Historical Changes of Sediment Phosphorus in a River-Lake System Due to Improvements in Wastewater Treatment

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Introduction

- Eutrophication problems associated with anthropogenic nutrient loading have led to large-scale initiatives to improve the rivers and lakes impaired by excess nutrients.
- Eutrophic conditions in the James River Arm (JRA) of Table Rock Lake, in southwest Missouri (Figure 1), led to point-source phosphorus (P) reduction in the James River Basin through upgrades in 2001 at the Springfield Southwest Wastewater Treatment Plant (SSWTP) (U.S. EPA, 2001).
- The purpose is to quantify sediment P patterns in the JRA in order to evaluate effects of Sewage Treatment Plant (STP) upgrades on P concentrations.
- The objectives are to:
  1. Analyze the lateral and longitudinal distribution of sediment P in the JRA
  2. Examine sedimentological and geochemical properties and processes affecting sediment P transport and deposition
  3. Determine the effects of STP upgrades on P reductions in the JRA

Study Area

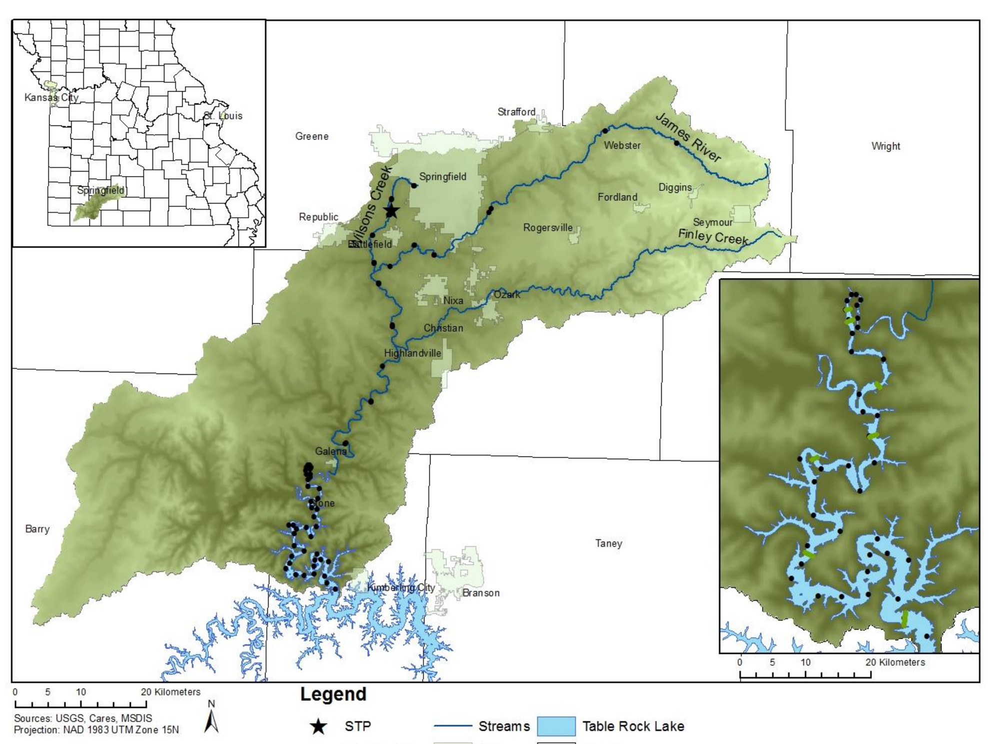

Figure 1. Sample sites on the James River, James River Arm, and Wilson's Creek. The SSWTP discharges into Wilson's Creek.

- Table Rock Lake is a United States Army Corps of Engineers reservoir on the White River (Figure 1). It was completed in 1959, has a surface area of 167 km², and a volume of about 4.27 km³ (USACE, 1985).
- The JRA of Table Rock Lake makes up about 20% of the total lake area, 30% of the total flow, and drains 2,500 km² (Knowlton and Jones, 1989).
- The James River Basin (Figure 1) is located in the Ozark Highland Province, where karst terrain is extensive in the Ordovician and Mississippian age limestone (Adamski et al., 1995).
- In 2001, the EPA accepted a TMDL for the James River Basin, About 27% of the P entering Table Rock Lake was from the SSWTP (U.S. EPA, 2001).
- In 2001 the SSWTP completed a biosolid upgrade, removing nearly 90% of the P from its effluent (City of Springfield, 2012; Obrecht et al., 2005).

