

Chapter 2

Problem Introduction, Research Idea, and Studying Zone

Due to “internal P-loading” for lake eutrophication, it is important to quantify the P-release intensity at SWI for the restoration of contaminated lake (Förstner et al. 1994). So, the environmental behavior and biogeochemistry of P, Fe, and S in sediments should be understood (Shaw et al. 1990). The chemical property in sediment porewater has been verified as the sensitive indicator of the biogeochemical reaction happening between water and sediment particle (Zhang et al. 2002; Fones et al. 2004; Wu et al. 2011, 2014, 2015a, b, c, d). The bioavailability and mobility for P or meals can be investigated by conventional methods, such as a linear distribution coefficient (K_d), a nonlinear adsorption isotherm (Freundlich or Langmuir), sequential extraction procedures, or other procedures and analytical methods (Hamilton-Taylor and Morris 1985; Cutter and Oatts 1987; Barbanti et al. 1994; Golterman 2004; Kopáček et al. 2005; Wilson et al. 2008; Lin et al. 2009; Shilla et al. 2009; Wang et al. 2009). Compared with “bulk” analysis methods, the diffusive gradients in thin films (DGT) technique (Davison et al. 1994, 2000) is an advanced method for DGT profile/image of trace elements in sediment porewater (Zhang et al. 2002; Fones et al. 2004; Wu et al. 2011, 2014, 2015a, b, c, d), geochemical process (Naylor et al. 2004; Ding et al. 2012), kinetic exchange at the DGT/sediment microzone (Harper et al. 1998; Ernstberger et al. 2002), and microniche research (Widerlund and Davison 2007). The root of aquatic plant is important for P-cycling, and the kinetic P-uptake at root/sediment interface plays a key role in lake restoration (Nuttall 1985). The mobility and bioavailability of P in the rhizosphere are influenced by the physicochemical properties of sediments (Christensen 1997; SØndergaard and Lægaard 1977; Farmer 1985). DGT test in root microenvironments can act as an indicator for element availability and the element taken up by root (Lehto et al. 2006; Mason et al. 2010).

In this chapter, we introduced the eutrophic problem in lake sediments (Dianchi and Erhai lakes), which should be revealed and assessed by DGT technique, and the layout of DGT and the related techniques has been discussed for the research of P-transfer across environmental interfaces, including DGT measurement for P, S(-II),

and Fe, the software and program for P-transfer in sediment microzone, the analytical method for element 2D-distribution in sediment microzone, and DGT's function to research P-bioavailability and P-transfer across sediment/root interface. Moreover, the studying zones for DGT at SWI (Dianchi Lake) or sediment/root interface (Erhai Lake) were also introduced.

2.1 Problem Introduction

DGT is the analytical tool and research method for the profile character, the remobilization character, and the geochemical reaction mechanisms, and it has been widely used in all kinds of water bodies (lake, sea, and river). However, DGT has seldom been used for the geochemical character of P at SWI of lakes (Monbet et al. 2008; Ding et al. 2012), and the mechanism of “internal P-loading” should be revealed more thoroughly. Moreover, the previous researchers have never assessed “internal P-loading” in eutrophic lake comprehensively, and only one or two kinds of DGT probes have been investigated. Lake sediment is significant for the nutrient cycle, the reason of which is that it is the internal pool and source for plant root and benthic alga. The soluble nutrient released from sediment porewater can supply P. Under the anaerobic condition, the reduction of Fe(III) hydroxyoxide may lead to the release of soluble reactive P (SRP) associated with mineral phases (Palmer-Felgate et al. 2011). The anoxic condition promotes the reduction of insoluble Fe(III) hydroxyoxide to soluble Fe(II), resulting in the P-release from the sediments and into the surrounding water (Böstrom and Pettersson 1982; Christophoridis and Fytianos 2006). For example, Sundby et al. (1986) found that inorganic P (DIP , PO_4^{3-}) and Fe^{2+} were released simultaneously in equivalent concentrations as oxygen concentrations approached near zero in a benthic chamber in the sediments of Gullmarsfjorden, Sweden. The last reason and the decomposition of algae/organic matter may cause “internal P-loading” of lake (Cook et al. 2010). Roden and Edmonds (1997) suggested an indirect reduction pathway, attributing P-release from Fe(III) hydroxyoxide due to sulfate-reducing bacteria which enhance the formation of insoluble FeS.

