PROGRESS ON DAM REMOVAL ANALYSIS GUIDELINES FOR SEDIMENT

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INTRODUCTION

The Subcommittee on Sedimentation (SOS) recognizes that dam removal has become somewhat common in the United States as dams age and environmental values increase. American Rivers estimates that nearly 1,150 dams that have been removed in the United States between 1912 and 2013 (http://www.americanrivers.org/initiatives/dams/faqs/), with most dam removals occurring after 1980. Sediment management can be an important component of some dam removals, but there are no commonly accepted methods to assess the level of risk to river-related resources associated with the sediment stored behind dams. Therefore, SOS began sponsoring an effort in 2008 to develop the Dam Removal Analysis Guidelines for Sediment. This project only provides technical guidance and makes no endorsement on the merits of dam removal.

The process began by convening two technical workshops of invited experts from Federal agencies, universities, consultants and non-governmental organizations: October 14–16, 2008 in Portland, Oregon and October 27–29, 2009 in State College, Pennsylvania. The second workshop tested the guidelines on actual case studies. Preliminary results from this effort were presented at the 9th Federal Interagency Sedimentation Conference (Randle et al., 2010). At the time of this preliminary work, available literature was sparse and nearly all of the removed dams were small with just three notable exceptions:

- The 12-foot high Stronach Dam on the Pine River in Michigan, USA was removed between 1997 and 2003 and the reservoir contained 1 million yd^3 of sediment (Burroughs et al., 2009).
- The 50-foot high Marmot Dam on the Sandy River in Oregon, USA was removed in 2007 and the reservoir contained 0.95 million yd^3 of sediment (Major et al., 2012).
- The 28-foot high Milltown Dam on the Clark Fork River in western Montana, USA was removed in 2008 and the reservoir contained 6.6 million yd^3 of sediment (Wilcox et al., 2008).

Since 2010, two other large dam removal projects were completed:

- The Elwha River Restoration Project on the Elwha River, Washington, USA included the concurrent removal of the 105-foot high Elwha Dam and 210-foot high Glines Canyon Dam between September 2011 and August 2014 (Bountry et al., 2015). The combined reservoir sediment volume of 27-million yd^3 was the largest ever associated with a dam removal project.
- The 125-foot high Condit Dam on the White Salmon River, Washington, USA, was suddenly breached on 26 October 2011 and the reservoir contained 2.4 million yd^3 of sediment (Wilcox et al., 2014).

A great deal more was learned from these large projects and associated recent literature about phased dam removal, cases where there is still a significant reservoir pool, timing of dam removal relative to seasonal hydrology, channel evolution in the reservoir sediments, and downstream transport (Wildman and MacBroom, 2005; Cannatelli and Curran, 2012; Sawaske and Freyberg 2012; Ferrer-Boix, 2014; East et al., 2015; Gelfenbaum et al., 2015; Magirl et al., 2015; Randle et al., 2015; Warrick et al., 2015). For example, phased dam removal can have significant control on the rate and extent of reservoir sediment erosion downstream sediment release. The actual hydrology, during and after dam removal, can affect the amount, rate, and timing of reservoir sediment erosion. The Dam Removal Analysis Guidelines for Sediment will now be completed using this new and important information.

GUIDELINE APPLICATION

The primary theme of the guideline is to link the amount of recommended pre-project data collection, analysis, and modeling to the risk associated with potential impacts from the reservoir sedimentation. The risk is defined as the product of the probability of impact and the consequence of impact. The greater the risk, the greater the recommended level of data collection, analysis, and modeling. The risk is intended to be a qualitative analysis in collaboration with technical experts, stakeholders and resource managers. The risk may be evaluated within the reservoir landscape or along the river channel upstream and downstream from the reservoir. For the purposes of this guideline, the reservoir sediment volume, relative to the annual sediment load or transport capacity of the river, is used as a surrogate for the probability of impact from releasing sediment as a result of dam removal. If the reservoir sediment contains contaminants above background levels, then the consequence of the potential release of contaminants to the environment will likely determine the level of risk for the project and if reservoir sediment can be released downstream.

In the guideline, the probability of reservoir sediment release is classified as negligible, small, medium, or large depending on the ratio of the reservoir sediment mass (γV_{res}) to the mean annual load or capacity of the river (Q_s):

Negligible Probability $$\frac{\gamma(V_{res})}{Q_s} < 0.1 \qquad (1)$$

Small Probability $$0.1 \leq \frac{\gamma(V_{res})}{Q_s} < 1 \qquad (2)$$

Medium Probability $$1 \leq \frac{\gamma(V_{res})}{Q_s} < 10 \qquad (3)$$

Large Probability $$10 \leq \frac{\gamma(V_{res})}{Q_s} \qquad (4)$$

Where the reservoir sediment mass is the product of the unit weight of sediment (γ) and the reservoir sediment volume (V_{res}). The ratios can be computed separately for coarse and fine sediment. For cases of little or no reservoir sediment, the probability and risk are assumed to be negligible and very little data collection and analysis are recommended.

