Federal Interagency Sedimentation Project (FISP) Memorandum 2013.03

June 11, 2013

Subject: Recommendation for Collecting at Least Two Depth-Integrations Per Vertical to Reduce Uncertainty as Part of Cross-Section Sampling with FISP Depth-Integrating Suspended-Sediment Samplers

INTRODUCTION

The Technical Committee (TC), Federal Interagency Sedimentation Project (FISP) has evaluated recommendations provided as part of U.S. Geological Survey (USGS) Professional 1774 (PP1774), "Field Evaluation of the Error Arising from Inadequate Time Averaging in the Standard Use of Depth-Integrating Suspended-Sediment Samplers" by David J. Topping, David M. Rubin, Scott A. Wright, and Theodore S. Melis. The TC evaluation was led by USGS TC member John R. Gray. An April 19, 2012, internal USGS memorandum from John to the report's principal author, David Topping, which provides a synopsis of key PP1774 findings and recommendations, and summarizes the USGS Office of Surface Water's general position on the subject, is appended herewith.

The FISP Technical Committee first wishes to recognize the extensive time and effort devoted to the data collection, analysis, and writing that culminated in publication of PP1774. It represents a long-term, intensive evaluation of uncertainties inherent in the discharge-integrated sampling techniques (using FISP depth-integrating samplers) promulgated by the FISP and long-embraced by FISP member organizations and many entities world-wide. PP1774 authors are to be commended for this excellent addition to the literature that pertains to "uncertainties in fluvial sediment monitoring."

PP1774 includes a thoughtful evaluation of the necessary tradeoff between the competing desires to maximize data accuracy while minimizing effort and cost. The authors found that errors arising from inadequate time averaging slightly dominate those arising from inadequate sampling of the cross-stream spatial structure in suspended-sediment concentration (SSC). Increasing the number of vertical stations ("verticals") as part of an Equal-Discharge-Increment (EDI) or Equal-Width-Increment (EWI) measurement (Edwards and Glysson, 1999; Nolan et al., 2005; Gray et al., 2008) was determined to be slightly more effective in reducing the total uncertainty in derived SSCs than by adding depth integrations[1] only at each vertical, because each additional

[1]A single depth integration with a FISP suspended-sediment sampler necessarily entails one downward transit from the water surface to the bed followed by a return transit to the surface for a total of two transits.

vertical contributes both temporal and spatial information. However, collection of additional depth-integrated samples is generally easier and faster than adding more verticals.

These observations led to the authors' key recommendation that appears as the last sentence in PP1774's abstract (modified as follows for contextual purposes):

> "…the most practical, best EDI or EWI sampling design to minimize the total uncertainty in time-averaged velocity-weighted SSCs is to repeat depth integration at a vertical to obtain at least two samples per vertical. Multiple depth integrations should be performed at as many verticals as is practical for a given measurement situation."

FISP RECOMMENDATION BASED ON PROFESSIONAL PAPER 1774

The FISP concurs that at least two depth integrations – equal to the number recommended by the USGS (Nolan et al., 2005) in a vertical with a FISP depth-integrating suspended-sediment sampler – is likely to reduce uncertainties in derived SSCs. From a data-quality perspective for water-column sediment and/or water-quality measurements, the more depth integrations performed at each vertical, the better. These perspectives are particularly pertinent for streams that carry "heavy loads of sand, and for some other streams" (Edwards and Glysson, 1999, p. 39), and/or when coarser fractions of sand are in suspension.

Individually analyzed samples collected by the EDI method provide more-spatially discrete, and useful information than that analyzed from a single EWI composite sample. Additionally, spatially discrete EDI data enhance the ability of the analyst to identify and discard erroneous SSC and/or particle-size data. Spurious suspended-sediment data can result from a number of mistakes, including sample contamination by gouging the sampler nozzle into the bed, or by sample spillage or evaporation. Therefore, the FISP recommends the following when funds for the additional analytical costs associated with individual sample analyses are available, and when a composite sample is not required for subsequent water-quality subsampling or other purposes:

> "Obtain two depth integrations at each EDI vertical[2]. Where there is evidence of substantial fractions of sand in suspension[3] – particularly at the higher flows that are inordinately influential in sediment transport – the FISP encourages hydrographers to collect additional depth integrations as practicable from a time and cost standpoint. The mean SSC for the measurement is the arithmetic mean of the concentrations analyzed from each EDI sample set."

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[2] The number of verticals recommended for a single EDI cross-section sample ranges from 4-9.

[3] A "…substantial fractions of sand…," considered to exceed about 20-percent sand by mass, can be inferred by observing sand-size material accumulating at the bottom of the sample upon examination immediately after sample collection.

