8. Water Treatment Technology Applicable to Developing Countries

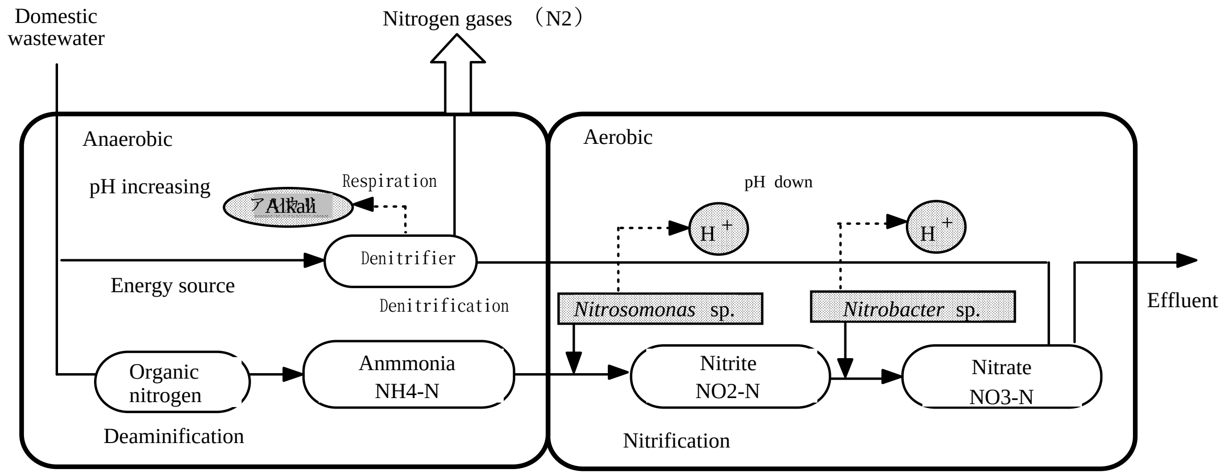
In the prevention of eutrophication of lakes and marshes, the direct transfer of technology from developed countries is not effective. The important thing is energy- and cost-saving, and low-maintenance cost technology based upon the conditions of each country. This chapter describes such technology applicable to developing countries.

8.1 Advanced Treatment Septic Tank

8-1-1 Principle and features of the system

(1) Principle of the system

The treatment of residential wastewater is roughly divided into sewerage systems utilized in densely populated areas and septic tanks utilized in dispersively populated areas. Of the two, the septic tank can return the treated wastewater to the water area onsite by improving its quality. Therefore, the diffusion of the advanced treatment septic tank is very effective in securing the amount of water required to maintain river water and underground water; that is, water recharge. This advanced treatment septic tank is a system for treating residential wastewater allowing nitrogen and phosphorous to be removed, and is available in a variety of sizes from small to large for use at individual households or housing complexes. The treatment methods are principally divided into the activated sludge process, where microorganisms are present suspended in the biological treatment reaction chamber, and the biofilm process where microorganisms are present attached to the carriers. In each process, the advanced removal of nitrogen and phosphorous in the septic tank is being put into effect for the conservation of lakes, marshes, inland seas and inland bay basins as a measure against eutrophication. In this case, certain devices are implemented to maintain alternately



Reaction	Deaminication	Nitrification	Denitrification
Consumption of alkalinity	Alkalinity of 3.57 mg/L is generated when organic nitrogen 1 mg/L is deaminated.	Alkalinity of 7.14 mg/L is generated when ammonium nitrogen 1 mg/L is nitrified.	If nitrate nitrogen 1 mg/L is denitrificated, alkalinity of 3. 57 mg/L is generated. C/N ratio is required in the range of 3 to 5 for denitrification reaction.
State of treatment functions	Nitrogen in wastewater is almost ammonium or organic nitrogen. And the ratio of ammonium and organic nitrogen is 4:6	pH value can drop if inflow alkalinity is low. 。 ⇩ Treatment capacity drops and sludge is removed	pH value can increase to generate alkalinity. pH value can be protected from lowering by combining nitrification with denitrification and processing functions are stabilized.

Fig. 8-1-1 Nitrogen removal mechanism in biological nitrification and denitrification reaction.

anaerobic and aerobic conditions, and remove human waste contained in residential wastewater and nitrogen and phosphorous deriving from gray water.

To remove nitrogen, it is first essential to transform amino acids and protein contained in residential wastewater as organic nitrogen into ammonia nitrogen through deamination reaction in the anaerobic reaction chamber, and then transform ammonia nitrogen into nitrate nitrogen in the aerobic reaction chamber by the nitrifying bacteria. This aerobic-treated water, transformed into nitrate nitrogen, is circulated back to the anaerobic reaction chamber; and by the work of denitrifying bacteria that can effectively utilize the oxygen bonded to nitrate nitrogen(NO_3 −N), and by utilizing the BOD that is an organic substance contained in the inflowing residential wastewater as the energy source and the bonded oxygen within NO_3 as the respiratory source, the nitrate nitrogen synthesizes bacteria and transforms itself into an N_2 gas. Thus, nitrogen is removed (Fig.8-1-1).

This kind of circulation of aerobic chamber-treated water back to the anaerobic reaction chamber is used in small-scale biofilm processes for 5 to 50 people as well as large-scale anaerobic-aerobic activated sludge processes. In medium- or large-scale types for more than 51 people, intermittent aeration-activated sludge processes and batch-activated sludge processes are also used to form anaerobic-aerobic conditions.

