6. Projects for Water Environment Renovation of Lake Kasumigaura as the Core for Eutrophication Control Strategy in Japan

In November 1997, the Science and Technology Agency (reorganized as part of Ministry of Education, Culture, Sports, Science and Technology) designated the Project for Water Environment Renovation of Lake Kasumigaura in Ibaraki Prefecture as a Collaboration of Regional Entities for the Advancement of Technological Excellence (CREATE), which launched this ongoing five-year joint research project commissioned by the Japan Science and Technology Corporation. A wide range of organizations, universities, independent administrative institutions, prefectural research institutes, and R&D-oriented enterprises, jointly participated in the project to address technological development for water environment remediation, under the banner of "research concerning the development of the aquatic environment restoration for polluted lake areas by introducing eco-engineering approaches, and research on the comprehensive evaluation of the improvement efficiency brought by the new system."

Ibaraki Prefecture is home to Lake Kasumigaura, the second widest freshwater lake in Japan and an essential water resource due to it providing service, industrial, and agricultural waters and nourishing freshwater fishery. At the same time, however, the lake suffers from an aggravated water quality going way over the permissive levels in environmental standards, with toxigenic cyanobacteria proliferation in summer and year-round manifestation of the filamentous blue-green algae. This lake pollution poses various, immense challenges, such as obstructions to water utilization and a deteriorating landscape. The fundamental solution to these problems requires the urgent implementation of radical measures focusing on the elimination of the nitrogen and phosphorus that feed the abnormal cyanobacterial proliferation. The damage caused by toxic blue-green algae, in particular, is emerging in many regions of the world, which the World Health Organization (WHO) addressed recently by setting a guideline value for microcystin, a toxin produced by cyanobacteria, under its Guidelines for Drinking Water Quality. Such a situation, where our water sources fall into conditions hazardous to human life, is grave enough to call for urgent control measures. Tsukuba and Tsuchiura Cities in Ibaraki Prefecture hosted the 6th World Lakes Conference in 1995, which delivered the Kasumigaura Declaration. Based on this declaration, Ibaraki Prefecture with Lake Kasumigaura must adopt strong leadership to serve as an arena for providing new proposals on lake water environment restoration and remediation to the rest of the world.

With an eye on making the efficiency of actions directed towards a healthy lake water environment noticeable to Ibaraki taxpayers, the project is to proceed with objectives of 1) developing various elemental technologies for water environment restoration, such as processing, monitoring, and multimedia utilization, under an organic teamwork of industry, academia, and government, and 2) fostering venture business for generalizing and disseminating these developed technologies in order to apply these technologies to Lake Kasumigaura and its basin in an optimal way, as well as to activate industry within the prefecture. Furthermore, Ibaraki Prefecture is currently pursuing a construction plan for a "Lake Kasumigaura Environmental Center (tentative name)". This project aims to establish a foundation for the center to function as a world-leading institute on water environment research, and concurrently to develop the area with this institute into a Center of Excellence (COE) on lake environment remedial technologies, with the institute as its mainstay. It envisages its ultimate goal as establishing a foothold to implement the Kasumigaura Declaration. This declaration is hoped to provide a gem not just for Japan but for the world through its collection of know-how to navigate by into the 21st century.

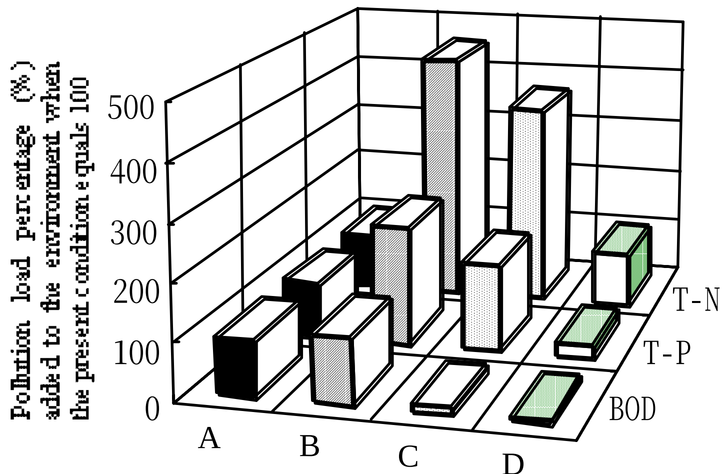
Nitrogen and phosphorus elimination essentially requires measures for source control and direct purification. For successful implementation, both control measures vitally need development of elemental technologies, keeping track of the state of water quality to effectively apply developed technologies to Kasumigaura and its basin, and development of bettering/predicting schemes after launching these technologies. The nucleus of such elemental technologies consists of the bioengineering approach using biological processing, and the eco-engineering approach by inducing engineering elements in natural ecosystem. In addition, development of techniques to achieve the optimal application of the elemental technologies is listed as one of the tasks in the project. These techniques include monitoring, analysis, assessment, and prediction.

These tasks of technological development are common to developing countries suffering from eutrophication of their precious water resources, just as with Lake Kasumigaura. In this sense, the project shares an important initiative role in the research and development of technologies to control such conditions.

Giving consideration to the above circumstances, the Kasumigaura Project has pursued research for developing bio-eco-engineering-based remedies for the water environment which feature energy-saving, cost-cutting, and low-maintenance applicable to eutrophication control in developing nations, as well as establishing area-wide maintenance schemes. The following sections will describe the achievements that were obtained so far through these research activities.

6-1 Pollutant Source Control Utilizing the Bioengineering Approach

Eutrophication of Lake Kasumigaura is chiefly ascribable to the inflow of nitrogen and phosphorus derived from domestic effluent. Yet, sewerage work covers less than 50 % of the catchment area. Since the population is fairly widely scattered in the basin area, a private sewer treatment system (known as JOKASOH), which processes wastewater on the site of the pollutant source, has been endorsed for household wastewater control, as opposed to developing a centralized sewerage plant. Nevertheless, the private sewer treatment system installed in the past focused its pollutant reducing capacity on the biochemical oxygen demand (BOD) only and not on nitrogen or phosphorus. Due to this inadequacy, the system could not contribute to efforts to counter eutrophication in Kasumigaura. The result of such a situation is demonstrated in Fig. 6-1-1, by comparing the differences of the pollutant load volumes between the household with a privy and untreated drainage of miscellaneous wastewater and households with a flush lavatory. The graph sets the environmental loads of BOD, total nitrogen (T-N) and total phosphorus (T-P) by the sewerage work as 100 each. On one hand, the treatment by only the septic tank registers 400 % and 150 % increases in T-N and T-P figures, respectively, substantially exceeding the sewerage rates. On the other hand, the combined type on-site sewer treatment system, capable of batch processing of night soil and other wastewater, can reduce the BOD level, but still increases T-N and T-P by 300 % and 100 %, respectively, failing to achieve any noticeable reduction. In the Kasumigaura catchment area, stringent add-on effluent standards, authorized by the Water pollution Control Law, extend to nitrogen and phosphorus as living environment items, setting the permissible values as T-N ≦ 10 mg/*l* and T-P ≦ 1 mg/*l*. In this context, the key to success in anti-eutrophication lies in the development and widespread use of a high-performance combined on-site sewer treatment system featuring denitrification and dephosphorization of the same level or even higher than the sewerage work. Against this backdrop, this project has been pursuing the development of various elemental technologies with the objectives of establishing and disseminating a bioengineering method that can process wastewater to meet the BOD ≦ 10 mg/*l*, T-N ≦ 10 mg/*l* and T-P ≦ 0.5 mg/*l* requirements to control household pollutant sources.



A : Night soil treatment facility
B : Night soil treatment Johkasou
C : Domestic wastewater treatment Johkasou
D : Advanced treatment Johkasou

Fig. 6-1-1 Comparison of Removal Effects by Type of Johkasou

(1) Advanced On-site Sewer Treatment System

Denitrification can be divided into two varieties of approaches: biological elimination making use of microorganismic activities, and physiochemical elimination such as ammonia stripping and zeolite adsorption. Nitrogen takes the form of organic nitrogen and ammonia nitrogen in household wastewater, whose T-N concentration, including both nitrogens, is approximately 50 mg/*l*. The high-performance combined private sewer treatment system, unlike the public sewerage system, does not receive constant monitoring by an administrator. For this reason, the biological elimination approach is applied to the system to allow easy maintenance, a simple structure, and a low running cost. The biological reaction in nitrogen elimination proceeds in three steps: deamination, nitrification, and denitrification, if setting organic nitrogen as the starting point. To facilitate the smooth development of these series of reactions, the high-performance combined on-site sewer treatment system has an anaerobic tank, an aerobic tank, a settling tank, a circulation line, and other parts all in one unit.