One possible drawback to the aforementioned recommendation – given the stipulation for separate analyses on each EDI sample[4] – is the potential inability to obtain at a single vertical an adequate sediment mass to enable particle-size distribution analyses representative of the flow in the cross section. If financial resources are inadequate to analyze the size and concentration characteristics of the sediment in each bottle of at least one cross-section sample set, or if the mass of sediment in each bottle is insufficient to perform a reliable size analysis, the following alternative sampling scheme is acceptable:

> "Collect a set of samples as part of a single EDI cross section, and a second sample set as part of a single EWI cross section. Have each EDI sample individually analyzed for SSC. Have a laboratory-generated composite of the EWI sample set analyzed for particle-size classes and SSC that represent the discharge-weighted flow in the cross section. The sum of the average SSC value from the EDI sample analyses and the single SSC value from the EWI composite analysis is halved to derive the mean measurement SSC, assuming the mean values of each cross-section measurement are comparable. Particle-size statistics from the EWI composite sample are representative of the entire cross section."

Regardless of the collection scheme, analyses of the original sample sets as opposed to one or more subsamples for production of suspended-sediment data are always preferred. Analytical results of subsamples – often field-derived using a cone or churn splitter (U.S. Geological Survey, 1997), or by other means, such as aliquots laboratory-pipetted from a stirred sample for Total Suspended Solids analyses (Gray et al., 2000) – can result in more variant and/or biased data. This is particularly true when sand constitutes a substantial fraction of the suspended sediment. Hence results from analytical techniques that measure all of the sediment and the total mass of the water-sediment mixture collected with physical samplers are considered to represent the most reliable and comparable suspended-sediment data.

Although collection of additional samples as part (or combination) of an EDI or EWI measurement initially may seem unnecessary and inordinately costly, the value of the derived high-quality data is hard to overstate when computing daily records of suspended-sediment loads. When one sums all costs associated with production of suspended-sediment and ancillary data – dominated by, but not limited to salaries, capital and travel costs, and overhead expenses – additional analytical costs from use of the EDI method with individual sample analyses can be shown to be relatively reasonable and justifiable. This is particularly true if the discretely analyzed EDI data are instrumental in identifying and discarding erroneous data that might otherwise adulterate the computed sediment-load record.

[4] If all samples collected as part of an EDI cross section have approximately equal volumes, a single SSC and particle-size distribution analysis can be performed on a laboratory-generated composite of the EDI samples.

REFERENCES CITED

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Topping, D.J., Rubin, D.M., Wright, S.A., and Melis, T.S., 2011, Field evaluation of the error arising from inadequate time averaging in the standard use of depth-integrating suspended-sediment samplers: U.S. Geological Survey Professional Paper 1774, 95 p. (http://pubs.usgs.gov/pp/1774/).

U.S. Geological Survey, 1997, Protocols for cleaning a Teflon cone splitter to produce contaminant-free subsamples for subsequent determinations of trace elements: Office of Water Quality Technical Memorandum 97.03 (http://water.usgs.gov/admin/memo/QW/qw97.03.html).

APPENDIX

The following April 19, 2012, internal USGS memorandum – from Office of Surface Water National Sediment Specialist John R. Gray to the principal author of USGS Professional Paper 1774, David J. Topping – summarizes the USGS Office of Surface Water's general position on the principal recommendations contained in the Professional Paper.

DATE: April 19, 2012
TO: David W. Topping, U.S. Geological Survey Flagstaff Science Center, Arizona
FROM: John R. Gray, U.S. Geological Survey Office of Surface Water, Reston, Virginia

SUBJECT: Professional Paper 1774 and USGS Policy

The purpose of this memorandum is to articulate my tentative conclusions regarding the thrusts of and recommendations contained in Professional Paper 1774 (PP 1774), "Field Evaluation of the Error Arising from Inadequate Time Averaging in the Standard Use of Depth-Integrating Suspended-Sediment Samplers." It is my eventual goal to develop a policy statement as joint a technical memorandum (Offices of Surface Water, and Water Quality); and perhaps also a Federal Interagency Sedimentation Project (FISP) memorandum. I have copied your co-authors in case they wish to weigh in. It is my goal to obtain comments and recommendations from the report authors before drafting a policy memorandum on the subject.