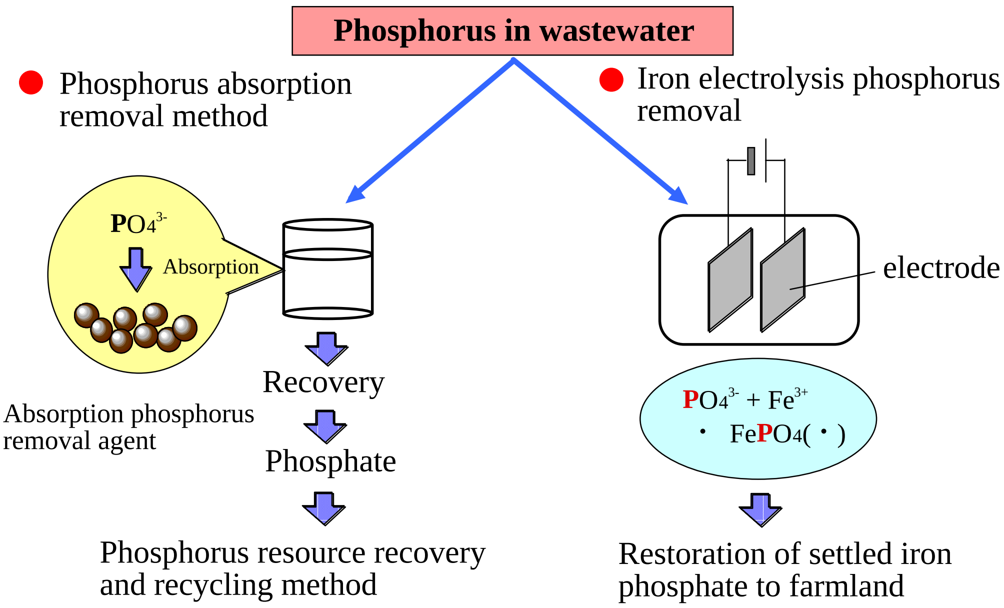


Fig. 8-1-2 Physicochemical phosphorus removal systems

Also, biological processes and physicochemical processes are used to remove phosphorous. One representative of these biological processes is the process where inanaerobic-aerobic conditions utilize the phosphorous-trapping speed in an aerobic condition. This gets to be ten times the phosphorous- releasing speed in an anaerobic condition, causing phosphorous to excessively accumulate in sludge in excess of 5% against the normal 1.5 to 2%. In this process, sludge needs to be extracted at an adequate frequency. Physicochemical processes include the coagulating sedimentation method, the adsorption-dephosphorylation method and the iron electrolysis-dephosphorylation method (Fig. 8-1-2). Of these, the adsorption-dephosphorylation method is one of the more important processes. In this method phosphorous is adsorbed in a tower packed with zirconium carriers; then alkali is added, and the phosphorous is desorbed and recovered for use as a resource. The iron electrolysis-dephosphorylation method is a process where a weak electric current is made to flow across the anodic and cathodic iron plates, and the eluted iron ions are reacted with phosphorous ions contained in the inflowing residential wastewater to become coagulated and removed. This kind of phosphorous removal method is applied to small-scale and large-scale treatments in a varying manner depending upon the characteristics of the treatment.

(2) Flow of the system

1) Flow of small-scale treatment

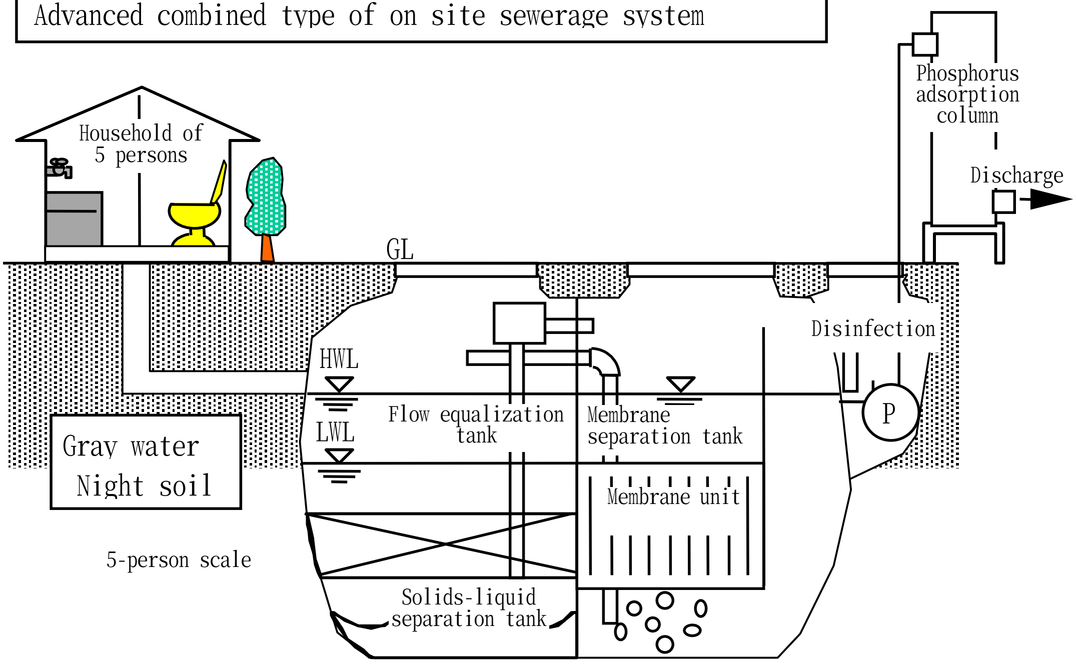
A small-scale advanced treatment septic tank is a system for removing nitrogen by controlling the flow and circulating the water treated in the aerobic reaction chamber in order of the anaerobic-aerobic chamber. For the aerobic chamber, the biological filtration method, the membrane separation- activated sludge method and the contact-aeration method are used. In addition to these nitrogen-removing methods, the adsorption-dephosphorylation method and the iron electrolysis method are employed to remove phosphorous (Fig.8-1-3). The treatment flow of a representative system is shown in Fig.8-1-4~6.

2) Medium and large-scale system

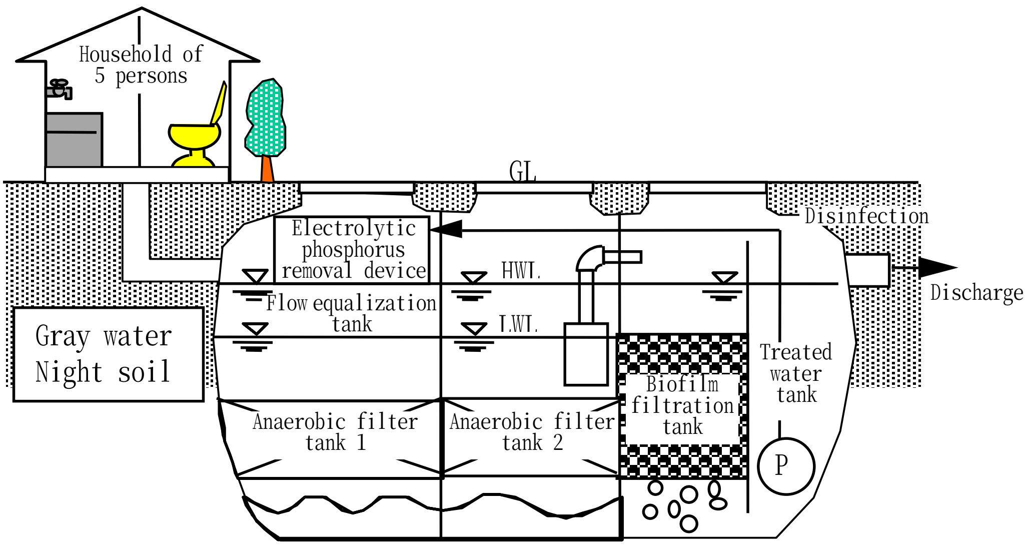
A medium- or large-scale advanced treatment septic tank is basically of the type that controls the flow causing the anaerobic and aerobic conditions to alternate. Processes employed principally to remove nitrogen are: the intermittent anaerobic-aerobic aeration-activated sludge process that has an on-off control of the air supply; the anaerobic-aerobic batch-activated sludge process that repeats inflow-aeration (aerobic)-non-aeration (anaerobic) –sedimentation -discharge; the anaerobic-aerobic circulation-activated sludge process that consists of a non-aeration (anaerobic) chamber, an aeration chamber (aerobic) and a sedimentation chamber, which returns or circulates the sedimented sludge and the activated sludge of the aeration chamber by 50% to 100% and 200% to 300%, respectively. In these anaerobic-aerobic activated sludge processes, phosphorous is also removed biologically. In case there is any stability problem due to fluctuating inflow loads or seasonal fluctuations of water temperatures, the stability in phosphorous removal will be obtained by adding in the activated sludge reaction chamber coagulants such as polyaluminum chloride(PAC), aluminum sulfate, ferrous chloride or ferric chloride to reach a molar ratio of two to phosphorous contained in the directly inflowing water in respect of Al or Fe($^{Fe}/_{p},\ ^{A\ell}/_{p}$) .