So, it is important to measure the concentration/flux of P/Fe/S involved in the geochemical process of P, which can be used for the mechanism of “internal P-loading.” When the lake environment permits P-release from sediment into water phase, total dissolved P (TDP) level in water can be elevated and “internal P-loading” appears, regardless of “external P-loading.” For example, Dianchi Lake is a lake with eutrophic status in southeast of China (Wu et al. 2015c, d). “Internal P-loading” is one important factor for P-cycle at SWI. So, it is important to research P-release mechanism and the mechanism of “internal P-loading.” Lake sediment, composed of complex minerals, porewater, as well as inorganic and organic compounds, can act as both a sink and a source of P (Christophoridis and Fytianos 2006). Temperature, pH, redox potential, nitrate, sulfate, bioturbation, algae bloom,

as well as the presence of Ca, Mn, Fe, Al, and Mg have been found to be able to control P-release (Kleeberg and Dudel 1997). The adsorption of P on $\text{Al}(\text{OH})_3$ or the precipitation process of hydroxylapatite or fluorapatite ($\text{Ca}_5(\text{PO}_4)_3(\text{OH},\text{F})$) is the main reason for P-sequestration at SWI.

The sediment has been identified as the important pool for P in a lot of aquatic ecosystems (Lebo 1991; Conley et al. 1995; Paludan and Morris 1999; Zwolsman 1994; Zhang and Huang 2007). Thus, the P-release across the SWI through adsorption–desorption processes and coprecipitation–dissolution reactions plays a key role in controlling the dissolved phosphate concentrations in the overlying waters and porewaters (Froelich et al. 1982; Froelich 1988). Understanding the kinetic P-release between the sediment and porewater interface is significant for assessing the release risk and the P-mobility in lake sediments. Some researchers have focused on the linear distribution coefficient (K_d) or the nonlinear adsorption isotherm (Freundlich or Langmuir) to investigate the P distribution at SWI; other researchers have investigated the sequential extraction method for P-fractionation in sediments for assessing the bioavailable P in the sediment or potential P-release (Wilson et al. 2008; Shilla et al. 2009; Wang et al. 2009; Lin et al. 2009). Commonly, the adsorption–desorption studies are performed in dilute suspensions, whereas the sequential extraction procedures can systematically alter the chemical environment (Ernstberger et al. 2002).

The recently developed skill (Davison et al. 1994)—diffusive gradients in thin films (DGT) technique—has been used to measure in situ concentrations and fluxes of elements in the sediment/soil/water. It operates through introducing a localized sink that induces a diffusion flux to the DGT resin. The quantity measured directly is the mass of one element accumulated by the sink (the binding gel) during DGT deployment. These in situ DGT measurements depend on the element concentrations in sediment porewater and the resupply from the solid phases. Thus, the in situ evaluation for rate constants of the element release from the solid phase and capacities of element reservoir in the solid pool can be reached.

The macrophytes such as *Zizania caduciflora* or *Myriophyllum aquaticum* are distributed widely in the lakes or rivers in China, such as Erhai Lake (the southeast of China). The technique for wetland treatment project to control “internal P-loading” has advantages for the ecological restoration of lake eutrophication. The water quality in lakes or rivers can be largely improved by macrophyte roots (Blindow et al. 1993; Barko et al. 1991; Gu et al. 2001; Brix and Schierup 1989; McNabb 1976; O’Dell et al. 1995; Canfield and Hoyer 1992; Leslie et al. 1983). Redox potential, pH, pCO_2 , PO_2 , and element concentrations in the proximity of macrophyte root determine the mobility and bioavailability of elements in rhizosphere (Hinsinger and Courchesne 2008). Aquatic plants in lake systems can effectively alter the chemistry of rhizosphere sediment by O_2 released from roots. The rhizosphere oxidation and the formation of Fe-plaque on roots of aquatic plants led to the accumulation of metals such as iron, zinc, and arsenic in rhizosphere (Otte et al. 1991; Kirk and Bajita 1995). Oxidation of ferrous iron to its ferric form would

lead to precipitation of Fe(III) hydroxyoxide in the rhizosphere (Otte et al. 1989), which in turn engenders a decreasing concentration gradient of dissolved iron toward the plant roots. These gradients would lead to the diffusion of iron, arsenic, and zinc in the direction of the roots. Assuming the uptake of the elements by roots is slower than supply through diffusion, an increase in the concentrations of all three elements would be expected to occur in the solid phase of the rhizosphere (Doyle and Otte 1997). Armstrong (1978) and Gambrell and Patrick (1978) suggested that the formation of Fe-plaque on roots served as a sink for elements and was consequently a hindrance to nutrient uptake by wetland plants. DGT technique for the measurement in the rhizosphere sediment can act as a predictor for the element taken up by plant root. The ferrihydrite-sorbent binding gel installed in DGT assembly is highly selective for labile P in sediment porewater. The diffusive gel layer in DGT assembly limits the largest flux of labile P from the sediment porewater into binding gel. This kind of induced flux of DGT is similar to that of P taken up by plant root. The Fick's law calculation ensures the accurate DGT concentration. DGT concentration depends on the soluble P in sediment porewater, and the resupply rate of P desorbed from sediment solid into porewater.

