BEFORE THE
UNITED STATES OF AMERICA
FEDERAL ENERGY REGULATORY COMMISSION

Sho-Me Power Electric Cooperative Niangua Hydroelectric Project	)	Project No. P–2561–057

AMERICAN WHITEWATER'S AND GREAT RIVERS ENVIRONMENTAL LAW CENTER'S COMMENTS ON ENVIRONMENTALASSESSMENT FOR APPLICATION TO SURRENDER LICENSE FOR THE NIANGUA HYDROELECTRIC PROJECT (P-2561-057)

American Whitewater files these comments in response to the Federal Energy Regulatory Commission's ("FERC") Environmental Assessment for Application to Surrender License filed by Sho-Me Electric Cooperative ("Sho-Me") for the Niangua Hydroelectric Project (P-2561-057) (the "Project"). The Project is currently operating under an annual license since the expiration of Sho-Me's 30-year license on June 1, 2024. FERC supports Sho-Me's plan to surrender its license without dam removal. As detailed below, FERC's analysis in its Environmental Assessment does not comply with the National Environmental Policy Act (NEPA), the Clean Water Act and the Endangered Species Act (ESA). Further, under the circumstances present here, dam removal is required under the Federal Power Act's (FPA) public interest standard.

American Whitewater is a national non-profit 501(c)(3) river conservation and recreation organization founded in 1954 and incorporated in Missouri in 1961. With more than 6,000 members and 85 affiliate clubs, representing tens of thousands of whitewater paddlers across the nation, American Whitewater's mission is to protect and restore our nation's whitewater resources and to enhance opportunities to enjoy them safely. Our members are primarily conservation-oriented kayakers and canoeists, some of whom live and/or engage in recreational boating in Missouri. American Whitewater has long been involved in advocacy related to FERC-licensed hydropower projects, and is often a party to settlement agreements that provide for recreational boating opportunities that partially mitigate for project impacts. American Whitewater and its members would use and enjoy the Niangua River in the project area if the project dam was removed, and thus will be directly impacted by the outcome of this proceeding.

Great Rivers Environmental Law Center is a 501(c)(3) nonprofit public interest law firm founded in 2001 that provides free services to citizens and advocacy groups seeking to protect the environment and public health throughout Missouri and Illinois. Great Rivers works to preserve and protect water quality, open spaces, forests, floodplains and wetlands for their recreational, aesthetic, and agricultural benefits, and their values as flood storage and habitat for migratory birds and other species. The law center promotes the public health by encouraging cleaner energy, improved environmental performance by businesses, and more efficient transportation and land use, thereby achieving cleaner air and water, and improving the quality of life in the region with particular focus on protecting disadvantaged populations from an unreasonable share of the environmental burdens of modern society.

FERC applies a public interest standard in assessing applications to surrender hydropower licenses. This standard derives from Section 6 of the FPA, 16 U.S.C. § 799. *See Niagara Mohawk Power Corp.*, 100 FERC 61,185 at 12–13 (2002). In issuing a Surrender Order for the Niangua Hydroelectric Project, FERC must evaluate whether the Surrender Plan is in the public interest, evaluate reasonable alternatives as part of its NEPA review of project impacts, and evaluate effects on species listed under the federal ESA. The public interest and environmental reviews must encompass, at a minimum, past, present and reasonably foreseeable future direct and cumulative environmental impacts, evaluation of dam safety considerations, impacts to recreational uses, and environmental justice concerns.

COMMENTS ON THE ENVIRONMENTAL ASSESSMENT

Purpose and Need for the Action Requires Detailed Consideration of Dam Removal Alternatives

Tunnel Dam is an 830-foot wide, 24-foot-high hydroelectric dam that impounds 2.25 miles of the Niangua River, upstream of Lake of the Ozarks in Camden County, Missouri. The dam diverts water flowing to the 3 MW powerhouse at the Niangua Hydroelectric Project under a 30-year FERC license issued in 1994. The Project was originally constructed for hydropower generation and serves no ancillary purpose such as water supply or flood control.

Under the licensee's surrender plan, Sho-Me would discontinue generating power at the Project, seal off the tunnel leading to the powerhouse, disconnect the generating equipment, and retire the Project leaving Tunnel Dam in place. The Project is currently operated in run-of-river mode with no usable storage. Lake Niangua is a shallow impoundment created by the dam with limited recreational use. During the consultation phase, Sho-Me dismissed dam removal alternatives, such as creating a nature-like fishway or dam removal, and ultimately proposed a surrender plan that leaves the river-fragmenting dams in place.

Sho-Me's application for license surrender triggers National Environmental Policy Act

("NEPA") review, including analysis of reasonable alternatives. NEPA's alternatives analysis is guided by the action's "purpose and need" statement, which provides the basis for the selection of alternatives. *Theodore Roosevelt Conservation P'ship v. Salazar*, 661 F.3d 66, 72–73 (D.C. Cir. 2011). Here, the purpose and need of the agency action is to surrender its FERC license. Clearly, Sho-Me can remove the dams and still surrender the Project. Tunnel Dam is the only dam along the length of the Niangua River upstream of the Bagnell Dam forming the Lake of the Ozarks, and its removal would reconnect the Niangua and form a free-flowing river. The fact that the dam removal alternative would meet the purpose and need of the proposed action renders it a "feasible alternative." *See, e.g., W. Watersheds Project v. Abbey*, 719 F.3d 1035, 1052 (9th Cir. 2013); *see also Pub. Emps. for Env't Resp. v. U.S. Fish & Wildlife Serv.*, 177 F.Supp.3d 146, 154 (D.D.C. 2016) (holding agency failed to consider a reasonable range of alternatives where alternatives that could meet the action's stated need were excluded from consideration). Therefore, the dam removal alternative must be considered in detail. *See W. Watersheds Project*, 719 F.3d at 1052.

The purpose and need of license surrender differs from relicensing because the latter involves balancing power generation with impacts from continued operations on environmental resources, while license surrender evaluates the public interest in the absence of the public benefit of power generation. The difference is significant because relicensing presumes the continued existence and operation of the project works where surrender does not. Consideration of the public benefit of power or the cost of mitigation measures for the effects of project operations in relicensing are irrelevant to a surrender proceeding. At surrender, the question of whether a licensee's surrender plan sufficiently addresses environmental impacts of the dam structures and other decommissioned facilities is paramount in FERC's public interest determination.[1] As such, FERC's determination of whether to require dam removal at surrender requires a detailed evaluation of the benefits and detriments of each alternative on environmental interests without taking into account power generation, as would be required under FERC's equal consideration and comprehensive development requirements for relicensing. *See* 16 U.S.C. §§ 797(e), 803(a).

The fact that Sho-Me did not propose removing the dam is irrelevant to FERC's alternatives analysis under NEPA. NEPA requires an agency to sufficiently consider all reasonable alternatives, including, for example, ones mentioned in comments that were not originally proposed by the project applicant. *See, e.g.*, *Env't Prot. Info. Ctr. v. U.S. Forest Serv.*, 234 Fed.Appx. 440, 442–43 (9th Cir. 2007). FERC's own Decommissioning Policy Statement states "[i]t is not unusual that [dams] be breached or removed." Project Decommissioning at

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[1] *See, e.g., PacifiCorp*, 181 FERC ¶ 61122 at 61705 (2022) (finding dam removal in the public interest despite concerns about water storage, future energy generation, and local roadways); *Ariz. Pub. Serv. Co.,* 109 FERC ¶ 61036 at 61141 (finding dam removal in the public interest despite the potential for future energy generation at the dam).

Relicensing, 60 Fed. Reg. 339 at 344 (Jan. 4, 1995). The Decommissioning Policy Statement further states:

> The Commission is of the opinion that implicit in the section 6 surrender provision is the view that a licensee ought not to be able simply to walk away from a Commission-licensed project without any Commission consideration of the various public interests that might be implicated by that step. Rather, the Commission should be able to take appropriate steps that will satisfactorily protect the public interests involved.

Id. Thus, NEPA, the FPA, case law, and FERC's policy statements all support a more detailed analysis of alternatives then FERC produced in its Environmental Assessment.

<u>FERC's NEPA Analysis Uses an Incorrect Baseline for Comparing Alternatives</u>

The Environmental Assessment discussed four alternatives following Sho-Me's application for license surrender: 1) Licensee's surrender plan to seal off the powerhouse tunnel, leave Tunnel Dam in place, and spill all flows over Tunnel Dam; 2) Restore natural flows by removing Tunnel Dam and seal off powerhouse tunnel; 3) Staged removal of the spillway, lowering the impoundment to the streambed and passing all flows, sealing off the powerhouse tunnel and leaving the remainder of Tunnel Dam in place; and, 4) No-action alternative and continue licensed operation of the project. Inasmuch as Sho-Me filed an application with FERC to discontinue its hydroelectric generation and surrender its Project license on June 29. 2023, the no-action alternative was infeasible because FERC cannot require Sho-Me to continue operating the Project under a new license beyond the completion of the approved surrender plan and no other entity is seeking to take over the Project.

The Environmental Assessment asserts that the no-action alternative serves as the baseline for evaluating the effects of the proposed action and any alternatives. EA at 5. In defining the no-action alternative as the environmental baseline for its NEPA analysis, the Environmental Assessment fails to consider the cumulative impacts of the project on the Niangua River, including past, present and reasonably foreseeable future impacts resulting from the construction, operation and continued presence of the dam. *See, American Rivers v. FERC*, 895 F.3d 32, 54–55 (D.C. Cir. 2018). As the D.C. Circuit Court of Appeals noted, by defining the environmental baseline as the current conditions, FERC "gave scant attention to those past actions that had led to and were perpetuating the Coosa River's heavily damaged and fragile ecosystem," *id*. at 55, and as a result, the Court found FERC's NEPA analysis and Endangered Species Act analysis arbitrary and capricious. *Id*. at 46, 55.

The cumulative impacts are similar for the Niangua Project and include, at a minimum, the past and ongoing adverse effects of sedimentation and the degradation of water quality caused by the presence of the dam, past and ongoing decreased river connectivity, and loss of upstream habitat for many species, including some listed under the federal ESA. FERC's alternatives analysis should have compared the proposed surrender plan, dam removal, and staged spillway removal to the conditions as they existed prior to the Sho-Me's operation of the Project rather than the conditions as they existed at the time Sho-Me filed its surrender application. Indeed, U.S. Fish and Wildlife Service (FWS) pointed this out to FERC in its comments on Sho-Me's Surrender Application:

> Additionally, we reference the United States Court of Appeals decision document for case #16-1195 decided on July 6, 2018, involving American Rivers and Alabama Rivers Alliance as petitioners vs. FERC and U.S. Secretary of the Interior as respondents. This case involved an environmental review, an effects analysis, and a biological opinion as it pertains to a FERC project. A primary component of the decision pertained to the analysis of environmental baseline conditions. We request FERC review this case while considering the existing proposal, anticipated outcomes, and potential impacts of the Project.

Document Accession # 20230831-5258 (Aug. 31, 2023), at 4–5. FERC's Environmental Assessment ignored FWS's request and is directly contrary to D.C. Circuit Court of Appeals case law establishing the appropriate baseline conditions for evaluating impacts and alternatives. *See generally American Rivers*, 895 F.3d 32.

When the appropriate baseline conditions are established—that is, the Niangua River prior to the construction of the dam—it is clear the cumulative effects on ESA-listed species and other environmental resources of the past and ongoing presence of the dam are significant and warrant an Environmental Impact Statement ("EIS"). *See* 40 C.F.R. § 1501.3(d)(2)(vi) (listing one of the intensity factors for whether an EIS is required as "[t]he degree to which the action may adversely affect an endangered or threatened species or its habitat"). The Environmental Assessment determined that the decline of at least three ESA-listed species found in the Niangua River was attributable to "habitat loss from habitat fragmentation as a result of dam and reservoir construction, disruption of stream channels, riparian habitat degradation and conversion, and reduced water quality." EA at 29. Despite this, FERC incongruously concluded that the proposed alternative of surrender and leaving the dams in place "would have no effect on eastern hellbender, Niangua darter, and spectaclecase populations." EA at 33. This conclusion is arbitrary and capricious under the ESA and inconsistent with *American Rivers*, as well as with the comments of FWS, the federal resource agency responsible for recovery of ESA-listed species.

Clean Water Act Section 401 is Applicable to License Surrender Proceedings

During the licensing proceeding, Sho-Me applied to the Missouri Department of Natural Resources (MDNR) for water quality certification under Section 401(a)(1) of the Clean Water Act on December 12, 1991. MDNR failed to act timely on the application and certification, and certification was deemed waived according to section 4.38(f)(7)(ii) of FERC's regulations. Notwithstanding a prior deemed waiver, an application for surrender triggers a Clean Water Act Section 401 review, as a Surrender Order is a permit or order within the meaning of Section 401. The Environmental Assessment, however, asserts that no water quality certification is needed for the Project surrender proceeding because "the proposed action with staff recommendations would not result in any discharges to waterways…" EA at A-1.

Under the Clean Water Act, the States are "the 'prime bulwark in the effort to abate water pollution,' … and Congress expressly empowered them to impose and enforce water quality standards that are more stringent than those required by federal law." *Keating v. F.E.R.C.*, 927 F.2d 616, 622 (D.C. Cir. 1991) (quoting *U.S. v. Com. of Puerto Rico*, 721 F.2d 832, 838 (1st Cir. 1983)). To ensure the States were able to fulfill this primary responsibility of protecting water quality, Congress enacted Section 401 to fill a potential gap in the overall regulatory structure of the Clean Water Act—namely, federally licensed activities that may otherwise escape compliance with the requirements of state law to protect water quality. *See S.D. Warren Co. v. Maine Bd. of Env't Prot.*, 547 U.S. 370, 386 (2006) ("Changes in the river like these fall within a State's legitimate legislative business, and the Clean Water Act provides for a system that respects the States' concerns.").

Through Section 401, the States have the right to review the potential impacts of proposed federally licensed projects that "may result in any discharge into the navigable waters" and the obligation to "set forth any effluent limitations and other limitations, and monitoring requirements necessary to assure that any applicant for a Federal license or permit will comply with any applicable [water quality requirements under the Clean Water Act] and with any other appropriate requirement of State law." 33 U.S.C. § 1341(a)(1), (d). And with respect to how the States use this authority, the Clean Water Act defers to States to establish "the water quality certification process." *City of Fredericksburg, Va. v. F.E.R.C.*, 876 F.2d 1109, 1112 (4th Cir. 1989); *Appalachian Voices v. State Water Control Bd.*, 912 F.3d 746, 754 (4th Cir. 2019) ("State Agencies have broad discretion when developing the criteria for their Section 401 Certification").

Section 401 requires a certification for any federally licensed or permitted activity that "may result in any discharge into the navigable waters." The Clean Water Act defines the term "discharge," when used without qualification, to "include[] a discharge of a pollutant, and a discharge of pollutants." 33 U.S.C. § 1362(16). "[D]ischarge of a pollutant," in turn, means "any addition of any pollutant to navigable waters from any point source." *Id.* § 1362(12). The Clean Water Act does not define the full scope of the term "discharge." A "point source" is "any discernable, confined and discrete conveyance . . . from which pollutants are or may be discharged." *Id.* § 1362(14). The Act does not define the term "nonpoint source," but the Ninth Circuit has stated that "[n]onpoint sources of pollution are non-discrete sources; sediment run-off from timber harvesting, for example, derives from a nonpoint source." *Pronsolino v. Nastri,* 291 F.3d 1123, 1126 (9th Cir. 2002).

In 2006, a unanimous Supreme Court in *S.D. Warren* rejected the notion that "discharge" should be limited to only to "discharge of pollutants." According to the Court, the term "'discharge' presumably is broader, else superfluous, and since it is neither defined in the statute nor a term of art, we are left to construe it 'in accordance with its ordinary or natural meaning.'" 547 U.S. at 376 (quoting *FDIC v. Meyer*, 510 U.S. 471, 476 (1994)). "When it applies to water," therefore, "'discharge' commonly means a 'flowing or issuing out.'" *Id.* (citing Webster's New International Dictionary 742 (2d ed. 1954)). The Court also rejected the dam operator's argument that "discharge" should equate simply to a "discharge of a pollutant"— and thus require an addition of a pollutant from a point source to trigger the Section 401 certification requirement. 547 U.S. at 378–80. The Court rejected the dam owner's argument based on the statutory context because it attempted to "extrapolate a common feature from what amounts to a single item." *Id.* at 379–80. *S.D. Warren* thus confirms that the plain language of the Clean Water Act means pollution caused by nonpoint sources is subject to Section 401.

In reaching this common-sense conclusion, *S.D. Warren* announced four principles that must now guide any approach to interpreting Section 401. First, the term "discharge" must be given its plain meaning, defined by the Supreme Court as a "flowing or issuing out" of water pollution. Second, "discharge" must be broader than "discharge of a pollutant." Third, the legislative history of the 1970 law that added "discharge" to the Clean Water Act is essential to understanding the proper scope of Section 401. Finally, the term "discharge" must be read and interpreted in light of the Clean Water Act's purposes of preventing water pollution and retaining state authority to address pollution from federally permitted activities.

Under Section 401, an applicant for a federal license to conduct an activity resulting in a discharge into navigable waters must first obtain a certification from the certifying authority where the project is located. The applicant must ensure that it will comply with state water quality standards. In the case of the Niangua Hydroelectric Project, Section 401 requires that Sho-Me apply to MDNR for water quality certification that its surrender plan meets state water quality standards or show evidence that MDNR has waived its Section 401 authority. Any conditions required by MDNR in its water quality certification would necessarily become a part of FERC's surrender order.

FERC's assertion that the application for surrender of license is not subject to Clean Water Act Section 401 requirements is inconsistent with *S.D. Warren* and contradicted by the facts and circumstances of the project surrender plan. Following surrender, water will continue "flowing or issuing out" over Tunnel Dam and the project spillway. Additionally, Missouri Department of Conservation estimates an ongoing seepage flow of 40 cfs through the powerhouse tunnel following surrender.

FERC's summary dismissal of the applicability of Section 401 based on the assertion that the surrender plan will not result in a discharge into navigable waters of the United States contradicts the plain language and purpose of the Clean Water Act. To the extent there is any ambiguity in the statutory language, FERC's interpretation of the Clean Water Act is not entitled to deference. *See Loper Bright Enterprises v. Raimondo*, 144 S. Ct. 2244, 2264–66 (2024).

FERC's NEPA Analysis is Deficient and Fails to Properly Assess Resource Impacts

The Niangua River flows 125 miles through riffles, runs, and pools before meandering to the Lake of the Ozarks. Flow on the Niangua is blocked by Tunnel Dam near Macks Creek, affecting an array of resources that were mentioned in the Environmental Assessment, although analysis of the environmental impacts on those resources was deficient, incomplete and contrary to law.

- Geology and Soils

Tunnel Dam, like all dams, traps sediment, both coarser-grained bedload further upstream as well as fine sediment closer to the dam. FERC concludes that representative data are not available to ascertain either the volume of sediment that has accumulated in the reservoir or the reservoir's remaining sediment storage capacity, and Sho-Me failed to include a sediment study in its license surrender application. Notwithstanding the lack of study data, FERC nonetheless finds that the proposed action would not affect geology and soils because the proposed surrender would not involve ground disturbance or substantial change from run-of-river operations.

Beyond the sheer lack of data supporting FERC's findings, its conclusion completely ignores the ongoing impacts on geology and soils from the continued presence of the dam. FERC's analysis of this resource, as well as other resources, equates no change from current operations with there being no effect on the resource. Rather than comparing the effect of the proposed surrender plan on geology and soils to the currently licensed operation without regard to ongoing and cumulative Project effects, the Environmental Assessment should have included an analysis of the effect of leaving the dam in place on normal sediment transport.