Also, in combination with the biological treatment process, the iron electrolysis-dephosphorylation process, the adsorption-dephosphorylation process and the coagulating sedimentation process are employed. The treatment flow of the representative systems is shown in Fig. 8-1-7~9.

Advanced combined type of on site sewerage system



Membrane separation activated sludge type of advanced combined type of on site sewerage system



Biofilm filtration type advanced combined type of on site sewerage system

Fig. 8-1-3 An outline of Advanced combined Johkasou

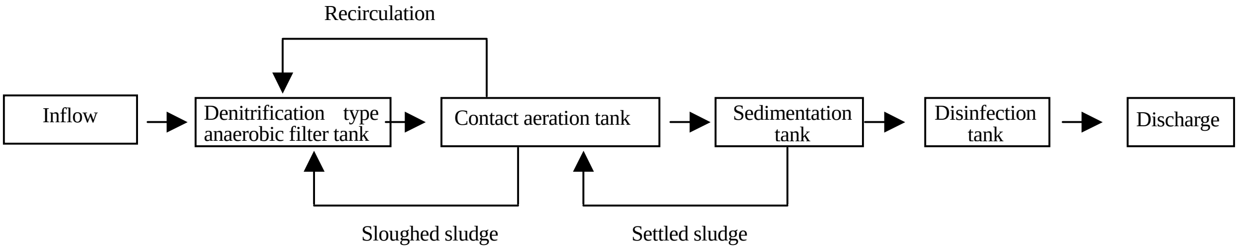


Fig. 8-1-4 Denitrification type anaerobic filter contact aeration process

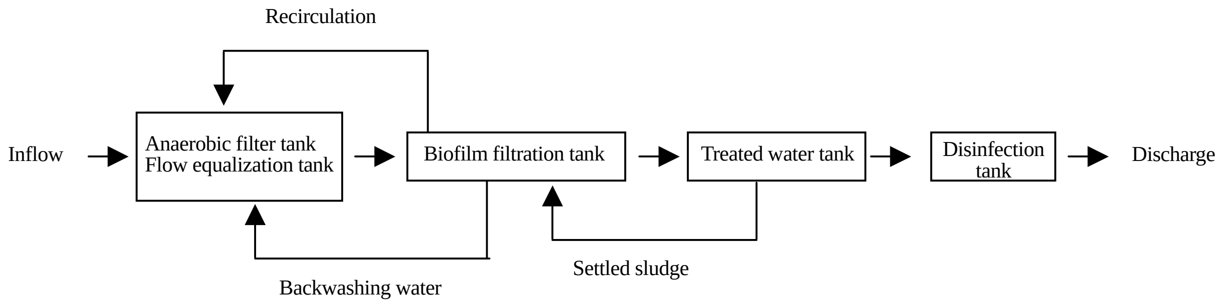


Fig. 8-1-5 Biofilm filtration process

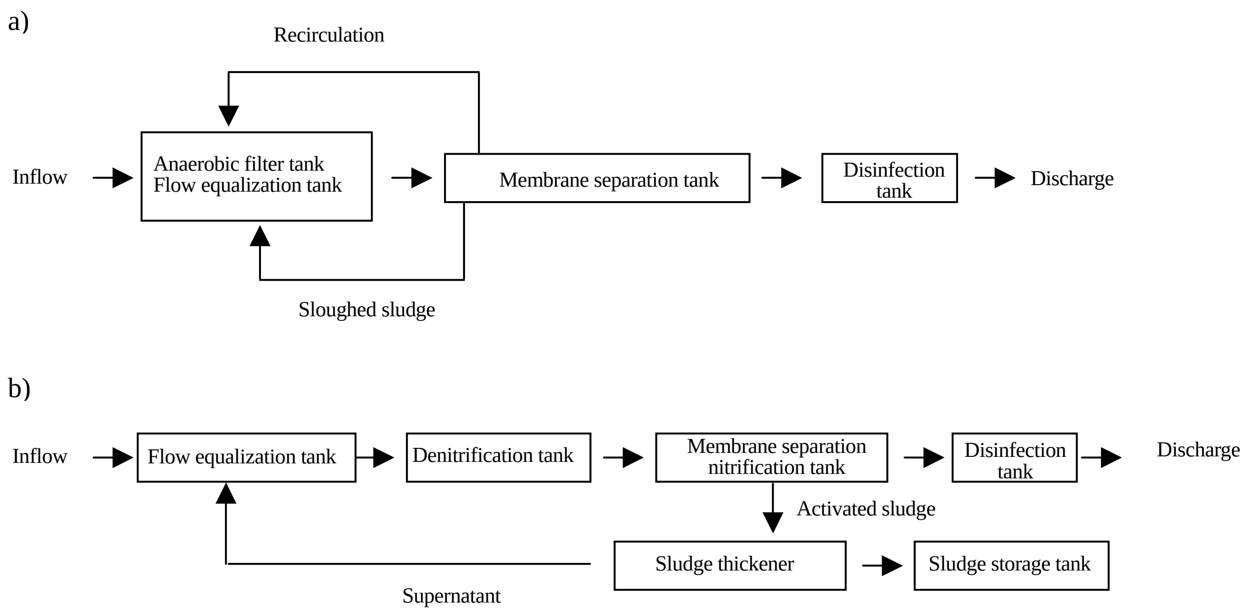


Fig. 8-1-6 Activated sludge process with membrane filtration

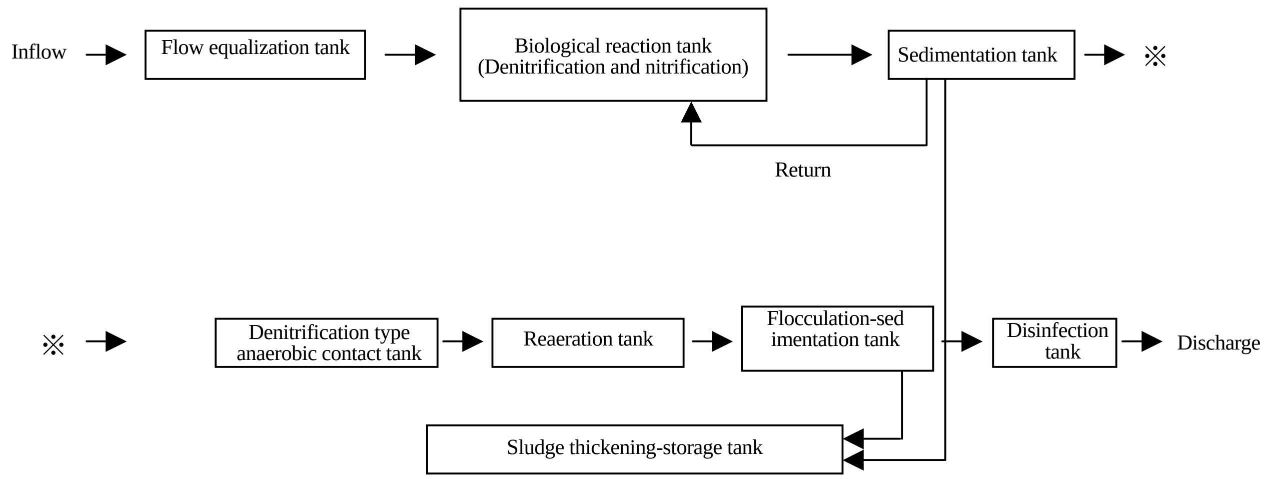


Fig. 8-1-7 Nitrified water recirculation type activated sludge process and tertiary treatment