At the SWI of eutrophic lakes, the eutrophic element, P, redox sensitive elements, Fe and S, undergo complex exchanges and cogeochemical reactions, which control the eutrophic status and P-release risk. So, some questions should be answered, including: (1) What does the geochemical reaction determine the P-release and "internal P-loading" character in the vertical direction of sediment microzones? (2) How do kinetic parameters and sediment pools determine P-release/P-diffusion across the DGT/sediment interface? (3) How are S(-II)- or Fe-microniches analyzed and assessed at fine spatial scales in order to predict P-release risk? (4) Whether can the P-transfer and P-uptake in root of aquatic plant be assessed by DGT parameter? (5) Can DGT with multi-functions achieve the last measurement and assessment? The DGT techniques and the related methods with multi-functions for the two case studies (Dianchi and Erhai lakes) introduced in the next sections "Chap. 3" can solve the last questions.

2.2 The Research Idea and the General Design for DGT Research

DGT has been widely applied in the water body worldwide, as a powerful tool for the measurement of multi-elements and the research of environmental process at SWI. In this research, two problems should be answered: The first is the mechanism of P-release in sediment and the assessment for P-release intensity in eutrophic Dianchi Lake and the second is the P-uptake mechanism and P-transfer across sediment/root interface in Erhai Lake. DGT can be applied as a chemical sensor or a

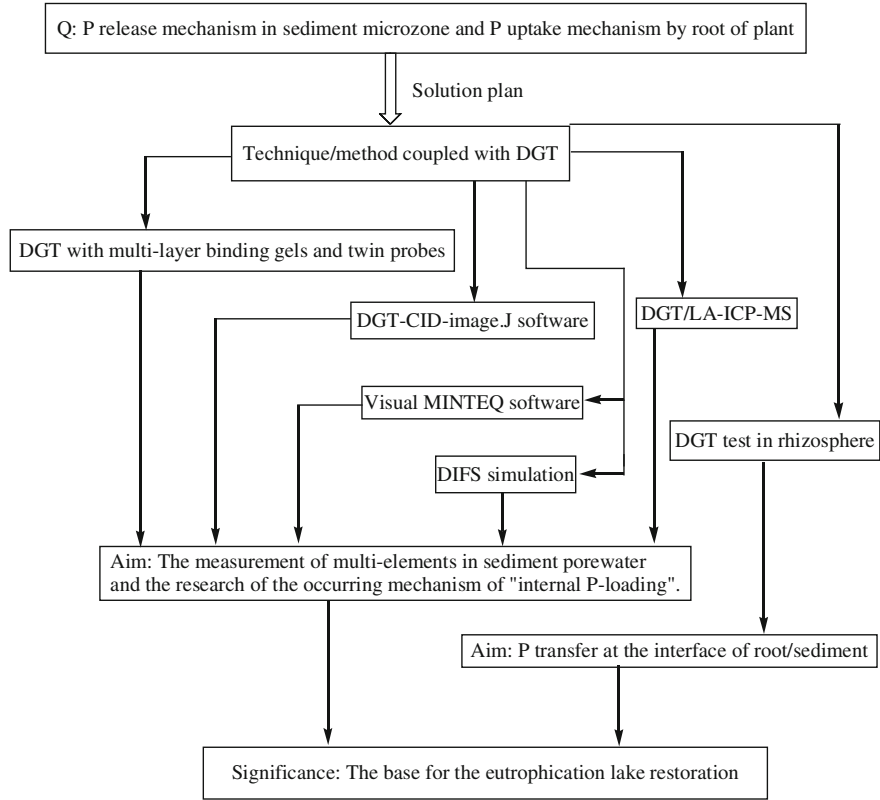


Fig. 2.1 The schematic graph of the general design for DGT research

passive sampler in the complex microenvironment (SWI) and the sediment/root microzone), and the other technique/method can be applied coupled with DGT technique in order to derive valuable data at fine spatial scales, environmental phenomenon, and the mechanism about P-transfer in sediment microzone or root/sediment interface. The schematic graph for the general design for DGT research is shown in Fig. 2.1. For the aim of the research for P-release mechanism and the related geochemical mechanism (Dianchi Lake), DGT probe with multilayer-binding gels and twin DGT probes have been developed for the simultaneous measurement of Fe/P/S elements in sediment porewater. The geochemical reactions were investigated, and the “internal P-loading” (Dianchi lake) was quantified. In order to quantify kinetic exchange of P and P-release/P-diffusion across DGT/sediment microzone, it is needed to develop numerical model to derive kinetic parameters and diagraph of P-exchange process as the functions of time/distance, and 1D-DIFS (DGT-induced fluxes in sediments) can be researched for input parameters, the operation of DIFS model, the discussion of output parameters and diagraphs, the mechanism for kinetic parameters controlling the

