BIOGEOCHEMICAL CHARACTERISTICS OF RIVER SYSTEMS

Norio Ogura
Professor, Department of International Environment and Agriculture Science, Tokyo University of Agriculture and Technology, Tokyo, Japan

Sentaro Kanki
Graduate School of Agriculture, Tokyo University of Agriculture and Technology, Tokyo, Japan. Present address: Asia Air Survey Co. Ltd., Nagoya, Japan

Keywords: Material Balance, Water Quality, Bioaccumulation, Decomposition, Sedimentation, Uptake, Nitrification, Denitrification, Carbon Cycle, Nitrogen Cycle

Contents

Summary

This chapter provides summaries of the main research concerning chemical substances changes in rivers. It is considered from four aspects: chemical, physical, biological and geo-scientific. In Section 2, approaches to changes in quantity are discussed, whereas Section 3 examines changes in quality, such as exchange processes. Section 4 examines research directed at approaches, such as models to explain phenomena.

1. Introduction

Rivers have played many important roles in the development of civilization since some 7,000 years ago, and have conferred various benefits on mankind. Rivers have been used as sources of drinking water, irrigation, and industrial waters, for transporting various products, as a force to generate electricity, and for recreation. Rivers are also important as habitat for algae, rooted-plants, benthic animals, fish, and other wild life.

Rivers play a significant role in the transport of carbon, nitrogen and other mineral nutrients from upstream to downstream regions, and these substances also influence the geochemical processes operating in water. Material balance is estimated from fluxes of chemical elements between upstream and the downstream points.

As illustrated in Figure 1, important biogeochemical processes occur in river water, transforming chemical elements during downstream transport. These processes include production, respiration, decomposition, nitrification, denitrification and others carried out by micro- and macro-organisms.

Chemical and physical factors such as temperature, light, riverbed substrates, and dissolved substances in the water are the main factors that influence the biogeochemical processes occurring in water.

At the land-sea boundary, especially in estuaries, various physical-chemical changes in chemical constituents occur during mixing of fresh and seawater, however, these processes are not included in the present review. In this article, the biogeochemical processes within river systems including transformation of organic carbon, nitrogen and other nutrients will be focussed on.

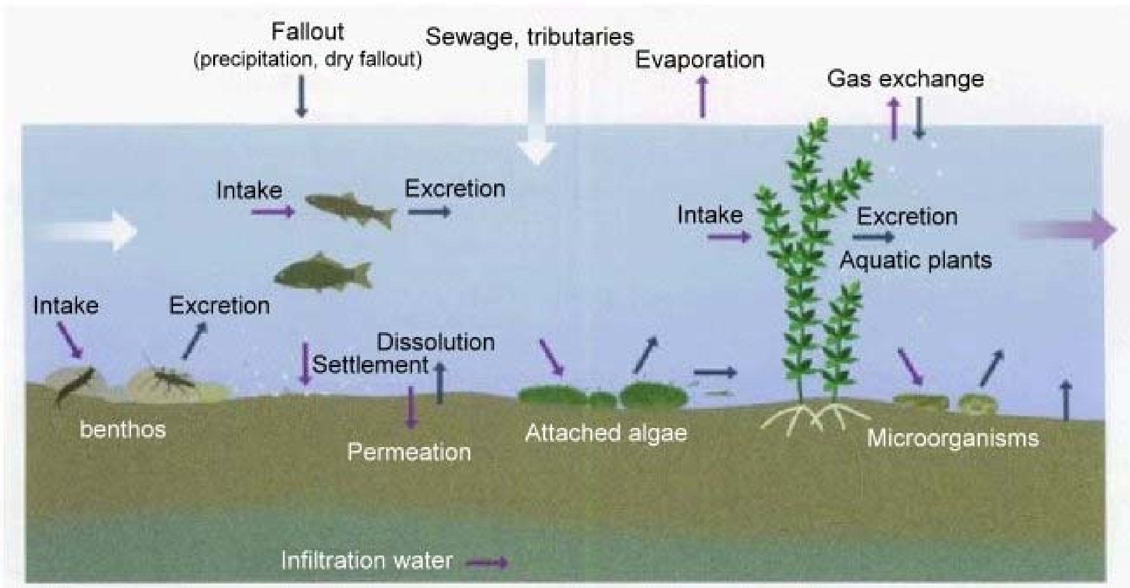

Fig. 1. Biogeochemical processes in River Systems (Ogura, 1980)

