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Model erroneously predicts failure for restoration of Lake Apopka, a hypereutrophic, subtropical lake

Claire L. Schelske & William F. Kenney
Department of Fisheries and Aquatic Sciences, University of Florida, Gainesville, FL 32653, U.S.A.
Address for offprints: Department of Geological Sciences, University of Florida, P.O. Box 112120, Gainesville, FL 32611, U.S.A.
Tel.: +352-392-2231. Fax: +352-392-9294. E-mail: schelsk@nersp.nerdc.ufl.edu

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Abstract

A recent paper (Bachmann et al., 1999) based on analysis of literature data predicts failure for restoration plans implemented by the St. Johns River Water Management District (SJRWMD) for Lake Apopka, a large (125 km^2), shallow (mean depth=1.63 m), polymictic lake in central Florida. A marsh flow-way designed to remove particulates from inflowing water from Lake Apopka as a means to improve down-stream and lake-water quality is part of the restoration plan. According to Bachmann et al. (1999), restoration "will be ineffective in removing particles from the lake" and fail because estimated time for removal of 2.21 million tons of historic sediments in this constructed marsh flow-way is 329 years. This inadvertently proposed mining hypothesis given as a condition for successful restoration is based on questionable assumptions, i.e. removing all the historic sediments deposited over a 50-year period with the flow-way and exporting concurrent sedimentation while historic sediments are being removed. These questionable assumptions are used in an erroneous, discontinuous model of sediment dynamics that does not justify the alternate approach for restoration of Lake Apopka suggested in their paper.

Introduction

A recent paper (Bachmann et al., 1999) provides pessimistic conclusions about restoration plans by the St. Johns River Water Management District (SJRWMD) for Lake Apopka, a large (125 km^2), shallow (mean depth=1.63 m), polymictic lake in central Florida. A marsh flow-way designed to remove particulates from inflowing water from Lake Apopka as a means to improve down-stream and lake-water quality is part of the restoration plan. Supposedly, the marsh flow-way constructed by SJRWMD will fail; i.e. "will be ineffective in removing particles from the lake" because estimated removal time (RT) is 329 years. Examining the model used to estimate RT shows the authors have inadvertently proposed a mining hypothesis with two questionable assumptions. First, that a 50-year accumulation of historic sediments must be exported to the flow-way. Second, that all in-lake sediments produced during the period of removal must be exported also. These assumptions require a shift in sedimentary processes because in-lake accumulation of historic sediments has been measured independently in two studies (Reddy & Graetz, 1991; Schelske, 1997). Bachmann, op. cit. do not consider that the flow-way was designed to reduce phosphorus concentration and phytoplankton standing crop and increase water clarity by exporting particulate matter from the lake. Instead, they contend that non-living particulate material resuspended from sediments is a major source of particulate matter and contributes significantly to light attenuation in the water column and that sediments are not permanently sedimented and must be exported to the marsh flow-way as a condition for successful restoration.

We do not disagree with Bachmann, op. cit. who indicate that Lake Apopka can be evaluated in terms of alternative stable states. We agree that the dominant primary producer community in Lake Apopka switched from macrophytes to a stable phytoplankton state in the late 1940s. The scenario of macrophytes being uprooted and replaced rapidly by phytoplankton as the consequence of a hurricane in 1947 is questioned using meteorological and other data (Lowe et al., 1999), but Bachmann, op. cit. still support a modified form that discounts nutrient loading effects. In addition, paleolimnological proxies (Schelske et al., 1999, Schelske, op. cit.) point to increased phosphorus loading as the causal mechanism.

Bachmann, op. cit. state that living algae represent $<$10% of total suspended solids (TSS) in the water column and, therefore, are not an important component of sedimenting particles. Previous studies, however, show that wind-induced resuspension of sediments from a nepheloid layer (NL) plays an important role in meroplankton dynamics (Carrick et al., 1993) and short-term variability in phytoplankton chlorophyll *a* (Schelske et al., 1995). Bachmann, op. cit. state: "As sediments are removed from the lake they will be replaced by resuspended particles from the flocculent sediment layer". However, instead of the water column being enriched by mining underlying historic sediments, the aphotic NL is enriched periodically by meroplankton produced photosynthetically in overlying waters (Carrick et al., 1993; Schelske et al., 1995).