FERC's analysis glosses over the permanent environmental benefits of restoring natural sediment transport through dam removal. Restoration of the natural sediment regime requires an analysis of conditions prior to the construction of dams and the intensive human disturbance of topography and land cover in the form of removed native vegetation through crops, timber harvest, urbanization, and other land uses.[2] When viewed through the proper analytical lens, it is clear that dam removal would have greater benefits on geology and soils, including unobstructed sediment transport, than the preferred alternative of allowing Sho-Me to leave Tunnel Dam in place following surrender. The Environmental Assessment's failure to so conclude and to weigh this benefit appropriately is a significant flaw in FERC's analysis.

Additionally, abandoned hydropower dams may fail as the recent failure of the Rapidan Dam in Minnesota so clearly illustrates, causing the massive discharge of sediment and erosion resulting from the uncontrolled water release that would result from dam failure.[3] With an increase in the number of extreme weather events due to climate change, the risk of dam failure is increasing. The importance of removing dams that no serve no important public purpose is demonstrated by the recent tragic events due to devastating storm damage from Hurricane Helene resulting in impending or actual dam failures. USFWS highlighted this concern, stating that it anticipates "further degradation" of Tunnel Dam's impoundment, spillway, and downstream habitat as "likely scenarios" resulting from climate change. Document Accession # 20230831-5258 (Aug. 31, 2023) at 9. This risk is compounded by the lack of regulatory oversight of Tunnel Dam following surrender as discussed below.

- Aquatic Resources

The Environmental Analysis discusses the effect of surrender on water quantity, water quality (including temperature, dissolved oxygen), and aquatic habitat. Under all surrender alternatives, water quantity in the bypassed reach would be improved through the sealing of the powerhouse tunnel and the passing of all flows other than seepage over the dam. Impacts on other aquatic resources vary substantially under each alternative.

Comments by FWS and Missouri Department of Conservation (MDC) show that Tunnel Dam impedes aquatic organism passage and alters the habitat conditions for numerous native species. Comments by FWS and MDC assert that the presence of Tunnel Dam has had and will continue to have adverse impacts on suitable habitat for two federally protected species,

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[2] Ellen Wohl et al., *The Natural Sediment Regime in Rivers: Broadening the Foundation for Ecosystem Management*, 65 BIOSCIENCE 358 (2015) (attached as Exhibit A).
[3] Evan Bush, *Dams in Distress: Partial Failure in Minnesota Offers a Nationwide Warning*, NBC NEWS (June 29, 2024), https://www.nbcnews.com/science/environment/minnesota-dam-calls-attention-others-poor-condition-rcna159094 (attached as Exhibit B).

Spectaclecase Mussel and Eastern Hellbender. Evidence of Spectaclecase was located just upstream of the project. Eastern Hellbender are known to occupy similar habitat and have been documented further upstream. The presence of the Tunnel Dam impoundment reduces suitable habitat for these federally protected species and creates a barrier that may ultimately lead to their extirpation from the river. The resource agencies indicate that suitable habitat is located downstream. The Environmental Assessment acknowledges that significant declines in Eastern Hellbender population size, extent of occurrence, and area of occupancy have occurred, predominately due to habitat degradation including dams, sedimentation, and water pollution.

Similarly, the Environmental Assessment acknowledges that ESA threatened Niangua Darter are endemic to the Osage River Basin and suitable habitat is available in the immediate vicinity of the Project. The Environmental Assessment appropriately finds that dam removal would provide lasting benefits to Eastern Hellbender, Niangua darter, and Spectaclecase populations and their associated habitats, would result in a net gain in function and quality, and have long-term, beneficial effects. EA at 33.

Notwithstanding these findings, the Environmental Assessment arbitrarily concludes that "[b]ecause no instream work or disturbance associated with the immediate decommissioning of the project facilities would occur, the proposed action would have no effect on eastern hellbender, Niangua darter, and spectaclecase populations." EA at 33. Again, FERC bases its conclusions and its FONSI on its faulty baseline assumptions that because the dam is being left in place that the aquatic habitat will suffer no adverse impacts. FERC's baseline is at odds with the D.C. Circuit's decision in *American Rivers v. FERC*, 895 F.3d at 47. ("attributing ongoing project impacts to the 'baseline' and excluding those impacts from the [ESA] analysis does not provide an adequate [ESA] analysis.").

The Project also impairs water quality in the Niagua River both upstream and downstream of the project. The Environmental Assessment states that Lake Niangua is "impaired under category 2B due to nutrients and turbidity, meaning available data suggest noncompliance for these parameters; however, data are insufficient to support a statistical test or to qualify as representative." EA at 15. Contrary to Sho-Me's assertion that license surrender without dam or spillway removal would have no effect on water quality, maintaining the impoundment behind the dam would result in the continued adverse effects of increased water temperature from solar warming due to the greater surface area and lack of tree cover as compared to a free-flowing river. Additionally, greater stratification and lower dissolved oxygen would likely be present in Lake Niangua due to the spilling of surface water and the discontinuation of the powerhouse tunnel diversion. The Environmental Assessment correctly finds that the dam removal alternative would result in benefits to water temperature and DO as those parameters would follow a more natural regime in the 2.25-mile-long impounded reach and the improved water quality would continue downstream, but then discounts those beneficial effects. EA at 24. Overall, dam removal would have far greater benefits to water quality than allowing Sho-Me to leave the dam in place, even taking into account the temporary water quality effects associated with removal. Indeed, dam removal is necessary to address the current impairments for that segment of the Niangua River, in order to comply with state water quality standards and achieve the goals of the Clean Water Act.

The removal of Tunnel Dam also would have far greater benefits to aquatic habitat than allowing surrender without dam removal. Tunnel Dam disrupts river connectivity and provides no upstream or downstream fish passage. We agree with FWS that the presence of the dam is contributing to the ongoing decline of aquatic organisms due to population fragmentation, lack of habitat connectivity, and reduced water quality. Removing Tunnel Dam would restore aquatic habitat where allowing surrender without removal would continue to fragment and degrade aquatic habitat for several more decades.

- Terrestrial Resources

As with other resources, the Environmental Assessment ignores the cumulative and ongoing effect on terrestrial resources from leaving Tunnel Dam in place by using a baseline that ignores past, ongoing and cumulative project effects. We do, however, agree with the finding that, following dam removal, the "long-term effects would range from moderate to beneficial, depending on the species in question, but effects would tend toward beneficial as aquatic habitats are converted to terrestrial habitats, increasing habitat for terrestrial species." EA at 27. Similarly, there would be long-term benefits to ESA threatened and endangered species from dam removal that more than offset any temporary negative impacts.

- Recreation, Land Use, and Aesthetics

The Niangua River provides quiet stretches of flatwater paddling and float trips as well as ample fishing opportunities. Kayakers, canoeists, and paddleboarders can be seen on various sections of the river, and there are numerous boat rental outfitters throughout the river. According to the Environmental Assessment, "Lake Niangua is a shallow, 360-surface-acre lake with numerous stumps and obstacles that limit water-based activities such as water skiing and powerboating." EA at 35. Non-motorized recreational activities include recreational boating, fishing, and swimming, but these activities are limited by Lake Niangua's large areas of shallow water, aquatic vegetation, and snags from old floodplain trees. Document Accession # 20230830-5102 (Aug. 30, 2023) at 14; *see also id*. at 15 ("Lake Niangua offers limited recreational opportunities compared to most lakes. . . . in addition to the physical limitations to recreation those same factors have resulted in a poor fishery."). While leaving Tunnel Dam in place would maintain certain existing recreational activities, other recreational activities would be enhanced through dam removal and the restoration of natural flows to a riverine reach above the dam, including floating and canoeing in the project area as well as paddling down river to the Lake of the Ozarks.

Comments by the National Park Service in response to the surrender application state that the Niangua River is a key natural and recreational resource for the area listed on the National Rivers Inventory (NRI) with outstandingly remarkable values that are recreational, scenic, wildlife, and fish. Document Accession # 20230825-5219 (Aug. 25, 2023) at 1. NPS requested an evaluation of the Niangua River's recreational, scenic, wildlife, and fish values to improve the overall understanding of how the surrender will impact these important resources. Notwithstanding the NPS study request, Sho-Me failed to conduct the study and none was required by FERC. FERC's conclusion that Sho-Me's surrender plan would not adversely affect recreational resources is not supported by any study data and relies on FERC's faulty baseline.

Tunnel Dam is a 20-foot high low-head dam on the Niangua River. American Whitewater along with numerous other federal and state agencies and other organizations have warned of the dangers of low-head dams to recreational users due to recirculating currents than can become drowning machines preventing escape. There are thousands of these structures in the United States; many like Tunnel Dam are a century old or more. The dangerous hydraulics created as water flows over these dams creates hazardous conditions for boaters. More than 1,000 fatalities have occurred at low-head dams in the United States.[4] American Whitewater works to remove low-head dams to protect public safety, restore free flowing rivers, and prevent needless drownings.

The removal of Tunnel Dam would allow downstream paddlers to travel freely throughout the length of the Niangua River above the Bagnell Dam without encountering dams needing portage. Following removal, the river would return to its original course and substrate as water flows through the currently impounded area. The Niangua below the project winds down to Ha Ha Tonka State Park and the Lake of the Ozarks over flatwater stretches, riffles, and runs providing an optimal paddling experience. Decommissioning and removing Tunnel Dam would return the river back to a natural pre-project condition and would improve riverine conditions and aquatic habitat with the return of this section of the Niangua River to a free-flowing state. We also agree with MDC and FWS that removing the dam would encourage additional public use and increase recreational opportunities on the Niangua River. Document Accession # 20230830-5102 (Aug. 30, 2023) at 5, 7, 14; Document Accession # 20230831-5258 (Aug. 31, 2023) at 8. Removing Tunnel Dam also would restore natural aesthetic views of a free-flowing river rather than the current view obstructed by dam structures and would provide the view of a flowing river rather than a still, shallow impoundment that provides little aesthetic viewing or recreational opportunities.

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[4] Hotchkiss, Rollin H., and Forrest R. Hansen. "Low-head Dams: Status and Legal Issues." *Journal of Dam Safety* 20.1 (2023).

- Cultural Resources

The Environmental Assessment identifies a number of cultural resources in the Project that could be impacted by the surrender. Regardless of the surrender alternative chosen by FERC (other than relicensing), protection of those resources will fall to the state as the succeeding regulatory authority rather than FERC. The loss of federal jurisdiction has the potential for degrading those resources under all surrender alternatives. It remains unclear, however, whether FERC has previously exercised its authority under the existing license to protect those resources. To the extent that the Environmental Assessment suggests that cultural resources will be better protected under Sho-Me's surrender plan as opposed to a dam removal alternative, the finding is purely speculative and lacking in support in the record on which the Environmental Assessment is based. According to Sho-Me's application for license surrender, "[c]urrently inundated sites, ***if present***, would remain protected from erosion and human disturbance as long as the impoundment remains at similar water levels." Document Accession # 20230629-5149 (June 29, 2023) at 4-74. (emphasis added) Without further study, FERC's conclusion that archeological or cultural resources would be adversely affected by either of the dam removal alternative is conclusory and unsupported by record evidence.

FERC says it intends to execute an MOA with Missouri State Historical Preservation Office ("SHPO") for the proposed decommissioning to protect cultural resources. EA at 53. But the Environmental Assessment does not indicate whether a similar MOA with SHPO was explored for the dam removal alternatives. Without such analysis, the record is incomplete on the potential differences to impacts of cultural resources with or without dam removal. Additionally, FERC claims that "implementation of partial or complete decommissioning would result in adverse effects to known archaeological resources through downstream erosion and could result in the exposure of currently inundated cultural resources," EA at 41, but this claim is not supported by record evidence.

- Environmental Justice

The primary reason FERC rejects the dam removal alternatives is cost to the dam owner, which purportedly would be passed on to consumers in the form of a rate increase, including to some unspecified Environmental Justice communities. However, FERC's analysis of the environmental justice impacts of each of the surrender alternatives is deeply flawed. As a result, the Environmental Assessment's conclusion that the dam removal alternatives would have permanent and significant negative consequences for Environmental Justice communities is both speculative and arbitrary and capricious.

Decommissioning costs are the responsibility of a licensee, and FERC presumes that licensees have the financial means to operate, maintain, decommission, and potentially remove project facilities at the end of their useful life.[5] Having benefitted from the opportunity provided by its FERC license to profit from power generation, the expense of retiring the project including costs for dam removal should be properly borne by the licensee rather than by the public. Nevertheless, costs associated with dam removal often come from a variety of sources and may include the licensee resources, private foundations, public bonding funds, federal funding provided through the Bipartisan Infrastructure Law, and other sources. *See, e.g.*, Document Accession # 0230901-5018 (The Nature Conservancy commenting "it is not apparent whether or not funding assistance or partnerships with other organizations were considered in the financial calculations that led Sho-Me Power to eliminate partial or full dam removal as an alternative. If the cost of dam removal was a significant factor in the decision to eliminate partial or full dam removal as a viable alternative, The Nature Conservancy is positioned to support and coordinate financial resources to assist with the safe removal of the dam."). According to FWS, Sho-Me declined to participate in any of the viable funding opportunities to help reduce the financial hardship upon the Licensee from implementing partial or complete dam removal. Document Accession # 20230831-5258 (Aug 31, 2023) at 2. These funding programs had the potential to partially or completely reimburse Sho-Me for its dam removal costs. *Id.* Having rejected assistance from FWS, Sho-Me should not be now heard to complain that the cost of dam removal will be a hardship on rate payers.

FERC's conclusion that "any adverse effects of the proposed action on members of environmental justice communities residing nearby or visiting the area would be permanent and significant," EA at 50, is not supported by either the data or FERC's own analysis. Even assuming that 170,000 rate payers would bear then entire cost of dam removal at the high-end cost of $17 million without subsidy from public or private funding sources, that cost would amount to $100 per rate payer, or as little as $2.77 per month over a 36-month period.[6] Costs

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[5] Under Section 10(b) of the Federal Power Act, each licensee must construct project works as authorized and then avoid any alteration "not in conformity with the approved plans." 16 U.S.C. § 803(b). Under Section 10(c), a licensee must "maintain the project works in a condition of repair adequate for the purposes of navigation and for the efficient operation of said works in the development and transmission of power." *Id.* § 803(c). It must "establish and maintain adequate depreciation reserves" for "all necessary renewals and replacements." *Id.* Under Section 10(d), a licensee must also establish "amortization reserves" and maintain them until the termination of the license. *Id.* § 803(d). Lastly, under Section 10(c), a licensee is responsible to address any damages caused by its project. *Id.* § 803(c). In sum, the statute requires that a licensee must have fiscal capacity for license compliance. This capacity is not limited to power revenues and must include "reserves," which are contingent mechanisms to address responsibilities for project maintenance and any license surrender.

[6] According to Sho-Me's Annual Report, the 170,000 member-owners of the cooperative pay 5.63 cents per kWh. Assuming an average 16,000 kWh annually or approximately $900, a 10 percent increase to pay for the cost of dam removal at the high-end of Sho-Me's estimate would amount to $90 per household, or approximately $2.50 per month if spread over three years. In

borne by rate payers for dam removal would be temporary and reasonable, not permanent and significant. Those costs would not fall disproportionately on Environmental Justice communities as the cost would be shared equally among all 170,000 rate payers. Similarly, effects of dam removal in terms of noise or dust would likewise be temporary, with limited effects, if any, on Environmental Justice communities living more than a mile away.

No Succeeding Regulatory Authority is Responsible for Dam Safety Following Surrender

The Dam and Reservoir Safety Program under the MDNR administers the provisions of the Missouri Dam and Reservoir Safety law. The program provides public safety for downstream residents against dam failure as well as protecting the investment and purpose of the reservoir. The program regulates nonfederal, nonagricultural dams 35 feet high and higher through inspections and issuance of registration, safety, and construction permits. Since Tunnel Dam is 20-feet high, it is not subject to oversight by the MDNR. With no succeeding regulatory authority responsible for dam safety. Sho-Me has entered a voluntary agreement with Camden County and is essentially self-monitoring dam safety at Tunnel Dam. The Owner's Dam Safety Program is not a substitute for a statutorily-mandated regulatory authority. This factor weighs heavily in favor of the dam removal alternative.

Conclusion

FERC's conclusion recommending license surrender without dam removal or staged removal of the spillway is arbitrary and capricious in violation of NEPA, the ESA, the CWA, and the Administrative Procedure Act and contrary to the public interest standard applicable to surrender proceedings under the Federal Power Act. FERC's analysis is flawed because it uses conditions under current operations as the Project baseline while ignoring past, ongoing and reasonably foreseeable cumulative effects. FERC's NEPA analysis relied on speculative conclusions based on incomplete data in recommending a preferred alternative rendering its conclusions arbitrary and capricious. Additionally, FERC incorrectly determined that Section 401 of the Clean Water Act is inapplicable to this surrender proceeding.

Contrary to FERC's conclusion, dam removal, or staged removal of the spillway, will better serve the public interest than surrender without dam removal. Dam removal will improve water quality and aquatic habitat, including habitat for ESA-listed threatened and endangered species, in the current impoundment area and downstream. Soil, terrestrial and aesthetic resources will benefit from flow restoration that would allow natural sediment transport rather continuing sediment blockage and accumulation behind the dam. While recreation and cultural resources may be temporarily affected by surrender, restoring the Niangua River to its natural

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the Environmental Assessment, FERC uses a percentage increase, which makes the impact look more significant than it is when reduced to real dollars. (Attached as Exhibit C) flows will benefit recreation in the long-term and any impacts to cultural resources can be mitigated and protected through management agreements with the state of Missouri.

As detailed in these comments, FERC's Environmental Assessment is flawed in multiple ways. Fundamentally, FERC is required to take a hard look and give detailed consideration to reasonable alternatives, which FERC did not do for the dam removal and staged spillway removal alternatives. Due to its many flaws, FERC must re-open its NEPA analysis to include, at a minimum, the following updates:

1. Use the proper baseline for its NEPA and ESA analysis, per the *American Rivers* D.C. Circuit Court of Appeals case.
2. Do an Environmental Impact Statement for the proposed license surrender.
3. Require the applicant to undertake all of the studies recommended by federal and state agencies in order to properly apply the public interest standard to license surrender.
4. Require the applicant to apply for Clean Water Act Section 401 certification.
5. Undertake a more extensive analysis of the applicant's ability to pay for the dam removal itself and the real dollar impact of any pass-through costs to ratepayers when spread over a reasonable timeframe.
6. Explore the possibility of an MOA with the Missouri SHPO to mitigate impacts, if any, to cultural resources caused by the dam removal alternatives.

Respectfully submitted this 30th day of September, 2024

Very truly yours,

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Exhibit A

The Natural Sediment Regime in Rivers: Broadening the Foundation for Ecosystem Management

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Water and sediment inputs are fundamental drivers of river ecosystems, but river management tends to emphasize flow regime at the expense of sediment regime. In an effort to frame a more inclusive paradigm for river management, we discuss sediment inputs, transport, and storage within river systems; interactions among water, sediment, and valley context; and the need to broaden the natural flow regime concept. Explicitly incorporating sediment is challenging, because sediment is supplied, transported, and stored by nonlinear and episodic processes operating at different temporal and spatial scales than water and because sediment regimes have been highly altered by humans. Nevertheless, managing for a desired balance between sediment supply and transport capacity is not only tractable, given current geomorphic process knowledge, but also essential because of the importance of sediment regimes to aquatic and riparian ecosystems, the physical template of which depends on sediment-driven river structure and function.

Keywords: sediment, adaptive management, river restoration, sediment balance

River systems—rivers, riparian zones, and floodplains—around the world are undergoing enormous changes as a result of human influences. Efforts to balance water supply, navigation, power generation, and other river uses against the need to protect river communities and ecosystem services demand an understanding of physical processes in river systems. Water and sediment supplied to and transported by rivers are the fundamental drivers of river condition, affecting water quality, thermal regime, habitat and aquatic communities, river stability, and natural hazards. Effective management of river systems therefore requires knowledge of water and sediment interactions.

