserve.org/explorer]. Date accessed June 2020.

A national database for species status listings, taxonomy, distribution, and lifehistory information. The database helps keep track of current statuses of Kansas fishes.

Shelley, J. E. 2019. *Analysis of a Hydrosuction Sediment Removal System for Tuttle Creek Lake, KS*. ERDC/TN RSM-19-5. Vicksburg, MS: U.S. Army Engineer Research and Development Center. https://hdl.handle.net/11681/33583

Shelley presents an analysis of a hydrosuction sediment removal system in Tuttle Creek Lake, Kansas studying the effectiveness of hydrosuction, changes in effectiveness over time, and the amount sediment available near the dam for removal. The author compared the cost of traditional dredging (aprox. $38.7 million/year) to the lower cost of hydrosuction for sediment removal in Tuttle Creek Lake. Results showed that hydrosuction can remove a significant amount of sediment from the dam if it removes from the lower 6,500 ft of the reservoir and when water releases are at 500cfs. However, hydrosuction is insufficient for longterm removal so additional management actions were suggested.

Shelley, J., M. Boyer, J. Granet, and A. Williams. 2016. *Environmental benefits of restoring sediment continuity to the Kansas River*. ERDC/CHL CHETN-XIV-50. Vicksburg, MS: US Army Engineer Research and Development Center.

Shelley et al. document environmental effects of sediment starvation in streams and sediment accumulation in reservoirs. The authors discuss the effects of sediment accumulation in reservoirs like nutrient accumulation and Harmful Algal Blooms (HABs) and fish kills, changes in fish diversity due to trophic changes, temperature changes, turbidity and water quality. Authors also present case studies of water quality in Milford Lake and Tuttle Creek Lake in Kansas discussing TN:TP nutrient ratios and phytoplankton (e.g., green algae, diatoms, and blue-green algae) and their relationship to increased sediment and decreased storage capacity in rivers. They also discuss the effects of sediment regime (altered by impoundments) on downstream ecosystems and possible benefits of restoring sediment downstream of reservoirs. One of these effects may be favoring of native-fish species as the sediment regime is restored to conditions more similar to the natural pre-dam conditions. Finally, the authors provide data on the average monthly suspended sediment in Tuttle Creek Lake and the amount that is passing downstream from 1984-2014 as well as, a comparison of sediment loads deficits in the Kansas River due to impoundments.