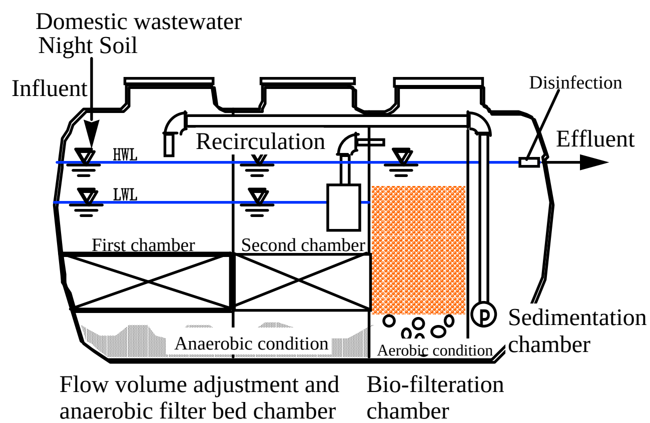


Fig. 6-1-2 Biological Filter Method Type Advanced Combined Johkasou

Fig. 6-1-2 presents the nitrogen removal flow in a high-performance combined sewerage system. The chart shows the example of such a JOHKASO capable of controlling the flow to deal with the two inflow peaks a day. The wastewater first enters the first chamber of the anaerobic tank, and then is pushed into the second chamber. In these chambers, anaerobic bacteria reduce the organic nitrogen into the ammonia nitrogen. The airlift pump transfers the semi-treated water in the second anaerobic chamber by batch into the aerobic tank. Under aerobic conditions, nitrifying bacteria oxidize the ammonia nitrogen into the nitrate nitrogen through two steps. First nitrite bacteria oxidize the ammonia nitrogen into nitrite nitrogen (shown in the equation 1), which is then oxidized into nitrate nitrogen by nitrate bacteria (shown in the equation 2). The semi-treated water containing the nitrate nitrogen is then pushed into the settling tank, from which the water returns to the first anaerobic chamber via a circulation line on a continual basis.

$$2NH_4 + 3O_2 \rightarrow 2NO_2^- + 4H^+ + 2H_2O \quad \cdots\cdots\cdots \quad 1)$$

$$2NO_2^- + O_2 \rightarrow 2NO_3^- \quad \cdots\cdots\cdots \quad 2)$$

$$2NO_3^- + 5(H_2) \rightarrow N_2\uparrow + 2OH- + 4H_2O \quad \cdots\cdots\cdots \quad 3)$$

At the first chamber of the anaerobic tank, the nitrate nitrogen in the returned semi-treated water is reduced by denitrifying bacteria all the way to nitrogen gas (shown in the equation 3). The bacteria involved in denitrification are common, facultative anaerobic bacteria. These bacteria use the dissolved oxygen in the water when available, otherwise, just as in the anaerobic tank, they take in the oxygen united to the nitrogen in the nitrate nitrogen and the ammonia nitrogen. The hydrogen shown in the equation 3 is provided through the organic substance (e.g., carbohydrate) in the effluent flow. Denitrification requires organic matters in the form of the BOD volume approximately 2.5-3 times larger than the nitrogen volume to be processed. The above denitrification process is called circulatory denitrification, which works for effluent with a BOD/N ratio of over 2.3 (household effluent usually registers about 4.0). As explained above, the high-performance on-site combined sewerage tank uses the principle where nitrogen is eliminated as a gas through the activities of nitrifying bacteria and denitrifying bacteria. This project concentrated its efforts into developing a microorganism-bonding carrier to facilitate a stable denitrification process by densely fixing the nitrifying bacteria in the aerobic tank, an arena of nitrification that determines the rate of nitrogen elimination as a whole. The developed carrier is a porous ceramic (see Photo 6-1-1), made from the sludge dredged from the bottom of Lake Kasumigaura to relieve the eutrophication. The manufacturing process of this sludge-made ceramic will be detailed later in section (5). The dredged sludge, previously buried in the designated reclaiming site on the lakeshore, is now successfully utilized under this project to benefit us as a microorganism-bonding carrier for a sophisticated on-site sewerage system, which plays a vital role in controlling eutrophication in Lake Kasumigaura.

Photo 6-1-1 Poruse sludge ceramic medium

(2) Dephosphorization and Resource Recovering System

Microorganismic activities can only eliminate a limited amount of phosphorus, a culprit in eutrophication. On this account, the Kasumigaura Project developed two physiochemical methods of dephosphorization. One is the iron electrolytic dephosphorization process, shown in Fig. 6-1-3: two iron electrodes dipped in the water treated by the on-site sewerage tank are charged with a slight direct current to produce from the anode the trivalent ferrous ions, which unite with the orthophosphate ions in the water to form precipitating iron phosphate. The deposited iron phosphate is dipped up along with the surplus sludge, and then made into compost for reuse in farmland. The verification tests of a high-performance on-site combined sewerage tank equipped with the sludge-ceramic and iron electrolytic dephosphorization have demonstrated that a) it delivers a performance of BOD ≦ 10 mg/*l*, T-N ≦ 10 mg/*l* and T-P ≦ 0.5 mg/*l*, b) the ferrous ions eluded from the iron electrode accelerate the flocculation of sludge to improve the solid-liquid separation capacity, and c) the level of surplus sludge produced by the tank displays no difference from the conventional on-site treatment system.

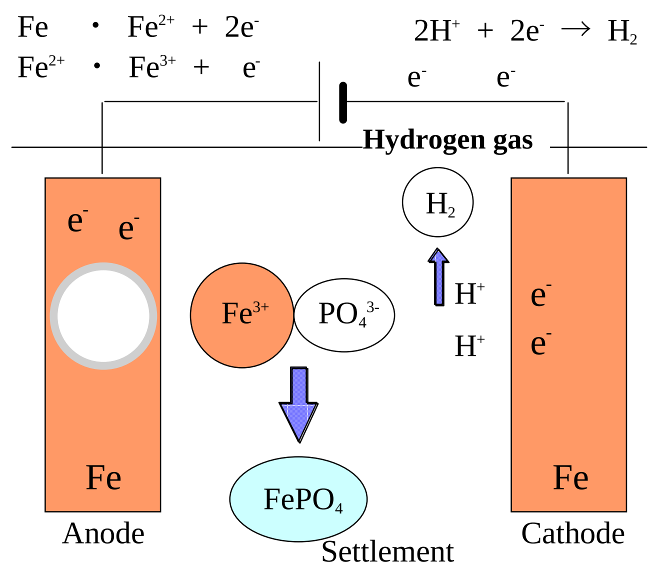


Fig. 6-1-3 Principles of the Iron Electrolysis Method

The other physiochemical method is the use of a phosphorus-adsorbing carrier. Though causing eutrophication, phosphorus is an essential resource for agricultural and industrial production, and Japan imports more than 1.4 million ton of phosphate ore every year. Since phosphorus is a finite resource just as is oil, the U.S. has instituted a no-export policy of phosphate ore to prevent phosphorus depletion. With no domestic mining resource, Japan completely depends on imports from overseas for its phosphorus, of which the U.S. accounts for approximately 30 %. Other phosphorus exporters may also ban the export or raise the price significantly. Under these circumstances, Japan will need to establish a social system to recover and recycle the phosphorus already existing at home. In this context, development of a dephosphorization method using a phosphorus-adsorbing carrier targets formation of a phosphorus recovery/recycle system as shown in Fig. 6-1-4. Spherical zirconium ferrites of ϕ 0.7 mm are used as the phosphorus-adsorbing carrier. The process in the field test is as follows. A column filled with these carriers is placed after the high-performance combined private sewerage system to adsorb the phosphate in the treated water. Once in every three months, the adsorbing carriers are taken into a phosphorus recovery station, where the carriers are