This article builds on Poff and colleagues' (1997) paper on the natural flow regime. Since the publication of that paper, management programs oriented around modifying flow releases from dams to restore some natural (preimpoundment) patterns and, therefore, to achieve downstream ecosystem objectives have been implemented in a number of rivers (e.g., Arthington et al. 2010, Shafroth et al. 2010, Olden et al 2014) and have guided water management activities in some states (Kendy et al. 2012). Modified flow releases may seek to promote the recruitment of native riparian vegetation species, create new habitat, or increase lateral and longitudinal connectivity for organisms by facilitating migration to spawning areas or access to floodplain nursery habitat. Modified flow releases may achieve limited restoration success, however, if management does not include explicit consideration of sediment inputs to and transport within the river system.

Sediment regimes are crucial to aquatic and riparian ecosystems in many ways. The physical habitat template is a fundamental concept in ecology (e.g., Southwood 1977) that, in rivers, encompasses a range of sediment-related processes that determine channel morphology, bed conditions and heterogeneity, disturbance regime, community structure, and water quality. Many aquatic and riparian organisms depend on certain sizes and size distributions of bed materials for various life stages. For example, salmonids can be sensitive to excess fine sediment in the bed (as are other benthic organisms; Jones et al. 2011), and they require gravels in a suitable size range for spawning (Riebe et al. 2014) and that can provide interstitial spaces for juvenile rearing. Aquatic organisms may also be sensitive to the mobility of bed materials, such that life history timing may be adapted to the typical timing of bed disturbances (e.g., Lytle et al. 2008). Suspended sediment and turbidity can influence aquatic food webs—for example, by altering visibility for predators (Newcombe and MacDonald 1991). Sediment conditions are also important for riparian plants: Fine-sediment patches are commonly key colonization sites;

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grain sizes influence moisture retention; and plant scour is strongly influenced by the size-dependent scour of surrounding substrates (e.g., Merritt 2013).

In this article, we discuss the physical processes involved in sediment regimes and their interactions with river condition. We have four primary objectives. The first is to highlight the challenges to integrating sediment regimes into river management. Second, we provide a conceptual framework for sediment regime that is applicable to rivers across a wide geographic and geomorphic spectrum. This includes explicitly discussing the temporal and spatial components of sediment regimes and the variability among rivers. Our third objective is to increase the awareness that sediment is a vital component of river systems and to explore differences in water and sediment regimes. Sediment is commonly viewed as a disturbance or pollutant that needs to be minimized. However, the natural disturbances associated with sediment are integral to river ecosystems, and even fine-grained sediment can be beneficial to the river condition. Our fourth objective is to broaden the natural flow regime concept into a more inclusive paradigm for river management that includes natural—or, at least, balanced—sediment regimes in order to promote more holistic, effective restoration and conservation of river systems. As part of this objective, we discuss key information gaps and metrics that can be used to characterize sediment regimes.

Challenges to integrating sediment regime into river management

Because water and sediment interact to create habitat structure and dynamics within a river system, effective river management requires that water and sediment be managed in concert, and neglecting considerations of sediment supply and transport can produce unintended results (Poff et al. 2006). High-flow releases below dams into sediment-starved reaches lacking sediment inputs can cause channel downcutting and disconnection from the floodplain, streambed coarsening, and the loss of fish spawning habitat, or bank erosion and the loss of channel-margin and riparian habitat (Collier et al. 1996, Jacobson and Galat 2008). Conversely, low flows below dams combined with abundant sediment supply can cause siltation of the streambed, the loss of benthic and fish habitat (Bhowmik and Demissie 1989), and altered hyporheic exchange along with associated changes in water chemistry and thermal regime (Hoehn and Cirpka 2006). Regulations in the United States specifying instream or channel maintenance flows but ignoring sediment regime exemplify management focused solely on hydrology (Stalnaker et al. 1995). In this article, we provide a framework for understanding why and how informed river management should include sediment regimes in the context of flow management.

Incorporating sediment in river management is challenging for several reasons. Rivers respond to changes in water and sediment inputs at varying temporal and spatial scales, but such scales can be substantially different for sediment and for water. Particulate sediment (differentiated from solutes) is transported downstream as suspended load (e.g., sand, silt, and clay) and as bed-material load remaining in contact with the streambed (e.g., sand and coarser sediment). Sand and coarser sediment, in particular, move via nonlinear and episodic processes, reflecting thresholds limiting sediment mobilization and grain–grain interactions during movement. Moreover, the paucity of long-term data sets on sediment inputs, transport, or storage makes it difficult to quantify sediment regime, let alone assess natural, least-disturbed, or reference sediment conditions. For example, whereas over 23,000 US Geological Survey gaging stations have long-term (i.e., longer than 10 years) records of water discharge in the United States, only 1640 sites have more than 10 years of suspended-sediment concentration data (see *http://cida.usgs.gov/sediment* and *http://waterdata.usgs.gov/nwis/sw*). Only nine sites (in seven rivers) have suspended sediment records more than 50 years old (figure 1). Such long-term data sets are necessary for characterizing the magnitude, frequency, duration, timing or predictability, and rate of change or flashiness (*sensu* Poff et al. 1997) of sediment transport for different regions and rivers. Direct measurements of bed-material load, which may be especially important in shaping channels and therefore creating the physical template for rivers, are especially rare. Evaluating sediment regimes to guide management is further complicated by the magnitude and duration (centuries to millennia in most river basins) of human alterations to sediment supply, transport, and storage within rivers and their catchments.

The spatial density and duration of water discharge records allow for regional assessments of long-term trends and the degree to which human activities have altered these (Richter et al. 1996, Carlisle et al. 2010), but this type of assessment does not exist for sediment discharge. The analogous evidence of altered sediment discharge comes primarily from major deltas around the world—of the Nile, the Mississippi, the Colorado, the Yangtze, the Yellow, the Ebro, the Danube, the Godavari, and the Krishna, among others—that have experienced accelerated erosion during the past century (Yang et al. 2011).

A sediment balance approach for river management

The complications of understanding the role of sediment in river systems do not, however, diminish the importance of sediment for river management. Although the current understanding of spatial and temporal sediment regime rarely allows the prescription of management actions and although data are limited in most river systems, tools and conceptual frameworks are available that can provide insight into the degree and types of alteration of sediment supply, transport, and storage, as well as into the implications for successful management intervention.

Sediment regime includes inputs and outputs of mobile sediment from a length of channel and storage of sediment within the channel and floodplain over a specified time interval. We use the phrase *natural sediment regime* to describe

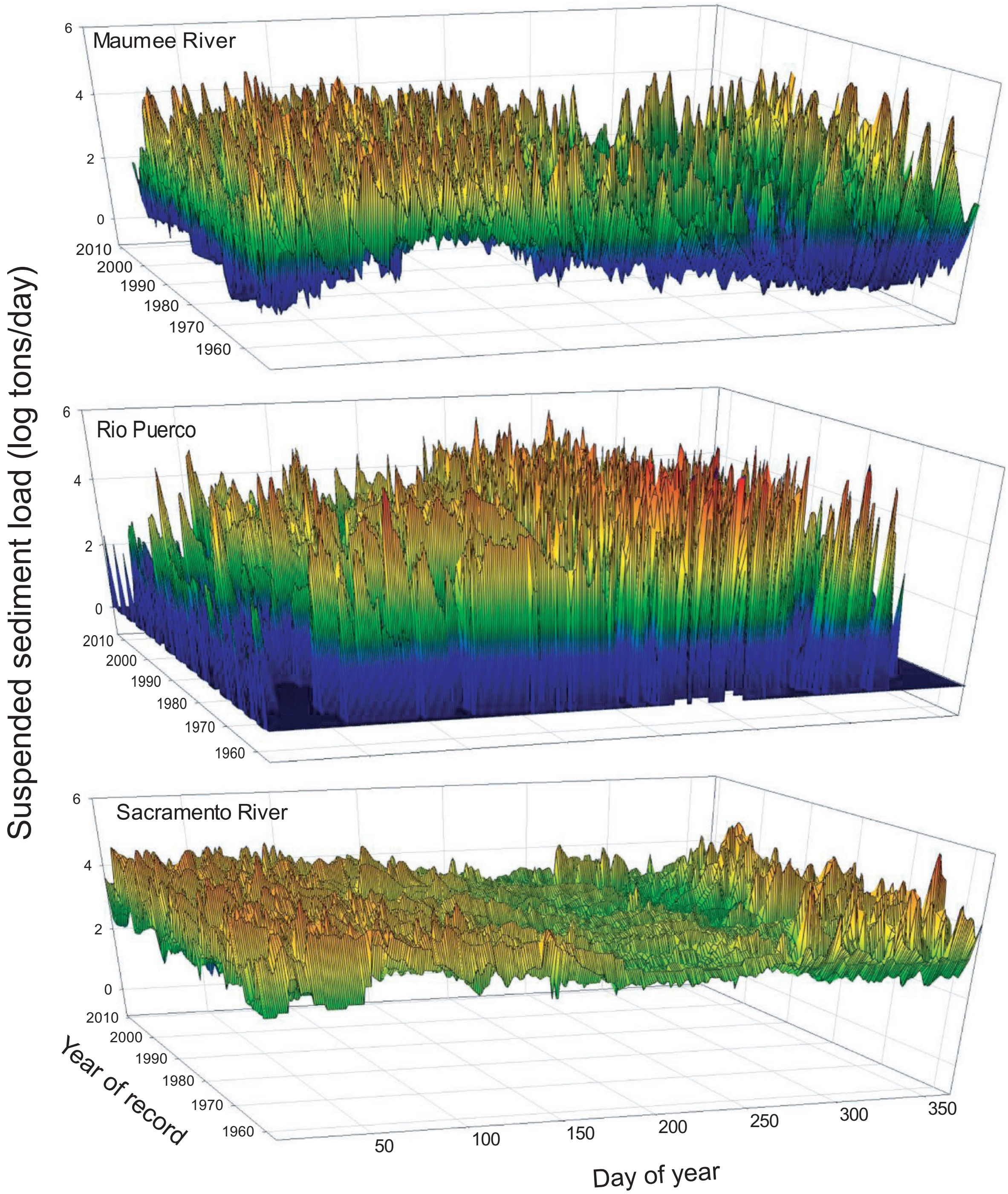

Figure 1. Suspended sediment histories from long-term (more than 50 years), daily mean records showing interannual and within-year variation for the Maumee River, Ohio (USGS gage 4193500) with a temperate climate; Rio Puerco, New Mexico (USGS gage 8353000) with an arid climate and summer monsoonal rains; and the Sacramento River, California (USGS gage 11447650) with a Mediterranean climate. The day of year begins on 1 January. The data were retrieved from **http://cida.usgs.gov/sediment** *on 16 April 2014.*

conditions prior to the construction of dams and the intensive human disturbance of topography and land cover in the form of removed native vegetation through crops, timber harvest, urbanization, and other land uses. Analogous to a natural flow regime, a fundamental benchmark for a natural sediment regime is that patterns of ecosystem organization and adaptations of riverine (aquatic and riparian) species reflect the spatial pattern and temporal variability of interacting water and sediment regimes. Key features such as natural disturbance, the spatiotemporal dynamics of hydraulic habitats, and specific types of depositional and erosional features arise from interactions of water and sediment.

The natural sediment regime is rarely observable, given the intensity of human alteration of land cover (inputs) and instream modification (storage and transport). Therefore, we distinguish between natural and balanced sediment regimes. A balanced sediment regime is present when the energy of flow available to transport sediment is in balance with sediment supply, such that the river form remains dynamically stable over a specified time period. This may reflect the absence of human alteration, as in a natural sediment regime, or it may reflect a human-altered condition in which both altered water and sediment supplies are in balance. In a management context, a balanced sediment regime is one that results in a channel that transports the sediment supplied to it with the available flow.

Although we believe that understanding the natural sediment regimes provides fundamental insight into the conditions to which a river system has adjusted over centuries to millennia, we recognize that because of the duration and extent of human modifications of sediment regimes, natural reference systems are rare, and the recreation of natural sediment regimes may be neither feasible nor desirable. As a result, we build on the premise that human activities have so fundamentally altered the natural sediment regime within rivers that identifying a balanced sediment regime may provide the most realistic management guideline. Although it may be expensive and politically difficult, for example, water can be released from a dam in a manner approximating a natural hydrograph, but downstream releases of sediment stored in a reservoir in a manner approximating natural sediment fluxes are much more problematic (Kondolf et al. 2014).

If water and sediment supply and other conditions in a river system have been altered by human activities, the resulting dynamically stable river system can be distinctly different than what would be present under natural conditions and to which ecosystems and biota are adjusted. Consequently, the key management questions may be *What are the supplies of water and sediment?* and *What river system structure and function can be achieved under a modified flow regime and balanced sediment regime?* (e.g., Wilcock 2012). The answer to the second question should be based on an understanding of the linkages between water and sediment regimes and river biota.

Managing for a balanced sediment regime may involve restoring more natural water and sediment inputs to a river system, or it may involve adjusting water inputs—flow regime—to create desired levels of sediment transport given an existing sediment supply (Schmidt and Wilcock 2008). In either scenario, the effective management of river condition requires knowledge of sediment regimes.

Conceptual framework for characterizing sediment regimes

Our conceptual framework for characterizing sediment regimes includes two primary parts. The first is a sediment budget (Reid and Dunne 1996) that includes inputs and outputs of sediment transported through a length of channel and exchanges between sediment mobile in the channel and sediment stored in the bed, banks, bars, and floodplain within a river system (figure 2). A sediment budget provides an organizing framework for tracking and relating these components of sediment regimes. Interactions among variables influencing sediment budgets govern where, how much, and for how long sediment is transported and stored in a river system and, therefore, the abundance, distribution, and stability of river habitat.

Sediment budgets can be applied at any spatial and temporal scale. Two examples are shown in figure 2 (basin and reach scales), with associated spatial and temporal ranges and primary controls on sediment regimes. Characteristics such as the magnitude, frequency, and duration of inputs and outputs are likely to vary throughout a river network. Suspended load inputs, for example, may be driven primarily by overland runoff in headwaters and primarily by bank erosion in lower portions of the network. The timing of sediment inputs or outputs, in terms of the seasonality and sequence of flows capable of transporting the sediment, can strongly influence river condition because sediment movement can constitute a disturbance that alters river habitat and directly stresses organisms via turbidity, abrasion, fine-sediment infiltration, and movement of the streambed (e.g., Jones et al. 2011). For the storage component, characteristics such as volume, grain-size distribution, and turnover time are likely to vary throughout the network and among different types of storage. An important aspect of figure 2 is that factors operating at the basin scale will influence sediment regimes, but factors operating at smaller spatial scales, such as the reach scale, will exert the strongest control on habitat abundance, distribution, and stability—and, therefore, river biota (Frissell et al. 1986, Beechie et al. 2008)—at spatial and temporal scales typically important for river management.

The relative importance of different sediment inputs, storage categories, and sediment outputs varies longitudinally (figure 3, top row). Some inputs vary progressively downstream (e.g., floodplains typically grow more extensive downstream and therefore store progressively more sediment; suspended load inputs from upstream reaches typically increase downstream as banks become more erodible), whereas others are less predictable because of local influences (e.g., tributary inputs of sediment to the main channel). The relative importance of sediment inputs via bank erosion from the headwaters to the mouth will depend on other conditions. Headwaters in a mountainous region are likely to have minimal sediment input from banks formed in bedrock or boulders, whereas headwaters in a low-relief environment could have more sediment input from banks in relatively fine-grained sediment such as sand. Regardless of the bank composition, bank inputs typically reach a maximum midway downstream. If the river is in dynamic equilibrium, inputs from bank erosion will be balanced by bank deposition.

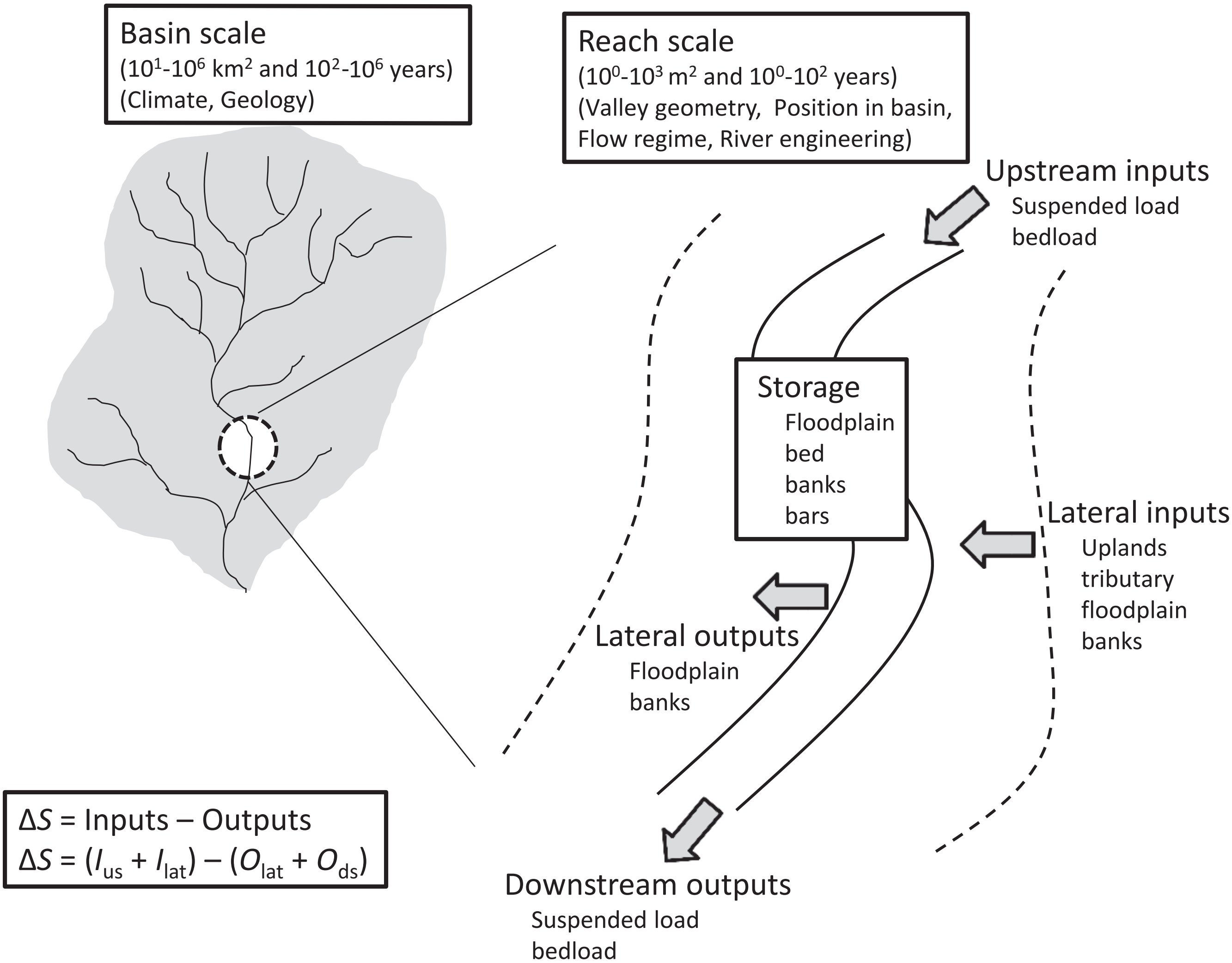

Figure 2. Aspects of sediment budgets, including the temporal and spatial scales relevant to sediment regime within entire drainage basins and individual river reaches and variables controlling sediment production and flux (in parentheses). The inputs and outputs to a channel are the sediment moving within the channel. The sediment budget equation at the lower left includes a simplified version and a slightly expanded version, listing the components of upstream and lateral inputs and lateral and downstream outputs. Abbreviations: ds, downstream; I, inputs; km, kilometers; lat, lateral; m, meters; O, outputs; us, upstream; S, storage.

The bottom row of figure 3 illustrates changes in the relationships shown in the first row that occur in response to specific human alterations. For example, construction of an upstream dam that traps most incoming sediment will directly alter the downstream inputs of suspended and bed-material load sediment and indirectly increase inputs from the banks and floodplain, as well as decreasing the storage in all components because of reduced sediment inputs from upstream. The construction of levees reduces lateral outputs to banks and largely eliminates outputs to floodplains, while likely increasing downstream outputs of suspended and bed-material load (e.g., Fitzpatrick et al. 2009).