2. Geochemical Approach -Mass Balance

There are two major geochemical processes for mass balance. One is“Input Process”and the other is “Output Process.” There are five main types of inputs taken into account in the former process: "Precipitation," "Dry fallout," "Tributaries," "Sewage," and "Gush out." These provide many chemical substance inputs to the river system. On the contrary, two types of outputs, "Permeation" and "Evaporation," eliminate many chemical substances from river systems. The quantity of input and output should be balanced in the ecosystems of rivers. However, it is usually not balanced because of the Exchange process, which is detailed in Section 3. This section focuses on water quality and self-purification from a mass balance approach.

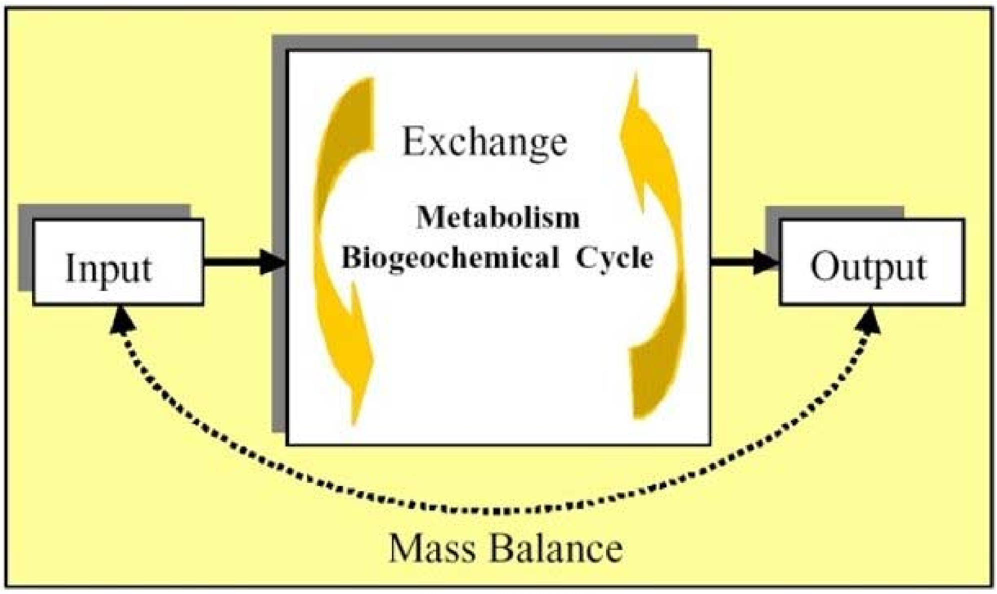

Fig. 2. Mass balance approach in river systems

The first study is about both point source and non-point source inputs of nutrients that are received by rivers. Delaune et al. (1991) conducted a water quality study of the Calcasieu River, which discharges into a major Louisiana Gulf Coast estuary (Calcasieu Lake). Data was used to characterize the water quality and trophic state of the river, with results showing the importance of nitrification and denitrification reactions in minimizing the effects of nitrogen input.

The next two studies are about water quality management in river systems. Correll et al. (1992) carried out extensive research in the Chesapeake Bay estuary and its drainage basin, and demonstrated that atmospheric deposition and diffuse land discharges are the largest sources for many parameters affecting estuarine water quality. For example, phosphorus and sediments are transported through water. Many pesticides and other toxic materials are present in surface waters and atmospheric deposition, and silicate is found primarily in groundwater. Concerns over point sources such as sewage treatment and industrial outfalls have led to greatly improved treatment methods, alleviating the relative magnitude of these sources. The realization of the magnitude and importance of diffuse sources has led to research on improved land use in the Chesapeake Bay landscape. One example is the use of and improved management of forested riparian buffer zones in the coastal plain part of the drainage basin.