Risk could be calculated by complex numerical analysis, but a more qualitative approach is presented in this guideline where the consequence and risk are categorized as small, medium, or large. A qualitative risk calculator is presented in Table 1. If the consequence to any of the resources of concern is considered high, then the risk will be either medium or high, depending on the relative reservoir sediment volume.

Table 1 Qualitative risk estimate based on the combination of probability and consequence.

	Consequence of resource impact		
Probability (Fine or Coarse sediment)	**Low**	**Medium**	**High**
Small	Low	Low	Medium
Medium	Low	Medium	High
Large	Medium	High	High +

For the qualitative analysis, a list of potential management concerns and associated sediment-related consequences is generated for the project. Each potential consequence is linked to whether consequence would occur from released coarse reservoir sediment, fine reservoir sediment, or both. For example, the release of an excessive amount of coarse sediment could aggrade the river bed resulting in burial of habitat features, increased flood stage and the potential for stream bank erosion. The release of fine sediment could affect water quality for the aquatic environment and downstream water users, or affect habitat by filling interstitial spaces in downstream riverbed gravels.

Examples of low consequence are where there is no infrastructure or property that could be impacted by the release of reservoir sediment, such as in a canyon reach of river. In addition, there are no threatened or endangered aquatic species that are sensitive to sediment and present at the time and location of impacts. Other examples of low consequence might include natural resources that would benefit from the release of reservoir sediment, such as spawning gravels, recovery of habitat beneath the reservoir, reconnection of the channel with adjacent wetlands and floodplains, or coastal beach restoration.

Medium consequence might include cases where sediment-related impacts would be localized or temporary and such impacts may require mitigation. A medium consequence might also include cases where the consequence is not necessarily low or high.

Examples of high consequences would include streambed aggradation, leading to flooding or erosion of property or infrastructure. High sediment concentrations that would make it very difficult or impossible for water users to obtain water for beneficial uses. Threatened or endangered species that would be irreversibly harmed.

The consequences of an impact depend on the potential effects, regulations, and the perception of stakeholders to resources of concern. The potential concerns of stakeholders needs to be identified to help determine the level of consequences from the release of reservoir sediment upon dam removal. A qualitative judgment may have to be used to estimate the level of consequence. Public and regulatory perception of the types and magnitude of potential sediment impacts may be greater than the actual impacts. Public education and outreach on hydraulic and sediment processes may be a useful way to help the public understand what the actual sediment effects may be and a collaborative way of determining the level of potential consequences to resources and stakeholders. For example, a medium relative reservoir sediment volume (and medium probability) would have a high level of risk if the consequence(s) were high. Conversely, a medium relative reservoir sediment volume would have a low level of risk if the consequence(s) were low.

For a given dam removal project, there may be a wide range of potential consequences of concern that could range from low to high. For determining the level of data collection, analysis, and modeling, it is recommended to take the highest risk associated with coarse and fine sediment separately. However, it is important to limit the potential consequences to what may actually occur based on the available reservoir volume and particle size gradation (fine versus coarse percentages). For example, Savage Rapids Reservoir near Grants Pass, Oregon had 98% coarse sediment stored in the reservoir with only 2% fine sediment (Bountry et al., 2013). Initially, there was concern about the potential for water quality impacts and release of contaminants. However, for this example, the sediment analysis emphasis was focused on coarse sediment because no contaminants were found above background levels and the fine sediment volume was too small to cause any significant water quality impacts. The types of data collection, analysis, and modeling needed for a high level of risk from coarse reservoir sediment would be different than from fine sediment.

GUIDELINE PROCUDURES

Application of the sediment analysis guidelines is described in the following nine steps:

Reservoir Data Gathering Steps

1. Reconnaissance
2. Characterize reservoir sediment
3. Contaminant assessment

Significance of Reservoir Sediment Volume

4. Determine the relative reservoir sediment volume

Sediment and Dam Removal Alternatives

5. Selection of dam removal and sediment management plan alternatives

Sediment Analysis and Modeling

6. Reservoir and downstream effects analysis

Uncertainty, Monitoring, and Adaptive Management

7. Assess prediction confidence
8. Discussion on sediment effects
9. Develop monitoring and adaptive management plan

An overview of the general guideline steps are presented in Figure 1.