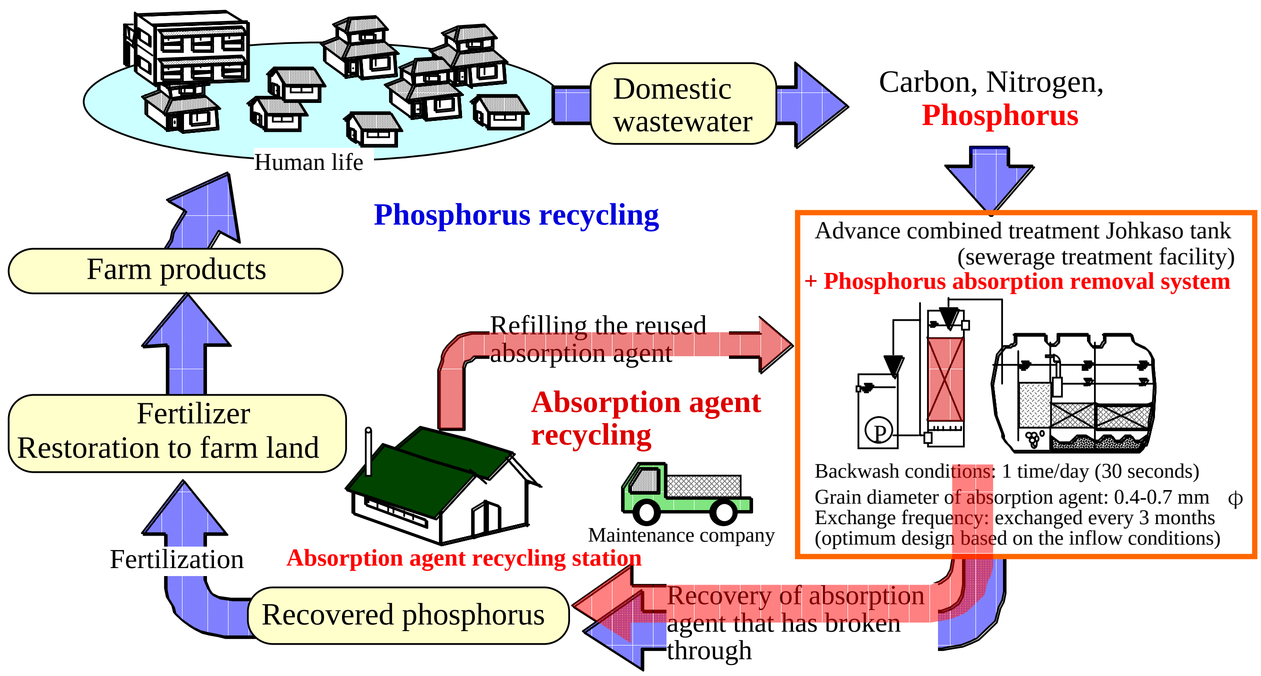


Fig. 6-1-4 Conceptual Chart of a Phosphorus Resource Recovery Type Ecosystem

dipped into a 7% sodium hydroxide solution to desorb the phosphorus, which then is crystallized by boosted sodium hydroxide solution to recover as over-90% sodium phosphate. The desorbed absorbing carriers are activated by the sulfate acidity to adjust the pH level around neutral, and then refilled into the column after the sewerage tank. This method demonstrated a remarkable treatment performance to achieve BOD $\leqq$ 10 mg/*l*, T-N $\leqq$ 10 mg/*l* and T-P $\leqq$ 0.5 mg/*l*, as well as achieving significant progress in developing a new recovery-type phosphorus resource recycling system technology that paves the road to high-purity recovery of finite phosphorus.

(3) Beneficial Microorganism Concentration Boosting System

Beneficial microorganisms play a key role in the sophisticated treatment of domestic wastewater. In particular, animalcules, which contribute to the transparency of the treated water, and nitrifying bacteria and denitrifying bacteria which respectively contribute to the ammonium nitrification and denitrification, essentially need to be fixed in the reaction chamber in high density. For this reason, the project undertook development research on a technique to boost the density of the *Philodina* genus (see Fig. 6-1-5) of rotifers in the private sewerage tank, and achieved it through biological filtration using a sponge carrier that proved to keep the transparency of the treated water extremely high. We also found that crop residues contain the reproduction-inducing ingredient for the *Philodina* genus, which successfully led to the mass culture of these rotifers. Furthermore, these results demonstrated that addition of the crop residues into the tank could selectively boost the density of the *Philodina* rotifers in a diverse-microorganism ecosystem undergoing biological filtration. Success in providing these beneficial microorganisms to a high-performance private sewerage system lies in easiness of use. The *Philodina* rotifers,

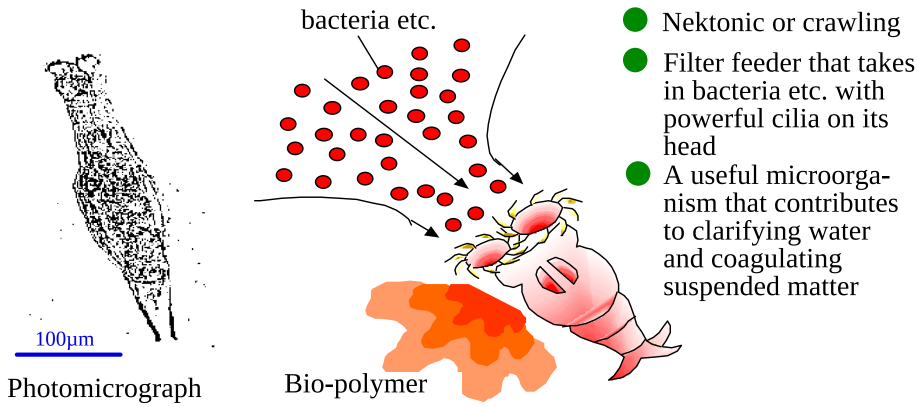


Fig. 6-1-5 Characteristics of a specimen of the rotifera *Philodina erythrophthalma*

coupled with its reproduction-inducing agent, have an emerging potential of being made into a formulation for market availability. These results are considered to develop into the creation of a new eco-industry where water-treatment-bettering microorganisms are formulated for market distribution

(4) River/Canal Hybrid Purification System

In the Kasumigaura Catchment, miscellaneous household effluent (domestic wastewater except for night soil) is a major contributor to lake pollution, yet this often drains into the canals and streams without being properly treated. Those tributaries containing the polluting wastewater merge into the main river to enter Lake Kasumigaura. Many canals and small streams, in this respect, serve as the pathway of the pollutants into the lake. Consequently, it is necessary to develop technology to purify the tributaries to reduce the pollutants before their inflow into the main stream and the lake. The canals and small streams vary in their flow rate, the degree of pollution, and their size, depending on the districts and areas, which means that the decontamination technology must be developed to fit the conditions of the place. The project particularly focused its

