

## “Proteus,” a new device for application of coagulants directly to sediment during its controlled resuspension

Ryszard Wiśniewski, Jerzy Ślusarczyk, Tomasz Kaliszewski, Adrian Szulczewski, Przemysław Nowacki

### Introduction

One basic problem in the restoration of lakes and other water basins is limitation of the fraction of bio-available phosphorus in the water volume. In practice the most frequently applied method is phosphorus precipitation from the water volume, with the aid of 2 basic coagulants: compounds of iron, chloride, or sulphate; and aluminium compounds, most often sulphate (BURLEY 1998, HANSEN et al. 2003, KLAPPER 2003). Rarely is  $\text{Ca}(\text{NO}_3)_2$  applied as the only substance, or as in the Riplox method, as a supplementary substance to the application of  $\text{FeCl}_3$  (RIPL 1976, EISELTOVÁ 1994). In recent phosphorus inactivation attempts, there is regard for the supplementation of coagulants with flocculants, which increase sediment particle consolidation, and for oxygen-releasing compounds.

The most frequent means of coagulant application, because it is the simplest and cheapest, is to spray it evenly on the water surface; rarely is it applied to subsurface water layers (COOKE et al. 1993). The application of coagulants to the water surface as a rule consists of even sedimentation to the sediment surface to create a uniform, compact isolating layer, preventing the release of  $\text{PO}_4$  from the sediments. In practice, as shown in current research, a coagulant with a large fractal dimension and a small negative buoyancy is deposited unevenly, creating an arrangement of islands on the sediment surface, with numerous, extensive empty areas. In the case of shallow lakes, after creating a solid layer of coagulant, even minor turbulence that does not cause sediment resuspension may displace the coagulant (RYDING & RAST 1989, VAN HULLEBUSCH et al. 2002).

Instances of the application of coagulant to the above-bottom water layer, and especially attempts to inactivate phosphorus directly in sediments, are few (RIPL 1976, QUAAK et al. 1993, OCETA 1995, WISNIEWSKI 1995).

The purpose of our research was to compare the effectiveness of phosphorus inactivation following application of coagulants to water versus to the sediment after prior subjection to intensive resuspension. The performance of the prototype “Proteus” device for the application of coagulant to bottom sediments was also tested (WISNIEWSKI 1999).

**Key words:** device, inactivation, phosphorus, sediments, shallow lake

### Materials and methods

Water and sediment for laboratory experiments were taken from the shallow, urban Lake Winiary in the city of Gniezno (Fig.1; Table 1). Chemical elements having an influence on the dynamics of phosphates and the redox potential, such as Ca, Mn, Mg, Fe, Al, Si, and  $\text{SO}_4$ , were analysed in sediments. In addition, fractions of phosphorus and the sediment phosphate absorption capacity ( $\text{EPC}_0$ ) were checked.

Sediment was taken from a shallow, partially isolated bay (Station 1), because the phosphorus concentration here was more than twice as high as in the deepest part of the lake (Table 2). About 75 % of the total phosphorus was in mobile fractions. Ten of a series of 2 L aquaria were filled with  $350 \text{ cm}^3$  of sediment and oxygenated lake water containing  $0.441 \text{ mg P-PO}_4/\text{L}$  (preventing sediment resuspension). One series of 5 aquaria was designated for the application of coag-

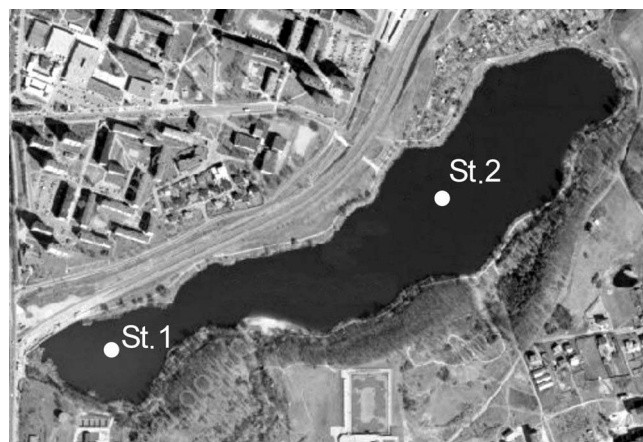


Fig. 1. Lake Winiary sampling stations.