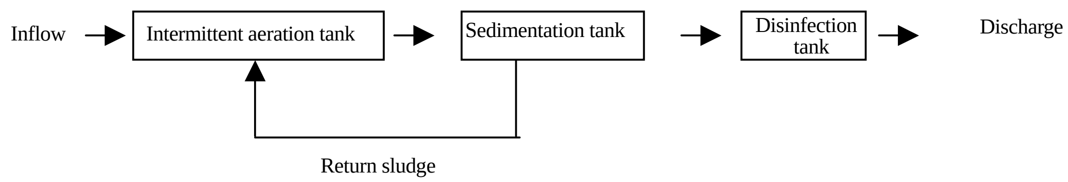


Fig. 8-1-8 Intermittent aeration type anaerobic-aerobic activated sludge process

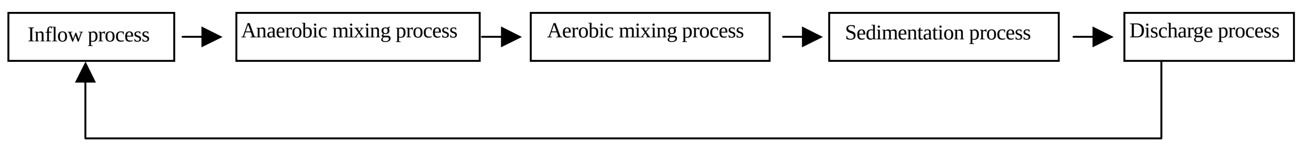


Fig. 8-1-9 Batch system anaerobic-aerobic activated sludge process

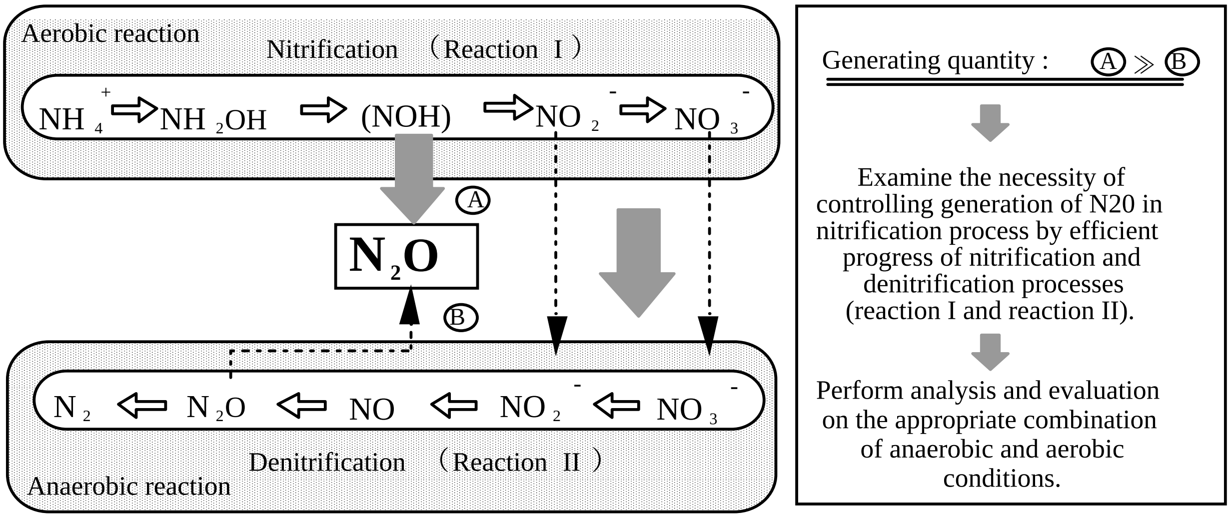
(3) Features of the system

The greatest feature of the advanced combined treatment septic tank system lies, whether it employs either the biofilm process as a biological treatment or the activated sludge process, in the alternate repetition of the anaerobic and aerobic conditions so as to ensure the efficient removal of nitrogen through the nitrification-denitrification reaction. Another important feature of the system is that it allows biological or physicochemical removal of P.

Table 8-1-1 Concept of basic specifications for septic tanks

Effects of performance that is improved with the principle of basic specifications incorporated.

- Eutrophication, that is, nitrogen as major causes of water bloom, red tide, and green tide can be highly and efficiently removed.
- Oxidization of pH in nitrificating reaction can be neutralized by alkalinity in denitrificating reaction, solids-liquid separation can be smoothly performed with improved coagulation capacity of microorganisms, and clearness of treated water can be improved.
- In contact aeration process, since water clearness increases in reaction vessel and sludge discharge can be controlled even at peak time if separated sludge is circulated within anaerobic filter tank, clear treated water and stabilized efficient treatment capacity can be maintained.
- Unusual increase of large vertebrates, such as cladocera, aseli, and gastropods, and offensive microorganisms, including sphaerotilus that can form bulking can be controlled.
- In anaerobic and aerobic circulation methods, nitrificating and denitrificating activations increase due to dilution effects, denitrification effects of inlet raw water by circulation, and effects of improved contact frequency with microorganism groups, and biological nitrification and denitrification can be advanced.
- Either by anaerobic or aerobic circulation, generation of global warming gasses such as CH_4 and N_2
tank, and near-future type water treatment that is familiar to the globe can be executed.



Where potentiality of greenhouse effect gasses causing global warming is assumed as 1 CO2, CH4 has global warming potentiality of 20 to 30 times and N20 has that of 200 to 300 times, and its reduction technology is extremely important.

Figure 8-1-10 N_2O generation mechanism and optimum control system at nitrification and denitrification reaction of biological wastewater treatment

The conventional combined treatment septic tank is aimed at removing only the BOD as an organic substance, and therefore, is impotent as a measure against water-blooms and red tides; in the Lake Kasumigaura basin, it has been confirmed that the diffusion of conventional septic tanks has been of no use in preventing eutrophication. Therefore, the high nitrogen and phosphorous removing function, which is an outstanding feature of the advanced combined treatment septic tank, has has a great impact on the creation of a healthy water environment.

In addition to the nitrifying, denitrifying and dephosphorylating reactions during the treatment process that incorporates anaerobic and aerobic conditions, the system has a great effect on restraining the generation of greenhouse gases as shown in Fig. 8-1-1 and 8-1-10. Thus, the system has versatile and important features of removing nitrogen and phosphorous as a preventive measure against eutrophication and restraining the generation of CH_4 (methane) and N_2O (dinitrogen monoxide), and exercises a great effect on advanced treatment functions.