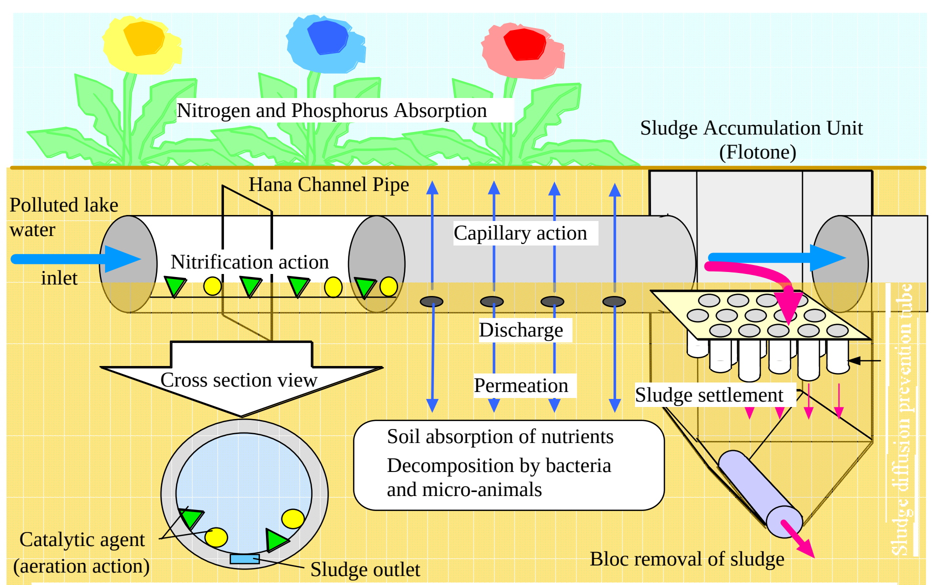


Fig. 6-1-6 Purification Mechanisms of the Hana Channel

technological development efforts on maintenance-free performance and cost reduction. For severely polluted tributaries with a relatively high flow rate, we developed the phosphorus-recovery-type purification system using the anaerobe/aerobe-cycle ceramic filling process in combination with the phosphorus elimination/adsorption process. The year-round verification tests demonstrated that this system has a high possibility for its application. For those with a relatively low flow rate, the purification system through eliminating pollutants, planting, and soil (hana channel) is being developed (see Fig. 6-1-6). Both systems proved to deliver a high performance of BOD ≦ 10 mg/*l*, T-N ≦ 10 mg/*l* and T-P ≦ 0.5 mg/*l*, and will undergo further field tests for simplifying the structure, and reducing the cost, of the systems.

(5) Non-Circulating Purification System Using the Soil Trench

Effective control of household wastewater essentially relies on the choice of purification method to be applied based on land availability. To be more specific, a bioengineering-oriented purification system, such as the high-performance private combined sewerage system, is most effective for the pollutant source with strictly limited land availability. For a pollutant source where a vast amount of land is available, a purification system with an eco-engineering approach is considered effective. This project pursued research on developing new technology utilizing the natural purification capacity of the soil, with minimal energy requiring no power input, e.g., a technique to link sets of anaerobic filter beds and the soil trenches to each other in sequence, according to the target water quality (Photo 6-1-2 and Fig. 6-1-7). Verification tests have found that the three connected-sets of anaerobic filter bed and soil trench, i.e., a system with an order of the first anaerobic filter bed, the first soil trench, the second anaerobic filter bed, the second soil trench, the third anaerobic filter bed, and the third soil trench, delivers a

Photo 6-1-2 Soil treatment system experiment equipment installed at Kokinu Experiment Site

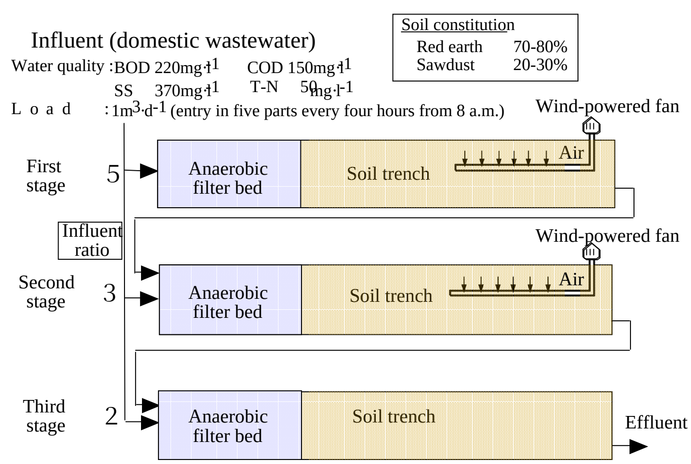


Fig. 6-1-7 Treatment flow for non-circulatory anaerobic/aerobic soil treatment system

purification performance of BOD ≦ 10 mg/*l*, T-N ≦ 10 mg/*l* and T-P ≦ 0.5 mg/*l* without circulation or power input, when the effluent inflow is divided so that 50 %, 30 %, and 20 % flow into the first anaerobic filter bed, the second anaerobic filter bed, and the third anaerobic filter bed, respectively. This system is recognized suitable for rural areas and developing countries where plenty of land is available. In the future, its study under the Kasumigaura project will focus on the life style of rural areas in Ibaraki Prefecture to clarify the relation between the inflow pollutant load fluctuation and the system's performance.

(6) Electrochemical Purification System

While most of the wastewater treatment methods employ biological processing approaches, this is a system where electrochemical approaches are applied. In many cases, the physiochemical treatment of wastewater requires the input of agents, such as flocculants, to facilitate separation of the suspended organic matters. Unlike conventional methods, this electrochemical purification system needs no chemical feeding. There are generally three methods of electrochemical purification: flotation of suspended organic matters, flocculation, and oxidization. Both the suspended and the dissolved organic matters in wastewater are eliminated through these reactions. Among them, the most important process for removing the dissolved organic matters is oxidization, which can be divided into direct oxidization and indirect oxidization. In the direct oxidization process, the organic matters are oxidized directly on the oxidized metal of an electrode by catalysis of the oxidized metals, such as TiO_2 and SnO_2. In the indirect oxidization process, the organic matters are oxidized by a hydroxyl radical (·OH) produced from the water through anodic discharge. This R&D project pursued elucidation of the detailed mechanism of these principles for their effective utilization in wastewater treatment, and the creation of practical reactor for wastewater disposal that takes account of the treatment cost, the site area, and the energy input. As a result, we have succeeded in developing a pilot-scale high-rate electrochemical wastewater treatment unit (processing capacity of 7.2 t/day). Its system flow is shown in Fig. 6-1-8.

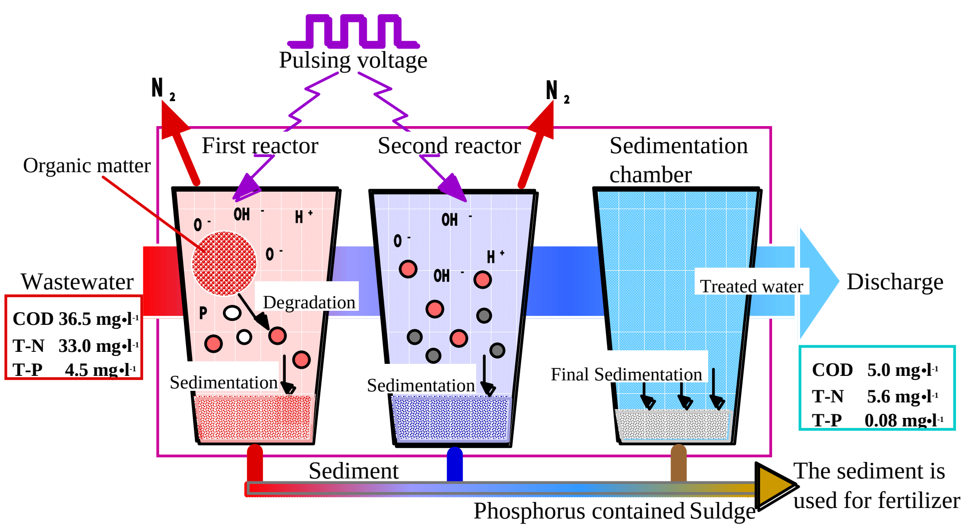


Fig. 6-1-8 Electrochemical Purification System

After large solids are eliminated from the wastewater through the screen, the wastewater undergoes the flocculation process for approximately 15 minutes in the oxidization tank, and then is sent to the first settling tank for solid/liquid separation. The supernatant liquid is processed in the reduction tank, and again sent to the second settling tank for solid/liquid separation. The final supernatant liquid is then discharged. The oxidization tank is charged with a low voltage to generate mainly the active oxygen radical (·O). The reduction tank is charged with a high-voltage pulse to generate mainly the hydroxyl radical (·OH). Both the oxidization and the reduction tanks are equipped with oxidized-metal (mainly TiO_2) electrodes. The verification tests of the unit on both household wastewater and lake water containing algae found that its elimination rates for T-N, T-P, NH_4-N, and COD in the domestic effluent achieved 83 %, 97 %, 89 %, and 86 %, respectively, and that its elimination rates of T-N, T-P, and COD in the algae-containing lake water reached 84 %, 94 %, and 92 %, respectively, with SS and chlorophyll α removal rates of over 99 %. Though no flocculant was added in the purification process, the treated water became clear. As seen above, the electrochemical system proved that it accelerates the reaction of organic matters, facilitates denitrification, and has excellent flocculation capacity for the reaction residues. In addition, the unit is showing its potential of reducing costs down to a third of the conventional electrochemical methods.