I have shared PP 1774 – electronically and in print copy – with at least 30 colleagues representing a fairly broad spectrum of specialists and field users. This includes selected colleagues in the Offices of Surface Water, and Water Quality; instructors at the NTC course, "Sediment Data-Collection Techniques"; those holding the positions formerly referred to as the regional surface-water and water-quality specialists; and a number of others. Additionally, the Technical Committee, FISP, received their copies in November. Suffice it to write that the report has had ample opportunity to be reviewed by a large number of folks – technical sorts and managers – with a vested interested in isokinetic sampling issues.

The report contains a large amount of meticulously gathered information (for which you and your co-authors are to be commended). However, for the purpose of policy development, the focus of many respondents centered on information provided on pages 42-45, with figure 15 (page 45) garnering the most attention and evaluation. I will try to 'cut to the quick' and provide what I believe to be the crux of the input that I have received.

The red line in Figure 15 – corresponding to two transits at each vertical – is essentially *informal* USGS policy for collecting suspended-sediment x-section samples, in which we collect an "a" and "b" cross-section, more or less independent of each other and (in the final analysis) reported as results of two mean sediment concentrations, and corresponding suspended-sediment discharges. When performing an Equal-Width Increment (EWI) cross-section, USGS policy for streams over 5 feet wide requires a minimum of 10 sampling verticals. Two cross-sections using 10 verticals each yields a total uncertainty (see y axis label) of 4%-5%. If one were to take 4 times more EWI cross-sections with dual transits, total uncertainty would decrease to 2%-3%.

If, instead, we perform a 4-section Equal-Discharge Increment (EDI) measurement (USGS policy requires 4-9 EDI verticals) and two transits per vertical yields a total uncertainty of about 7%. Quadrupling the number of transits decreases the total uncertainty to about 5%.

These statistics are for suspended-sand concentrations, which, compared to suspended fines concentrations, should be a 'worst case scenario.' Truth be told, based on hydraulic theory and information in FISP Report #5, one might expect more divergent statistics from a system transporting a coarser fraction of sand than was measured and summarized in the report. Although that is an important observation, I will stick with the information-at-hand in the ensuing discussion.

In summary, given present protocols for sediment sampling (a) the maximum total uncertainties is about 7%, and (b) no more than about a 2% reduction in the total uncertainties is achieved by quadrupling the number of transits under any USGS-accepted operational scenario.

If I've summarized the essence of figure 15 correctly, and if there are no other salient considerations, here is the essence of what I have heard from colleagues, which match my own conclusions:

It is a statistical truism that the probability of obtaining "the true value" increases with the number of samples collected. The essence of the issue at hand is whether or not requiring extra transits will provide a sufficiently substantial decrease in the total uncertainty to warrant the extra time (and, in most cases, expense) expended. Given that maximum total uncertainties in correctly collected operational sediment cross-sections is 7% – and that we can at best improve on this only by about 2% unless (presumably) we collect more than quadruple the number of transits from a minimum of two – an obvious question to ask is whether we might be subject to diminishing returns for the extra cost and effort expended.

This conclusion is particularly germane to the EWI method for two reasons: First, we routinely collect 10+ EWI verticals. Second, the EWI method (as opposed to the EDI method) normally requires separate passes across the stream, which can be time-consuming (hence expensive), particularly if sampling from a superstructured bridge, very wide cross-section, etc.

On the other hand, taking extra transits using the EDI method might be more cost-effective, for two reasons. First, one only needs to traverse the cross-section once, collecting more than 2 transits per EDI section. Second, it makes more sense to augment the often smaller number of verticals with more transits. However, more transits will require more bottles which will increase time and cost (both in the field and lab) and, as we all know, one of the major reason for the decrease over the last two decade of daily sediment sites is the increasing costs of operating a sediment station. Also, the accuracy gained with additional transects assumes a stationary stream conditions, and could be more than offset by lost accuracy due to averaging under dynamic concentration conditions.

My sense is to write a technical memorandum summarizing the essence of PP 1774, including (and highlighting) the uncertainty statistics. It should provide a balanced discussion on reduced uncertainty versus time and effort. It might favor using the EDI method for sediment work, and to take more than two transits and perhaps up to 8 transits per vertical, and to encourage the hydrographer to collect more rather than less verticals (caveat – we have to keep in mind the potential for added lab costs along with some increase in time/labor may result in field folks avoiding this option).

However, if this analysis is valid, I cannot imagine the OSW or OWQ articulating policy to require doubling or quadrupling transits when the maximum benefit of the policy would result in a 2% reduction in total uncertainty of suspended-sand concentrations.

Thanks for bearing with me in my attempt to summarize the relevance of PP 1774 to the USGS (and others). If you beg to differ with these conclusions and suggested response – particularly if I and a number of others have misconstrued the essence of the report – I'd prefer to discuss this, but feel free to respond in writing.