The second part of our conceptual framework involves water and sediment interactions as they drive river condition within a valley context (figure 4, supplement 1). Valley context includes valley geometry (gradient and width of the valley bottom relative to the active channel), the substrate in which the active channel is formed and the living and dead vegetation, which can strongly influence bank stability and channel complexity. Water and sediment interact within the valley context to govern river geometry, aquatic and riparian habitat, and the disturbance regime for river biota (Bellmore and Baxter 2014).

Characterizing sediment inputs, outputs, and storage within a river system is important, because changes in these factors play a key role in channel form adjustments and the disturbance regime. At the simplest level, a river in which sediment inputs increase whereas water inputs remain constant is likely to accumulate sediment. This accumulation can take many forms, some of which are sequential

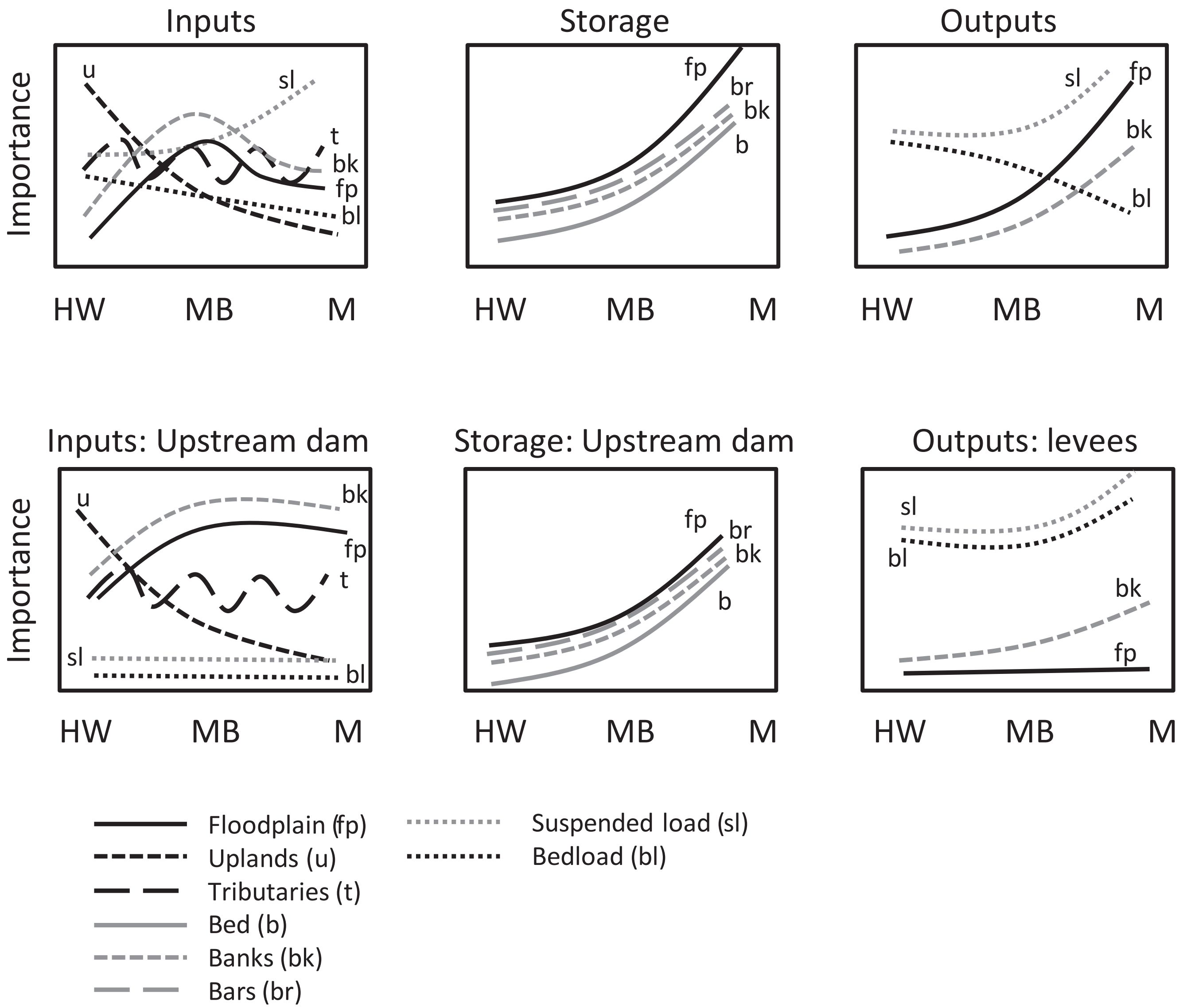

Figure 3. The relative importance of different sediment inputs, outputs, and storage areas moving downstream from headwaters (HW; first- to second-order streams) to midbasin (MB; third order and higher) and the mouth (M; the highest levels of stream order present) for unaltered rivers (top row) and in response to specific human alterations along the river profile (bottom row).

(figure 5). Conversely, a river in which sediment inputs decrease under stable water inputs (e.g., grade-control structures that reduce downstream sediment transport) is likely to have net erosion. Most scenarios of changing inputs are more complicated, with both water and sediment inputs changing, as well as changes in riparian vegetation and other components of valley context (e.g., in response to river damming and water export from the reservoir). Under these conditions, the sediment balance—the ratio between the flow energy available to transport sediment and the supply of sediment, with both variables integrated through time—is more important than absolute changes in either water or sediment inputs. Sediment balance still has to be evaluated in the spatial context of valley geometry and its location within the drainage basin and in the temporal context of the ongoing trajectory of river response to past changes.

The scales governing sediment regimes

Sediment inputs, transport, and storage in river systems vary over temporal and spatial scales different from those of water, and sediment inputs and transport are commonly nonlinear and episodic. The majority of water entering rivers moves downslope and downstream over timescales of less than a year. Because of the responsiveness of river flow to precipitation and the seasonality of precipitation, natural flow regimes have seasonal patterns such as spring snowmelt peak flows or winter rainfall floods that are predictable despite interannual variations (Poff et al. 1997). Although

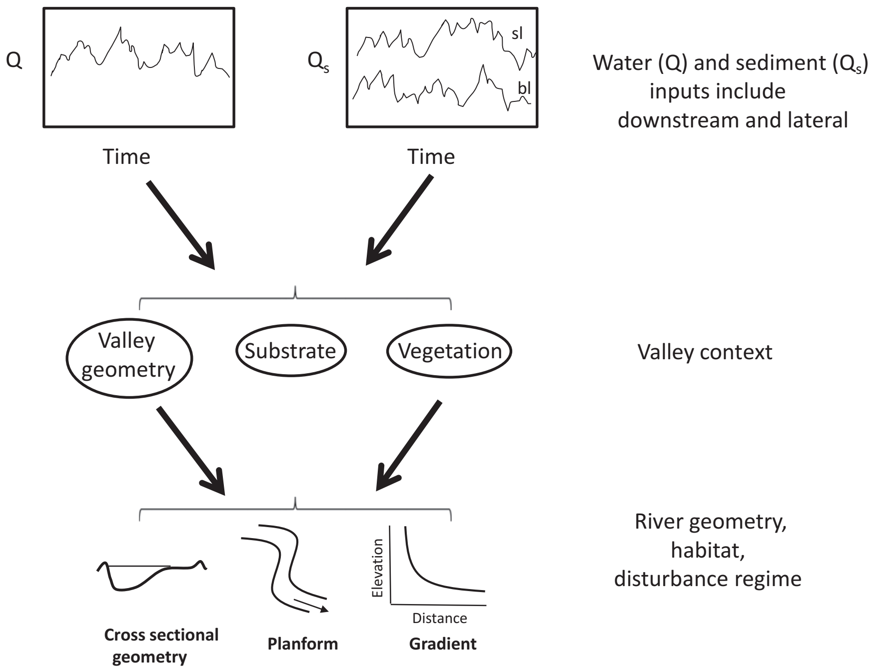

Figure 4. Interactions between water (Q) and sediment (Q_s), including suspended load (sl) and bed-material load (bl), discharges in the context of a specific valley configuration and erosional resistance created by substrate and vegetation to influence river geometry. Human alterations at the upper level (Q, Q_s) and intermediate level (substrate, vegetation) strongly influence river geometry (the bottom level). River management can manipulate water and sediment discharge and valley context to influence river geometry. Adapted from Thorne (1997).

most sediment inputs are driven directly by precipitation or by streamflow that reflects precipitation, sediment inputs tend to be even more nonuniformly distributed through time and space and much less predictable than water inputs. Disproportionate sediment inputs typically originate from small parts of drainage basins over a small fraction of time, whether they are considered annually or over multiple decades. For example, the Peruvian and Bolivian Andes constitute only about 10% of the basin area of the Amazon River but supply more than 80% of the sediment load (Meade 2007). More than 75% of the multiyear sediment flux from rivers in Taiwan occurs in less than 1% of the time (Kao and Milliman 2008). Sediment introduced to a river system, rather than immediately moving long distances downstream, is typically stored for periods much longer than a year and can be repeatedly exchanged among bar, bank, and floodplain storage, such that downstream transport during a river journey can last for as long as 10,000 years on a river such as the Amazon (Mertes et al. 1996).

Although sediment can be conceptualized in a simplified context of only longitudinal (mainstem) dynamics, the sediment regime in most basins is strongly influenced by the basin-wide configuration and network-scale processes (Jacobson and Gran 1999). Equal or greater volumes of sediment can be introduced to the mainstem from adjacent uplands and from tributaries as from mainstem downstream transport (Dunne et al. 1998). Tributary junctions and downstream changes in valley geometry create the potential for major discontinuities in sediment inputs and storage, as well as the associated river physical and ecological condition and disturbance regime (Rice et al. 2001, Benda et al. 2004). A key point here is that managing sediment regimes requires an understanding of the inputs of sediment originating beyond the mainstem channel.

The different forms and spatial scales of sediment connectivity are another important element of sediment regimes. Sediment connectivity describes both the movement and the storage of sediment into channels and along river networks (Fryirs et al. 2007). Highly connected river segments minimize sediment storage, whereas features such as a wider, lower gradient valley segment can create sediment disconnectivity along a river network by storing sediment. Sediment connectivity can vary in relation to sediment size, with high connectivity for suspended sediment, for example, but limited connectivity for cobble-size bed material.

Geomorphically and ecologically relevant spatial scales for river management relative to sediment can be highly variable, depending on the river or river segment under consideration. We illustrate this variability in the context of three examples of dammed rivers in which different forms and spatial scales of sediment connectivity strongly influence sediment regime and aquatic habitat.

On the mainstem Lower Missouri River, upstream dams trap sand-sized sediment, resulting in channel erosion and greater downstream sediment supply and transport. This, along with discrete points of sediment introduction at tributary junctions, discrete areas of sediment removal for commercial aggregate production, and channelization, has increased sediment transport capacity. The resulting channel adjustments to sediment surpluses and deficits on the Missouri River are apparent over decades. These combined processes create a complex longitudinal pattern of sediment mobilized via channel erosion and sediment deposited along the channel, with implications for flood hazards and ecological restoration efforts (Jacobson et al. 2009). Along the Missouri, the lack of longitudinal sediment connectivity because of dams exerts a particularly important limitation on habitat availability for pallid sturgeon (*Scaphirhynchus albus*), piping plover (*Charadrius melodus*), and interior least tern (*Sterna antillarum athalassos*) (Jacobson et al. 2009, Skalak et al. 2013).

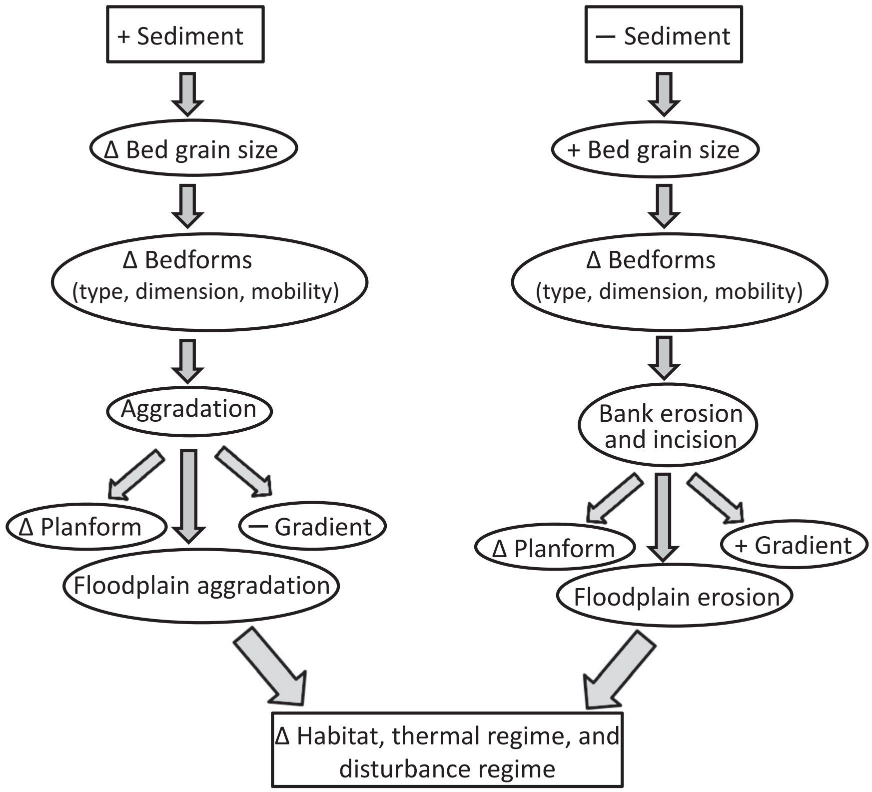

Figure 5. Hypothetical responses to increased sediment inputs (left) and decreased sediment inputs (right), with each change in sediment inputs occurring in the absence of changes in water inputs. Not all stages of response shown here will occur in every channel, and the sequence of responses could vary. Change, indicated by Δ, reflects the fact that the direction of change is highly dependent on specific details (e.g., conditions within a reach). An increase in fine-grained sediment will likely cause a decrease in bed grain size, for example, whereas an increase in coarse-grained sediment will likely cause an increase in bed grain size. At the lower level of the sequence on the left, an increase in sediment supply could cause a meandering channel to become braided (Δ planform), could reduce reach-scale gradient (Δ gradient), or could cause increased overbank sedimentation (floodplain aggradation), or could result in all three changes simultaneously.

In contrast, sediment supply in the Black Canyon of the Gunnison River, Colorado, is less influenced by the presence of a large upstream dam than by local inputs from the canyon walls and short, steep tributaries that extend only a few kilometers from the mainstem. These local boulder-size sediment inputs form channel constrictions and step–pool sequences that create channel-margin irregularities and distributions of hydraulic forces that strongly influence entrainment and deposition of finer sediments, as well as aquatic and riparian habitat (Friedman and Auble 1999, Dubinski and Wohl 2007). Along the Gunnison, lateral sediment connectivity between the channel and uplands strongly influences the sediment regime and its associated river process and form.

A third example comes from the Bill Williams River, Arizona, a dammed, dryland, sand-bed river. Here, dam-induced sediment deficits are restricted to a relatively short reach downstream from the dam; farther downstream, the availability of sediment from large alluvial valleys mitigates the reduction in supply from the upstream watershed (Wilcox and Shafroth 2013). Prescribed flow releases (environmental flows) have been used to maintain native willow (*Salix gooddingii*) and cottonwood (*Populus fremontii*) riparian forests (Shafroth et al. 2010), which depend not only on flows but also on the deposition of suitable-size sediment for seedling recruitment and moisture availability.

Sediment regime in the context of river management

The complexities outlined in the preceding sections do not preclude using metrics of river form to infer sediment regime, including metrics of changes in river form as indicators of changes in sediment regime. These complexities do, however, highlight the importance of several considerations.

The first consideration is the importance of designating the timescale of interest in a management context. Short-term fluctuations of days to weeks may function as hydrologic disturbances for river biota, for example, but they may or may not indicate a significant, persistent shift in river process and form over a period of multiple years. A large flood that elevates turbidity and suspended sediment transport may be a transient phenomenon that does not indicate a continuing change in sediment regime. An example comes from the North Fork Poudre River, in Colorado, where a large input of sand and silt released from a dam temporarily overwhelmed transport capacity, causing the infilling of pools and the fining of cobble-boulder riffle substrate. The next year's snowmelt peak flow exported much of the introduced sediment and returned the river system to its former configuration, including substrates suitable for native benthic macroinvertebrates and fish (Wohl and Cenderelli 2000). Analogously, dam removals can produce sediment pulses and downstream disturbances from which rivers, depending on geomorphic conditions and post-dam-removal flows, can recover within a few months to a year (Wilcox et al. 2014).

A second important consideration is synchronicity—or the lack thereof—between sediment production and routing across a river network. An example comes from Trimble's (2013) work in the Upper Mississippi Valley Hill Country of the north-central United States, where nineteenth-century clearing of native upland vegetation resulted in massive increases in sediment inputs to the river network. As native vegetation recovered during the twentieth century, changes in sediment budgets were markedly asynchronous among the tributaries, the upper main valley, and the lower main valley over a 60,000-square-kilometer area. Spatial and temporal variability in sediment inputs and sediment transport capacity are particularly important in the context of synchronicity between river components.

A third consideration is that, although most management is focused on smaller spatial and shorter temporal scales, an awareness of the greater context is crucial. The start of agriculture in any region is recorded by a change in the volume and type of sediment stored along river corridors, for example, as well as changes in river form and stability (Wohl 2014). Likewise, the damming of rivers, urbanization, and other land-use changes have greatly altered sediment supply, channel geometry, and sediment flux, with effects evident over decade to century time frames (Syvitski et al. 2005, Walter and Merritts 2008). Management occurring at the reach scale (figure 2) that ignores basin-scale influences is unlikely to achieve the desired ends. For example, river restoration designed to achieve a meandering river is not likely to succeed if sediment inputs from upstream reaches are conducive to the maintenance of a braided river (Kondolf et al. 2001).

A final consideration in characterizing the sediment regime in a management context is that, in most river systems, it is more useful to focus on deviation or alteration from natural conditions than to focus on absolute standards. This reflects the inherent variability of natural systems, whereby fluctuations occur within some range of variability (Rathburn et al. 2013). Also, because individual rivers are diverse with respect to sediment inputs, transport, and storage, designating some absolute standard that applies to multiple rivers or regions can be misleading and inappropriate (e.g., figure 1; Brierley and Fryirs 2005). Although sediment is widely recognized as a common pollutant in rivers, the diversity of natural sediment transport rates among rivers has made setting sediment-related water quality standards problematic, especially in view of rivers such as the Colorado and the Missouri and their tributaries, in which natural aquatic ecosystem processes have been disturbed by sediment deficits (NRC 2011).

Focusing on deviations from natural conditions is inappropriate, however, under at least two scenarios. First, if all of the river systems in a region have been altered for many decades or centuries, inferring the natural sediment regime may be impossible. Second, where alteration has been very intensive, has been extensive, or is ongoing, restoring the natural sediment regime may not be feasible. In these situations, sediment should be examined in the context of the sediment balance and how that balance relates to the achievement of management objectives. This can be done by comparing sediment regimes above and below a specific anthropogenic alteration such as a dam (e.g., Grant et al. 2003, Schmidt and Wilcock 2008). The sediment balance can also be assessed as an indicator of likely trends in river adjustment based simply on whether sediment supply exceeds, equals, or falls below transport capacity (Schmidt and Wilcock 2008). In these scenarios, managing for a balanced sediment regime that results in desired river system structure and function is likely to be more realistic and appropriate.

Relevant metrics for characterizing sediment regime

With these considerations in mind, we suggest several river characteristics that can be measured to assess contemporary sediment regimes, including assessing existing conditions in relation to natural sediment regimes in river systems altered by human activities (table 1, supplement 2). The only direct measure of sediment regimes that we include is the measurement of suspended-sediment concentrations. This reflects the difficulty, expense, and time required to measure bed-material load. Without question, the bed-material load is of fundamental importance in river form, process, and physical habitat characteristics, but bed-material load data are seldom available at present. The paucity of direct, long-term measurements of sediment in transport is the key gap in our understanding of river sediment regimes.