6-2 Intra-Lake Control Utilizing the Eco-Engineering Approach

Lake eutrophication is ascribable to not only the external loads flown in from rivers and other waterways, but also to the internal loads derived from sludge. These internal loads, i.e., the nitrogen and phosphorus elution from the sludge, increase when the bottom layer become anaerobic due to the oxygen consumption near the sludge by microorganisms decomposing excessively accumulated organic matters on the lake bottom. In this sense, intra-lake direct purification targets technological development for to curb the organic sediments in the sludge and anti-elution of nitrogen and phosphorus from the sludge, in addition to the decomposition/elimination of toxigenic Cyanophyceae and the direct removal of nitrogen and phosphorus.

(1) Purification System with Hydroponics and Biopark

Though having been studied before, the purification method using aquatic plants such as reeds and cattails has drawbacks in resource recovery and recycling. Taking this aspect into account, this project focused its technical development efforts on forming a purification system using edible plant hydroponics. The biopark-style purification system with hydroponic edible plants, e.g., watercress and swamp cabbage, has been created for researching its water purification capacity. The results of the study revealed that its purification reached nearly 10 times that of the reed/cattail approach, and that proper selective harvest of the plants maintained a high purification capacity. In terms of the selective harvest, this system proved that it allowed the recovery of a resource with market values as a "product". In addition, a substantial propagation of freshwater clams was identified in the rooting zones of the plants. The monitoring of their growth led us to believe that they significantly contribute to the water purification. A freshwater clam is a benthos ingesting through filtration: it eats suspended matters in the water to dramatically improve the water transparency, and is also a highly valuable fishery resource as a food product. Removing these products out of the ecosystem is expected to exert a spillover effect for water purification. Under the project, we opened the biopark to the public where they were encouraged to harvest the plants and the freshwater clams to take them back home free of charge. This public-participation selective harvesting demonstrated itself to be effective for improving the purification capacity, and on top of that, it served as an arena for environmental education to raise the eco-awareness of the citizens. As seen above, the hydroponics/biopark purification system (shown in Fig. 6-2-1) was found capable of producing edible plants and fishery products and water purification all at the same time, while contributing to environmental education and edification. In the future, the project will pursue research and development to apply the system to practical use in optimal conditions: the study typically targets a) the planting method to contribute to easy maintenance, cost reduction, and boosted purification capacity, and b) analysis of its purification capacity in highly-closed, hypertrophic water areas.

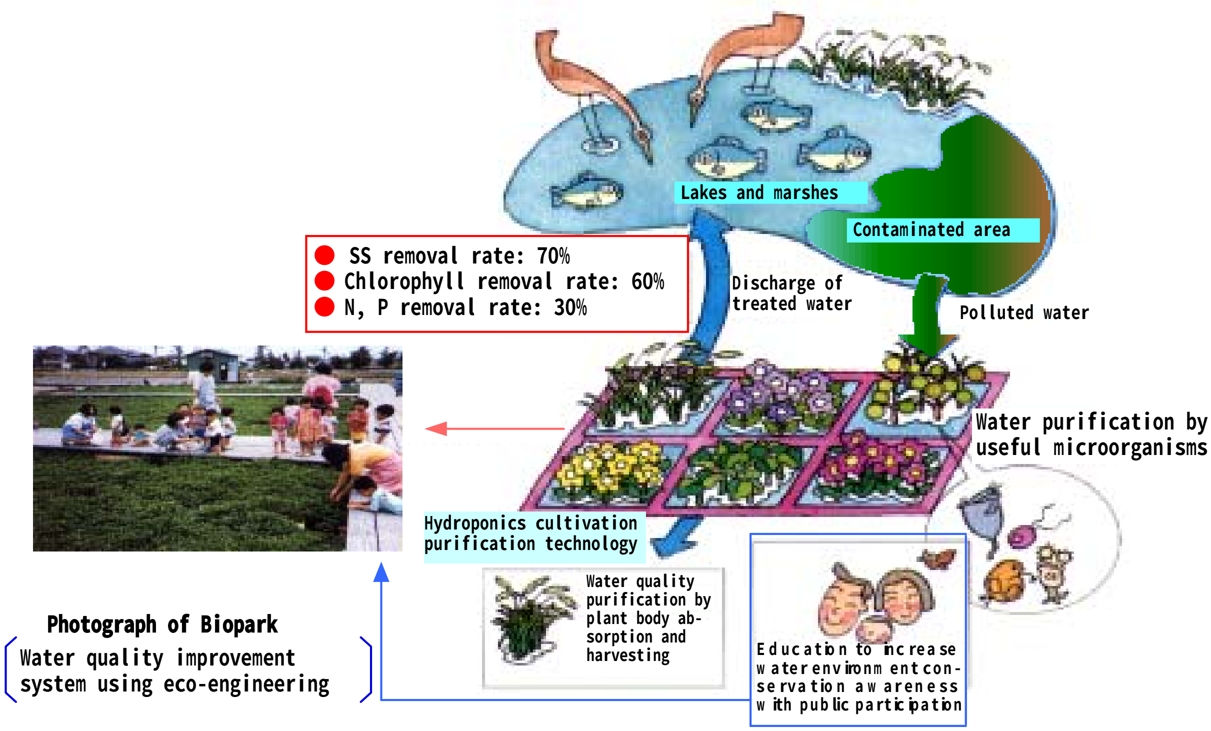


Fig. 6.2.1 Hydroponics cultivation purification system based on eco-engineering with public participation (Biopark)

(2) Ultrasonic Algae Removal System

The *Microcystis* algae of a blooming nature form a colony with numerous cells, which contain air bags, called gas vesicles. By expanding and contracting the vesicles, the alga can float and submerge at will. This system combines the physiochemical approach and the biological approach, where ultrasonic irradiation kills the *Microcystis* algae floating near the surface, which then undergoes sedimentation to a part of the lake bottom by generating a single-direction water current in order to decompose them using super-decomposing bacteria. Fig. 6-2-2 presents the flow of the prototype unit. This system proved itself to be highly applicable as an algae eliminator for small to medium lakes with some algae bloom and the water areas extensively infested by the cyanobacteria. In addition to this method, the project has been undertaking a commercialization study of the lake density current dispersion method, which blocks the nutrient supply to the *Microcystis* algae from the sludge by making the bottom layer aerobic, and facilitates the aerobic decomposition of the suspended matters in the water. This method also incorporates an ultrasonic generator. The system aims at disabling the *Microcystis* algae, being equipped with a unit to suppress the algae reproduction by destroying their gas vesicles