Methods

- Site locations were identified from prior studies, before the 2001 STP upgrades (Frederick, 2001; Owen, 2003).
- GPS locations were collected with a Trimble GeoXT; a Lowrance Mark 4 depth finder collected water depth.
- Lake-bottom surface sediment samples were collected using an Ekman grab sampler (Owen, 2003).
- Stream sediment was collected from bar tail, bench, and floodplain surfaces using an entrenchment tool (Frederick, 2001).
- Sediment was dried in an oven at 60°C for 3-10 days followed by disaggregation by mortar and pestle and sieved to less than 2 mm.
- Geochemical composition was determined by ALS Chemex using ICP analysis with Aqua Regia digestion.
- Organic matter content was determined using both loss-on-ignition and elemental CNS analyzer methods (OEWRI, 2007a; OEWRI, 2007b).
- Particle size was determined using hydrometer and laser particle sizer methods (OEWRI, 2008; Gee and Bauder, 1986).
- SPSS software was used for statistical analyses of the data.
- ArcMap 10.1 was used to create the maps and investigate spatial relationships.

Results

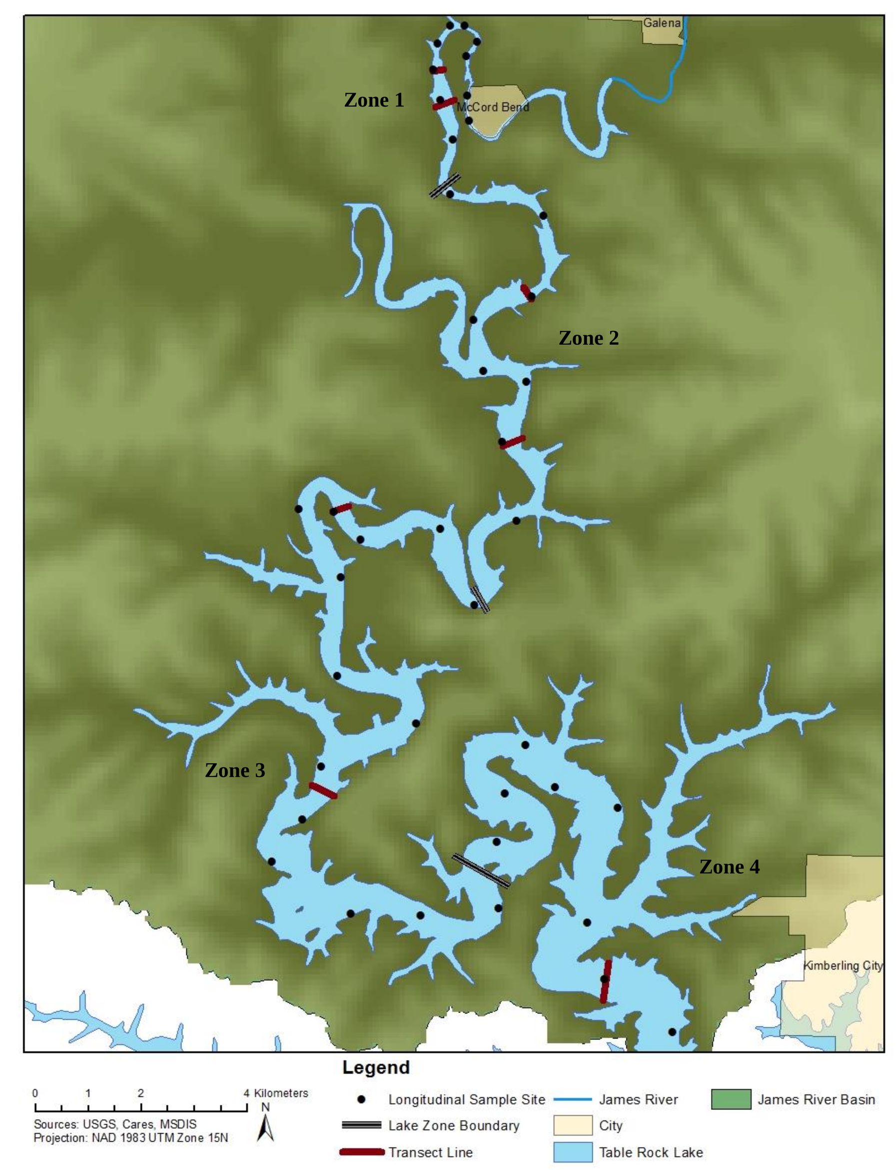

Figure 2. Sedimentation Zones of the JRA.

- Sedimentation zones are based on geochemical and physical sediment properties (Figure 2).
- Zone 1 has variable concentrations of Al, Fe, Mn, and organic matter (Figures 3 and 4). Percent sand is high (max 65%) within this zone (Figure 5).
- Zones 2, 3, and 4 are characterized by increasing concentrations of Al, Fe (Figure 3).
- Organic carbon content increases through zones 2, 3, and 4; inorganic carbon decreases in zone 4 (Figure 4).
- Sediment P increases down-lake (Figure 6)
- Lateral sediment P content increases with depth (Figures 7). Lateral transects are shown in Figure 2.

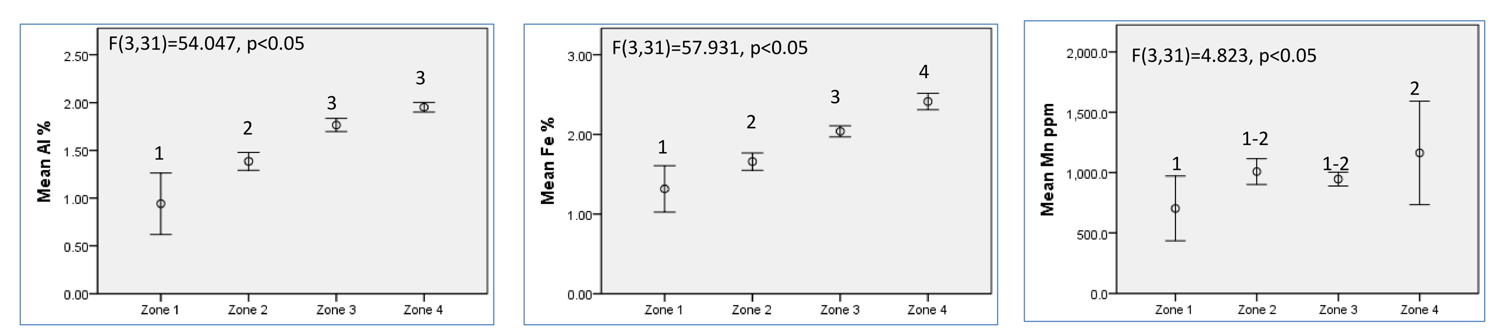

Figure 3. Longitudinal geochemical characteristics of the JRA by sedimentation zone. Sample size: Zone one, 6; Zone two, 8; Zone three, 15; and Zone four, 6. Statistically significant mean concentrations and F values are noted.

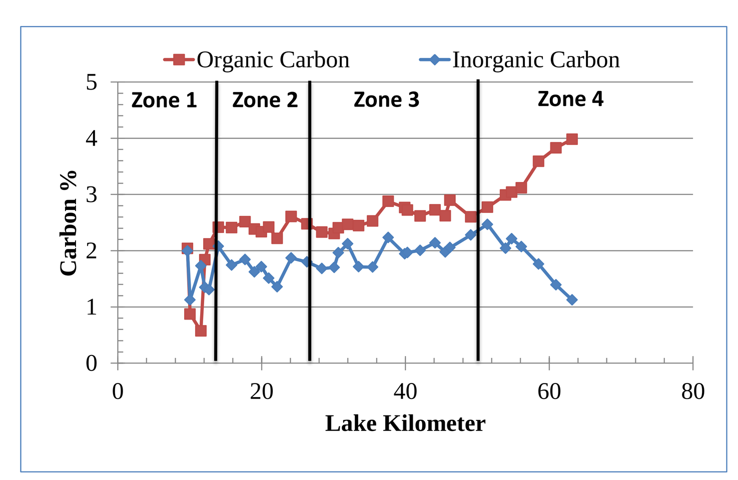

Figure 4. Longitudinal organic and inorganic carbon of the JRA (OEWRI, 2007b method)