In the absence of past direct measurement of sediment transport, diverse tools are available for assessing river sediment regimes. Sediment regimes can be indirectly measured via changes in river form, substrate characteristics, and floodplain characteristics through time or with respect to reference reaches. These changes can be assessed over a time span ranging from instantaneous, ground-based measurements to decadal differences inferred from remote-sensing imagery. Changes in river form and floodplain characteristics can reflect net increases or decreases in the relative sediment supply, but because they result from a change in storage, they do not necessarily provide useful information for sediment flux (Church 2006).

Many methods and metrics exist for assessing sediment dynamics in rivers (table 1). However, even quantitative assessments of the specific river parameters listed in table 1 will allow only first-order predictions of potential future changes, rather than fine-scale understanding, because of the complexities of sediment regimes. If the management objective is to manage or restore to a more natural condition, then being able to demonstrate that a river system is outside the natural range of variability, as well as the direction in which deviation occurs (e.g., is the floodplain more or less diverse in terms of sediment grain size, turnover time, and wetland habitat?), can provide an important context. Knowledge of the parameters in table 1 can also provide important context when the management objective requires assessment of likely trends in river geometry resulting from changes in relative sediment supply above and below a specific alteration such as a dam or a basin-wide alteration such as urbanization and associated changes in water and sediment regime.

Of the characteristics listed in table 1, the most integrative approach is to assess the sediment balance, particularly as reflected in changes to the sediment balance caused by human activities. Of the methods available for assessing the sediment balance (supplement 2), the most comprehensive is the time-integrated ratio of sediment transport capacity and the time-integrated sediment supply, or the capacity supply ratio (CSR; Soar and Thorne 2001). CSR is defined as

Table 1. Metrics useful for assessing sediment dynamics.

Category	Potential metrics	Description
Cross-sectional channel geometry	Width, depth, width:depth ratio, bedform type and dimensions, bank stability, residual pool volume	Bedform type and dimensions refers to infrequently mobile bedforms such as gravel-bed pool-riffle sequences, with dimensions including downstream spacing and vertical variation in bed elevation (Wohl 2014). Bank stability can be assessed using qualitative and quantitative measures, as well as numerical simulation (Simon and Rinaldi 2013). Residual pool volume is the volume in a pool below the elevation of minimum flow surface, when flow barely spills over the downstream lip of the pool (Lisle and Hilton 1992).
Bars and islands	Number and successional stages	Development of bare sediment bars and vegetated islands reflect interactions among water, sediment, and riparian vegetation, including instream wood. Gurnell and colleagues (2012) discusses how to infer sediment dynamics from characteristics of islands and bars.
Substrate	Grain-size distribution, particle stability	Most useful for channels with bed material coarser than sand size. Particle stability refers to the frequency with which some measure of bed grain size (e.g., fiftieth percentile in a particle size distribution) is mobilized: this can be estimated via equations for critical shear stress or velocity, which are then related to a threshold discharge and frequency of exceedance of the threshold discharge.
Suspended sediment	Concentration, grain-size distribution	
Bedload sediment	Mass or volume per unit time, grain-size distribution	
Floodplain	Lateral extent, longitudinal extent, turnover time via chronology (e.g., radiocarbon, tree rings, ^{137}Cs), topographic/substrate diversity	Floodplain lateral and longitudinal extent may be discernible in remote sensing imagery. Field measurements may be needed to quantify spatial or temporal diversity of floodplain topography or substrate. Floodplain turnover time is average time period required to completely replace sediment within a floodplain segment; can be assessed using chronologic indicators such as radiocarbon ages, cosmogenic isotopes (Wittmann et al. 2011), ages of woody riparian vegetation, or via numerical simulations or simple extrapolations of known annual erosion rate and floodplain area (Mertes et al. 1996).
Channel planform	Sinuosity, number of channels	Most readily measured from remote sensing imagery, but may require field-based coring or stratigraphic assessment. Number of channels in a braided channel can be assessed using a braiding index based on remote imagery, although such indices depend on flow stage at time of measurement (Ashmore 2013). Number of channels in an anabranching channel planform is less likely to be stage dependent. Sinuosity and the degree of braiding or anabranching can change as relative sediment supply changes.
Vegetation patterns	Spatial heterogeneity of species and plant ages	Channel cross-sectional geometry and planform, as well as floodplain characteristics, reflect interactions among water and sediment regime and aquatic and riparian vegetation. The spatial distribution of different types of vegetation and the successional stages of vegetation communities can provide insight into sediment dynamics. Seedling establishment and germination may be severely reduced along river segments that lack replenishment of bar and floodplain sediments, for example, leading to even-aged riparian forests (Nilsson and Berggren 2000, Gurnell et al. 2012).
Sediment balance	S, CSR, T*	S* is changes in water and sediment supply pre- and posthuman modification; or dimensionless sediment supply ratio above and below dam (Schmidt and Wilcock 2008). CSR is capacity supply ratio (Soar and Thorne 2001). T* is fractional change in sediment-transporting flows pre- and postdam construction (Grant et al. 2003). See supplement 2
Channel evolution models (CEM)	Models describing multiple stages of channel adjustment following changes in base level, water supply, or sediment supply	CEMs describe adjustments in width, depth, gradient, and planform of alluvial channels and can be used to assess sensitivity of channel form to disturbances and altered hyrology and sediment regimes. Most sequence start with a deep, narrow channel that subsequently widens, accumulates sediment, and eventually stabilizes (Simon and Rinaldi 2013). Planform simulation models have also been applied usefully to evaluate sensitivity to disturbances, quantification of bank erosion rates and channel widening, and evaluation of erodible corridors (Larsen et al. 2007, Parker et al. 2011).
Emerging technologies	*In situ* produced cosmogenic nuclides, fallout radionuclides, airborne and terrestrial lidar, indirect monitoring of suspended and bedload, numerical models of sediment transport, reservoir sedimentation	See supplement 2

the bed-material load transported through the river reach by a sequence of flows over an extended time period divided by the bed-material load transported into the reach by the same sequence of flows over the same time period:

$$CSR = \frac{\int_{time\ 1}^{time\ 2} \text{Sediment transport capacity of response reach}}{\int_{time\ 1}^{time\ 2} \text{inflowing sediment supply from upstream reach(es)}}$$

Box 1. How to fail by managing water without considering sediment dynamics.

Continuing inputs of sediment accumulate within the channel and floodplain as a result of flow regulation that limits frequency and duration of flows capable of mobilizing sufficient volumes of sediment. Flow regulation focused solely on maintaining minimum flow depths for navigation or base flows for water supply exacerbates problems. Aquatic and riparian habitat abundance and diversity are reduced (e.g., Illinois River, Illinois; Bhowmik and Demissie 1989).

Urbanization-induced increase in impervious area and stabilization of surfaces increase runoff and reduce sediment inputs to streams, resulting in erosion of channel boundaries. Efforts to reverse problems by reducing storm runoff will be of limited success if sediment supply reduction is neglected—for example, Pennsylvania (Pizzuto et al. 2000) and Japan (Kadomura 1980).

Upstream dam reduces inputs of bedload and suspended sediment, resulting in erosion of channel boundaries, deltas and nearshore areas, or the loss of biologically important elements such as silica that travel with sediment. Experimental flood releases from the dam will not restore desired habitat and ecosystem services in the absence of sufficient sediment supply—for example, the Colorado River, Arizona (Collier et al. 1996); the Missouri River (Jacobson and Galat 2008); the Danube Delta and Black Sea (Lancelot et al. 2002); rivers throughout Japan (Guangwei 2011); the Ganges River, India (Thakur et al. 2012); the Yangtze River and its delta (Yang et al. 2011).

Numerous types of river contaminants (e.g., heavy metals, synthetic chemicals, radioactive isotopes, and excess nutrients) readily adsorb to fine sediment that moves primarily in suspension. Periods of suspended sediment transport can redistribute contaminants and increase contaminant exposure for riverine organisms—for example, the Mississippi River (Goolsby et al. 1993) and the Ob River, Russia (Kenna and Sayles 2002).

When CSR is less than 1, sediment is likely to accumulate in the channel. When CSR is greater than 1, the channel is likely to erode. Values close to 1 are most likely to result in channel stability. The CSR can be applied to any spatial or temporal scale (Thorne et al. 2011), but the CSR of a reach is typically calculated at timescales of years to decades in a management context.

The utility of numerical simulations to model catchment sediment supply through time lags far behind that for hydrologic regimes (Richter et al. 1996, Smith 2011); however, numerous options exist for modeling sediment inputs to a river reach, transport through the reach, and resulting river form (supplement 2). This information can guide management actions to change the balance by altering either water or sediment supply in order to potentially achieve the desired river form and associated habitats.

Understanding sediment regime has been central to many river restoration efforts. For example, the recognition of gravel deficits downstream from dams has motivated gravel augmentation for salmonid spawning habitat on several California rivers (e.g., Zeug et al. 2013). Similarly, sand has been augmented (through the direct addition of sediment) on the Platte River, Nebraska, to restore nesting habitat for endangered interior least terns and roosting habitat for whooping cranes along river reaches in sediment deficit (Smith 2011). The augmentation amount has been calculated as the difference between transport capacity and empirically measured sand transport rates. The extensive research and monitoring of sand budgets on the Colorado River in the Grand Canyon have been used both to assess the effects of experimental flow releases from Glen Canyon Dam and to adaptively manage those releases by, for example, accounting for estimated sand inputs occurring from unregulated tributaries downstream from the dam (Wright et al. 2008, Melis et al. 2012). Recently implemented restoration efforts in Europe (e.g., Habersack and Piégay 2008; REFORM, *www.reformrivers.eu*, and Room for the River, *www.ruimtevoorderivier.nl/room-for-the-river-programme*) also explicitly include sediment regime.

Management implications

Either sediment excess or sediment deficit in a river system can result in fundamental changes to river form and process and, therefore, the loss of ecosystem services and other societal costs. For example, excess sediment from mining operations in the catchment of the Fly River, Papua New Guinea, has led to aggradation of the streambed, increased flooding, and the accelerated delivery of copper-rich sediment to the floodplain, with negative effects on fish and floodplain vegetation (Day et al. 2008). Sediment excess in the Illinois River, Illinois, has resulted in an accelerated filling of floodplain lakes and the loss of aquatic habitat, as well as deposition along the mainstem and continual dredging to maintain navigational pathways (Bhowmik and Demissie 1989). Sand deficit in the Grand Canyon has resulted in the loss of habitat for endangered native fish and recreational sites for river rafters (Melis et al. 2012). In these and many other rivers, it is clear that effective management must include a consideration of the sediment regime and not just of the flow regime.

The conceptual understanding of sediment regime can limit internally contradictory or counterproductive actions, such as allowing aggregate mining in a sediment-limited river (box 1) or narrowly implementing elements of a natural flow regime that exacerbate sediment-deficit conditions (e.g., Schmidt and Wilcock 2008). For example, an attempt to naturalize the flow regime of the Lower Missouri River in order to achieve floodplain connectivity led to greater amounts of riparian vegetation. As a result, the deposition of unvegetated sandbars for shorebird nesting habitat was severely hampered by sediment deficits and the associated channel incision that prevented floodplain connectivity over a large part of the river (Jacobson and Galat 2008).

Finally, the conceptual understanding of sediment regime can facilitate the consideration of nested scales of space and time, such as sediment regime within individual river reaches over a period of weeks to months, considered in the greater context of the entire drainage basin over a period of years to decades. In some cases, for example, channel erosion upstream creates a source of excess sediment inputs to downstream reaches. In other cases, upstream management actions such as installing grade-control structures can induce channel erosion downstream by limiting longitudinal sediment transport. Changes in land use and river configuration, including urbanization, channelization, and flow augmentation, can increase transport capacity and decrease sediment supply, resulting in a sediment deficit and the erosion of downstream river reaches. In this context, large dams receive a great deal of attention for their effects on sediment supply (Syvitski et al. 2005), but smaller, spatially extensive changes in sediment and water balance throughout a river network can have substantial cumulative effects (Walter and Merritts 2008).

Despite complications introduced by nonlinear interactions among water, sediment, and river geometry, in many cases, sediment regime can be managed to achieve desired ends within some flow-sediment balance. Passive intervention can involve strategies such as allowing the river to access its historic floodplain or distributary channels in order to restore channel–floodplain or channel–delta sediment exchanges, thereby enhancing habitat for fish spawning, fish rearing, and waterfowl (Florsheim and Mount 2002). Active intervention can involve methods such as gravel augmentation below dams or in other sediment-impoverished river segments (Zeug et al. 2013), or larger experimental releases from dams that facilitate redistribution of sediment already present within the river system (Kondolf 2011). Either type of intervention requires reliable knowledge of where sediment enters a channel, how and when sediment moves down the channel, and where and for approximately how long the sediment is stored—in other words, a sediment budget. This sediment budget can be used to guide management so as to create a balanced sediment regime in which flow is able to transport available sediment in a manner that maintains a desired sediment balance, as well as river structure and function.

Conclusions

Our intent in this article is to heighten awareness of the many interacting components that govern sediment regime in river systems and that must, therefore, be managed explicitly to achieve many restoration goals. A more focused discussion of how to integrate flow regime and sediment regime in management applications is greatly overdue. Although the concept of developing a balanced sediment regime is straightforward, the difficulties of quantitatively predicting sediment mobilization and transport in rivers create uncertainties and challenges for management.

The ability to understand and manage the temporal and spatial dynamics of water or sediment depends on the precision of the records of these dynamics through time and among locations. Direct data on sediment transport, in particular, are severely limited relative to discharge records. The management of river systems will be handicapped until we invest in the more-comprehensive collection of sediment data. In the absence of direct measurement of sediment transport, isotopic and other emerging technologies (table 1) can be used to understand sediment regime in river systems.

At a minimum, the current understanding and tools allow us to predict the trajectories of river change in response to changes in sediment regime. Decreasing the relative sediment supply will trigger the types of river responses indicated on the left side of figure 5, and increasing the relative sediment supply will trigger those on the right side of this figure. Measures of sediment balance can be used to determine whether the relative sediment supply is increasing or decreasing within a river segment and to assess the magnitude of change. These variables can also be used to design management that creates a balanced sediment regime and facilitates channel stability. A channel in dynamic equilibrium may not necessarily create the desired river system structure and function required to support native biota, however, so channel stability in itself may not always be a sufficient management goal. An understanding of sediment regime can be used to manage for a dynamically stable channel in which water and sediment interact to create the habitat and disturbance regime needed to support river biota. With the tools and understanding currently available, there is no justification for managing river systems without explicitly considering sediment regime and every incentive to do so.

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Supplemental material

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References cited

Arthington AH, Naiman RJ, McClain ME, Nilsson C. 2010. Preserving the biodiversity and ecological services of rivers: new challenges and research opportunities. Freshwater Biology 55: 1–16.

Ashmore P. 2013. Morphology and dynamics of braided rivers. Pages 290–312 in Shroder, J, ed. in chief, Treatise on geomorphology, v. 9, Wohl E, ed., Fluvial geomorphology. Academic Press.

Beechie T, Moir H, Pess G. 2008. Hierarchical physical controls on salmonid spawning location and timing. Pages 83–101 in Sear D, DeVries P, eds. Salmonid spawning habitat in rivers: physical controls, biological responses, and approaches to remediation. American Fisheries Society Symposium 65, Bethesda, MD.

Bellmore JR, Baxter CV. 2014. Effects of geomorphic process domains on river ecosystems: a comparison of floodplain and confined valley segments. River Research and Applications 30: 617–630.

Benda L, Andras K, Miller D, Bigelow P. 2004. Confluence effects in rivers: interactions of basin scale, network geometry, and disturbance regimes. Water Resources Research 40: W05402. doi:10.1029/2003WR002583, 15 p.

Bhowmik NG, Demissie M. 1989. Sedimentation in the Illinois River valley and backwater lakes. Journal of Hydrology 105: 187–195.

Brierley GJ, Fryirs KA. 2005. Geomorphology and river management: applications of the river styles framework. Blackwell Publishing.

Carlisle DM, Falcone J, Wolock DM, Meador MR, Norris RH. 2010. Predicting the natural flow regime: models for assessing hydrological alteration in streams. River Research and Applications 26: 118–136.

Church M. 2006. Bed material transport and the morphology of alluvial river channels. Annual Review of Earth and Planetary Sciences 34: 325–354.

Collier M, Webb RH, Schmidt JC. 1996. Dams and rivers: primer on the downstream effects of dams. U.S. Geological Survey Circular 1126, Tucson, Arizona.

Day G, Dietrich WE, Rowland JC, Marshall A. 2008. The depositional web on the floodplain of the Fly River, Papua New Guinea. Journal of Geophysical Research 113: F01S02, doi: 10.1029/2006JF000622.

Dubinski IM, Wohl E. 2007. Assessment of coarse sediment mobility in the Black Canyon of the Gunnison River, Colorado. Environmental Management 40: 147–160.

Dunne T, Mertes LAK, Meade RH, Richey JE, Forsberg BR. 1998. Exchanges of sediment between the flood plain and channel of the Amazon River in Brazil. Geological Society of America Bulletin 110: 450–467.

Fitzpatrick FA, Knox JC, Schubauer-Berigan JP. 2009. Channel, floodplain, and wetland responses to flood and overbank sedimentation, 1846–2006, Halfway Creek Marsh, Upper Mississippi Valley, Wisconsin. Geological Society of America Special Papers 451: 23–42.

Florsheim JL, Mount JF. 2002. Restoration of floodplain topography by sand-splay complex formation in response to intentional levee breaches, Lower Cosumnes River, California. Geomorphology 44: 67–94.

Friedman JM, Auble GT. 1999. Mortality of riparian box elder from sediment mobilization and extended inundation. Regulated Rivers 15: 463–476.

Frissell CA, Liss WJ, Warren CE, Hurley MD. 1986. A hierarchical framework for stream habitat classification: viewing streams in a watershed context. Environmental Management 10: 199–214.

Fryirs, KA, Brierley GJ, Preston NJ, Spencer J. 2007. Catchment scale (dis) connectivity in sediment flux in the upper Hunter catchment, New South Wales, Australia. Geomorphology 84: 297–316.

Grant GE, Schmidt JC, Lewis SL. 2003. A geological framework for interpreting downstream effects of dams on rivers. Pages 203–219 in O'Connor JE, Grant GE, eds. A peculiar river: geology, geomorphology, and hydrology of the Deschutes River, Oregon. American Geophysical Union Press.

Goolsby DA, Battaglin WA, Thurman EM. 1993. Occurrence and transport of agricultural chemicals in the Mississippi River basin, July through August 1993. U.S. Geological Survey Circular 1120-C, Washington, D.C.

Guangwei H. 2011. Time lag between reduction of sediment supply and coastal erosion. International Journal of Sediment Research 26: 27–35.

Gurnell AM, Bertoldi W, Corenblit D. 2012. Changing river channels: the roles of hydrological processes, plants and pioneer fluvial landforms in humid temperate, mixed load, gravel bed rivers. Earth-Science Reviews 111: 129–141.

Habersack H, Piégay H. 2008. River restoration in the Alps and their surroundings: past experience and future challenges. Pages 703–737 in Habersack H, Piégay H, Rinaldi M, eds, Gravel-bed rivers VI: from process understanding to river restoration. Elsevier.

Hoehn E, Cirpka OA. 2006. Assessing hyporheic zone dynamics in two alluvial flood plains of the southern Alps using water temperature and tracers. Hydrology and Earth System Sciences Discussions 3: 335–364.

Jacobson RB, Blevins BW, Bitner CJ. 2009. Sediment regime constraints on river restoration – an example from the Lower Missouri River. Pages 1–22 in James LA, Rathburn SL, Whittecar GR, eds., Management and restoration of fluvial systems with broad historical changes and human impacts. Geological Society of America Special Paper 451, Boulder, Colorado.