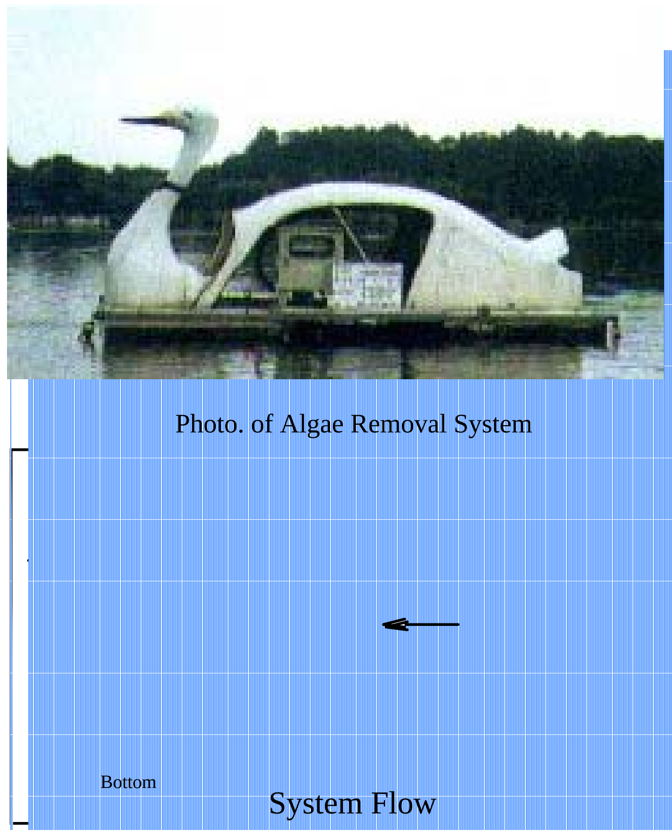


Fig. 6-2-2 Algae Removal System using Ultrasonic Waves

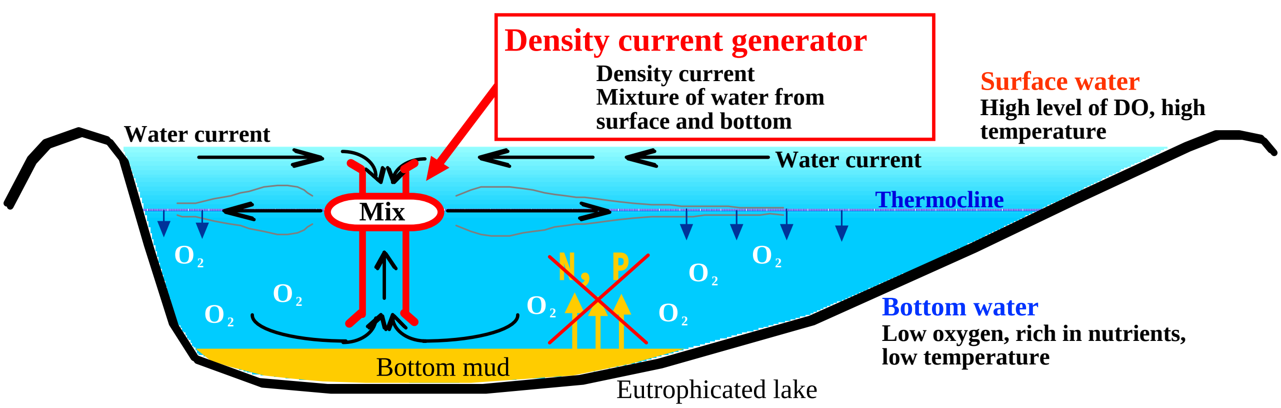


Fig. 6-2-3 Lake water density current dispersion technology

with slight ultrasonic irradiation and forcing them to settle on the lake bottom in a low photosynthetic environment. Verification tests of its performances are also under way (shown in Fig. 6-2-3).

(3) High-Rate Superconductive Flocculating Filtration System

This system eliminates magnetic particles in the fluid by separating them by the magnetic force. It has traditionally been used to remove iron oxides from the effluent from steelworks and from the circulating water from thermoelectric power stations. Application of this method to solid-liquid separation at algae-infested lakes requires magnetization of the non-magnetic suspended particles (algae). The solid-liquid separation mechanism of this system is that first magnetic powder and flocculant are added to the lake water to form a magnetic flock made of the magnetic powder and the algae. Then, this flock passes through water in a magnetic separation section to be caught by the magnetic filter in a magnetic field generated by twin electromagnets. Based on this mechanism, we produced a prototype (the bore diameter of the superconductive electromagnet at the room temperature: 310 mm, the magnetic field between the twin electromagnets: approximately 1 sr) to effectively recover and eliminate the algae, and conducted verification tests on its performance. The system treated 400 m^3/day, and the treated water showed high removal rates of 86 % of COD, 71 % of T-N, 93 % of T-P, and 95 % of algae. Being open to miniaturization, this system has reached the commercial stage as a decontamination unit installed on a small boat. It can also be applied to the high-rate removal of algae at dams and reservoirs.

(4) Filamentous Blue-Green Algae Elimination System Using Beneficial Animalcules

For the past few years, the filamentous blue-green algae as *Oscillatoria* and *Phormidium* genera came to manifestly dominate Lake Kasumigaura from autumn through to spring when the water temperature drops. With the increasing biomass of these algae, the COD level rose and transparency decreased in the lake even during the low water temperature seasons. The *Oscillatoria* algae, in particular, produce a substance to significantly abate flocculation, which causes disablement of the solid-liquid separation of the water treatment process. Against this background, the project pursues the development of a lake water purification system using the beneficial

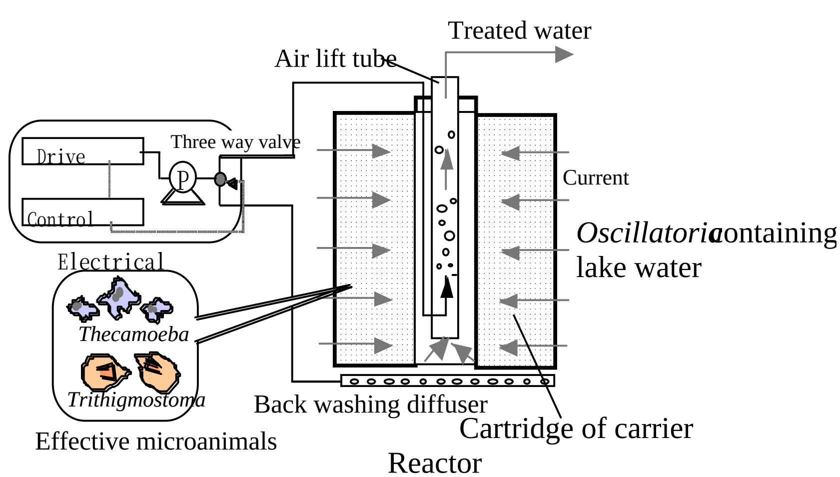


Fig. 6-2-4 Constitution of the Predatory Microanimals Inhabiting in Bio-film

animalcules that eat and decompose the filamentous blue-green algae. *Trisigmostoma* and *Thecamoeba* genera were explored so far, where they were isolated for cultivation tests to elucidate their reproduction and feeding properties and the density boosting method. Furthermore, we strive toward prototyping a biological filter fixable with these beneficial animalcules, and conducting field demonstration tests, using a prototype, on its direct purification capacity in Lake Kasumigaura. The flow of purification under this system is described in Fig. 6-2-4. The current study is under way according to plan to 1) comprehensively analyze its performances on aspects of the elimination rates of the filamentous cyanobacteria and COD, the treatment volume, the population behavior of the animalcules, and the dynamic energy consumption rate of the unit, and 2) formulating proper design and maintenance guidelines for its commercialization by determining any problems and their remedies. In order to apply this direct purification system to the actual water area, we designed a mobile unit, whereby floats support a charcoal-filled cartridge densely fixed with the beneficial animalcules (presented in Fig. 6-2-5). The unit can easily be transferred to the target water area by a small boat, and the power necessary for operation is supplied by a combination of solar batteries and a capacitor circuit. Due to its low-cost, low-energy features, the system is expected to be highly suitable for developing countries, and in fact, there is a plan for its introduction into China through the Sino-Japanese research collaboration "Water Environment Remediation Project at Lake Taihu".

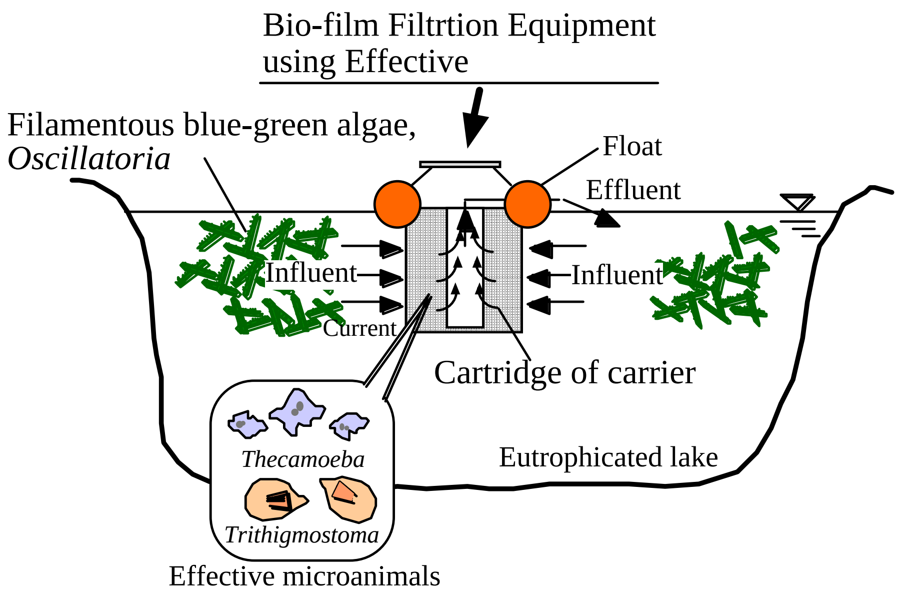


Fig. 6-2-5 Direct Purification of Eutrophicated Lake by Predatory Microanimals Inhabiting in Bio-film Filtrtion System