change character of DIFS curves, and P-release characters in sediment microzones. Due to the coupled biogeochemical process of Fe–S–P in sediment porewater, it is needed to research solubility of Fe-sulfide and Visual MINTEQ software can be used to achieve this aim; sulfide microniche determines the distribution of soluble inorganic sulfide in sediment porewater and influences the P-release from Fe-bound P; AgI-CID technique and ImageJ 1.38e software can be used to research sulfide microniche distribution character and the coupled Fe–S–P mechanism for P-release. Labile Fe-distribution in sediment microzone is the main factor for P-release from Fe-bound P, and LA-ICP-MS can be used for the analysis of labile Fe-bound by SPR-IDA gel in DGT probe. Based on chemical image of DGT-Fe in sediment microzone, Fe-distribution character and the prediction of P-release in “hot spots” in chemical image can be researched. The above-mentioned method/technique can be used to reveal P-release mechanism in sediment microzone and “internal P-loading,” thoroughly. Moreover, in order to research P-transfer and P-uptake at the interface of sediment and the rhizosphere of aquatic plants in Erhai Lake, DGT piston can be used for the tests in situ or in rhizobox to achieve the last aim; the derived C_E value can be used to provide a major step forward in assessing hazards posed by P in eutrophic lake sediments. Finally, P-process at SWI or sediment/root interface and the release mechanism in microzone can be revealed, which is the base for the designation of the restoration of the eutrophic lake using in situ technology such as Al dose to prevent P-release or the ecological engineering technique of aquatic plants.

2.3 Studying Zones in Dianchi and Erhai Lakes

Dianchi Lake (102°37'59.76"–102°45'55.07"E, 24°40'38.89"–25°1'21.39"N) is the sixth largest freshwater lake of China at the foot of the Western Hills in southwest of Kunming city of Yunnan Province (southwest China). Dianchi Lake consists of two parts, which are the internal lake and the outer lake. The total area of Dianchi Lake is 306.3 km², with a length of 39 km (N–S), a width of 13 km (E–W), an average depth of about 5 m, and a total water capacity of 1.593 billion m³. The different areas of Dianchi Lake are eutrophic in the various degrees. In 2009, the average total phosphorus (TP) concentrations in sediments are 2–3 g kg^{−1} (0–5 cm), 1–2 g kg^{−1} (5–10 cm), and 1–2 g kg^{−1} (10–20 cm) in turn. The average contents of metal-bound P and organic P (OP) are about 17.57–48.82 % and 20–30 % of those of TP, respectively. The contents of OM in sediments are 8.24–677 g kg^{−1} (0–5 cm), 4.5–590 g kg^{−1} (5–10 cm), and 7.07–649.03 g kg^{−1} (10–20 cm), respectively. The content of TN in sediments (0–20 cm) is 4.91 g kg^{−1}. Extensive blue algal blooms have happened frequently in recent years, and biomass of alga is 4.402×10^6 – 1.102×10^9 cell l^{−1} (Chinese Research Academy of Environmental Sciences 2014). Despite reduced “external P-loading,” Dianchi Lake has failed to recover from eutrophic status partially due to the P-release from