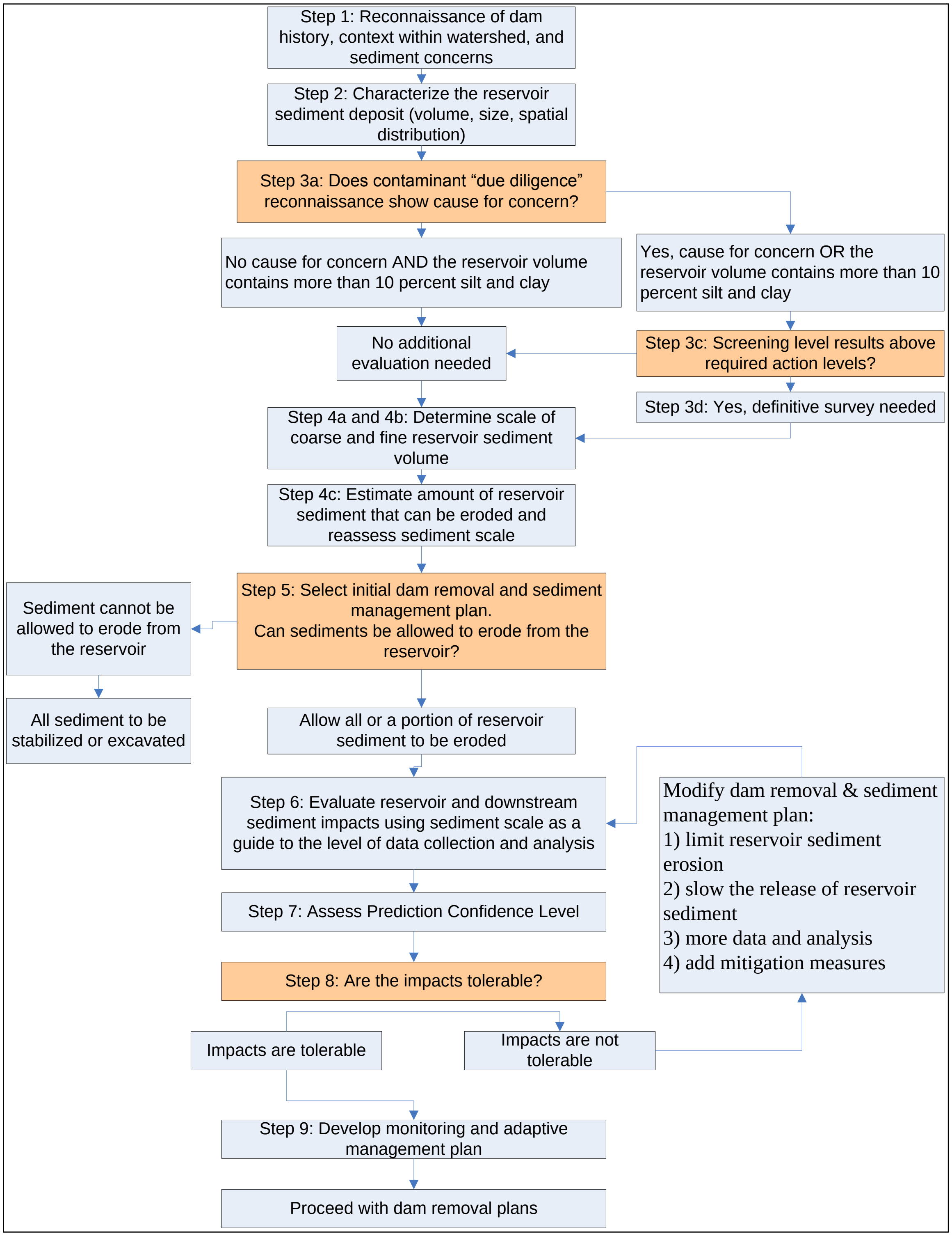

Figure 1 General sediment analysis steps are outlined in a flowchart.

TESTING OF ANALYSIS GUIDELINES

The dam removal sediment analysis guidelines will be tested with data from at least 20 actual dam removals case studies. These case studies will include dams from the eastern, Midwestern, and western United States and include reservoirs with negligible to very large relative sediment volumes.

CONCLUSIONS

The sediment-related impacts of dam removal fundamentally depend on the reservoir sediment characteristics (mass, size gradation, quality, and spatial distribution) and on the extent and rate of reservoir sediment erosion. The level of investigation for sediment impact predictions should be a function of the sediment risk, which is related to the relative reservoir sediment volume or mass.