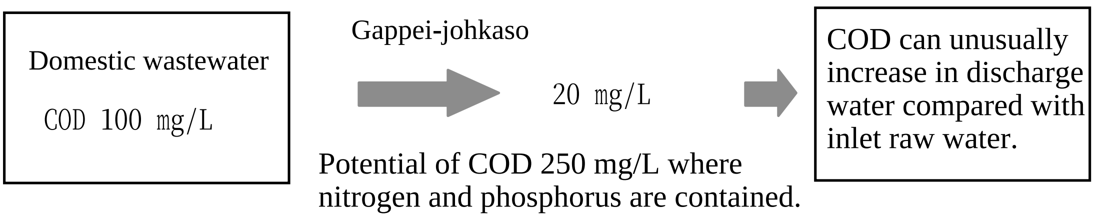
8-1-2 Performance of the System

The performance of the advanced combined treatment septic tank system lies basically in providing water qualities below BOD10 mg/L, T-N10 mg/L and T-P1 mg/L. Thanks to technological development, small-scale systems are capable of providing qualities below T-P1 mg/L in addition to BOD10 mg/L and T-N10 mg/L. In order to prevent eutrophication in particular, the system is required to provide qualities below 10 mg/L on T-N and 1 mg/L on T-P. Such requirements are clearly shown by a comparative analysis of the nitrogen and phosphorous loads that will be

Table 8-1-2 Typical AGP in final effluent discharged from combined aeration-type septic tank

Provided *Cyanobacteria* \ Facilities	AGP (mg/L) A	B	C	D	Average
Selenastrum capricornutum	430	520	590	580	530
Chlorella sp.	290	370	440	370	368
Chattonella sp.	450	430	430	390	425

If AGP measured is 500 mg/L or less, CODMn of 250 mg is produced from one final effluent from septic tank.



AGP Test : This is an evaluation method of potential algae increasing capacity that evaluates specimen water for capacity of increasing algae in public water areas through testing with flasks filled with treated wastewater to inoculate the specimen water with algae and to measure the increased number of algae at maximum after cultivation of 10 days under direct lighting.

imposed on the water area when vault toilets are converted into flush toilets. That is, the primary units relating to the residential wastewater discharged daily per person from flushed human waste and from the kitchen, bathroom, laundry, etc. are: 50L and 200L(250L in total), respectively in the amount of water; 13 g and 27 g (40 g in total), respectively in the BOD; 8 g and 2 g (10 g in total), respectively in the T-N; and 0.7 g and 0.3 g (1 g in total), respectively, in the T-P.

In the case of vault toilets, residential gray water is discharged untreated; however, human waste is collected and cleared completely of nitrogen and phosphorous through high-tech treatment at human waste treatment facilities. In this case, concentrations of nitrogen and phosphorous that are discharged as residential gray water are calculated from the primary units in the following manner:

For nitrogen 2 g ÷ 200L = 10 mg/L

For phosphorous 0.2 g ÷200L=1 mg/L (use of phosphorous-free detergents is taken into consideration)

At present although gray water is discharged untreated, human waste is rendered almost completely free from nitrogen and phosphorous at treatment facilities; then, the above calculations indicate that converting vault toilets storing such treated human waste into flush toilets for a more advanced lifestyle will not reduce the nitrogen and phosphorous loads in the water areas unless the treatment performance of residential wastewater consisting of both human waste and gray water is capable of lowering the concentrations of nitrogen and phosphorous below T-N10 mg/L and T-P1 mg,/L which are equivalent to the concentrations of gray water discharged untreated. Consequently, in closed water areas such as lakes, marshes, inland seas and inland bay basins, it is essential for the system to be provided with a feature that ensures water qualities below T-N10 mg/L and T-P1 mg/L; otherwise, pollutant loads to the environment will not be reduced below the level maintained by vault toilet systems.

There is an evaluation test called the AGP (algal growth potential) test to analyze and evaluate, prior to its discharge into public waterways, the potential of treated residential wastewater to cause algal proliferation. In this method, samples of various kinds of wastewater are collected before and after treatment, placed in triangular flasks, inoculated with algae, irradiated by light (bright for 12 hours, dark for 12 hours) and cultured for ten to fourteen days at a controlled temperature of around 20°C until algae reach the maximum proliferation that is close to the actual conditions of lakes, marshes, inland seas and inland bays. Then, by checking the samples' capacity to cause proliferation, a prior evaluation can be made to show the potential of the discharged water to cause algal proliferation in water areas.

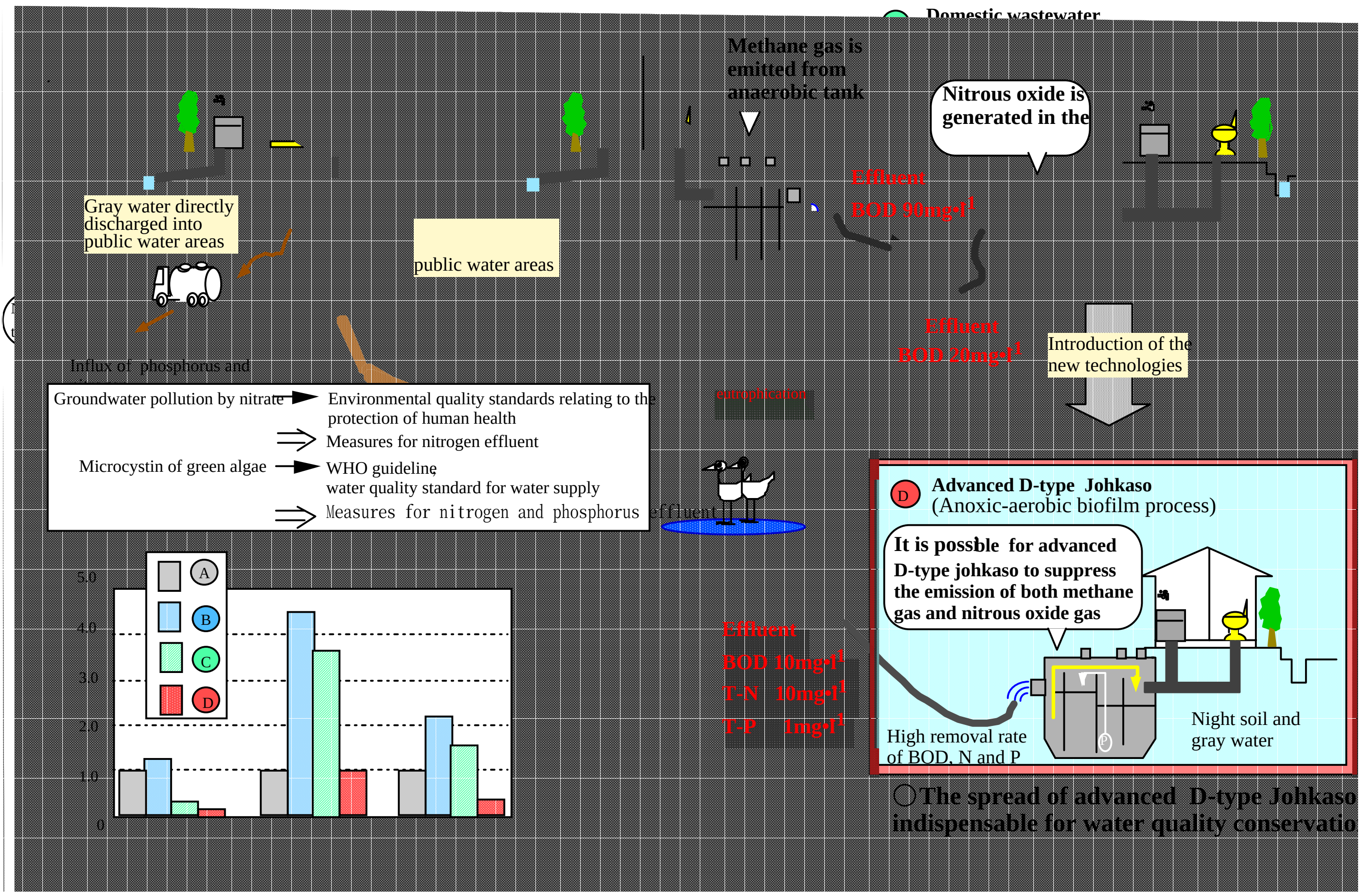
The effects of removing nitrogen and phosphorous from residential wastewater based on AGP tests are shown in Fig. 8-1-2. The results indicate that similar tendencies are observed on the algae that compose water-blooms appearing in lakes and marshes, and the algae that form red tides appearing in inland seas and inland bays. Such AGP tests show how measures aimed at removing the BOD alone are impotent in sewerage systems, small-scale wastewater treatment facilities in agricultural villages and septic tanks. This leads to an understanding of the essentiality of changing to nitrogen and phosphorous removal.