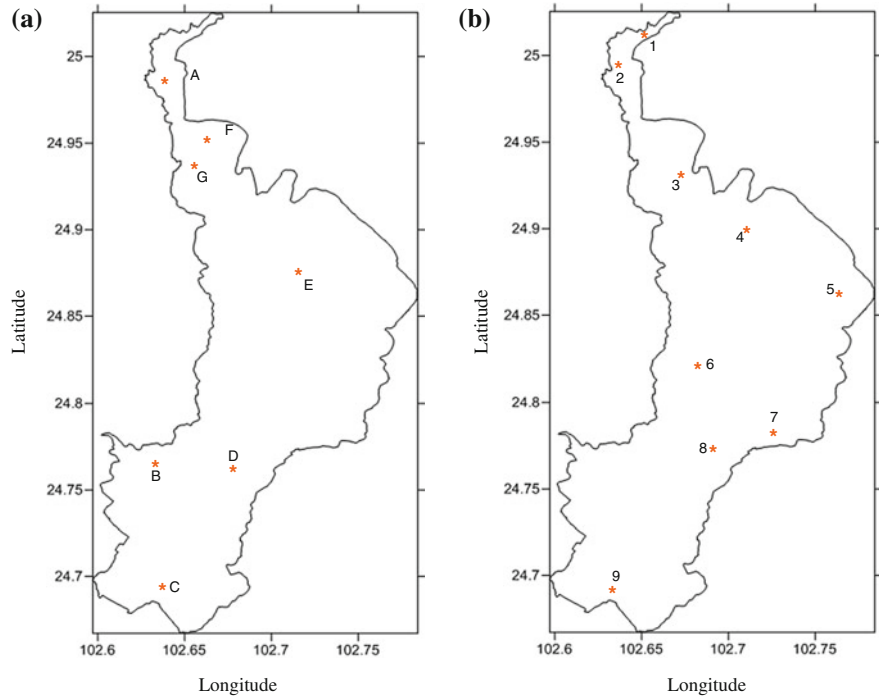


Fig. 2.2 Sampling sites for DGT probe tests and DIFS test at Dianchi Lake. **a** Seven sites (A–G) for DGT probes; **b** nine sites (1–9) for DIFS test. (Reprinted from *Water Air Soil Pollut*, 225:2188–2194, Wu, Z.H., Wang, S.R., Jiao, L.X., Wu, F.C., The simultaneous measurement of phosphorus, sulfide, and trace metals by Ferrihydrite/AgI/Chelex-100 DGT (Diffusive Gradients in Thin Films) probe at sediment/water interface (SWI) and remobilization assessment, copyright (2015), with the permission from Springer; Reprinted from *J. Geochem. Explor.*, 156: 145–152., Wu, Z.H., Wang, S.R., Jiao, L.X., Geochemical behavior of metals-sulfide-phosphorus at SWI (sediment/water interface) assessed by DGT (Diffusive gradients in thin films) probes, copyright (2015), with the permission from Elsevier)

the sediment (“internal P-loading”). The sampling locations (Dianchi Lake) for DGT probe test are indicated in Fig. 2.2a (Wu et al. 2014, 2015d). The sampling locations for P-DIFS test (Dianchi Lake) are indicated in Fig. 2.2b. The longitudes and latitudes for all sampling sites are listed in Table 2.1 (Wu et al. 2014, 2015c, d).

Erhai Lake (100°5'E–100°17'E, 25°35'N–25°58'N) is situated at Dali Bai Autonomous Prefecture in Yunnan Province (China) and the second largest lake in Yunnan Plateau. The shape of this lake is like an ear with the length of 43 km and the width of 8.4 km. The lake has a surface area of 249 km² with the maximum water depth of 21.5 m. The storage capacity is 2.88 × 10⁹ m³, and the water

Table 2.1 Sampling locations of DGT tests in Dianchi Lake. (Seven sites (A–G) for DGT probe test; nine sites (1–9) for DGT–DIFS test)

Site	Longitude	Latitude	Site	Longitude	Latitude
	E	N		E	N
A	102°38'34"	24°59'30"	1	102.67	25.02
B	102°37'48"	24°46'24"	2	102.63	24.99
C	102°38'12.149"	24°41'22.542"	3	102.68	24.93
D	102°41'24.463"	24°47'52.517"	4	102.73	24.91
E	102°43'40.84"	24°52'27.39"	5	102.77	24.87
F	102°39'45.54"	24°57'1.01"	6	102.68	24.86
G	102°40'55.99"	24°52'27.39"	7	102.74	24.8
			8	102.72	24.78
			9	102.62	24.69

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residence time is 2.75 years. The nutrient level of Erhai Lake is changing from mesotrophication to eutrophication in recent years. The location for DGT test in situ and in rhizobox for P taken up by plant root is shown in Fig. 2.3.

2.4 Summary

This chapter reported the environmental problem of Dianchi and Erhai lakes in the southwest of China. The “internal P-loading” in Dianchi Lake and two aquatic plants (*Zizania caduciflora* and *Myriophyllum aquaticum*) for the ecological restoration in Erhai Lake have been introduced. To reveal the mechanism of “internal P-loading” (Dianchi Lake) and P-uptake mechanism by plant roots (Erhai Lake), DGT and related techniques should be developed and applied. The DGT technique for lake sediment and rhizosphere should be designed to illustrate the environmental problem related to lake eutrophication. In order to lay out the DGT research program for the P-transfer across SWI or sediment/root interface, a series of DGT probes with new types, LA-ICP-MS, CID, 1D/2D-DIFS, Visual MINTEQ and ImageJ 1.38e softwares, and DGT test in rhizosphere have been arranged to achieve DGT profile/image at fine scale, DGT image of S(-II) or P, kinetic P-release at DGT/porewater/sediment interface, P-transfer across root/sediment interface for the quantification of “internal P-loading,” geochemical reactions for P-release, sulfide or Fe microniche for P-release, and the DGT function as a surrogate of plant

Fig. 2.3 The site for DGT test in rhizosphere of aquatic plants at Erhai Lake. *Open triangle* the site of the experimental base for aquatic plants in Erhai (Institute of Hydrobiology, Chinese Academy)



root for P-uptake. The logical stratification of the components (all sorts of DGT techniques) making up the general design for DGT research has been discussed. Moreover, DGT test locations for probe, piston, and DIFS in Dianchi Lake and DGT test in rhizosphere in Erhai Lake were also introduced.