Jacobson RB, Galat DL. 2008. Design of a naturalized flow regime on the Lower Missouri River. Ecohydrology 1: 81–104.

Jacobson RB, Gran KB. 1999. Gravel routing from widespread, low-intensity landscape disturbance, Current River Basin, Missouri. Earth Surface Processes and Landforms 24: 897–917.

Jones JI, Murphy JF, Collins AL, Sear DA, Naden PS, Armitage PD. 2011. The impact of fine sediment on macro-invertebrates. River Research and Applications 28: 1055–1071.

Kadomura H. 1980. Erosion by human activities in Japan. GeoJournal 4.2: 133–144.

Kao SJ, Milliman JD. 2008. Water and sediment discharge from small mountainous rivers, Taiwan: the roles of lithology, episodic events, and human activities. Journal of Geology 116: 431–448.

Kendy E, Apse A, Blann K. 2012. A practical guide to environmental flows for policy and planning, with nine case studies in the United States. The Nature Conservancy, Arlington, VA.

Kenna TC, Sayles FL. 2002. The distribution and history of nuclear weapons related contamination in sediments from the Ob River, Siberia, as determined by isotopic ratios of plutonium and neptunium. Journal of Environmental Radioactivity 60: 105–137.

Kondolf GM. 2011. Setting goals in river restoration: when and where can the river "heal itself"? Pages 29–43 in Simon A, Bennett SJ, Castro JM, eds. Stream restoration in dynamic fluvial systems: scientific approaches, analyses, and tools. American Geophysical Union Press.

Kondolf GM, Gao Y, Annandale GW, Morris GL, Jiang E, Zhang J, Cao Y, Carling P, Fu K, Guo Q, Hotchkiss R, Peteuil C, Sumi T, Wang H-W, Wang Z, Wei Z, Wu B, Wu C, Yang CT. 2014. Sustainable sediment management in reservoirs and regulated rivers: experiences from five continents. Earth's Future 2: 256–280.

Kondolf GM, Smeltzer MW, Railsback SF. 2001. Design and performance of a channel reconstruction project in a coastal California gravel-bed stream. Environmental Management 28: 761–776.

Lancelot C, Martin J-M, Panin N, Zaitsev Y. 2002. The north-western Black Sea: a pilot site to understand the complex interaction between human activities and the coastal environment. Estuarine, Coastal and Shelf Science 54: 279–283.

Larsen EW, Girvetz EH, Fremier AK. 2007. Landscape level planning in alluvial riparian floodplain ecosystems: using geomorphic modeling to avoid conflicts between human infrastructure and habitat conservation. Landscape and Urban Planning 79: 338–346.

Lisle TE, Hilton S. 1992. The volume of fine sediment in pools: an index of sediment supply in gravel-bed streams. Water Resources Bulletin 28: 371–383.

Lytle DA, Bogan MT, Finn DS. 2008. Evolution of aquatic insect behaviours across a gradient of disturbance predictability. Proceedings of the Royal Society B 275: 453–462.

Meade RH. 2007. Transcontinental moving and storage: the Orinoco and Amazon Rivers transfer the Andes to the Atlantic. Pages 45–63 in Gupta A, ed. Large rivers: geomorphology and management. John Wiley and Sons.

Melis TS, Korman J, Kennedy TA. 2012. Abiotic and biotic responses of the Colorado River to controlled floods at Glen Canyon Dam, Arizona, USA. River Research and Applications 28: 764–776.

Merritt DM. 2013. Reciprocal relations between riparian vegetation, fluvial landforms, and channel processes. Pages 219–243 in Wohl E, ed. Fluvial geomorphology, vol. 9 in Shroder JF, ed. Treatise on geomorphology. Academic Press.

Mertes LAK, Dunne T, Martinelli LA. 1996. Channel-floodplain geomorphology along the Solimões-Amazon River, Brazil. Geological Society of America Bulletin 108: 1089–1107.

NRC (National Research Council). 2011. Missouri River planning – recognizing and incorporating sediment management. National Academy Press, Washington, D.C.

Newcombe CP, MacDonald DD. 1991. Effects of suspended sediments on aquatic ecosystems. North American Journal of Fisheries Management 11: 72–82.

Nilsson C, Berggren K. 2000. Alterations of riparian ecosystems caused by river regulation. BioScience 50: 783–792.

Olden JD, Konrad CP, Melis TS, Kennard MJ, Freeman MC, Mims MC, Bray EN, Gido KB, Hemphill NP, Lytle DA, McMullen LE, Pyron M, Robinson CT, Schmidt JC, Williams JG. 2014. Are large-scale flow experiments informing the science and management of freshwater ecosystems? Frontiers in Ecology and Environment 12: 176–185.

Parker G, Shimizu Y, Wilderson GV, Eke EC, Abad JD, Lauer JW, Paola C, Dietrich WE, Voller VR. 2011. A new framework for modeling the migration of meandering rivers. Earth Surface Processes and Landforms 36: 70–86.

Pizzuto JE, Hession WC, McBride M. 2000. Comparing gravel-bed rivers in paired urban and rural catchments of southeastern Pennsylvania. Geology 28:79–82.

Poff NL, Allan JD, Bai, MB, Karr JR, Prestegaard KL, Richter BD, Sparks RE, Stromberg JC. 1997. The natural flow regime. BioScience 47: 769–784.

Poff NL, Olden JD, Pepin DM, Bledsoe BP. 2006. Placing global stream flow variability in geographic and geomorphic contexts. River Research and Applications 22: 149–166.

Rathburn SL, Rubin ZK, Wohl EE. 2013. Evaluating channel response to an extreme sedimentation event in the context of historical range of variability: upper Colorado River, USA. Earth Surface Processes and Landforms 38: 391–406.

Reid LM, Dunne T. 1996. Rapid evaluation of sediment budgets. Catena, Verlag: Reiskirchen, Germany.

Richter BD, Baumgartner J., Powell J, Braun DP. 1996. A method for assessing hydrologic alteration within ecosystems. Conservation Biology 10: 1163–1174.

Rice SP, Greenwood MT, Joyce CB. 2001. Tributaries, sediment sources, and the longitudinal organisation of macroinvertebrate fauna along river systems. Canadian Journal of Fisheries and Aquatic Sciences 58: 824–840.

Riebe CS, Sklar LS, Overstreet BT, Wooster JK. 2014. Optimal reproduction in salmon spawning substrates linked to grain size and fish length. Water Resources Research 50: 898–918.

Schmidt JC, Wilcock PR. 2008. Metrics for assessing the downstream effects of dams. Water Resources Research 44: W04404, doi:10.1029/2006WR005092.

Shafroth PB, Wilcox AC, Lytle DA, Hickey JT, Andersen DC, Beauchamp VB, Hautzinger A, McMullen LE, Warner A. 2010. Ecosystem effects of environmental flows: modelling and experimental floods in a dryland river. Freshwater Biology 55: 68–85.

Simon A, Rinaldi M. 2013. Disturbance, stream incision, and channel evolution: the roles of excess transport capacity and boundary materials in controlling channel response. Geomorphology 79: 361–383.

Skalak KJ, Benthem AJ, Schenk ER, Hupp CR, Galloway JM, Nustad RA, Wiche GJ. 2013. Large dams and alluvial rivers in the Anthropocene: the impacts of the Garrison and Oahe Dams on the Upper Missouri River. Anthropocene 2: 51–64.

Smith CB. 2011. Adaptive management of the central Platte River – Science, engineering, and decision analysis to assist in the recovery of four species. Journal of Environmental Management 92: 1414–1419.

Soar PJ, Thorne CR. 2001. Channel restoration design for meandering rivers. ERDC/CHL CR-01-1, US Army Corps of Engineers, Engineer Research and Development Center, Flood Damage Reduction Research Program, Vicksburg, MS.

Southwood TRE. 1977. Habitat, the template for ecological strategies? Journal of Animal Ecology 46: 337–365.

Stalnaker C, Lamb BL, Henriksen J, Bovee K, Bartholow J. 1995. The Instream Flow Incremental Methodology: A Primer for IFIM. National Biological Service, US Department of the Interior, Biological Report no. 29, Fort Collins, CO.

Syvitski JPM, Vorosmarty CJ, Kettner AJ, Green P. 2005. Impact of humans on the flux of terrestrial sediment to the global coastal ocean. Science 308: 376–380.

Thakur PK, Laha C, Aggarwal SP. 2012. River bank erosion hazard study of river Ganga, upstream of Farakka barrage using remote sensing and GIS. Natural Hazards 61: 967–987.

Thorne CR. 1997. Channel types and morphological classification. Pages 175–222 in Thorne CR, Hey RD, Newson MD, eds., Applied fluvial geomorphology for river engineering and management. John Wiley and Sons.

Thorne CR, Wallerstein NP, Soar PJ, Brookes A, Wishart D, Biedenharn DS, Gibson SA, Little CD, Mooney DM, Watson CC, Green APE, Coulthard TJ, Van de Wiel MJ. 2011. Accounting for sediment in flood risk management. Pages 87–113 in Pender G, Faulkner H, eds., Flood risk science and management. Wiley-Blackwell.

Trimble SW. 2013. Historical agriculture and soil erosion in the Upper Mississippi Valley Hill Country. CRC Press.

Walter RC, Merritts DJ. 2008. Natural streams and the legacy of water-powered mills. Science 319: 299–304.

Wilcock PR. 2001. Toward a practical method for estimating sediment-transport rates in gravel-bed rivers. Earth Surface Processes and Landforms 26: 1395–1408.

Wilcock P. 2012. Stream restoration in gravel-bed rivers. Pages 137–149 in Church M, Piron BM, Roy AG, eds., Gravel bed rivers: processes, tools, environments. Wiley-Blackwell.

Wilcox AC, Shafroth PB. 2013. Coupled hydrogeomorphic and woody-seedling responses to controlled flood releases in a dryland river. Water Resources Research 49: 2843–2860.

Wilcox AC, Major J, O'Connor J. 2014. Rapid reservoir erosion, hyperconcentrated flow, and downstream deposition triggered by breaching of 38-m-tall Condit Dam, White Salmon River, Washington. Journal of Geophysical Research-Earth Surface DOI: 10.1002/2013JF003073.

Wittmann H, von Blanckenburg F, Maurice L, Guyot JL, Kubik PW. 2011. Recycling of Amazon floodplain sediment quantified by cosmogenic ^{26}Al and ^{10}Be. Geology 39: 467–470.

Wohl E. 2014. Rivers in the landscape: science and management. Wiley-Blackwell.

Wohl EE, Cenderelli DA. 2000. Sediment deposition and transport patterns following a reservoir sediment release. Water Resources Research 36: 319–333.

Wright SA, Schmidt JC, Melis TS, Topping DJ, Rubin DM. 2008. Is there enough sand? Evaluating the fate of Grand Canyon sandbars. GSA Today 18: 4–10.

Yang SL, Milliman JD, Li P, Xu K. 2011. 50,000 dams later: erosion of the Yangtze River and its delta. Global and Planetary Change 75: 14–20.

Zeug SC, Sellheim K, Watry C, Rook B, Hannon J, Zimmerman J, Cox D, Merz J. 2013. Gravel augmentation increases spawning utilization by anadromous salminds: a case study from California, USA. River Research and Applications doi:10.1002/rra.2680.

Ellen Wohl (ellen.wohl@colostate.edu) and Sara L. Rathburn are affiliated with the Department of Geosciences, Brian P. Bledsoe is affiliated with the Department of Civil and Environmental Engineering, and N. LeRoy Poff is affiliated with the Department of Biology at Colorado State University, in Fort Collins. Robert B. Jacobson is affiliated with the US Geological Survey, in Columbia, Missouri. David M. Walters is affiliated with the US Geological Survey's Fort Collins Science Center, in Fort Collins, Colorado. Andrew C. Wilcox is affiliated with the Department of Geosciences, at the University of Montana, in Missoula.

A drone photo shows a home as it teeters before partially collapsing into the Blue Earth River at the Rapidan Dam in Minnesota on June 25. Andrew Weinzierl / AP

ENVIRONMENT

Dams in distress: Partial failure in Minnesota offers a nationwide warning

Almost 4,100 dams are categorized at the same risk level and condition – or worse – as the Rapidan Dam, according to an NBC News analysis.

June 29, 2024, 9:00 AM EDT

By Evan Bush

The partial failure of Minnesota's 114-year-old Rapidan Dam highlights risks that many communities face as the number of dams in disrepair rises and climate change makes rainfall more frequent and severe.

Before the breach, which led floodwaters to carve away at the bank of the Blue Earth River and swallow a waterside home, local leaders in Blue Earth County, Minnesota, had been contemplating whether to tear down the old structure or perform costly long-term repairs. Regulators considered the dam a "significant" hazard, and it was graded as in "poor" condition as of April 2023, according to the National Inventory of Dams.

Almost 4,100 dams are categorized at the same risk level and condition – or worse – according to an NBC News analysis of the inventory's data. Every state has at least one such dam. Ohio has the most at 373.

As a whole, America's dams – more than 91,000 in total – are aging. Many need expensive rehabilitation. Few were designed for today's climate, with a warmer atmosphere that can hold – and dump – more water. The number of people living in inundation zones below these dams continues to grow.

Heavy rains cause high water levels at the Rapidan Dam near Mankato, Minnesota, on Monday.

Mark Vancleave / AP

The average U.S. dam is 57 years old, and dam safety experts say the pace of investment has been too slow to keep the infrastructure up to the standards it was built for, much less for worsening climate hazards.

“It’s falling behind,” said Sharon Tapia, president of the Association of State Dam Safety Officials. “We’re in a situation where we’re seeing more and more dams needing to be rehabilitated or repaired to meet current standards.”

The association estimated in a report last year that it would take $157.5 billion to bring nonfederal U.S. dams up to par. That pertains just to today’s safety standards – it does not factor in enhancements to address additional, future risks from climate change, she said.

President Joe Biden’s 2021 infrastructure bill included $3 billion for dam safety projects – a sliver in comparison to the overall need.

It’s too early for scientists to say whether global warming played a role in the Rapidan Dam’s partial failure, but it made the conditions that led to it more likely.

For every degree Fahrenheit of warming, the atmosphere can hold and deliver about 3% to 4% more moisture, giving storms a stronger punch and making rainfall totals that were once considered rare much more common. That, in turn, raises the risk of devastating floods.

Views of the Rapidan Dam on Sept. 6, 2011, and on June 26, after floodwaters overcame parts of the structure. Maxar Technologies via AP

The Rapidan Dam, built in 1910 and managed by Blue Earth County, was described on the county's website as in a "state of disrepair." After flooding in 2019 and 2020, a power generation company stopped leasing the dam, leaving it without a hydropower operator.

But the Federal Energy Regulatory Commission, which regulates the dam, was not overly concerned about the structure's integrity as recently as last month. According to FERC documents, the dam was inspected May 21 and "found to be in overall satisfactory condition."

"No major dam safety deficiencies were observed that would require immediate remedial action," the letter said, though it noted severe concrete deterioration, exposed rebar and cracking that it said should be closely monitored.

The inspection, an analysis of the structure's safety and stability, was separate from the assessment by the National Inventory of Dams, which considers the full performance of the project, a FERC spokesperson said.

Blue Earth County officials had been weighing whether to remove the dam, at a cost of more than $82 million, or repair it for around $15 million. Both options had downsides: Repairs might only last 40 years, while removal could take five years to plan and secure permits, according to engineering documents from 2021. A county spokesperson said officials were not able to respond to questions, beyond providing updates at news conferences.

A riverside home seen on Tuesday before it partially collapsed, near at the Rapidan Dam in Minnesota. Andrew Weinzierl / AW Aerial via AP

The dam's partial failure came after three days of intense rainfall that left the Minnesota River at its third-highest flood height since at least 1881, according to Brennan Dettmann, a National Weather Service meteorologist based in the Twin Cities. The Blue Earth River flows into the Minnesota River.

In the Mankato area, where the dam is located, 7 to 8 inches of rain fell over three days, based on an analysis from Kenny Blumenfeld, a senior climatologist at the Minnesota State Climate Office.

“That elbow of the Minnesota River got hit pretty hard,” he said, adding that in southern Minnesota, such heavy rainfall would have between a .5% and 2% chance of happening each year.

Floods batter the Midwest as concerns grow over Minnesota dam

04:14

Bill McCormick, who led the state of Colorado’s dam safety program from 2011 to 2021, said that extreme rainfall has added strain across the nation.

“We’re getting more frequent, intense storms that are testing the aging infrastructure. Spillways and dams that maybe didn’t see as many storms in a given year are now seeing more storms,” he said. “All those aging systems are now being tested more and more.”

Housing development is raising hazard levels for some dams, too, McCormick added, as people settle in once-rural areas, where dams constructed for farmland are now guarding subdivisions.

Hiba Baroud, an assistant professor of civil and environmental engineering at Vanderbilt University, said the Rapidan’s partial failure, among others, should prompt lawmakers to take a hard look at how to bolster dam infrastructure and triage repairs.

"We really need to think proactively to project potential scenarios for all the dams in the U.S. and start prioritizing which dams need to be rehabilitated or upgraded to avoid a situation like this," she said, "as opposed to witnessing a big event and using it as a wake-up call about this particular dam."

Floodwaters continue to carve a channel around the Rapidan Dam on Thursday.

Mark Vancleave / AP

From 2013 to 2023, 283 dams in the U.S. experienced some kind of failure, according to data provided by the Association of State Dam Safety Officials and analyzed by NBC News. Some didn't cause sizable problems, but others had grave consequences. In 2019, a blizzard precipitated a dam failure that washed away the home of a Nebraska man, drowning him.

Tapia said dam rehabilitation is too often constrained by insufficient funding and lengthy environmental permitting processes.

"They're just taking too long to get fixed because of the funding issues and the permitting issues," she said. "The engineering is typically the easiest part."

Evan Bush
Evan Bush is a science reporter for NBC News.

Exhibit C

Sho-Me Power Electric Cooperative

A Touchstone Energy® Cooperative

THE NEXT CHAPTER

ANNUAL REPORT

The Passing Of The Torch

2023

TABLE OF CONTENTS

OUR MISSION

Sho-Me Power and its employees are dedicated to providing safe, reliable, low cost power and communication services to the members we serve which improves the quality of life for their members.

ABOUT US

STRUCTURE

The Missouri Cooperative Structure consists of four levels: Generation, Transmission, Distribution and the ultimate consumer, or member. The Generation Cooperative creates the power, the Transmission Cooperative delivers the power to a distribution substation, and the Distribution Cooperative then provides the power to the member-owner for final use.

The rural residents of Missouri came together in the 1930's to form local distribution cooperatives. Transmission cooperatives like Sho-Me Power were formed by their distribution cooperative owners in the 1940's to connect to various power sources. In the 1960's the transmission cooperatives banded together to create a generation cooperative, Associated Electric Cooperative, Inc. (AECI).

ORGANIZATION

The predecessors of Sho-Me Power Electric Cooperative were Sho-Me Power Cooperative, formed in 1941 as an agriculture cooperative, followed by Sho-Me Power Corporation, incorporated in 1947 as a public utility. This corporate entity, fully regulated by the Missouri Public Service Commission (MoPSC), provided wholesale electric service to its nine-member distribution cooperatives as well as retail electric service to many communities until 1984, when the remaining facilities serving retail consumers were sold to four rural electric cooperatives (REC). In 1992 the Missouri Secretary of State allowed Sho-Me Power to be converted pursuant to the provisions of the Rural Electric Cooperative Act, Chapter 394, specifically §394.070 of the Revised Statutes of Missouri, 1989, as amended, and since February 27, 1992, the name has been Sho-Me Power Electric Cooperative. In September 1993 the MoPSC released Sho-Me Power from its rate regulation, leaving it free to be regulated by its nine REC member-owners.

Sho-Me Power, a Generation and Transmission type Electric Cooperative, serves nine distribution cooperatives across 26 counties in south-central Missouri.

SHO-ME TECHNOLOGIES

Sho-Me Technologies, L.L.C. is a subsidiary of Sho-Me Power Electric Cooperative which was formed in 1997 to operate an advanced optical network providing state of the art communications services to the rural electric members and beyond.