(5) Resource Exploitation System from Dredged Sludge

The Kasumigaura Project devised a use of the otherwise-wasted sludge eliminated from the lake bottom (*dredged*) as materials for purifying contaminated lakes and rivers, and started an applied study on manufacturing ceramics made from the dredged sludge. Specifically, we pursued development of a manufacturing technology for porous ceramics highly capable of bonding organisms in order to use the sludge from polluted lakes as microorganism carriers for direct lake purification and for effluent treatment. As a result, this technical development study successfully established the manufacturing processes of the sludge-made ceramics, as shown in Fig. 6-2-6. The sludge dredged from Lake Kasumigaura is first dried by a fan dryer (at 120 ºC for 24 hours), and then roughly ground by a jaw crusher. A Fret mill pulverizes the ground substance into 1.0 mm size, which is then burned by a rotary kiln (at 1,150 ºC for 15-20 minutes). This process allows us to manufacture a low-specific-gravity (1.2-1.4), porous sludge-made ceramics appropriate as the filling carrier in the bio-filtration process. As mentioned in Section 6.1 Part 1), this porous sludge-made ceramics underwent field tests of its decontamination performance in a high-performance, combined-type, on-site sewerage system, which demonstrated sufficient capacities. Based on the results from these basic studies, we will study its manufacturing cost reduction methods to establish a mass-production process, as well as to undertake field tests to determine the direct purification capacity in polluted lakes and its applicability to other water purification technologies.

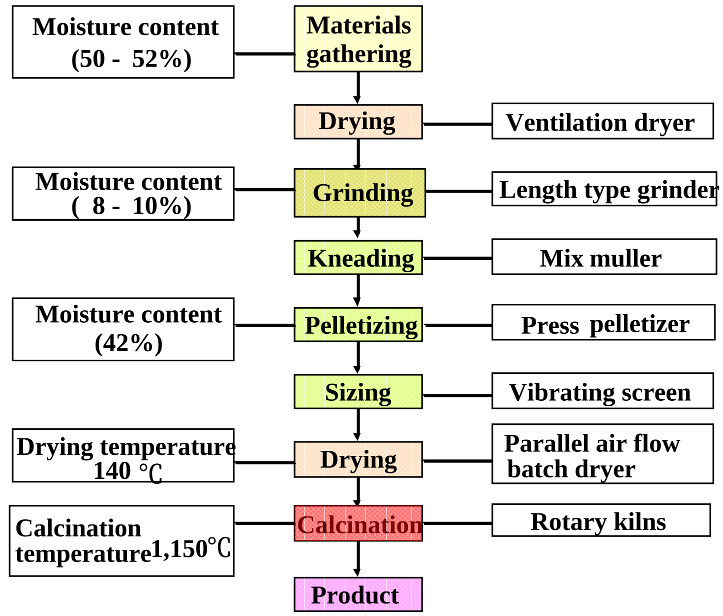


Fig. 6-2-6 Sludge Ceramic Processing Flow

6-3 Comprehensive Analysis and Assessment of the Water Quality Renovation Effect

Unerring management of the Kasumigaura catchment area needs constant monitoring of the water quality fluctuation of the lake and its catchment area. For this, the elemental technologies developed under this project must find their most suitable application where they can exert their maximum effect to control the pollutant sources and the lake itself with minimum cost. Determining such applications will essentially require a remedy prediction method after the system's introduction, and a comprehensive analysis and assessment, based on the follow-up method, of the on-site water decontamination effect. For the analysis and assessment of the water quality renovation effect, the Project has pursued the development of a catchment management monitoring system, and of an evaluation method for the catchment management on the cost/investment and energy input to improve the water quality.

(1) Development of the Water Quality Analysis Method for Catchment Management

As for proper catchment management and the elucidation of the relation between the lake-water quality change and the algae occurrence, the prediction of algae bloom from the water quality change, if these became possible, would allow the prompt implementation of catchment control measures. On this account, we have employed neural network analysis (shown in Fig.6-2-7) for comprehensive analysis of the water quality data of Lake Kasumigaura for the past 24 years. The result of this analysis has so far revealed that phosphorus has greater correlation with both the particular algae bloom as an environmental factor and the eutrophication as an effect than nitrogen does, and that the algae diversity index drops when *Microcystis* algae dominate the lake. Through further analysis of these water quality properties, the project aims to develop an analytic method to realize algae bloom prediction.

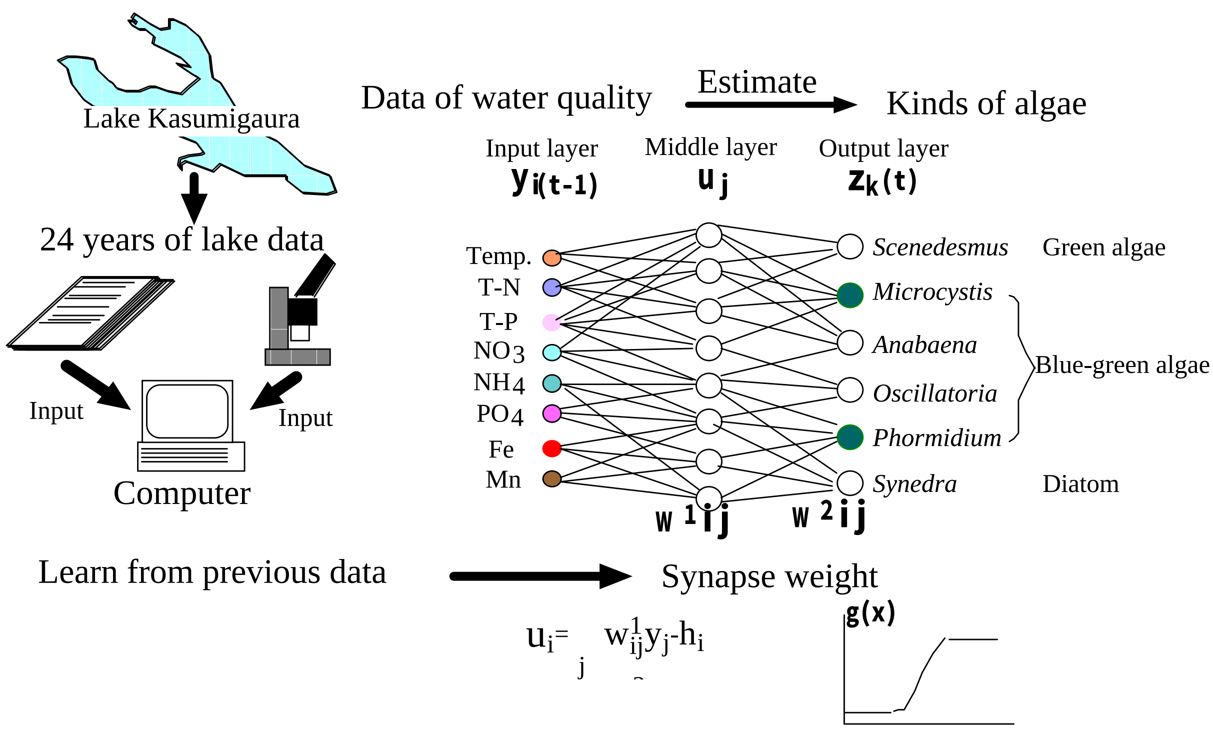


Fig. 6-2-7 Neural Network Water Quality Evaluation

(2) Development of the Catchment Management Monitoring System

Water quality analysis needs speedy obtainment of a large number of data. Conventional water quality analysis required a specific analytic method for each parameter, which imposed a phenomenal amount of time and labor of data obtainment. Under this circumstance, the Kasumigaura Project has pursued the development of an analytic method for lake water quality using near infrared light extinction (NIR method), shown in Fig. 6-2-8. In this method, the samples are irradiated with the near infrared to obtain the absorption data of the target parameters, which undergo such statistical analysis methods as multiple regression analysis and principal component analysis to extract the necessary information. Every substance has its own absorption wavelength in this region. For this reason, analysis of the absorption peaks and the waveforms with various methods is very likely to offer the biomass of a particular matter even in a solution containing a mixture of various substances. This method was found to allow the swift analysis of water with numerous parameters, including nitrogen, phosphorus, and COD. In addition, it is becoming clear that this method allows the analysis of the humic acid suspected to influence algae reproduction and the glycolic acid produced by algae, which may pave the way to count the biomass of the *Microcystis* algae. Based on the results of these foundational studies, the Project is to undertake field tests of an on-site monitoring device equipped with this method.