8-1-3 Ripple Effect of the System

There has been remarkable progress in the technological development of septic tanks that are positioned as a key measure of residential wastewater treatment as opposed to the sewerage system. As the conventional BOD- removing tanks are incapable of preventing the progressive acceleration of eutrophication, the 1995 amendment to the standards on septic tank structures added a nitrogen and phosphorous removing structure in place of the BOD removing structure. For small-scale combined treatment septic tanks, the technically established nitrogen- removing method was introduced while for medium- and large-scale combined treatment septic tanks, the combination of the nitrogen-and phosphorous-removing, nitrifying liquid-circulating and anaerobic-aerobic activated sludge process, and the coagulating sedimentation process was introduced.

Table 8-1-3 Outline of method and performance of small-scale advanced combined treatment septic tank

Treatment method	Quality of dis-charged water (mg/l)	Representative features	Representative operating conditions
Flow-controlled anaerobic filter bed biofilm filtration circulation method	BOD 10 T-N 10 SS 10	Treated water is circulated from an aerobic to anaerobic condition; is sent to an aerobic biological treatment chamber in a constant controlled volume; then, is highly cleared of nitrogen through biological filtration combined with the above process.	BOD space loading in bio-logical filter chamber: 1 Rate of carrier packing: 70% Circulation ratio: 4 Packing carrier: made of porous ceramics
Flow-controlled anaerobic filter bed carrier fluidized aeration and highspeed solid-liquid separation method	BOD 10 T-N 10 SS 10	Treated water is circulated from an aerobic to anaerobic condition; is sent to an aerobic biological treatment chamber in a constant controlled volume; then, is highly cleared of BOD, nitrogen and SS through fluidized aeration packed with small cylindrical carriers and high-speed solid-liquid separation using the carriers in combination with the above process.	BOD space loading in fluidized carrier aeration chamber : 0.4 Circulation ratio: 2 Packing carrier: made of polyethylene
Flow-controlled agitating filter bed biofilm filtration circulation method	BOD 10 T-N 10	Treated water is circulated from an aerobic to anaerobic condition; the water level fluctuates in all chambers; the discharged water is controlled in a constant volume and cut at its peak; and furthermore, through biofilm filtration, the water is highly cleared of BOD, nitrogen.	BOD filter material space loading in biological filtration chamber: 0.2 Circulation ratio: 4 Packing carrier: made of porous ceramics



Discharge of untreated wastewater regarding

nitrogen and phosphorous

・Make a comparison on the assumption that at present, gray water is discharged untreated while human waste is 100% dipped and treated at human waste treatment facilities, thus giving pollutant loads of 100.

・Show the increase or decrease in pollutant loads due to the difference in applied treatment methods when vault toilets are converted into flush toilets

・Set up the percentage of nitrogen and phosphorous removal at each treatment facility

Treatment facilities	BOD	T-N	T-P
Human waste treatment facilities	100%*	100%*	100%*
Individual treatment septic tank	65%	12%	25%
Combined treatment septic tank	90%	27%	37%
Advanced combined treatment septic tank	95%	80%	90%**

* Set at 100% because the rate of removal obtained for the concentration of treated wastewater to the concentration of primary wastewater is higher than 99.9%.

** Percentage obtained by advanced combined treatment septic tanks when iron materials are added.

○ The diffusion of combined treatment septic tanks that put into effect the advanced treatment greatly contributes to improving water environments.

○ In residential wastewater treatment, this comparative evaluation commonly applies to septic tanks, sewerage systems and small-scale wastewater treatment facilities in agricultural villages; the evaluation indicates the essentiality of advanced treatment.

Fig. 8-1-11 Importance of the spread for installation of advanced domestic wastewater treatment Johkaso for the conservation of closed public water bodies.

A particularly higher performance, compact size, energy conservation, low cost and easier maintenance and management are important tasks for proceeding with future technological development; therefore, by allowing such new technology to be freely implemented, new technology septic tanks are positioned as type Notification No.13. Table 8-1-3 shows the method that enables this small-scale advanced combined treatment septic tank to provide water qualities below 10 mg/ using such new technology.Furthermore, in and after June 2000, technical evaluation will be conducted additionally based on performance criteria, or evaluation based principally upon the ideas incorporated into Type 13. The new evaluation criteria are expected to give a great impetus to the development of technology for removing nitrogen and phosphorous. In view of all this, it is important to promote the development of technology for advanced combined treatment septic tanks aimed at creating healthy water environments and their diffusion, in such a manner that the general public may become aware of the importance and the promotion be conducted, not in a system conducted vertically among government ministries and agencies, but across all ministries and agencies. Fig. 8-1-11 shows how healthy water environments should be created through the diffusion of advanced combined treatment septic tanks. The provision and installation of advanced combined treatment septic tanks is also important as a measure not only against eutrophication, but also nitric acid pollution of underground water. In February 1999, the concentrations of nitrous acid and nitric acid lower than 10 mg/ were positioned among the health items of the environmental standards. In such circumstances, Tokyo has put into effect guidelines that require the installation of advanced combined treatment septic tanks in underground water-permeating areas that are capable of providing water