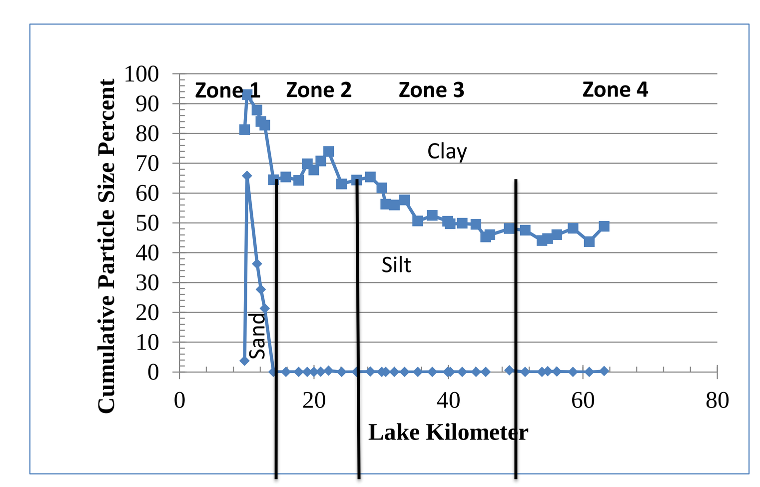

Figure 5. Longitudinal sediment grain size of the JRA.

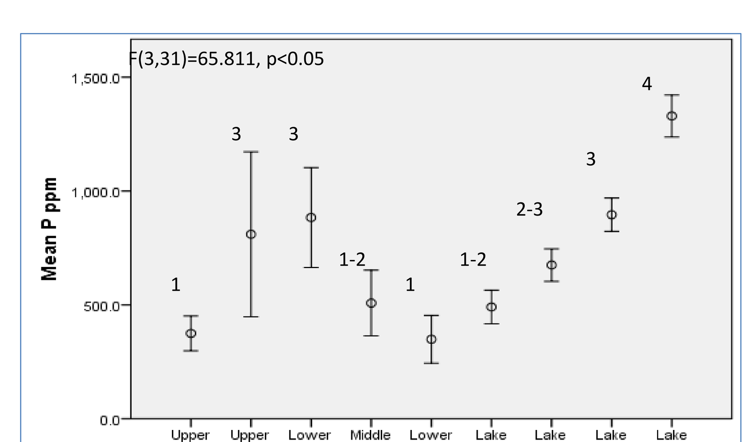

Figure 6. Sediment P in the James River Basin.

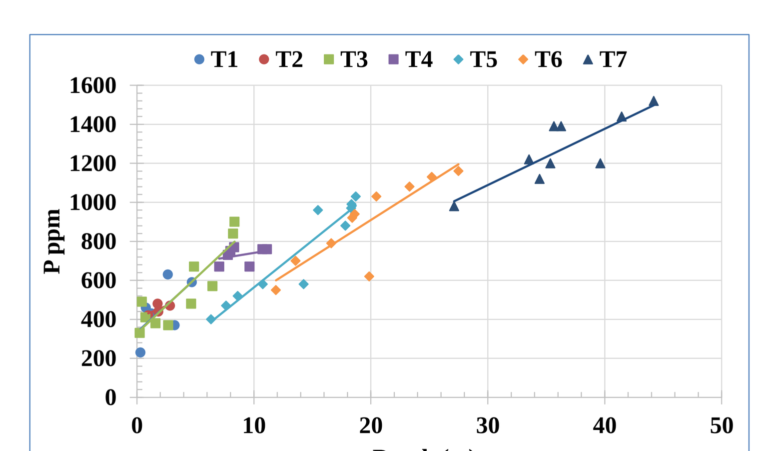

Figure 7. Lateral variations in sediment P by depth in the JRA.