Today, Sho-Me Technologies' optical network covers most of Missouri, crossing major rivers and spanning the region both in the air and underground. What began as an upgrade to the extensive internal communications network has now grown to encompass over 8,000 miles of fiber optic connectivity. With 138 communities served, Sho-Me Technologies boasts the highest coverage of optical bandwidth to rural Missouri.

TRANSMISSION

Sho-Me Power provides service to 158 delivery points served by 156 distribution and transmission substations through 1,044 miles of 69 kV, 11 miles of 138 kV, and 419 miles of 161 kV electrical transmission line. Additionally, Sho-Me operates and maintains 139 miles of 161 kV transmission line owned by Central Electric Cooperative, headquartered in Jefferson City, Missouri, and approximately 228 miles of 345 kV line and three 345/161 kV substations with a combined capacity of 1,440,000 kVA owned by AECI, headquartered in Springfield, Missouri.

POWER SUPPLY

Sho-Me's power needs are provided through an all requirements contract with Associated Electric Cooperative that extends through May, 2050.

Sho-Me Power is an equal opportunity provider and employer.

JOHN RICHARDS RETIRES

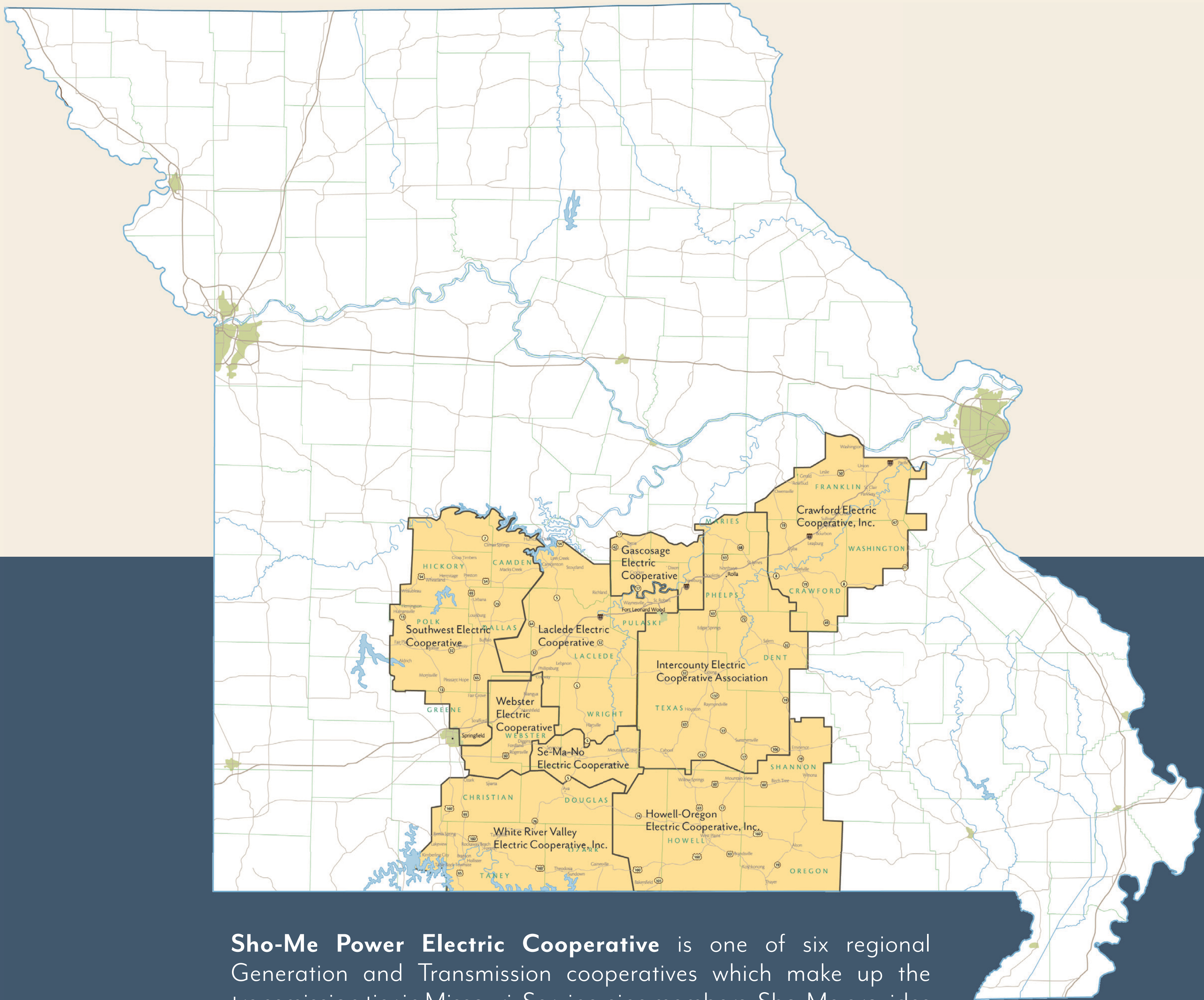
After 48 years at Sho-Me Power, CEO/ General Manager John Richards announced his retirement in 2023.

John began his career with Sho-Me Power in September 1975 as a supervisor trainee in the accounting department. Less than a year later, John was promoted to an accountant, and in 1979, he became the Manager of Finance, later referred to as Chief Financial Officer, a position he would hold for 37 years. In 2016, John was appointed by Sho-Me Power's board of directors to become the Cooperative's fifth CEO and General Manager.

John graduated college in 1975 after studying accounting at Missouri Southern State College and University of Tulsa. He later received his Master of Business Administration from Drury University in 1978. While in school, John interned for KAMO Power and was later hired on full-time before joining Sho-Me Power.

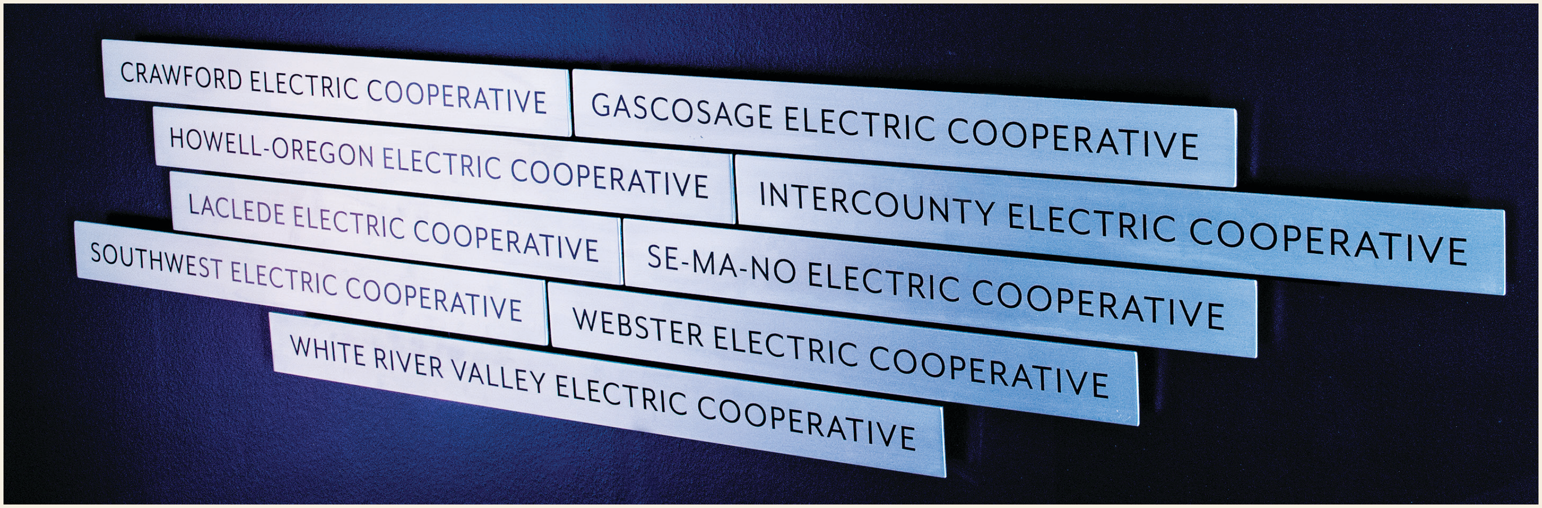
In his retirement, John most looks forward to spending more time with his four granddaughters, traveling with his wife, and golfing. The Board of Directors, Staff, and Employees of Sho-Me all thank John for his 48 years of dedication and leadership and wish him all the best in retirement.

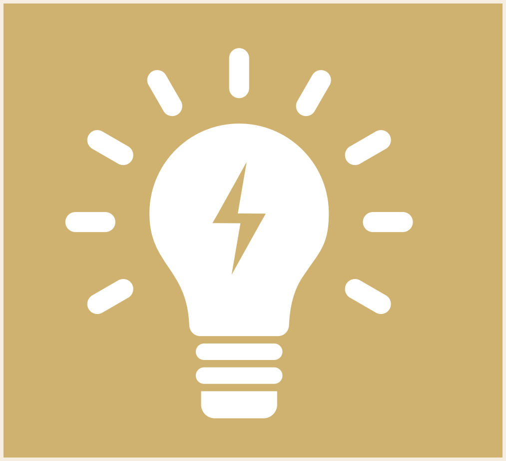

NEMESIS
WHERE WE SERVE



Sho-Me Power Electric Cooperative is one of six regional Generation and Transmission cooperatives which make up the transmission tier in Missouri. Serving nine members, Sho-Me provides power for 170,300 ultimate meters from 158 delivery points via 1,842 miles of energized transmission line.

WHO WE SERVE





9
MEMBER COOPERATIVES

26
COUNTIES SERVED

170,300
ULTIMATE MEMBERS

BOARD OF DIRECTORS

BOARD OF DIRECTORS

John Campbell
President
Se-Ma-No Electric

Dan Singletary
Vice President
Howell-Oregon Electric

Matt Duncan
Secretary Treasurer
Intercounty Electric

Gary Mullen
Crawford Electric

Carmen Hartwell
Gascosage Electric

Melvin Hoffman
Laclede Electric

Jack Bybee
Southwest Electric

Tom Houston
Webster Electric

Chris Hamon
White River Electric


MEMBER MANAGERS

MEMBER MANAGERS

Tony Mallory
CEO/General Manager
Crawford Electric Cooperative, Inc.

Carmen Hartwell
CEO/General Manager
Gascosage Electric Cooperative

Dan Singletary
CEO/General Manager
Howell-Oregon Electric Cooperative, Inc.

Doug Lane
CEO/General Manager
Intercounty Electric Cooperative Association

Terry Rosenthal
CEO/General Manager
Laclede Electric Cooperative

Dan Sisco
General Manager
Se-Ma-No Electric Cooperative

James Ashworth
CEO/General Manager
Southwest Electric Cooperative

Tom Houston
General Manager
Webster Electric Cooperative

Chris Hamon
CEO
White River Valley Electric Cooperative, Inc.

SENIOR STAFF

OUR LEADERSHIP TEAM

Jason L. Marshall
Chief Executive Officer
& General Manager

2023 turned a new chapter in the history of Sho-Me Power with the board selecting Jason Marshall to be the sixth CEO/General Manager of Sho-Me. With a proven track record of developing and managing electric transmission systems, Jason brings a wealth of experience and expertise that will undoubtedly continue Sho-Me's mission of providing safe, reliable, low-cost power and telecommunication services.

Jason comes to us from Wabash Valley Power where he served as the Executive Vice President, Transmission and Regulatory Affairs. Jason has extensive experience in the energy industry working for a generation and transmission cooperative, regional transmission organization, energy risk management firm, and an investor-owned utility.

Jason has a bachelor's degree in electrical engineering from Rose-Hulman Institute of Technology, a Master's in Electrical Engineering from Clemson University and an MBA from the University of Indianapolis. Jason has served on the boards of the SERC Reliability Corp. and ReliabilityFirst, and currently serves on the North American Electric Reliability Corporation (NERC) Member Representatives Committee.

SENIOR STAFF

Cindy Keeler
Executive & HR Assistant

Chris Bolick
Chief Operating Officer

Peter Dawson
Chief Compliance Officer

Rebecca Gunn
Human Resource Director

Micah Johnson
Chief Information Officer

Kari Harles
Chief Telecommunications Officer

Erica Lafferty
Chief Financial Officer

Tim Lewis
Member Service & Corporate Communications Director

"Find a group of people who challenge and inspire you, spend a lot of time with them, and it will change your life."

\- Amy Poehler

MESSAGE TO OUR MEMBERS

The Next Chapter. As we contemplated the theme for this year's annual report, the analogy of turning the page in a book to discover you have completed one chapter and are eager to see what the next chapter holds seemed most appropriate. The story of Sho-Me Power has been a great one so far. Sho-Me Power has safely and reliably provided low-cost power and communication services for more than eight decades, most recently under the leadership of John Richards who retired after a storied 48-year career. But the story is far from over as we face many continuing and new challenges. Our infrastructure is aging. Load growth and electrification of the economy are creating the need for additional generation and transmission capacity. Rural America needs more telecommunication capabilities to enhance opportunities for economic development. Cyber and physical security threats are constantly evolving and becoming more challenging to thwart. Many in our work force are nearing retirement age. Balancing reliability and affordability will be daunting while addressing all these challenges, and we believe history has proven that Sho-Me Power is well-suited to rising to them. We thank John Richards for his leadership of the cooperative over the past eight years, setting a strong foundation for the future, and congratulate him on his retirement.

While we faced our fair share of challenges in 2023, Sho-Me Power's performance was strong. Financially, results improved significantly compared to 2022. Net margins increased driven by sound financial discipline, Sho-Me Tech's continued strong performance, and improved net margins from Associated. Notwithstanding the strong performance, the board did authorize a 10% increase in rates to address cost increases in power supply and financial needs driven by transmission construction and to ensure Sho-Me Power remains a financially strong cooperative. The board demonstrated through their decision that a financially sound Sho-Me Power is important to the success of their cooperatives, and we thank them for their leadership in this tough but important decision. Even with this rate increase, Sho-Me Power's rates are the lowest in the state among its sister G&Ts and remain among the lowest in the nation.

Sho-Me Power demonstrated a focus on operational excellence in 2023 which supports the balance between reliability and affordability. Power was available to our members at the substation 99.9957% of the time. Maintenance activities to prolong the life, replace damaged or recalled equipment, and prevent unexpected failures supported this level of reliability, in addition to creative low-cost transmission reinforcements. While working with Associated Electric planning future transmission facilities, necessary transmission upgrades were identified crucial to maintaining and improving this level of reliability.

Sho-Me Technologies continued to demonstrate its capabilities as the premier middle-mile provider of telecom services. Revenues exceeded 2022 and net margins exceeded budget, offsetting some of Sho-Me Power's costs and allowing it to continue to be a low-cost provider of power. Sho-Me Technologies continued to expand its network by adding 46 miles of fiber while upgrading communications equipment to continue meeting our mission.

Serving as your President for the last year and being selected as your new CEO & General Manager has been an honor and privilege for us, and we thank the board for their dedicated service and commitment to maintaining a financially strong cooperative and the employees for their commitment to excellence. We anticipate the next chapter with excitement and look forward to the story as it unfolds. Together we will accomplish great things.

John Campbell
President

Jason L. Marshall
CEO/General Manager

COOPERATIVES IN THE COMMUNITY

INDUSTRY
COMMERCIAL
MANUFACTURING
PROPERTY
MACHINERY
ELECTRONICS
CONSUMER GOODS
TRANSPORTATION
GOVERNMENT
EDUCATION
AGRICULTURE
RESIDENTIAL
SMALL BUSINESS
CONSTRUCTION
FORESTRY
FOOD SERVICES
TOURISM
HEALTHCARE

FINANCIALS

FACTS & FIGURES

Sho-Me Power exceeded expectations with net margins reaching $9.3 million in 2023, significantly surpassing the budgeted amount. Several factors contributed to the variance between actual and budgeted net margins.

Electric revenues for the year totaled $181.8 million, slightly below the budgeted $185.2 million due to lower-than-expected electric sales caused by mild weather conditions. This weather also led to reduced Purchased Power costs from Associated Electric Cooperative, Inc. (AECI), resulting in a decrease of approximately $200,000 in net margins.

Other variances in 2023 included approximately $1.7 million less in Transmission Operations and Maintenance expense, as well as Administrative and General expense. These reductions were mainly due to more labor and materials being capitalized rather than expensed during the year. Additionally, higher-than-anticipated Interest Expense and Interest Income led to a further $100,000 decrease in net margins, attributed to higher interest rates in 2023.

Sho-Me Technologies also contributed to Sho-Me Power's net margins, performing better than expected due to lower operating expenses, particularly in Depreciation and Property Tax expenses. Reduced Depreciation expenses stemmed from decreased capitalization of labor and materials. Property Tax expenses were lower due to a reduction in the state's tax assessment factor. These variances added $240,000 to net margins.

Despite various factors influencing margins, the main driver for the higher-than-expected net margins was AECI's patronage allocation to Sho-Me Power for 2023. Initially budgeted at $8.3 million, this allocation increased to $13.1 million due to AECI's improved financial performance.

Significant construction activities related to utility and telecommunications plants were undertaken by both Sho-Me Power and Sho-Me Technologies in 2023, impacting the cash needs. Sho-Me Power increased its lines of credit and began drawing down on them, while also submitting a Rural Utilities Service (RUS) loan application for $129 million, expected to be approved in the second quarter of 2024. Final approval of the RUS loan will alleviate the need for extensive reliance on lines of credit.

Overall, 2023 was another financially successful year for Sho-Me Power and Sho-Me Technologies, aligning with their commitment to providing safe, reliable, and low-cost power and communication services to their members. Consequently, Sho-Me Power met its Indenture requirements by year-end 2023.