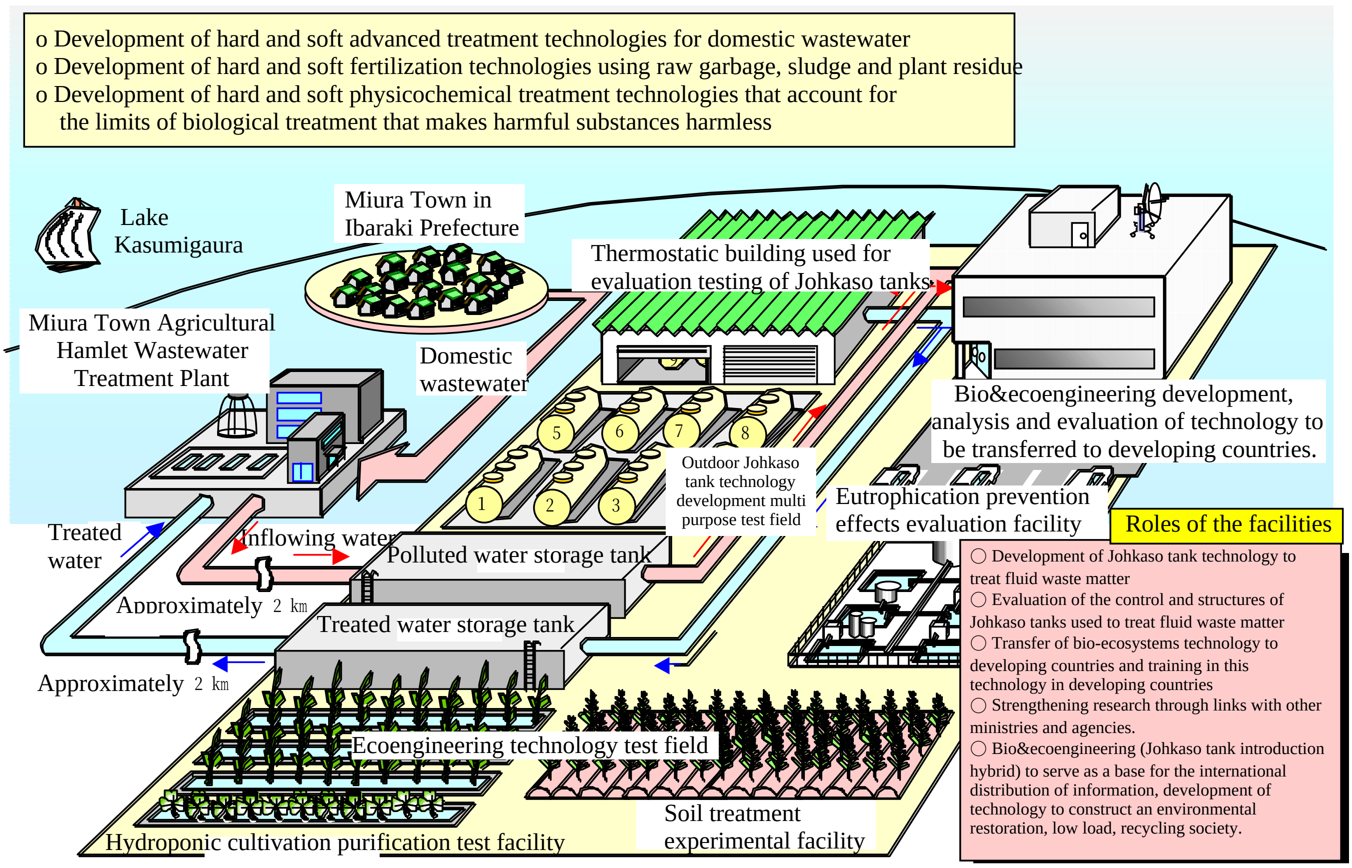


Fig.8-1-12 The Bio&Ecoengineering Research Center Positioned to Perform Hard and Soft Development and Reseach on Soil and Fluid Waste Matter

and Research on Solid and Fluid Waste Matter

qualities below BOD10 mg/L and T-N10 mg/L to ensure that such tanks keep within the environmental standards and observe the quality of underground drinking water below 10 mg/L as stipulated in the guidelines.

It is also very important that in relation to the use of disposers stated in the Comprehensive Technological Development Project (Comprehensive Project drawn up by the Ministry of Construction ─now the Ministry of Land and Transport), an agreement was reached on septic tanks described in the latter part with advanced treatment methods to provide water qualities below BOD10 mg/L, T-N10 mg/L and T-P1mg/L so as not to increase loads on the sewerage systems. Concurrently, with the above system, advanced combined treatment septic tanks have been developed for disposers that provide water qualities below BPD10 mg/L and T-N10 mg/L. Thus, disposers are expected to play an important role in building a recycle-oriented society with less load on the environment, provided that the installation of individual disposers is prohibited and proper arrangements are made in areas where vault toilets or independent treatment septic tanks are in use. Bioecoengineering research facilities in charge of such technological development were made available at the National Institute for Environmental Studies (Fig. 8-1-12).

Recently, triggered by nitrogen and phosphorous, a certain phenomenon is becoming increasingly patent; at lakes and marshes water-blooms, which form microcystins ─a toxin stronger than potassium cyanide ─ are proliferating, while in inland seas and inland bays, toxic red tides are spreading more frequently. All this indicates the essentiality of developing technology for advanced treatment septic tanks intended to prevent wastewater treated in septic tanks from affecting the ecosystem.

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8-3. Biopark Aquaculture Purification

8-3-1 Principle of the system and its features

(1) Outline of the system

A. Introduction

Tracheophytes, except free-floating plants and air plants, are normally planted and cultivated in cultivation-beds made of earth, sand or sponge. However, the biopark system sets up an environment with shallow-running water, where each plant is forced to make its own cultivation-bed by its rootstalks, and cultivates the plants amid successively supplied polluted water. The biopark is a system that uses the rootstalks of cultivated plants as filter materials, makes the organisms inhabiting the rootstalks perform bio-accumulation and sludge reduction, and by extracting all of the growing plants and accumulating sludge as well as the fish and shellfish gathering and proliferating there, it extracts nutritive salts and turbidity from the water and puts them to use. The capacity and cost of the system to remove nutritive salts and pollution-indicator substances in eutrophicated lakes and marshes is greater and lower in comparison with those of purification by aquatic plant cultivation or water treatment plants, per area of the facilities and per gram of removed nutritive salts. The system is aimed at producing plants and animals with the highest possible marketable prices to partially recover and reduce the purification cost while contributing to improving the productivity and nutritional state of the area as shown in Fig. 8-3-1(coexistence of purification and production by the biopark system).