References

- Armstrong W (1978) Root aeration in the wetland condition. In: Hook DD, Crawford RMM (eds) Plant life in anaerobic environments. Ann Harbor Science Publishers Inc., Ann Harbor, MI, pp 269–297
- Barbanti A, Bergamini MC, Frascari F, Miserocchi S, Rosso G (1994) Critical aspects of sedimentary phosphorus chemical fractionation. Environ Qual 23(5):1093–1102
- Barko JW, Gunnison D, Carpenter SR (1991) Sediment interactions with submersed macrophyte growth and community dynamics. Aquat Bot 41:41–65

- Blindow I, Andersson G, Haregy A (1993) Long-term pattern of alternative stable states in two shallow eutrophic lakes. *Freshwater Biol* 30:1159–1167
- Böstrom B, Pettersson K (1982) Different patterns of phosphorus release from lake-sediments in laboratory experiments. *Hydrobiologia* 91–2:415–429
- Brix H, Schierup HH (1989) The use of aquatic macrophytes in water-pollution control. *Ambio Stockh* 18:100–107
- Canfield DE, Hoyer MV (1992) Aquatic macrophytes and their relation to the limnology of Florida lakes. Final Report Submitted to the Bureau of Aquatic Plant Management, Florida Department of Natural Resources, Tallahassee, FL, pp 596
- Chinese Research Academy of Environmental Sciences (2014) The survey and the investigation of “internal loading character” of Dianchi Lake (Chinese)
- Christensen KK (1997) Differences in iron, manganese, and phosphorus binding in freshwater sediment vegetated with *Littorella uniflora* and benthic microalgae. *Water Air Soil Pollut* 99:265–273
- Christophoridis C, Fytianos K (2006) Conditions affecting the release of phosphorus from surface lake sediments. *J Environ Qual* 35(4):1181–1192
- Conley DJ, Smith WM, Cornwell JC, Fisher TR (1995) Transformation of particle-bound phosphorus at the land sea interface. *Estuar Coast Shelf Sci* 40:161–176
- Cook PLM, Holland DP, Longmore AR (2010) Effect of a flood event on the dynamics of phytoplankton and biogeochemistry in a large temperate Australian lagoon. *Limnol Oceanogr* 55:1123–1133
- Cutter GA, Oatts TJ (1987) Determination of dissolved sulfide and sedimentary sulfur speciation using gas chromatography-photoionization detection. *Anal Chem* 59:717–721
- Davison W, Zhang H, Grime G (1994) In situ speciation measurements of trace components in natural waters using thin-film gels. *Nature* 367:546–548
- Davison W, Fones G, Harper M, Teasdale P, Zhang H (2000) Dialysis, DET and DGT: in situ diffusional techniques for studying water, sediment and soils. In: Buffle J, Horvai G (eds) *In situ monitoring of aquatic systems: chemical analysis and speciation*. Wiley, Chichester, pp 495–570
- Ding S, Sun MQ, Xu D, Jia F, He XA, Zhang CS (2012) High-resolution simultaneous measurements of dissolved reactive phosphorus and dissolved sulfide: the first observation of their simultaneous release in sediments. *Environ Sci Technol* 46:8297–8304
- Doyle MO, Otte ML (1997) Organism-induced accumulation of iron, zinc and arsenic in wetland soils. *Environ Pollut* 96(1):1–11
- Ernstberger H, Davison W, Zhang H, Tye A, Young S (2002) Measurement and dynamic modelling of trace metal mobilization in soils using DGT and DIFS. *Sci Total Environ* 36:349–354
- Farmer AM (1985) The occurrence of vesicular arbuscular mycorrhiza in isoetid-type submerged aquatic macrophytes under naturally varying conditions. *Aquat Bot* 21:245–249
- Fones GR, Davison W, Hamilton-Taylor J (2004) The fine-scale remobilization of metals in the surface sediment of the North-East Atlantic. *Cont Shelf Res* 24:1485–1504
- Förstner U, Calmano W, Hong J, Kersten M (eds) (1994) Effects of redox variations on metal speciation: implications on sediment quality criteria assessment. The Royal Society of Chemistry, London, pp 83–102
- Froelich PN (1988) Kinetic control of dissolved phosphate in natural rivers and estuaries: a primer on the phosphate buffer mechanism. *Limnol Oceanogr* 33:649–668
- Froelich PN, Bender ML, Luedtke NA, Heath GR, DeVries T (1982) The marine phosphorus cycle. *Am J Sci* 282:474–511
- Gambrell RP, Patrick WH (1978) Chemical and microbiological properties of anaerobic soils and sediments. In: Hook DD, Crawford RMM (eds) *Plant life in anaerobic environments*. Ann Harbor Science Publishers Inc., Ann Harbor, MI, pp 375–423
- Golterman HL (eds) (2004) *The chemistry of phosphate and nitrogen compounds in sediments*. Kluwer, Dordrecht, The Netherlands