Results

- Sediment-P concentrations are highest in Wilson's Creek and the JRA, and are higher in floodplain sediment compared to channel sediment (Figures 6 and 8).
- Sediment-P enrichment can be seen in floodplain sediments between SSWTP and the James River, and in channel sediments from SSWTP to the Finley River (Figure 9).
- Similar P/Al values for floodplain and JRA sediment suggests sediment-P concentrations in the JRA are responding to sediment associated with storm flows (Figure 9).
- Variability of P/Al in zone 4 can be reduced by normalizing P/Al/Fe (Figure 10). This is likely due to geochemical redistribution of sediment-P associated with seasonal hypoxia in the hypolimnion.

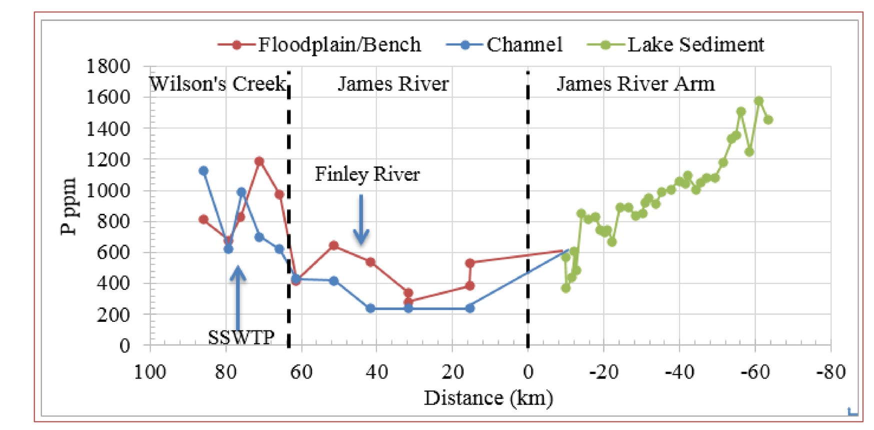

Figure 8. Longitudinal profile of P in the James River Basin.

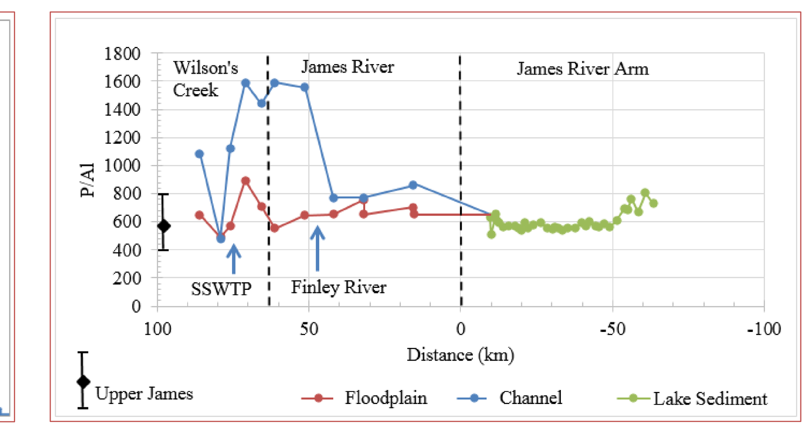

Figure 9. Longitudinal profile of P normalized to Al.

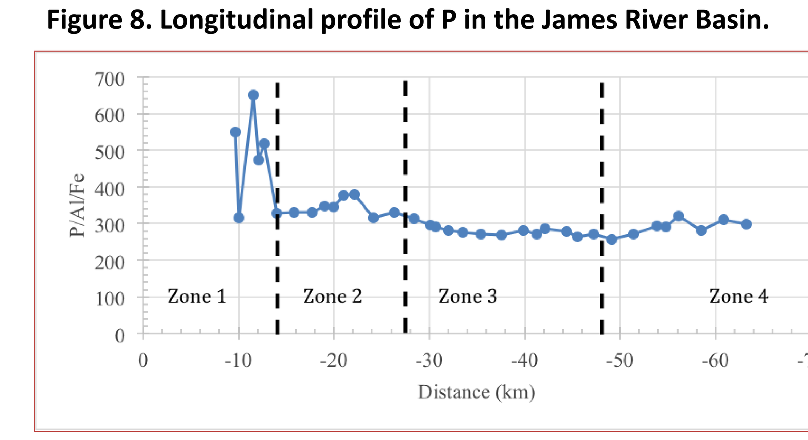

Figure 10. Longitudinal profile of P/Al/Fe for the JRA.