Kadlec and Hey (1994) reported that the Des Plaines River Wetlands Demonstration Project has reconstructed four wetlands in Wadsworth, Illinois, USA. The river drains an agricultural and urban watershed, and carries a non-point source contaminated load of sediment, nutrients and agricultural chemicals. Up to 40% of the average stream flow is pumped to wetlands, and allowed to return from the wetlands to the river through control structures followed by vegetated channels. From this research, sediment removal efficiencies ranged from 86-100% for the four cells during summer and from 38-95% during winter. Phosphorus removal efficiencies ranged from 60-100% in summer and 27-100% in winter. The river contains both old, persistent chemicals, and modern degradable agricultural chemicals. The principal modern pollutant is atrazine, of which the wetlands remove approximately 50%. The project is successfully illustrating the potential of artificial wetlands for controlling non-point source pollution at an intermediate position in the watershed.

The following is a list of research papers that include the keyword “water quality.” Hunsaker and Levine (1995), Vandijk et al. (1994), Vaux et al. (1995), Quinn et al. (1997), Ichino and Kasuya (1998), Alexander et al. (1998), Krizan and Vojinovicmiloradov (1997), Kelly et al. (1995), Somlyody et al. (1998), Kalkhoff et al (1995). Prochazkoza et al (1996). These are some additional research papers in which the keyword “water quality” is also included. (see bibliography for details of each paper). Zagorc-Koncan et al. (1999), Libois and Hallet-Libois (1987), Koussouris et al. (1989), Zagor-ckoncan and Dular (1992), Cao et al. (1993), Suschka et al. (1994), Cao et al. (1996)

3. Biogeochemical Approach -Metabolism and Biogeochemical Cycles

In this section, some research is introduced which takes a biogeochemical approach to river systems. "Biogeochemical processes in river systems" can be rephrased as “metabolism,” “biogeochemical cycle,” or “exchange process.” These processes are shown in Figure 1. Most of these processes are carried out by aquatic plants, algae, benthos, fish and other biota.

3.1 Bioaccumulation (Bioconcentration)

The words bioaccumulation and bioconcentration mean an accumulation of a substance, such as a toxic chemical, in various tissues of a living organism. Chemical substances are not decomposed in river systems. The concentration of such kinds of substances in river water is normally low, however, the chemical concentration in organisms in the river is extremely high. This high concentration of chemical substances is caused by the accumulation without discharge by organisms living in the same area. This sub-section introduces some research on bioaccumulation in river systems.

The first two research projects are about heavy metals. Eglin et al. (1997) reported a study with the purpose of demonstrating the efficiency of two biological methods in the study of exchange between the canalized Rhine River and its riverside aquifer. The infiltration of Rhine water into groundwater is revealed by a high level of nutrients and the micropollutant mercury. One method made use of aquatic macrophyte communities as bio-indicators of the degree of eutrophication based on phosphorus and nitrogen, and the second method made use of the capacity of the bryophyte to accumulate mercury. The results obtained from both methods show that bio-indication using autochthonous aquatic macrophyte species can be used as an efficient method in river and groundwater.

Zakova and Kockava (1999) carried out a monitoring project of heavy metal content (lead, mercury, cadmium) in biomass of water plants (algae, mosses, macrophytes) and sediments in the Dyje/Thaya River basin during the period between 1992-1994. Heavy metal content was investigated in all the more abundant species or groups of plants in 14 localities along the entire Dyje/Thaya River. High heavy metal concentrations were also measured in sediments and in algal water blooms in the Vranov and Nove Mlyny Reservoirs. A substantial part of lead, mercury and cadmium contamination in the Dyje/Thaya River basin has its origin in non-point sources of pollution. These sources include agricultural application of mineral fertilizers containing trace elements, preservation of cereal grains before planting with mercury agent until 1990, and atmospheric deposition, despite the fact that atmospheric deposition of lead from traffic emissions has been decreasing.

The next study is about organic chemical compounds. Pereira et al. (1996) reported a study conducted in 1992 to assess the effects of anthropogenic activities and land use on the water quality of the San Joaquin River and its major tributaries. This study focused on pesticides and organic contaminants, looking at distributions of contaminants in water, bed, and suspended sediment, and the bivalve *Corbicula fluminea*. Results indicated that this river system is affected by agricultural practices and urban runoff. Sediments from Dry Creek contained elevated concentrations of polycyclic aromatic hydrocarbons (PAHs), possibly derived from urban runoff from the city of Modesto; suspended sediments contained elevated amounts of chlordane. Trace levels of triazine herbicides atrazine and simazine were present in water at most sites. Sediments, water, and bivalves from Orestimba Creek, a westside tributary draining agricultural areas, contained the greatest levels of DDT and its degrades DDD and DDE. Sediment absorption coefficient Koc, and bioconcentration factors (BCF) in *Corbicula* of DDT, DDD, and DDE at Orestimba Creek were greater than predicted values. Streams of the western San Joaquin Valley can potentially transport significant amounts of chlorinated pesticides to the San Joaquin River, the delta, and San Francisco Bay. Organochlorine compounds accumulate in bivalves and sediment and may pose a problem to other biotic species in this watershed.