Here, we show that Bachmann, op. cit. present an erroneous, discontinuous model of sediment dynamics in Lake Apopka to justify an alternate approach for restoration of Lake Apopka.

Lake Apopka sediments

There is no disagreement that distinct characteristics differentiate recent phytoplankton-derived sediments from underlying macrophyte-derived deposits. Reddy, op. cit. and Bachmann, op. cit. refer to phytoplankton-derived sediments as unconsolidated flocculent sediments (UCF) and macrophyte-derived sediments as consolidated floc (CF). Bachmann, op. cit. also use 'fluid mud' in discussing these sediments. The physical appearance of phytoplankton-derived sediments is so distinct that the contact with macrophyte sediments was identified while cores were sectioned in the field (Reddy, op. cit.). This separation is possible because phytoplankton-derived sediments are highly unconsolidated, containing $>$95% water by weight, and macrophyte sediments are more consolidated with a markedly larger bulk density. In addition, these sediments can be characterized by total phosphorus (TP) concentration, total carbon/total nitrogen (TC/TN) ratio of organic matter and diatom species composition (Schelske et al., 1999; Schelske, op. cit.); sponge spicules and biogenic silica (Schelske, op. cit.) and physical properties (Reddy, op. cit.). Several variables, therefore, distinguish sediments deposited since approximately 1947 from those deposited earlier.

Two whole-basin studies provide evidence that recent sediments are derived from organic matter produced by phytoplankton and also provide data that can be used to estimate dry mass sedimentation rate during the phytoplankton phase. These studies were conducted in 1987 at 66 stations arranged on a rectangular grid (Reddy, op. cit.) and in 1996 at 46 stations arranged on an equal area grid (Schelske, op. cit.). Collected cores were sectioned in the field by sediment type in 1987 and at 5-cm intervals in 1996. Phytoplankton sediments were $<$5% dry weight and highly organic, with loss on ignition @ 550 °C averaging 54.3% and 62.9% in 1987 and 1996, respectively. We calculated an average dry mass sedimentation rate of 33.2×10^6 kg yr^{-1} from the dry mass inventories at stations sampled by Reddy, op. cit. and compared it with the reported estimate of 44.2×10^6 kg yr^{-1} (Table 8; Schelske, op. cit.). These data provide independent estimates of both dry mass and organic mass sedimentation during the phytoplankton phase, or since approximately 1947.

Although the analysis by Bachmann, op. cit. was based on dry mass sedimentation, data on TP in sediments (Reddy, op. cit.; Schelske, op. cit.) could have been used in the analysis. Average TP concentrations in phytoplankton-derived sediments were 0.986 mg g^{-1} (1987) and 1.018 mg g^{-1} (1996). These results indicate that phosphorus concentration of phytoplankton sediments increased with time. Phytoplankton-derived sediments, in fact, are enriched in TP relative to macrophyte sediments, with TP concentration increasing upcore several fold to an average concentration of 1.41 mg g^{-1} in the upper 5 cm of 1996 samples (Schelske, op. cit.). We calculated an average TP storage of 32.7×10^3 kg yr^{-1} from data in Reddy, op. cit. to compare with the reported estimate of 45×10^3 kg yr^{-1} (Table 8; Schelske, op. cit.). These data indicate that TP sedimentation increased in the period from 1987 to 1996.