The next steps to complete the guidelines are listed below:

- Include information from dam removals with large reservoir sediment volumes
- Synthesize results from tested case studies
- Obtain independent peer review
- Obtain approval from Subcommittee on Sedimentation
- Obtain approval from Federal Advisory Committee on Water Information
- Publish guidelines

REFERENCES

Bountry, J.A., Lai, Y.G., Randle, T.J., 2013. Sediment impacts from Savage Rapids Dam removal, Rogue River, Oregon. In: DeGraff, J.V., Evans, J.E. (Eds.), Reviews in Engineering Geology, 21. Geological Society of America, pp. 93–104.

Bountry, J.A.; Crain, P.; Chenoweth, J.; Randle, T.J.; Ritchie, A. (2015). Role of Adaptive Sediment Management in Elwha Dam Removal in Proceedings of the 10th Federal Interagency Sedimentation Conference, Reno, NV, April 20-23.

Burroughs, B.A., Hayes, D.B., Klomp, K.D., Hansen, J.F., Mistak, J. (2009). Effects of Stronach dam removal on fluvial geomorphology in the Pine River, Michigan, United States, Geomorphology 1010, 96-107.

Cannatelli, K.M., Curran, J.C. (2012). Importance of hydrology on channel evolution following dam removal: case study and conceptual model. Journal of Hydraulic Engineering 138(5), 377–390.

East, A.E., Pess, G.R., Bountry, J.A., Magirl, C.S., Ritchie, A.C., Logan, J.B., Randle, T.J., Mastin, M.C., Duda, J.J., Liermann, M.C., McHenry, M.L., Beechie, T.J., Shafroth, P.B., 2015, in press. Large-scale dam removal on the Elwha River, Washington, USA: River channel and floodplain geomorphic change. Geomorphology.

Ferrer-Boix, C., Martín-Vide, J.P., Parker, G., 2014. Channel evolution after dam removal in a poorly sorted sediment mixture: Experiments and numerical model. Water Resources Research 50, doi:10.1002/2014WR015550.

Gelfenbaum, G., Stevens, A.W., Miller, I.M., Warrick, J.A., Ogston, A.S., Eidam, E., 2015, in press. Large-scale dam removal on the Elwha River, Washington, USA: Coastal geomorphic change. Geomorphology.

Magirl C.S., Hilldale, R.C., Curran, C.A., Duda, J.J., Straub, T.D., Domanski, M., Foreman, J.R., 2015, in press. Large-scale dam removal on the Elwha River, Washington, USA: Fluxes of river sediment. Geomorphology.

Major, J.J., O'Connor, J.E., Podolak, C.J., Keith, M.K., Grant, G.E., Spicer, K.R., Pittman, S., Bragg, H.M., Wallick, J.R., Tanner, D.Q., Rhode, A., Wilcock, P.R., 2012. Geomorphic response of the Sandy River, Oregon, to removal of Marmot Dam. U.S. Geological Survey Professional Paper 1792. 64 pp.

Randle, T.J., Bountry, J.A., Blair P. Greimann, B.P. 2010. "Guidelines for Assessing Sediment-Related Effects of Dam Removal," in 9th Federal Interagency Sedimentation Conference, Las Vegas, Nevada, June 27 - July 1, 2010.

Randle, T.J., Bountry, J.A., Ritchie, A., Wille, K., 2015, in press. Large-scale Dam removal on the Elwha River, Washington, USA: Erosion of reservoir sediment. Geomorphology.

Sawaske, S.R., Freyberg, D.L., 2012. A comparison of past small dam removals in highly sediment-impacted systems in the US. Geomorphology 151, 50–58.

Wilcox, A. C., Brinkerhoff, D., & Woelfle-Erskine, C. (2008). Initial geomorphic responses to removal of Milltown Dam, Clark Fork River. In Montana, USA American Geophysical Union Fall Meeting.

Wilcox, A.C., O'Connor, J.E., Major, J.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 Science, 119, 1376–1394 .

Wildman, L.A.S., MacBroom, J.G., 2005. The evolution of gravel bed channels after dam removal: case study of the Anaconda and Union City dam removals. Journal of Geomorphology 71, 245–262.

Warrick, J.A., Bountry, J.A., East, A.E., Magirl C.S., Randle, T.J., Gelfenbaum, G., Ritchie, A.C., Pess, G.R., Leung, V., Duda, J.J., 2015, in press. Large-scale dam removal on the Elwha River, Washington, USA: Fluxes of river sediment. Geomorphology.