-
-
-

Bibliography

Albering H. J., S. M. V. Leusen, E. J. C. Moonen, J. A. Hoogewerff and J. C. S. Kleinjans (1999). Human health risk assessment: A case study involving heavy metal soil contamination after the flooding of the river Meuse during the winter of 1993-1994. *Environmental Health Perspectives*, **107** (1), 37-43.

Alexander R. B., J. R. Slack, A. S. Judtke, K. K. Fitzgerald and T. L. Schertz (1998). Data from selected US-geological-survey national stream water quality monitoring networks.*Water Resources Research*, **34**, 2401-2405.

Anderson J. M.(1994).Water quality management in the River Gudenaa, a Danish lake-stream-estuary system.*Hydrobiologia*, **275/276**, 499-507.

Aucour A.M., S. M. F. Sheppard, O. Guyomar and J. Wattelet(1999).Use of C13 to trace origin and cycling of inorganic carbon in the Ryone river system.*Chemical Geology*, **159**, 87-105.

Barth J. A. C. and J. Veizer(1999).Carbon cycle in St. Lawrence aquatic ecosystems at Cornwall (Ontario), Canada: seasonal and spatial variations.*Chemical Geology*, **159**, 107-128.

Beyerle U., W. Aeschbach-Hertig, M.Hofer, D. M. Imboden, H. Baur and R. Kipfer(1999).Infiltation of river water to a shallow aquifer investigated with 3H/3He, noble gases and CFCs.*Journal of Hydrology*, **220**, 169-185.

Billet M. F. and M. S. Cresser(1992). Predicting stream-water quality using catchment and soil chemical characteristics. *Environmental Pollution*, **77**, 263-268

Boon P. I. and A. Mitchell(1995).Methanogenesis in the sediments of an Australian freshwater wetland: Comparison with aerobic decay, and factors controlling methanogenesis.*FEMS Microbiology Ecology*, **18**, 175-190.

Boorman D. B., J. M. Hollis and A. Lilly(1995). Hydralogy of soil types: a hydrologically-based classfication of the soils of the United Kingdom. *Institute of Hydrology, Oxon, England* Report, No. 126

Burns D. A.(1998).Retention of NO3- in an upland stream environment: A mass balance approach.*Biogeochemistry*, **40**, 73-96.

Cao Y.S. and G. J. Alaerts(1996).A model for oxygen consumption in aerobic heterotrophic biodegradation in dual-phase drainage systems.*Water Research*, **30** (4), 1010-1022.

Cao Y.S., G. J. Alaerts, C. M. Hooijman and H. J. Lubberding (1992).Oxygen consumption and organic decomposition in drainage systems with attached biofilm.*Water Science and Technology*, **26** (3-4), 683-692.

Cao Y.S., G. J. Alaerts, C. M. Hooijmans and H. J. lubberding(1993).Using batch reactors to drainage systems with attached biofilm.*Water Science and Technology*, **28** (7), 231-238.

Cazelles B., D. F. D and N. P. Chau(1991).Self purification in a lotic ecosystem: a model of dissolved organic carbon and benthic microorganisms dynamics. *Ecological Modelling*, **58** (1-4), 91-117.

Chaudhury R. R., J. A. H. Sobrinho, R. M. Wright and M.Sreenivas(1998).Dissolved oxygen modeling of the Blackstone river (Northeastern united states).*Water Research*, **32**, 2400-2412.

Chen C. H., L. M. Leong, J. Liu and J.C. Huang(1999).Study of oxygen uptake by tidal river sediment.*Water Research*, **33** (13), 2905-2912.