Bachmann, op. cit., however, state that not enough information is available to determine whether 'fluid mud' was "formed by liquefaction of the sediments laid down during the macrophyte phase or represents new sediments", even though Reddy, op. cit. and Schelske, op. cit. identify these recent sediments as UCF or phytoplankton-derived sediments. In an apparent contradiction, Bachmann, op. cit. state (based on data from Reddy, op. cit. and Schelske, op. cit.) that the average thickness of UCF sediments increased from 10 cm in 1968 to 32 cm in 1987 to 45 cm in 1996. Their wind-induced scenario of fluid mud formation (i.e. liquefaction of macrophyte-derived sediments), however, describes a self-attenuating process with steady-state dynamics, not the exponential increase indicated by UCF data. Similar to other lakes, sediment accumulation over the Lake Apopka basin is spatially variable, adding to the improbability of liquefaction. Of the 46 stations sampled in 1966, UCF depths were <27 cm at 11 stations and >75 cm at 10 stations (Table 2; Schelske, op. cit.). Liquefaction of CF would be expected to decrease with increasing depth of overlying UCF and is not consistent with the known exponential increase in UCF depth.

Mining hypothesis

Bachmann, op. cit. developed a model (Equation 1) to calculate the time required to export sediments from Lake Apopka to the SJRWMD marsh flow-way. We show in Equation 1 how variables from their Table 3 were used to calculate RT.

$$\mathrm{RT} = \frac{\text{Fluid mud to be removed (2210)}}{\mathrm{FWSR}(30.7) + \mathrm{COF}(0.800) - \mathrm{LSR}(24.8)} = 330\ \mathrm{yr} \qquad (1)$$

Values in parentheses are in units of 10^6 kg dry weight with rates in 10^6 kg dry weight yr^{-1}. FWSR is flow-way sedimentation rate (weight of particles deposited in marsh flow-way), COF is canal outflow rate (weight of particles lost with outflow) and LSR is lake sedimentation rate (pre-1947 rate of sediment accumulation). Thus, the calculated RT is 330 years. We believe the calculation of such a long removal time is based on two questionable assumptions. The first is that 2210×10^6 kg of 'fluid mud', a 50-year accumulation of historic, phytoplankton-derived sediments (Table 8, Schelske, op. cit.), must be exported as a condition for restoration. The second is that, because LSR is a negative term, all in-lake sedimentation must be exported concurrently. The model (Equation 1), therefore, is based on two questionable assumptions that require mining historic sediments and exporting all concurrent in-lake sedimentation.

We also question why Bachmann, op. cit. ignored available direct measurements of dry mass sedimentation during the period of phytoplankton dominance and instead used data from ^{210}Pb-dated sediment cores (Schelske, op. cit.) to estimate LSR. They indicate this takes "... into account the amount of sediments that might be expected to be added to the sediment pool each year in the absence of any cultural eutrophication" and estimated sedimentation rates for the "... century prior to the hurricane and the diking of the muck farms". We do not understand how the sedimentation rate during the period of macrophyte dominance is relevant to present dynamics of sedimentation. In addition, the dramatic switch in the primary producer community in the late 1940s and the large reduction in lake area (ca. 195–125 km^2) associated with diking of the lake in the 1940s to facilitate muck-farm agriculture may have changed sediment dynamics. These factors which violate assumptions implicit in ^{210}Pb dating models were used to discount sediment accumulation rates during the macrophyte phase that might be calculated from ^{210}Pb data (Schelske, op. cit.).

Simple test calculations in which FWSR and LSR are varied provide evidence that the model's predicted RT (Equation 1) is not reliable. First, the decrease in RT with increasing FWSR is not linear as might be expected (Fig. 1a). In fact, RT changes markedly only with a doubling in FWSR. Second, if LSR is varied, the smallest possible, positive RT is 70 years when LSR is zero (zero lake sedimentation would appear to be an unlikely scenario). In addition, RT is discontinuous, i.e., becomes infinite when LSR is 31.5×10^6 kg yr^{-1} and negative when LSR is $>31.5\times10^6$ kg yr^{-1} (Fig. 1b). Negative numbers result from the model-mandated, continuous export of 'pre-1947 sediments' to the flow-way, i.e. no net in-lake sedimentation. Finally, predicted RT is also very sensitive to small errors in the precision of estimating FWSR and LSR. Combining a 10% precision in estimating both FWSR and LSR, predicted RT ranges from 180 to 1922 yr. The model's extreme sensitivity to the values selected for FWSR and LSR, therefore, demonstrates inherent flaws in the model's design.