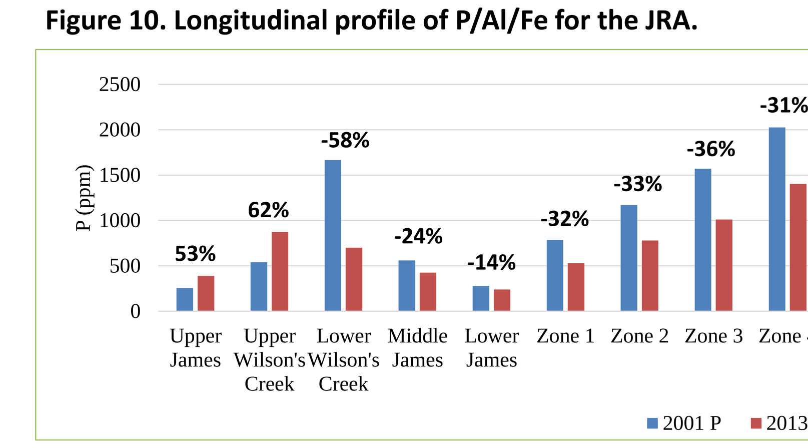

Figure 11. Sediment P change between 2001 and 2013-14. Stream samples are from in-channel sediment only. ^^2001 data from Frederick, 2001 and Owen, 2003

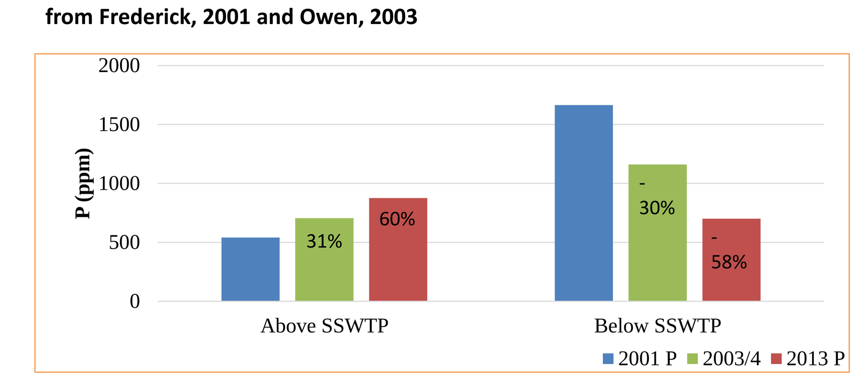

Figure 12. Average channel sediment-P change in Wilson's Creek

- Sediment P reduction has occurred in every zone downstream of SSWTP (Figure 11)
- Increased sediment P content is observed in the Upper James and Upper Wilson's Creek zones, warranting future attention (Figure 14).
- Sediment-P response in Wilson's Creek occurred quickly, with half of the observed response in the first 2-3 years (Figure 12).
- Sediment-P reduction increases with depth in the JRA, with the majority of reduction occurring below 50% total depth (Figure 13).