**Table 1.** Lake Winiary morphometric features.

Surface ha	Volume thous. m <sup>3</sup>	Depth max. m	Depth mean m	Length max. m	Width max. m	Shore line development
14.4	302.4	4.2	2.1	1050	230	1.90

**Table 2.** Sediment chemical composition, and phosphate sorption capacity (EPC<sub>0</sub>). P-M mobile P fractions, P-NM non mobile P fractions.

Stations	Org. mat.	SiO <sub>2</sub>	Ca	Mg	SO <sub>4</sub>	NNH <sub>4</sub>	P <sub>tot</sub>	Fe	Mn	Fe/P	EPC <sub>0</sub>	P-M	P-NM
	%	%	g kg <sup>-1</sup> d.m.	g kg <sup>-1</sup> d.m.	g kg <sup>-1</sup> d.m.	g kg <sup>-1</sup> d.m.	g kg <sup>-1</sup> d.m.	g kg <sup>-1</sup> d.m.	g kg <sup>-1</sup> d.m.		PO <sub>4</sub> mg lL <sup>-1</sup>	%	%
St. 1 2.0 m	20.0	45.0	100.0	6.5	28.0	0.55	3.268	4.628	1.310	1.74	1.646	74.5	25.5
St. 2 3.5 m	16.0	50.1	87.5	21.8	29.0	0.41	1.230	4.388	0.743	3.07	0.912	55.9	44.1

ulant into water (series A), the other 5 for the application of coagulant during forced sediment resuspension (series B). The first aquarium in each series served as a control (i.e., no phosphorus, and no coagulant was added). To the remaining aquaria, 2.0 mg/L of PO<sub>4</sub> (as KH<sub>2</sub>PO<sub>4</sub>) was added. Every aquarium, except the controls, thus contained water with 1.095 mg/L of P-PO<sub>4</sub>. Measured total phosphorus (P<sub>tot</sub>) in sediments was 3.268 mg/g. d.m., of which 74 % were mobile fractions.

Coagulants were applied as follows: aquaria 2 A and 2 B: 5.0 ml/L of Al<sub>2</sub>(SO<sub>4</sub>)<sub>3</sub> (working solution 50 g L<sup>-1</sup>); aquaria 3 A and 3 B: 5.0 ml/L of FeCl<sub>3</sub> (working solution 50 g L<sup>-1</sup>); aquaria 4 A and 4 B: 1.05 g/L of Phoslock; aquaria 5 A and 5 B: FeCl<sub>3</sub> + Ca(NO<sub>3</sub>)<sub>2</sub> – 3.0 ml/L + 2.0 ml/L (working solutions 50 g L<sup>-1</sup>).

Phosphorus and suspension concentration was measured 6 hr after coagulant application, then sediment resuspension was activated again in all the aquaria. After another 6 hours the measurement of phosphorus and suspension concentration was repeated.