Christopheresen N., C. Neal, R. P. Hooper, R.D. Vogt and S.Anderson (1990). Modelling streamwater chemistry as a mixture of soilwater end-members – A step towards second generation acidification models. *Journal of Hydrology*, **116**, 307-320.

Correll D. L., T. E. Jordan and D. E. Weller (1992).Cross media inputs to eastern United States watersheds and their significance to estuarine water quarity.*Water Science and Technology*, **26**(12), 2675-2683.

Cosby B. J., R. F. Wright, G. M. Hornberger and J. N. Galloway (1985). Modelling the effects of acid deposition: Assessment of a lumped parameter model of soil water and streamwater chemistry. *Water*

Resource Research, **21**, 51-63.

Cosby B. J., G. M. Hornberger, R. F. Wright, and J. N. Galloway (1986). Modelling the effects of acid deposition: Control of long-term surfate dynamics by soil sulfate adsorption. *Water Resource Research*, **22**, 1283-1291.

Delaune R. D., L. M. Salinas, R. S. Knox, M. N. Sarafyan and C. J. Smith (1991). Water quality of a coastal river receiving nutrient inputs -Ammonium nitrogen transformation-.*Water science and technology*, **26**(7), 1287-1302.

Dodds W. K., J. R. Jones and E. B. Welch(1998).Suggested classification of stream trophic state: distributions of temperate stream types by chlorophyll, total nitrogen, and phosphorus.*Water Research*, **32**, 1455-1462.

Eglin I., U. Roeck, F. Robach and M. Tremolieres(1997).Macrophyte biological methods used in the study of the exchange between the Rhine river and the groundwater.*Water Research*, **31**(3), 503-514.

Ferguson R. I., S. T. Trudgill and J. Ball (1994).Mixing and uptake of solutes in catchments: Model development.*Journal of Hydrology*, **159**, 223-233.

Garcia-Ruiz R., S. N. Pattinson and B. A. Whitton(1998a).Denitrification and nitrous oxide production in sediments of the Wiske, a lowland eutrophic river. *Science of the Total Environment*, **210/211**, 307-320.

Garcia-Ruiz R., S. N. Pattinson and B. A. Whitton(1998b).Denitrification in sediments of the freshwater tidal Yorkshire Ouse. *Science of the Total Environment*, **210/211**, 321-327.

Heathwaite A. and P. Johnes(1996). Contribution of nitrogen species and phosphorus fractions to stream water-quality in agricultural catchments. *Hydrological processes*, **10** (7), 971-983.

Hope D., M. F. Billett and M. S. Cresser(1994). A review of the export of carbon in river water: Fluxes and processes. *Environmental Pollution*, **84**, 310-324

Hunsaker C. T. and D. A. Levine (1995). Hierarchical approaches to the study of water quality in rivers.*Bioscience*, **45** (3), 193-203.

Ichino K. and M. Kasuya(1998).Nitrogen removal in paddy fields- an option for water-quality improvement in rivers. *Ecological Engineering*, **10** (2), 159-164.

Jakeman A. J., I. G. Littlewood and P. G. Whitehead(1990). Computation of the instantaneous unit hydrograph and identifiable component flows with application to small upland catchments. *Journal of Hydrology*, **117**, 275-300.

Jarvie H. P., B. A. Whitton and C. Neal(1998).Nitrogen and phosphorus in east coast British rivers: Speciation, sources and biological siginificance. *Science of the Total Environment*, **210/211**, 79-109.

Kadlec R. H. and D. L. Hey(1994).Constructed wetlands for river water-quality improvement.*Water Science and Technology*, **29**(4), 159-168.

Kalkhoff S. J (1995).Relation between stream-water quality and geohydrology during baseflow conditions, Roberts Creek watershed, Clayton County, Iowa.*Water resources bulletin*, **67**(1-2), 593-604.

Kelly M. G (1998). Use of community-based indexes to monitor eutrophication in European rivers.*Environmental Conservation*, **25**(1), 22-29.

Kelly M. G., C. J. Penny and B. A. Whitton (1995).Comparative performance of benthic diatom indices used to assess river water quality.*Hydrobiologia*, **302**, 179-188.

Komai Y (1996).Evaluation of nutrient runoff from the Kako River by continuous daily sampling.*Water*

Science and Technology, **34**, 67-72.