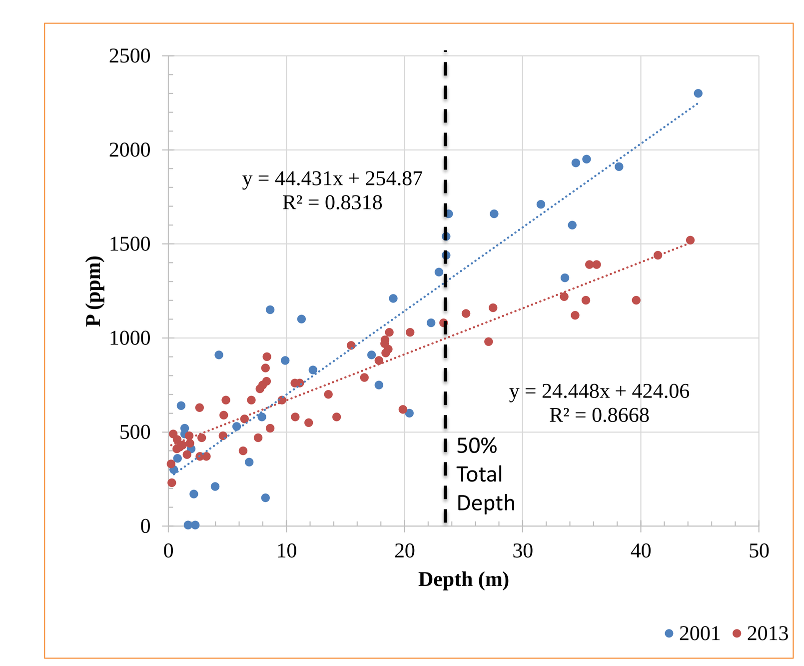

Figure 13. Lateral sediment-P change in the JRA.

Conclusions

- **Physical and geochemical sediment properties were used to identify four sedimentation zones in the JRA.**
- **Sediment P distribution is primarily influenced by fine grained sedimentation in the JRA. Sediment P is focused in the deepest part of the cross section and lake. Concentrations of Fe seem to influence P distribution in zone 4 of the JRA. Sediment P concentrations are still enriched near SSWTP.**
- **Sediment-P concentrations have decreased in all zones downstream of SSWTP, suggesting point source nutrient load reductions have improved sediment quality. Sediment-P concentrations decreased by 33% in the JRA.**

References

Adamski, J.C., J.C. Peterson, D.A. Freiwald, and J.V. Davis, 1995. Environmental and Hydrologic Setting of the Ozark Plateaus Study Unit, Arkansas, Kansas, Missouri, and Oklahoma. U.S. Geological Survey Water- Resources Investigations Report 94-4022.
City of Springfield, 2012. Southwest Wastewater Treatment Plant. Accessed 3-8-2014 https://www.springfieldmo.gov/cleanwater/southwest.html
Frederick, B.S., 2001. Spatial Distribution of Phosphorus in Fluvial Sediments from the James River Basin, SW Missouri. Thesis. Southwest Missouri State University.
Gee, G.W. and J.W. Bauder, 1986. Particle-size Analysis. Methods of Soil Analysis Part 1. A. Klute (editor), Soil Science Society of America Book Series 5, Madison, Wisconsin, USA: 383-411.
Knowlton, M.F. and J.R. Jones, 1989. Summer Distribution of Nutrients, Phytoplankton and Dissolved Oxygen in Relation to Hydrology in Table Rock Lake, a Large Midwestern Reservoir. Archiv für Hyrdobiologie –83(2): 197-225.
Obrecht, D., A.P. Thorpe, and J.R. Jones, 2005. Responses in the James River Arm of Table Rock Lake, Missouri (USA) to Point-Source Phosphorus Reduction. Verhandlungen des Internationalen Verein Limnologie 29:1043-1048.
Ozarks Environmental and Water Resources Institute (OEWRI), 2007a. Standard Operating Procedure: Organic Matter in Sediment, Loss on Ignition Method. Missouri State University.
Ozarks Environmental and Water Resources Institute (OEWRI), 2007b. Standard Operating Procedure: Vario EL III CHNOS Elemental Analyzer operation. Missouri State University.
Ozarks Environmental and Water Resources Institute, 2008. Standard Operating Procedure: LS13320 Laser Diffraction Particle Size Analyzer Operation. Missouri State University.
Owen, M. R., 2003. Phosphorus Contamination and Storage in Bottom Sediments of the James River Arm of Table Rock Lake, Southwest Missouri. Thesis. Southwest Missouri State University.
United States Army Corps of Engineers (USACE), 1985. Dissolved Oxygen Study Table Rock Dam and Lake, White River, Missouri. Reconnaissance Report, Little Rock District.
United States Environmental Protection Agency, 2001. Phased Total Maximum Daily Load (TMDL) For James River. Region 7. United States Environmental Protection Agency.