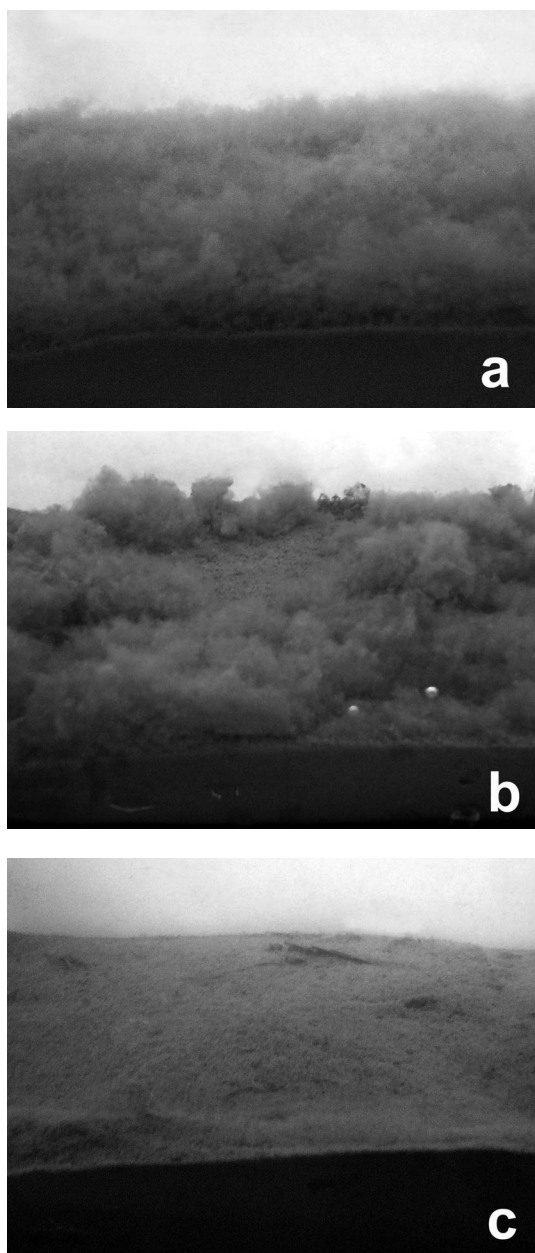
## Results and discussion

The experiment findings (Table 3) demonstrated that phosphorus reduction following coagulant application to resuspended deposits was considerably smaller than in aquaria with the coagulant applied into the water. The highest reduction was achieved with application of a mixture of FeCl<sub>3</sub> + Ca(NO<sub>3</sub>)<sub>2</sub>; however, after repeated resuspension in all aquaria, the concentration of phosphorus remaining in the water was halved in the aquaria in which the coagulant was administered to the sediment deposit, and the amount of suspension was smaller. In 2 aquaria of series A the coagulant layer was dislodged by gas bubbles emission (Fig. 2b).

The design prototype Proteus device consists of a surface module containing a navigation system and a substance application concentration control system, and an

**Table 3.** The results of phosphorus inactivation applying different coagulants into water (column A), and into resuspended sediment (column B).

	Control		Al <sub>2</sub> (SO <sub>4</sub> ) <sub>3</sub>		FeCl <sub>3</sub>		Phoslock		FeCl <sub>3</sub> + Ca(NO <sub>3</sub> ) <sub>2</sub>		
	A	B	A	B	A	B	A	B	A	B	
P-PO <sub>4</sub> mg L <sup>-1</sup>											
6 hours after coagulants addition	0.441	0.193	0.016	0.156	0.000	0.082	0.033	0.193	0.016	0.049	
Resuspension in both series											
6 hours after resuspension in both series	0.984	0.441	0.651	0.255	0.539	0.230	0.502	0.218	0.329	0.156	
Suspension mg L <sup>-1</sup> d.m.											
6 hours after coagulants addition		38.1		12.0		7.1		60.1		18.0	
Resuspension in both series											
6 hours after resuspension in both series	109.9	60.7	67.6	44.3	82.7	18.1	70.7	57.6	63.4	35.4	



**Fig. 2.** (a) Sediment surface after applying coagulant ( $\text{FeCl}_3$ ) into water; (b) Resettled coagulant layer after gas bubbles release; (c) Sediment surface after applying coagulant into resuspended sediment.

underwater module with a chamber and nozzles to administer the coagulant during controlled resuspension (Fig. 3). The operation principles resemble the solutions of RIPPL (1976), QUAACK et al. (1993), and OCETA (1995) except for an earlier triggering of intense resuspension of deposits and of administering coagulant to the accurately determined layer of deposits. Both resuspension and the coagulation processes are conducted under the shield of the underwater module that restricts

the escape of sediment particles, which enables the change and control of coagulation parameters (i.e., redox potential and pH), optimising the process and thus the efficiency of phosphorus inactivation (JENSEN & ANDERSEN 1992).