Koussouris T. S., A. C. Diapoulis, I. T. Bertahas and K. C. Gritzalis (1989).Self-purification processes along a polluted river in Greece.*Water Science and Technology*, **21**(12), 1869-1872.

Kozerski H. P. and K. Leuschner (1999). Plate sediment traps for slowly moving waters.*Water Research*, **33**, 2913-2922.

Krizan J. and M. Vojinovicmiloradov (1997).Water quality of Yugoslav rivers (1991-1995).*Water Research*, **31**(11), 2914-2917.

Langen S. J., S. J. Wade, R. Smart, A. C. Edwards, C. Soulsby, M. F. Billett, H. P. Jarvie, M. S. Cresser, R. Owen and R. C. Ferrier (1997).The prediction and management of water quality in a relatively unpolluted major Scottish catchment - current issues and experimental approaches. *Science of the Total Environment*, **194**(FEB), 419-435.

Leu H.G., C. F. Ouyang and J.l. Su (1996). Effective of flow velocity changes on nitrogen transport and conversion in an open channel flow.*Water Research*, **30**, 2065-2071.

Lewis D. L., R.J. Williams, P.G. Whitehead (1997). Quality Similation along Rivers (QUASAR) Part II: An Application to the Yorkshire Ouse. *Science of the Total Environment*, **194/195**, 399-418.

Libois R. M. and C. Hallet-Libois(1987). Theunionid mussels (Mollusca, Bivalvia) of the Belgian upper river Meuse- an assessment of the impact of hydraulic works on the river water self-purification.*Biological Conservation*, **42** (2), 115-132.

Lokkegaard B. H., Hvitved-Jacobsen. T., Teichgraber. B. and Schlegel. S. (1998). Modelling of aerobic wastewater transformations under sewer conditions in the Emscher River, Germany.*Water Environment Research*, **70**, 1151-1160.

Marion L. and L. Brient (1998). Wetland effects on water quality: input output studies of suspended particulate matter, nitrogen and phosphorus in Grand Lieu, a natural plain lake.*Hydrobiologia*, **374**, 217-235.

Morehead M. D. and J. P. Syvitski(1999).River-plume sedimentation modeling for sequence stratigraphy: application to the Eel margin, northern California.*Marine Geology*, **154**, 29-41.

Nolan A. L., G. A. Lawrance and M. Meader(1995).Phosphorus speciation in the Williams River, New South Wales: eutrophication and a chemometric analysis of relationships with other water quality parameters.*Marine & Freshwater Research*, **46** (7), 1055-1064.

Ogura, N (1980) Metabolism of bioelements in the Minami Asakawa River and human activities affecting it. *The Japanese Journal of Limnology*, **41**, 138-146.

Pattinson S. N., R. Garcia-Ruiz and B. A. Whitton(1998).Spatial and seasonal variation in denitrification in the Swale-Ouse system, a river continuum. *Science of the Total Environment*, **210/211**, 289-305.

Pereira W. E., J. L. Domagalski, F. D. Hostettler, L. R. Brown and J. B. Rapp(1996).Occurrence and accumulation of pesticides and organic contaminants in river sediment, water and clam tissues from the San Joaquin river and tributaries, California.*Environmental Toxicology and Chemistry*, **15**, 172-180.

Perona E., I. Bonilla and P. Mateo(1999).Spatial and temporal changes in water quality in a Spanish river. *Science of the Total Environment*,**241**,75-90.

Prochazkoza L., P. Blazla and J. Kopacek(1996).Impact of diffuse pollution on water quality of the Vltava river (Slapy reservoir), Czech-republic.*Water Science and Technology*, **33** (4-5), 145-152.

Robson, A. J. and C. Neal(1997a). Regional water quality of the river Tweed basin, *Science and Total*

Environment, 194/195, 173-192.

Robson, A. J. and C. Neal(1997b). A summary of regional water quality for eastern UK rivers, *Science and Total Environment*, 194/195, 15-37.

Quinn J. M., A. B. Cooper, R. J. Daviescolley, J. C. Rutherford and R. B. Williamson(1997).Land-use effects on habitat, water-quality, periphyton and benthic invertebtrates in Waikato, New-Zealand, hill-country streams.*New Zealand Journal of Marine and Freshwater Research*, **31** (5), 579-597.