Bachmann, op. cit. not only specify exporting (mining) 2210×10^6 kg of 'fluid mud' (Equation 1) in 329 years as a condition for successful restoration, but also specify 821 years to export an additional 5500×10^6 kg of 'other low density sediments' (presumably, macrophyte-derived sediments). Their

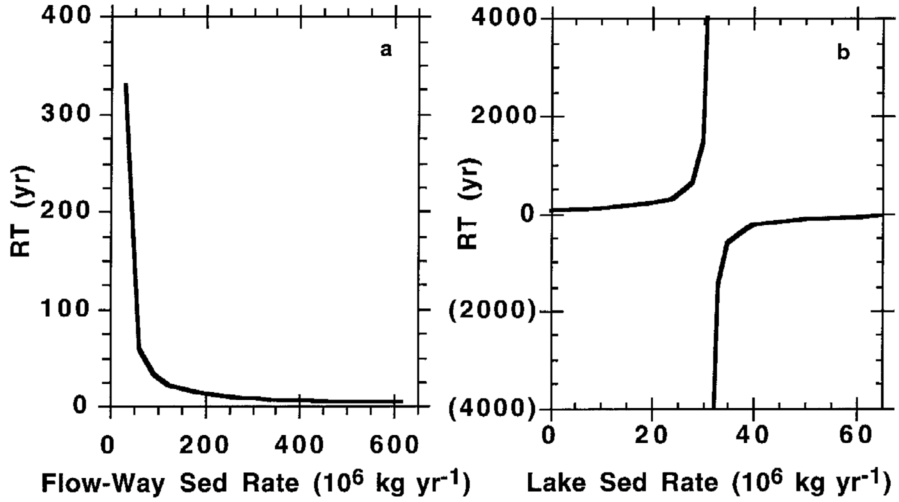

Figure 1. Calculations of removal time (RT) of 'fluid mud' for a constructed marsh flow-way at Lake Apopka using Equation (1) and data in Bachmann et al. (1999: Table 3). (a) Nonlinear relationship between removal time (RT) and marsh flow-way sedimentation rate (FWSR). (b) Discontinuous relationship between removal time (RT) and lake sedimentation rate (LSR). See text for additional explanation.

mining scenario invokes a shift in sedimentation processes because inventories of phytoplankton-derived sediments that have accumulated since approximately 1947 have been measured directly (Reddy, op. cit.; Schelske, op. cit.). It also conflicts diametrically with classic concepts of lake sedimentation associated with eutrophication, i.e. that over time sediment accumulation in lake basins reduces lake volume by infill. No mention is made as to whether Lake Apopka is considered to be unique in this respect or if the uniqueness of their hypothesis is recognized.

In summary, our purpose here is not to analyze critically the entire effort by Bachmann, op. cit. to discount current strategies directed to reducing phosphorus concentrations and improving water clarity in Lake Apopka. Other questionable points in their paper have been addressed separately (Lowe et al., 2001). Studies that support restoration plans for Lake Apopka are listed in papers cited by Bachmann, op. cit. as well as in papers by Battoe et al. (1999), Lowe et al. (1999) and Schelske et al. (2000). Our purpose is to point out that Bachmann, op. cit. use a model based on two questionable assumptions to erroneously predict failure of the restoration plan. The assumptions are that a 50-year accumulation of historic sediments must be exported to a constructed marsh flow-way and that all in-lake sediments produced during the period of removal must be exported also. The unique nature of large-scale mining of historic sediments with gravity outflow apparently is not recognized. Mining historic sediments is based on the assumption that sediments are a source of water-column particulates and is at variance with studies that report net sedimentation in Lake Apopka (Reddy, op. cit.; Schelske, op. cit.) and with generally accepted concepts that assume sediments can be a permanent sink for materials produced within or advected into the water column. Obviously the success of restoration can be predicted only with some uncertainty. Bachmann, op. cit. may be correct that restoration efforts will not be successful; but, if so, we question whether the failure will be explained by their unique model used to estimate the time required to mine 'fluid mud'.

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