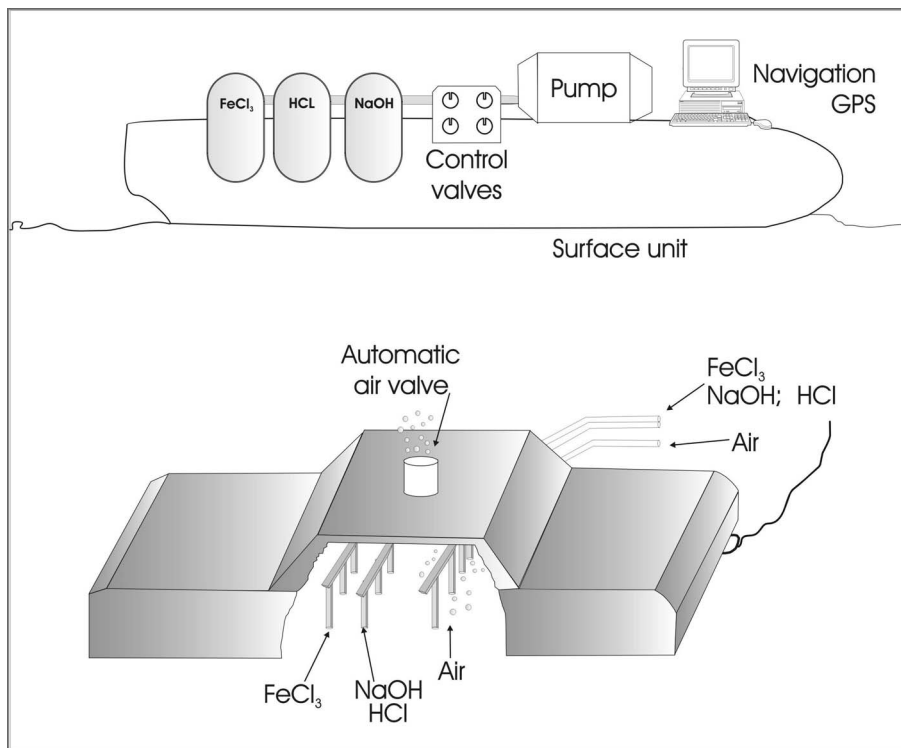
Our results demonstrated that application of the coagulant to the water volume does not guarantee the achievement of a solid and long-lasting layer of coagulant that effectively prevents  $\text{PO}_4$  release from deposits, which can be essential in the case of shallow lakes. We observed during experiments conducted on Lake Winiary that even a little turbulence in the above-bottom layer of water could dislodge fragments of the coagulation layer, demolishing its continuity and exposing large deposit surfaces (Fig. 2).

In the case of accidental sediment resuspension after performing the treatment, the amount of phosphorus released from the bottom deposits depends on the method of coagulant application. Phosphorus release is about half as much when the coagulant is administered directly to deposits than when applied to the water.

The prototype design Proteus device enables the precise control of the coagulant concentration, pH, redox potential, and depths of application to deposits, enabling optimal effectiveness of  $\text{PO}_4$  inactivation.

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**Fig. 3.** The “Proteus” scheme. Upper part – surface unit. Bottom part – underwater unit.

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**Authors' addresses:** R. Wiśniewski, Nicolaus Copernicus University, Institute of Ecology and Environment Protection, Toruń, Poland. E-mail: wisniew@biol.uni.torun.pl

J. Ślusarczyk, T. Kaliszewski, A. Szulczewski, P. Nowacki, Prote Technologies for Environment Sp. z o.o., Poznań, Poland. E-mail: prezes@prote.pl