Reilly J. F., A. J. Horne and C. D. Miller (2000).Nitrate removal from a drinking water supply with large free-surface constructed wetlands prior to groundwater recharge.*Ecological Engineering*, **14**, 33-47.

Sverdrup H. and P. Warfvinge (1988). Weathering of primary silicate minerals in the natural soil environment in relation to a chemical weathering model. Water, *Air and Soil Pollution*, **38**, 387-408.

Sharpley A. N., J. S. Robinson and S. J. Smith (1995).Bioavailable phosphorus dynamics in agricultural soils and effects on water-quality.*Geoderma*, **67** (1-2), 1-15.

Somlyody L., M. Henze, L. Koncsos, W. Rauch, P. Reichert, P. Shanahan and P. Vanrolleghem(1998).River water quality modelling: III. Future of the art. *Water Science and Technology*, **38**, 253-260.

Suschka J., S. Ryborz and I. Leszczynska (1994).Surface-water and sediment contamination in an old industrial region of Poland - 2 critical examples.*Water Science and Technology*, **29** (3), 107-114.
Twist H., A. C. Edwards and G. A. Codd(1999).Algal growth responses to waters of contrasting tributaries of the River Dee, North-East Scotland.*Water Science*, **32** (8), 2471-2479.

Vandijk G., L. Venliere, W. Admiraal, B. Bannink and J. Cappon(1994).Present state of the water-quality of Europian rivers and implications for management. *Science of the Total Environment*, **145** (1-2), 187-195.

Vaux P. D., L. J. Paulson, R. P. Axler and S. Leavitt(1995).The water quality implications of artificially fertilizing a large desert reservoir for fisheries enhancement.*Water Environment Research*, **67** (2), 189-200.

Vought L. B. M., J. Dahl, C. L. Pedersen and J. O. Lacoursiere (1994). Nutrient retention in riparian ecotones.*AMBIO*, **23** (6), 342-348.

Whitehead P. G. (1979). Applications of recursive estimation techniques to time variable hydrological systems. *Journal of Hydrology*, **40**, 1-16.

Whitehead P. G., R. J. Williams and D. L. Lewis (1979). Quality Simulation along Rivers (QUASAR) Part I: Model Theory and Development. *Science and Total Environment*, **194/195**, 447-456.

Wiesche M. V. D. and A. Wetzel(1998). Temporal and spatial dynamics of nitrite accumulation in the River Lahn.*Water Research*, **32**, 1653-1661.

Wright G. G., A. C. Edwards, J. G. Morrice and K. Pugh (1991). North East Scotland river catchment nitrate loading in relation to agricultural intensity. *Chemical Ecology*, **5**, 263-281.

Zagorc-Koncan J.(1996).Effects of atrazine and alachlor on self purification processes in receiving streams.*Water Science and Technology*, **33** (6), 181-187.

Zagorc-Koncan J. and J. Somen (1999). A simple test for monitoring biodegradable industrial pollution in a receiving stream.*Water Science and Technology*, **39** (10-11), 221-224.

Zagorc-Koncan J. and M. Dular (1992). Evaluation of toxicity in receiving streams.*Water Science and Technology*, **26** (9-11), 2357-2360.

Zakova Z. and E. Kockova (1999). Biomonitoring and assessment of heavy metal contamination of streams and reservoirs in the Dyje/Thaya river basin, Czech Republic.*Water Science and Technology*, **39** (12), 225-232.

Zessner M., R. Denz and H. Kroiss(1998).Wastewater management in the Danube Basin.*Water Science and Technology*, **38**.

Biographical Sketches

Norio Ogura is an emeritus professor of environmental science at the Tokyo University of Agriculture and Technology, Japan. In addition to numerous biogeochemical studies on organic matter and nutrients in aquatic environments, he has an intense interest in citizens action in environmental science, his book entitled Investigation Method of Water Quality (1995, Maruzen Co. Ltd. in Japan) is one of the leading book for understanding water quality and its significance in aquatic environments.

Sentaro Kanki is a construction consultant at the Asia Air Survey Co.Ltd. in Japan. He received his master's degree in Agriculture at Tokyo University of Agriculture and Technology,Japan. His thesis, "Quantitative evaluation of self purification in different types of river systems", made clear quantitatively that river ecosystems are important for self-purification of a city river.