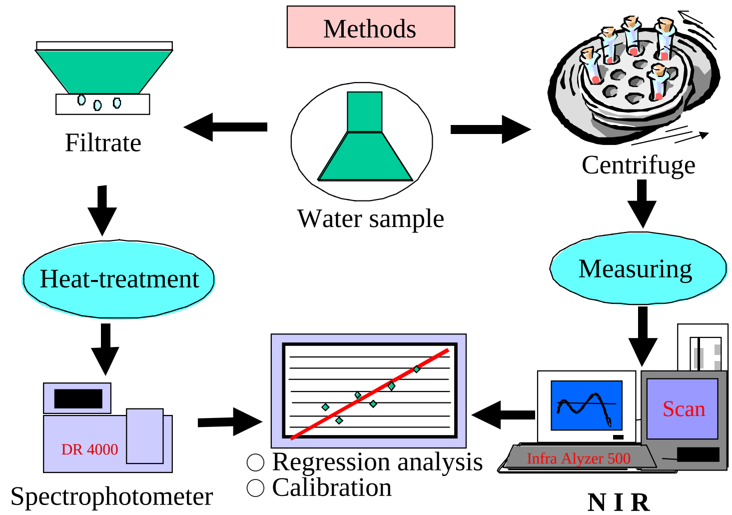


Fig. 6-2-8 Flow of NIR (Near infrared) analysis

(3) Development of a Cost Effectiveness Assessment Method for Catchment Management

This project aims at establishing a scheme to effectively implement and disseminate the pollutant source control technologies and intra-lake purification techniques developed by the project, and suggesting and instituting a lake/catchment management system through simulating catchment management techniques for the most effective purification with the minimum cost and energy requirements. For these objectives, the project pursues the development of adjusting techniques and the establishment of comprehensive analysis and assessment techniques. The abovementioned concept of this project has been introduced in Fig. 6-2-9.

6-4 Future Challenges and Perspectives

In conformity with the objectives set under the Collaboration of Regional Entities for the Advancement of Technological Excellence (CREATE) program, the Project for Water Environment Renovation of Lake Kasumigaura pursues the feasible development of the elemental technologies and effective area-wide application methods of these feasible technologies to maximize their effect on water quality renovation in Lake Kasumigaura, with a view to decontaminating the lake and fostering the formation of venture industries. As for the elemental technologies with a potential for generalization, Phase I of the project saw efforts to establish commercialization of the system with special attention to low-cost, maintenance-free, and recycling features. In order to present the achievements of the

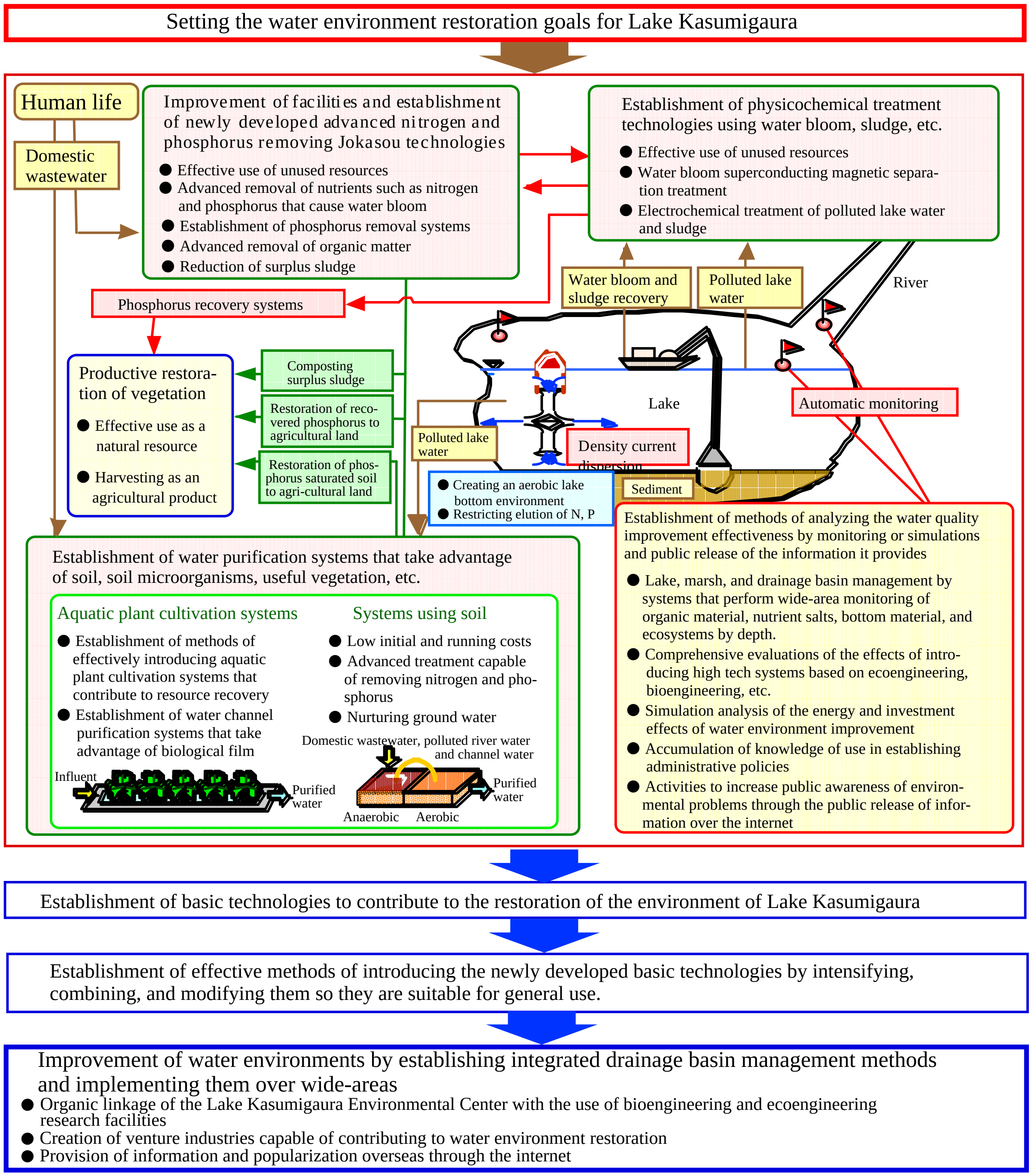


Fig. 6-2-9 Lake Kasumigaura Water Purification Technology Developments : Effective Approaches and Future Prospects

project in a more visible way, we must concentrate our efforts in Phase II on reinforcing the development of techniques for the appropriate combination of the elemental techniques to permit technical improvement and sophistication during the field tests. In addition, Ibaraki Prefecture will need to institute an evaluation and certification system for these developed technologies to contribute to fostering venture industries. It is also necessary for the project to prepare for Phase III by instituting a system and organizational mechanism for the Lake Kasumigaura Environmental Center, which is scheduled for construction in Ibaraki Prefecture, and the Bio-Eco-engineering Research Center scheduled for development at the National Institute for Environmental Studies to contribute to the establishment, actual dissemination and sophistication of the systems technology at these facilities. Through these activities and efforts, it is greatly hoped that the achievements of the project visible to the community members will ripple through domestically and internationally to exert their effects on water environment renovation.

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