$194.1

Million in Operating Revenue

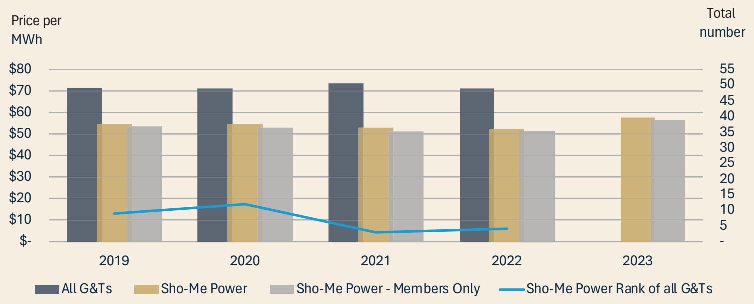
$478.8

Million in Consolidated Assets

45.05%

Consolidated Equity Ratio

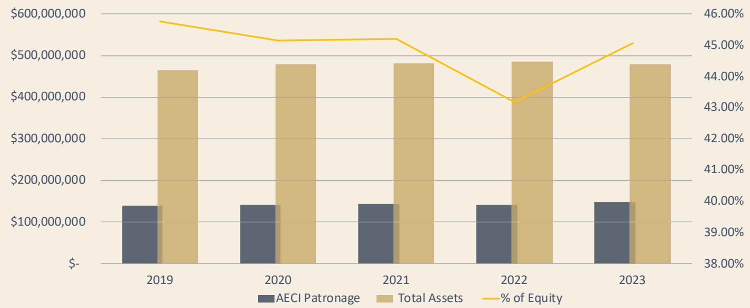
AVERAGE RATE PER MWH



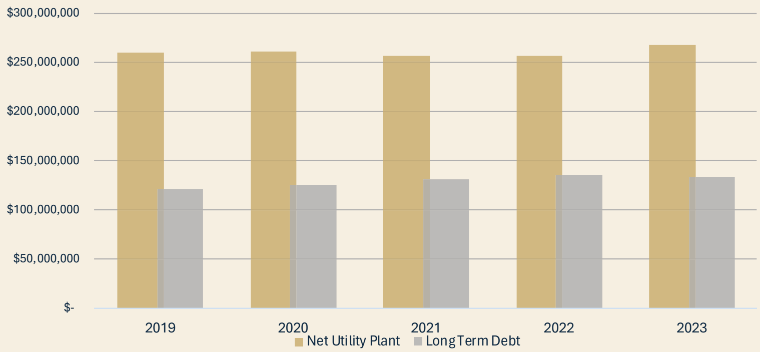
Information provided by G&T Accounting and Finance Association

**2023 G&T information not yet available*

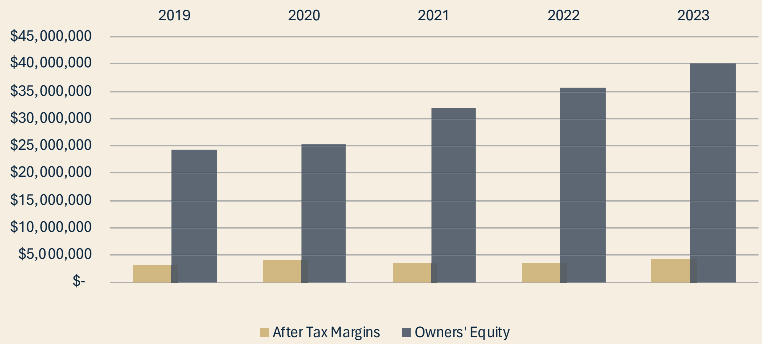
REC MEMBER EQUITY



NET UTILITY & LONG TERM DEBT



SHO-ME TECHNOLOGIES ANNUAL MARGINS & TOTAL EQUITY



$3.5

Million Capital Credit Retirements to Member-Owners

5.63¢

Per Kilowatt-Hour to Member-Owners

3.2

Billions Kilowatt-Hours Sold

FACTS & FIGURES

CONSOLIDATED SUMMARY OF OPERATION	2019	2020	2021	2022	2023
Operating Revenue:					
Electric Revenue	$ 185,134	$ 171,836	$ 176,952	$ 187,429	$ 194,070
Telecom Revenue	35,135	36,119	37,355	37,106	37,237
Total Operating Revenue	220,269	207,955	214,307	224,535	231,307
Operating Expenses:					
Purchased Power, Net of Pooling Credits	145,772	137,734	143,657	151,687	156,977
Other Operating Expenses	72,868	72,158	74,481	77,990	79,879
Total Operating Expenses	218,640	209,892	218,138	229,677	236,856
Operating Margins	1,629	(1,937)	(3,831)	(5,142)	(5,549)
Non-Operating Margins	2,080	1,348	1,119	1,076	1,178
Margins Before G&T Capital Credits	3,709	(589)	(2,712)	(4,066)	(4,371)
G&T Capital Credits	8,337	8,560	8,591	4,088	13,146
Margins Before Income Taxes	12,046	7,971	5,879	22	8,775
Income Tax Expense	(1,808)	(2,529)	(2,001)	(34)	(525)
Net Margins	$ 13,854	$ 10,500	$ 7,880	$ 56	$ 9,300

CONSOLIDATED BALANCE SHEET SUMMARY	2019	2020	2021	2022	2023
Assets					
Net Utility Plant	$ 259,980	$ 261,063	$ 257,310	$ 256,427	$ 268,018
Investments	159,897	177,215	179,593	176,289	167,558
Other Assets	43,764	40,260	43,615	53,110	43,265
Total Assets	$ 463,641	$ 478,538	$ 480,518	$ 485,826	$ 478,841
Liabilities and Equity					
Members' Equity	$ 212,144	$ 216,054	$ 217,082	$ 209,750	$ 215,711
Long Term Debt	120,980	125,936	131,149	135,666	133,198
Other Liabilities	130,517	136,548	132,287	140,410	129,932
Total Liabilities and Equity	$ 463,641	$ 478,538	$ 480,518	$ 485,826	$ 478,841

CONSOLIDATED CASH FLOWS SUMMARY	2019	2020	2021	2022	2023
Net Cash					
Provided By Operating Activities	$ 26,790	$ 28,591	$ 18,213	$ 17,845	$ (6,881)
Used In Investing Activities	(6,874)	(29,500)	(10,481)	(13,809)	(9,442)
Provided By (Used In) Financing Activities	(18,067)	(105)	(1,104)	(3,149)	7,482
Net Increase (Decrease) In Cash and Cash Equivalents	1,849	(1,014)	6,628	887	(8,841)
Cash and Cash Equivalents At Beginning of Year	1,295	3,144	2,130	8,758	9,645
Cash and Cash Equivalents At End of Year	$ 3,144	$ 2,130	$ 8,758	$ 9,645	$ 804

ADDITIONAL INFORMATION	2019	2020	2021	2022	2023
Margins for Interest - MFI (Required 1.10)*	3.25	2.40	1.97	1.65	1.59
Debt Service Coverage - DSC (Required 1.00)*	3.75	3.61	3.70	2.86	3.54
Energy Sales - MWh					
Member REC Sales	2,948,336	2,859,040	2,928,591	3,131,789	2,924,967
Other	252,139	246,148	244,957	243,102	227,991
Total Energy Sales	3,200,475	3,105,188	3,173,548	3,374,891	3,152,958
Systems Peaks - MW					
Winter	783	751	943	994	722
Summer	643	633	658	712	713

All dollars in thousands

Year ending December 31st, 2023

* Ratios are calculated per Sho-Me Power's Indenture requirements.

PROJECTS

REVITALIZING THE GRID

STRATEGIES FOR UPGRADINGAGING TRANSMISSION LINES

Of the 1,842 miles of transmission line Sho-Me operates and maintains, most of the lines were built 50 to 70 years ago (462 miles during the 1950's, 392 miles during the 1960's, and 357 miles during the 1970's). With good maintenance, the conductor, hardware, and poles will typically last between 50 and 75 years. After analysis by helicopter aerial inspections, bi-annual foot patrols, and Light Detection and Ranging (LiDar) on these aging lines, it was determined that complete replacement would be the recommended approach for those lines exceeding useful life.

As part of Sho-Me's four year work plans, the goal is to energize 60 miles of rebuilt lines per year. Priority for rebuilds will depend on the age of the line, clearance concerns, maintenance issues, and reliability metrics. Utilizing Rural Utility Service funding for utility plant additions, by 2038 all lines on the Sho-Me system will not exceed their useful life of 75 years of age.

PROJECTS

While Sho-Me Tech sells fiber optic services to retail customers such as banks, hospitals, and other businesses, the majority of Sho-Me Tech's income comes from selling services to other telecom providers. In addition, Sho-Me Tech uses other telecom providers to reach customers outside of our area or where we don't have fiber optic facilities in order to maintain the lowest cost possible. Finding potential providers to serve our needs and introducing telecom providers to the services we provide is sometimes a daunting task.

In 2023, Sho-Me Tech began utilizing Connectbase to help solve this problem. A database used by the telecom industry to help solve connectivity issues, Connectbase serves as a partner to the industry, providing automated tools to help telecom providers fill gaps within their networks and allowing service providers to connect and share data. By revamping what used to be a slow, manual, and labor-intensive process, Connectbase has allowed us to identify our market footprint, set pricing, and communicate serviceability to partners, transforming the way connectivity is bought and sold.

In our 2021 Annual Report, we shared our involvement with Cyber Dome, which provides threat detection, rapid response, and mutual assistance for cyber security threats and events across the three-tiered system. By the time of this current report, all nine of Sho-Me's members are now participating in Cyber Dome, and there are 50 cooperatives across the family who have been onboarded with the project.

The six G&T's and AECI have developed a "Cyber Dome Goal" to serve as a mission statement:

> *The goal of Cyber Dome is to defend, detect, and respond to elements that threaten cyber security, and thus the reliability of the three-tiered system.*

As Cyber Dome matures and handles more incidents, having a strong cooperative value system will help remove political risk and increase the speed in which co-ops are assisted with an IR (Incident Response) event. The values of Cyber Dome are to overcommunicate with clarity while maintaining transparency. This means while Cyber Dome itself defaults to transparency with respect to HOW we do things (processes, procedures, etc.), individual member data is kept private and communication systems are created to involve all three tiers: AECI, G&Ts, and co-ops.

TRANSMISSION PLANNING ANALYSIS

A LONG RANGE PLAN

AECI prepares a coordinated ten-year transmission system plan every two years as a guide for ensuring future reliability. This Long-Range Plan (LRP) serves as a reference document for G&T construction work plans and the basis and technical reference for RUS loan requests, while also providing an indication of future costs for financial planning. Requiring coordination with the G&T Operations Committee, neighboring utilities, adjacent Regional Transmission Organization (RTOs), and other stakeholders, the LRP process is open and transparent.

Historically, LRP studies have anticipated future transmission system upgrades based on firm load, generation, and transfers. In 2023, however, Sensitivity Cases were also included, considering variable resources, generation retirements, and changes in transmission flows that impact the AECI transmission system. Significant system improvements included for Sho-Me in the LRP were the installation of two 84MVA 161/69kV transformers at the Crocker substation, the upgrade of both West Plains substations to 112 MVA units, and a rebuild of the Protem to Gainesville 69kV line as a 161kV line.

ENSURING RESILIENCE

DESIGNING EMERGENCY SUBSTATIONS FOR POWER CONTINUITY

Sho-Me's Hartville substation, which serves over 1,800 meters, is currently supplied by a 10.4-mile radial 69kV line from Mansfield, the only transmission source for the substation. Constructed 52 years ago, and with two miles of the line located just outside of Mansfield on structures with multiple 69kV circuits, this line often requires difficult maintenance. To address these concerns, a unique solution was developed.

With a 161kV mobile transformer installed at a backup power location five miles west of the Hartville substation, Sho-Me will utilize Laclede's three-phase feeder that crosses under Sho-Me's 161kV line. The entire load can be served with this feeder at Hartville, and the backup site could be used for planned maintenance activities to avoid lengthy member outages. Laclede will route a quarter-mile, 3-phase feeder tap to the backup site for delivery of power back to the Hartville substation.

This mobile backup substation will be substantially scaled down from a normal Sho-Me distribution substation, with no high voltage or low voltage equipment, reducing the cost of the substation to an estimated $317,000. The planned in-service date for this substation is June 2024.

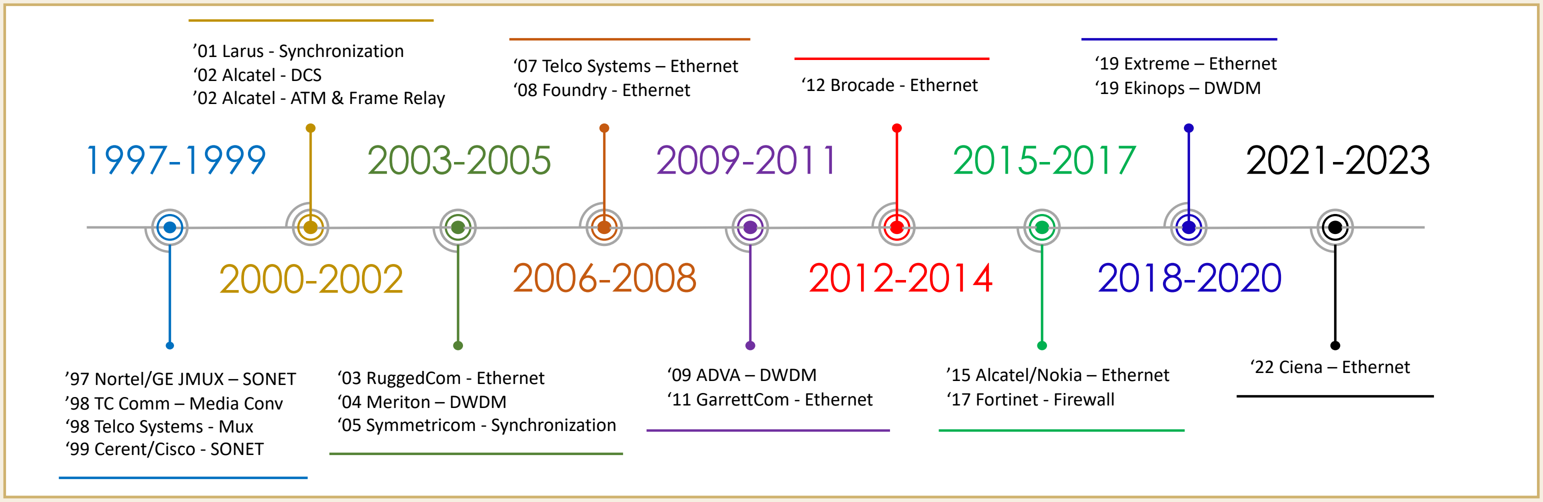
FIBER FAST-TRACK

UNLEASHING HIGH-SPEED ETHERNET UPGRADES

Since its beginning, Sho-Me Tech has offered our customers the ability to use Ethernet to move data between their locations. Ethernet was initially utilized with local area networks, with its use as a method of transport between cities coming much later. Sho-Me Tech offered this type of service in our area before any other telecommunications carriers. Due to strict service level agreements on cellular traffic, two separate networks are implemented for delivering Ethernet services: cellular and non-cellular. When building networks, Sho-Me Tech does not intermingle cellular sites with other types of businesses.

Twelve years ago, Sho-Me Tech began establishing its 4th generation network to provide Ethernet services to non-cellular customers. This service was provided by a three-tier network consisting of access, aggregation, and core. Operating at 10Gb/s, the aggregation and core networks connected approximately 700 locations via 100 access networks statewide.

In 2022, due to network demand, a 5th generation non-cellular network was deemed necessary to support 400Gb/s speeds in the core, 200Gb/s in the aggregation layer, and 25Gb/s to 100Gb/s in the access layer. Ciena was chosen as the preferred vendor for this 5th generation non-cellular network. Between October and December of 2023, 82 Ciena nodes were commissioned to complete the core and aggregation layers. In 2024, the remaining nodes will be deployed to complete this 5th generation network.



BALANCING PROGRESS

NAVIGATING ENVIRONMENTAL REVIEWS FOR POWER PROJECTS

As a federal borrower, Sho-Me is subject to the National Environmental Policy Act (NEPA), National Historic Preservation Act (NHPA), the Endangered Species Act (ESA), and several other federal and state environmental regulations. Environmental permitting is made more complex because Sho-Me's service territory includes numerous crossings through the Forest Service (USFS), US Army Corps of Engineers (USACE), and Park Service (US Department of Interior). Through participation with the Environmental Policy Council of the G&T Managers' Association and with NRECA, Sho-Me's Environmental personnel have advocated for proposed rulemakings to relieve some of the burdensome requirements. In the meantime, by partnering with respected entities such as Missouri State University's Center for Archaeological Research for field surveys, Sho-Me continues to try to avoid lengthy delays or lead times and increased project costs due to rapidly changing environmental guidelines.

COLLECTIVE SOLUTIONS

COOPERATION AMONG COOPERATIVES

After completion of the project to add a 138kV terminal into the existing 69kV distribution substation, the Macedonia 138/69kV 56MVA transformer took load for the first time on June 27, 2022. Less than a month later, the new transformer failed and was taken out of service.

Transformers are typically reliable for decades of service, but this unexpected repair meant taking the unit from the substation to ship it back to the manufacturer under warranty, leaving Sho-Me without a needed 138kV source in the Rolla area for a prolonged period. Fortunately, AECI and the G&Ts have long collaborated on maintaining joint spares for the higher voltage transmission transformers. Sho-Me crews traveled to Bristow, Oklahoma to assist in the disassembly and testing of the spare unit alongside KAMO crews, a great exercise in cooperation as these crews worked side by side. This spare transformer arrived at Macedonia on November 29 and was put into service on December 19, barely in time before winter storm Elliott arrived on December 23.

In May of 2023, work began to swap out the spare unit as the repaired unit arrived from the factory. Less than a month later, the repaired unit was placed in service and the spare was returned to KAMO.

SMART GRIDS, SMARTER DECISIONS

THE ROLE OF AI IN COOPERATIVES

Electric cooperatives are actively embracing artificial intelligence (AI) to enhance their operations, improve member services, and foster a resilient energy system. AI can be used to augment work, both directly and through third party applications and services, helping with tasks like writing policies and procedures, contracts, and legal documents. In vegetation management, AI is used to identify hotspots. A hotspot area typically refers to a location along the right-of-way where vegetation control is particularly challenging or critical. Using AI to identify these areas significantly reduces right of way management costs by pinpointing the use of resources with a logical approach.

AI can also be used by IT and cybersecurity teams to assist with writing code and queries, detecting anomalies, identifying threats, preventing cyberattacks, and automating processes. In addition, Sho-Me's Media Team uses AI in graphics, communications, and video development. Some of the content of this annual report was generated using the assistance of AI.

While exploring the ways that AI can help productivity, Sho-Me remains committed to ensuring that AI is used in an ethical manner and company data is protected. To assuage concerns about overreliance on AI responses and data privacy and integrity, thoughtful planning, policy implementation, and employee training are ways Sho-Me is preparing to maneuver these exciting new challenges.

NAVIGATING THE SKIES

HOW DRONES ARE REVOLUTIONIZING UTILITY ASSET MANAGEMENT

For several years, Sho-Me Power has used drones to get a different viewpoint in the inspection and preventative maintenance of the system. From inspecting lines from a bird's eye view, to using infrared cameras to detect potential issues, Sho-Me's fleet of drones has proven to be valuable in providing safe, low cost, and reliable power.

The Federal Aviation Administration (FAA) regulates drone operations in the United States and the Small Unmanned Aircraft System Rule (Part 107) outlines the requirements for commercial drone pilots. Utility employees conducting drone operations fall under this commercial category, and compliance with Part 107 is mandatory. Currently, Sho-Me has 17 licensed operators with 7 drones in the fleet. Obtaining an FAA Remote Pilot Certificate ensures that our drone operators understand aviation rules, safety procedures, and airspace regulations.

Our crews have several tools in their toolbox that help keep the lights on for our members. The use of drones is another great tool at hand, playing a critical role in operations, routine inspections, and infrastructure management.

FROM NAMEPLATES TO REALITIES

THE JOURNEY OF FACILITY RATINGS

NERC's FAC-008 standard requires utilities to ensure that Facility Ratings used in the planning and operation of the Bulk Electric System match the ratings of all equipment in the field at any given time. Recent audits and field verifications have identified multiple instances of discrepancies between documented equipment and/or Facility Ratings and actual field conditions across much of the electric transmission industry, making compliance difficult for many utilities.

Sho-Me personnel performed field verifications on all substations operating at 200kV and above as part of a Facility Ratings mitigation plan being enacted across the industry. Members of Sho-Me's Substation and Meter & Relay crews worked to identify differences between software data and field data, and minor discrepancies on substation jumpers and current transformers were updated with no notable impact to reliability. All substations 100kV and higher will be required to undergo field verification on no less than a five-year basis going forward.

ELECTRIC COOPERATIVES
SERVING OUR MEMBERS

Electric cooperatives and the communities they serve share a reciprocal relationship. The cooperative provides essential services and support, while the community actively participates in the cooperative's governance and contributes to its success. This collaborative approach fosters a sense of ownership, responsibility, and shared purpose, ultimately leading to a stronger and more vibrant community.

Seven Cooperative Principles:

01 **Open and Voluntary Membership:** Membership in a cooperative is open to all people who can reasonably use its services and are willing to accept the responsibilities of membership.

02 **Democratic Member Control:** Cooperatives are democratic organizations controlled by their members. Members actively participate in setting policies and making decisions.

03 **Members' Economic Participation:** Members contribute equitably to, and democratically control, the capital of their cooperative.

04 **Autonomy and Independence:** Cooperatives are autonomous, self-help organizations controlled by their members following the co-op values of self-responsibility, democracy, and self-help, making the co-op enterprise sustainable.

05 **Education, Training, and Information:** Communication about the nature and benefits of cooperatives, especially with the general public and opinion leaders, promotes cooperative understanding.

06 **Cooperation Among Cooperatives:** By working together through local, national, regional, and international structures, cooperatives improve services, bolster local economies, and address social and community needs.

07 **Concern for Community:** Cooperatives work for the sustainable development of their communities through policies supported by the membership.

Sho-Me Power Electric Cooperative

A Touchstone Energy® Cooperative

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