- Gu B, DeBusk T, Dierberg FE, Chimney M, Pietro K, Aziz T (2001) Phosphorus removal from Everglades agricultural area runoff by submerged aquatic vegetation/limerock treatment technology: an overview of research. *Water Sci Technol* 44:101–108
- Hamilton-Taylor J, Morris EB (1985) The dynamics of iron and manganese in surface sediments of a seasonally Anoxic Lake. *Archiv Für Hydrobiologie-Supplement* 72:135–165
- Harper MP, Davison W, Tych W, Zhang H (1998) Kinetics of metal exchange between solids and solutions in sediments and soils interpreted from DGT measured fluxes. *Geochim Cosmochim AC* 62:2757–2770
- Hinsinger P, Courchesne F (2008) Biogeochemistry of metals and metalloids at the soil-root interface. In: Violante A, Huang PM, Gadd GM (eds) *Biophysico-chemical processes of heavy metals and metalloids in soil environments*. Wiley-Interscience, Hoboken, NJ, pp 268–311
- Kirk GJD, Bajita JB (1995) Root-induced iron oxidation, pH changes and zinc solubilization in the rhizosphere of lowland rice. *New Phytol* 131:129–137
- Kleeberg A, Dudel GE (1997) Changes in extent of phosphorus release in a shallow lake (Lake Großer Müggelsee; Germany, Berlin) due to climatic factors and load. *Mar Geol* 139:61–75
- Kopáček J, Borovec J, Hejzlar J, Ulrich KU, Norton SA, Amirbahman A (2005) Aluminum control of phosphorus sorption by lake sediments. *Environ Sci Technol* 39:8784–8789
- Lebo ME (1991) Particle-bound phosphorus along an urbanized coastal plain estuary. *Mar Chem* 34:225–246
- Lehto NJ, Davison W, Zhang H, Tych W (2006) Analysis of micro-nutrient behaviour in the rhizosphere using a DGT parameterised dynamic plant uptake model. *Plant Soil* 282:227–238
- Leslie AJ, Nall LE, Van Dyke JM (1983) Effects of vegetation control by grass carp on selected water-quality variables in four Florida lakes. *Trans Am Fish Soc* 112:777–787
- Lin CY, Wang ZG, He MC, Li YX, Liu RM, Yang ZF (2009) Phosphorus sorption and fraction characteristics in the upper, middle and low reach sediments of the Daliao river systems, China. *J Hazard Mater* 170:278–285
- Mason S, McNeill A, McLaughlin MJ, Zhang H (2010) Prediction of wheat response to an application of phosphorus under field conditions using diffusive gradients in thin-films (DGT) and extraction methods. *Plant Soil* 337(1):243–258
- McNabb CD (1976) The potential of submersed vascular plants for reclamation of wastewater. In: Tourbier J, Pearson RW (eds) *Biological control of water pollution*. The University Press, Philadelphia, PA, pp 120–132
- Monbet P, Mckelvie ID, Worsfold PJ (2008) Combined gel probes for the in situ determination of dissolved reactive phosphorus in porewaters and characterization of sediment reactivity. *Environ Sci Technol* 42:5112–5117
- Naylor C, Davison W, Motelica-Heino M, Van Den Berg GA, Van der Heijdt LM (2004) Simultaneous release of sulfide with Fe, Mn, Ni and Zn in marine harbor sediment measured using a combined metal/sulfide DGT probe. *Sci Total Environ* 328:275–286
- Nuttall PM (1985) Uptake of phosphorus and nitrogen by *Myriophyllum aquaticum* (velloza) Verdc. growing in wastewater treatment system. *Aus J Mar Res* 36:493–507
- O'Dell KM, Van Arman J, Welch BH, Hill SD (1995) Changes in water chemistry in a macrophyte-dominated lake before and after herbicide treatment. *Lake Res Manage* 11(4): 311–316
- Otte ML, Rozema J, Koster L, Haarsma MS, Broekman RA (1989) Iron plaque in roots of *Aster tripolium* L.: interaction with zinc uptake. *New Phytol* 111:309–317
- Otte ML, Dekkers MJ, Rozema J, Broekman RA (1991) Uptake of arsenic by *Aster tripolium* in relation to rhizosphere oxidation. *Can J Bot* 69:2670–2677
- Palmer-Felgate EJ, Mortimer RJG, Krom MD, Jarvie HPR, Williams JR, Spraggs E, Stratford CJ (2011) Internal loading of phosphorus in a sedimentation pond of a treatment wetland: effect of a phytoplankton crash. *Sci Total Environ* 409:2222–2232
- Paludan C, Morris JT (1999) Distribution and speciation of phosphorus along a salinity gradient in intertidal marsh sediments. *Biogeochemistry* 45:197–221
- Roden E, Edmonds JW (1997) Phosphate mobilization in iron-rich anaerobic sediments: microbial Fe(III) oxide reduction versus iron-sulfide formation. *Arch Hydrobiol* 139(3):347–378

- Shaw T, Gieskes JM, Jahnke RA (1990) Early diagnosis in differing depositional environments: the response of transition metals in pore water. *Geochim Cosmochim Acta* 54:1233–1246
- Shilla DA, Asaeda T, Kalibbala MM (2009) Phosphorus speciation in Myall lake sediment, NSW, Australia. *Wetlands Ecol Manage* 17:85–91
- Søndergaard M, Lægård S (1977) Vesicular arbuscular mycorrhiza in some aquatic vascular plants. *Nature* 268:232–233
- Sundby B, Anderson LG, Hall POJ, Iverfeldt A, Vanderloeff MMR, Westerlund SFG (1986) The effect of oxygen on release and uptake of cobalt, manganese, iron and phosphate at the sediment-water interface. *Geochim Cosmochim AC* 50(6):1281–1288
- Wang S, Jin XC, Zhao HC, Wu FC (2009) Phosphorus release characteristics of different trophic lake sediments under simulative disturbing conditions. *J Hazard Mater* 161:1551–1559
- Widerlund A, Davison W (2007) Size and density distribution of sulfide-producing microniches in lake sediments. *Environ Sci Technol* 41:8044–8049
- Wilson TA, Norton SA, Lake BA, Amirbahman A (2008) Sediment geochemistry of Al, Fe, and P for two historically acidic, oligotrophic Maine lakes. *Sci Total Environ* 404:269–275
- Wu ZH, He MC, Lin CY (2011) In situ measurements of concentrations of Cd Co, Fe and Mn in estuarine porewater using DGT. *Environ Pollu* 159:1123–1128
- Wu ZH, Wang SR, Jiao LX, Wu FC (2014) The simultaneous measurement of phosphorus, sulfide, and trace metals by Ferrihydrite/AgI/Chelex-100 DGT (diffusive gradients in thin films) probe at sediment/water interface (SWI) and remobilization assessment. *Water Air Soil Pollut* 225:2188–2194. (Reprinted from *Water Air Soil Pollut*, 225:2188–2194, Wu, Z.H., Wang, S.R., Jiao, L.X., Wu, F.C., The simultaneous measurement of phosphorus, sulfide, and trace metals by Ferrihydrite/AgI/Chelex-100 DGT (Diffusive Gradients in Thin Films) probe at sediment/water interface (SWI) and remobilization assessment, copyright (2015), with the permission from Springer)
- Wu ZH, Wang SR, He MC, Wu FC (2015a) The measurement of metals by diffusive gradients in thin films (DGT) at sediment/water interface (SWI) of bay and remobilization assessment. *Environ Earth Sci* 73(10):6283–6295
- Wu ZH, He MC, Wang SR, Ni ZK (2015b) The assessment of localized remobilization and geochemical process of 14 metals at sediment/water interface (SWI) of Yingkou coast (China) by diffusive gradients in thin films (DGT). *Environ Earth Sci* 73(10):6081–6090
- Wu ZH, Wang SR, He MC (2015c) Element remobilization, “internal P-loading” and sediment-P reactivity researched by DGT (diffusive gradients in thin films) technique. *Environ Sci Pollut R*. doi:10.1007/s11356-015-4736-8
- Wu ZH, He MC, Wang SR (2015d) Multi-metals measured at sediment/water interface (SWI) by diffusive gradients in thin films (DGT) technique for geochemical research. *Arch Environ Con Tox*. doi:10.1007/s00244-015-0184-1 (online published)
- Wu ZH, Wang SR, Jiao LX (2015e) Geochemical behavior of metals-sulfide-phosphorus at SWI (sediment/water interface) assessed by DGT (Diffusive gradients in thin films) probes. *J Geochem Explor* 156:145–152. (Reprinted from *J. Geochem. Explor.*, 156: 145–152., Wu, Z. H., Wang, S.R., Jiao, L.X., Geochemical behavior of metals-sulfide-phosphorus at SWI (sediment/water interface) assessed by DGT (Diffusive gradients in thin films) probes, copyright (2015), with the permission from Elsevier)
- Zhang JA, Huang XL (2007) Relative importance of solid-phase phosphorus and iron on the sorption behavior of sediments. *Environ Sci Technol* 41:2789–2795
- Zhang H, Davison W, Mortimer RJG, Krom MD, Hayes PJ, Davies IM (2002) Localised remobilization of metals in a marine sediment. *Sci Total Environ* 296:175–187
- Zwolsman JJG (1994) Seasonal variability and biogeochemistry of phosphorus in the Scheldt Estuary, southwest Netherlands. *Estuar Coast Shelf S* 39:227–248

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