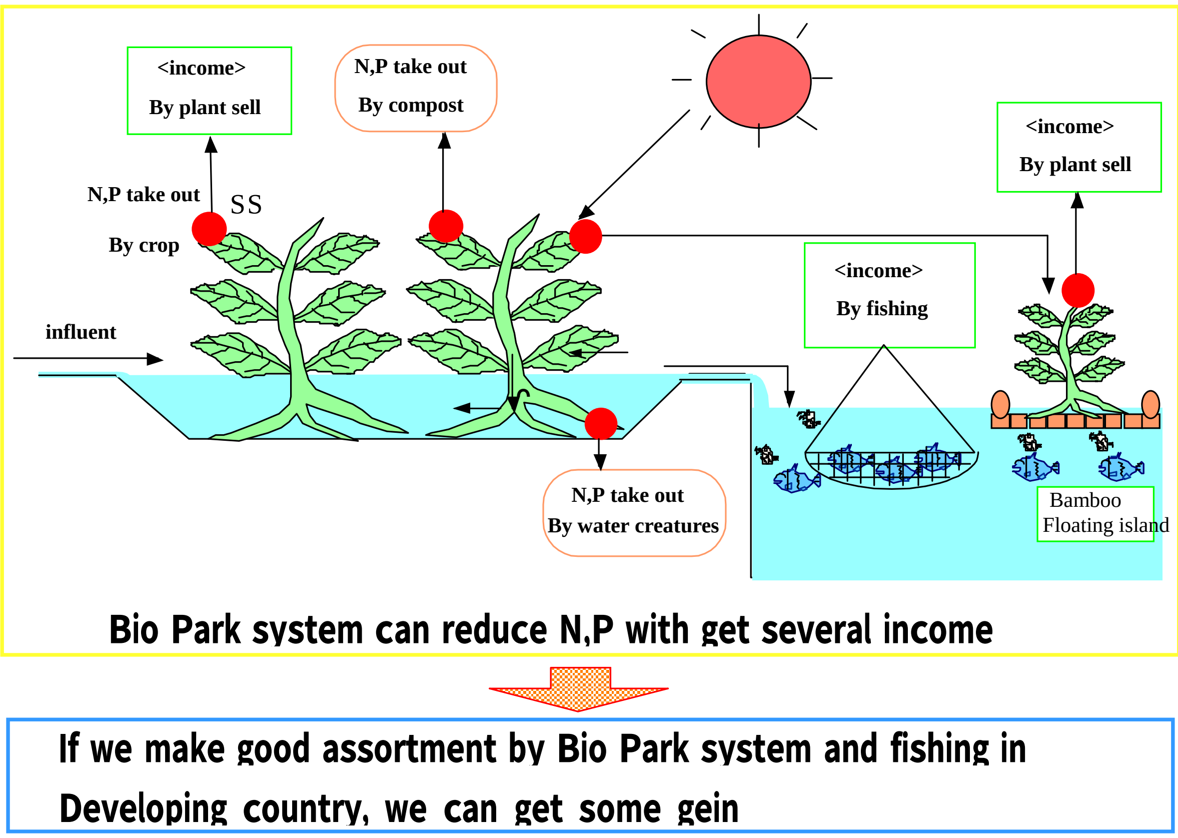


Fig8-3-1 N,P reduce and sell income by Bio Park system

B. Structure of the facilities

In biopark aquaculture purification, plants suitable for the water quality, climatic conditions and market demand are arranged in a shallow and wide waterway, which is inclined 1 to 0.5%, over one meter wide and more or less 20 meters long, and made of materials that permit no water permeation or destruction by plant roots; and through the waterway, the primary water is made to flow at the rate of 3 m^3 per m^2 a day. Several waterways are installed in parallel along with an individual structure that is capable of controlling, stopping completely or draining the water supplied through each waterway (See photo 8-3-1 showing experimental biopark facilities in Thailand). Outlets to discharge treated water into rivers, lakes or marshes attract a large number of fish and shellfish; therefore, it is recommendable to set some devices to capture them as shown in Photo 8-3-2 (a total of 74 crucian carp and other fish gathered in a coop placed at the outlet of the discharged treated water at the biopark).

C. Cultivated plants

Plants to be cultivated shall chiefly be evergreen, perennial, aquatic or wet plants that form flat communities, and mixed with standing plants and/or deciduous plants according to demand or landscaping purposes. For rivers, lakes and marshes polluted as a result of eutrophication, plants suitable for the temperature and the COD can be selected; however, as many species suffer from lack of ingredients in highly treated sewage or underground water rich in nutritive salts, plants other than those that develop tuberous stalks or underground stalks are difficult to cultivate. Community-forming plants that are suitable for cultivation with the highest purifying capacity are watercress for the temperate zones (shown in Photo 8-3-3), and swamp cabbage for the tropical regions (shown in Photo 8-3-4). The plant suitable for purification of underground water and treated sewage in the temperate regions is known as *zantedeschia aethiopica* shown in Photo 8-3-5 (being cultivated at sewage treatment facilities); however, no advanced study has been made regarding the tropical regions. The biopark method has been put into practice in Japan, Thailand and China, and these plants mentioned are known to be obtainable. In diffusing the method in other areas, it will be better to review the maximum and minimum temperatures of the area, obtain and cultivate seeds or inserted ears of watercress or swamp cabbage, trying at the same time to cultivate locally consumed plants.

(2) Principle of purification

A. Biofilm treatment

Water purification in the biopark system starts with microorganisms forming biofilms at the surface of the rootstalks of the cultivated plant and eating the turbidity of the primary water. The rootstalks of the cultivated plant form a mat-like layer so thick that the overall length of the roots contained in 1 cm^3 of the mat may extend to ten meters. It is tiny animals such as *Physidae* shown in Photo 8-3-6 that eat the biofilms formed on the root surface, prompt its metabolism and keep it active, dropping at the same time between the rootstalks, in the form of excrements, the pollution- originated nutritive salts trapped by the biofilms (Photo shows a *Physidae* perched on the root of a swamp cabbage eating the bilofilms). In building and operating biopark facilities, there is no need to inoculate microorganisms that form biofilms; however, small-size snails such as *Physidae* may be collected from the surrounding environments and released in the waterways for a better start-up of the purification.

B. Ecological accumulation and sludge reduction

Leeches that eat snails, crawfish that eat leeches and other diverse animals form an ecosystem; their excrement and bodies turn into sludge and accumulate among plant roots. This accumulation, if compared with the turbidity that is removed in the waterways, has condensed nutritive salts and reduced volume. Animals that form saprophytic food chains such as aquatic insects and aquatic earthworms also appear; they accumulate nutritive salts, reduce sludge volume, mineralize the salts and render them absorbable by plants.

C. Absorption of nutritive salts and harvest

Plants absorb nutritive salts from sludge derived from water turbidity and formed through ecological accumulation, grow new rootstalks in the water and continue to retain sludge; humans harvest the plants that have grown absorbing nutritive salts as vegetables and flowers; as a result, nutritive salts are extracted while simultaneously, a new space is made for plants to grow again actively absorbing nutritive salts.

D. Removing composted sludge and restart of purification

When sludge has accumulated sufficiently, the water supply to the facilities waterways is alternately cut; water is let out and the plants are made to absorb and vaporize the water contained in the sludge. When the sludge has dried up and the plants withered, the remnants in the waterways are extracted and piled up; they ferment at high temperature and turn into useful compost; then, plant seedlings are introduced through the waterways to restart the purification.

E. Catching fish and shellfish and their removal

Part of the microorganisms and small animals that purify water flow out of the facilities on the treated water and amass around the discharge outlet, where fish and shellfish feed on them. If they are captured, the nutritive salts within can be extracted. Many of the fish and shellfish enter the waterways as eggs or larvae, or go upstream through the treated water discharge canals, reach the waterways and grow and proliferate; if captured, nutritive salts can also be extracted. The balance of removing nutritive salts through the above mechanism is summarized in Fig.8-3-2.

Photo 8-3-1 Bio-park facilities in the Kingdom of Thailand

Photo 8-3-2 Fish caught around the discharge outlet

Photo 8-3-3　Watercress

Photo 8-3-4　Swamp cabbage

Photo 8-3-5 *Zantedeschia aethiopica*

Photo 8-3-6　*Physidae*

(3) Features

1) The system removes not only pollution-indicator substances removable by the treatment to decompose BOD, COD, SS, etc., but also removes substances responsible for eutrophication such as nitrogen and phosphorous, turns them into useful products and produces no waste substances.

2) The facilities provide a landscape made up of purified water and low green plants, and are safe and comfortable. As their purifying capacity is little affected by intruding people, the facilities can be opened to the general public as a park.

3) If opened to the public, the facilities can show people how wastewater is purified and have them participate in picking and harvesting vegetables, flowers, compost and fish, all of these being products of the purification process.

4) The system will allow part of the purification expenses to be covered by sales of high-value products.

5) Environmental education can be made available using vegetables, flowers or living creatures that are of great interest to the general public and children. Such education will win popularity that will lead to a deeper understanding of the eutrophication problem.

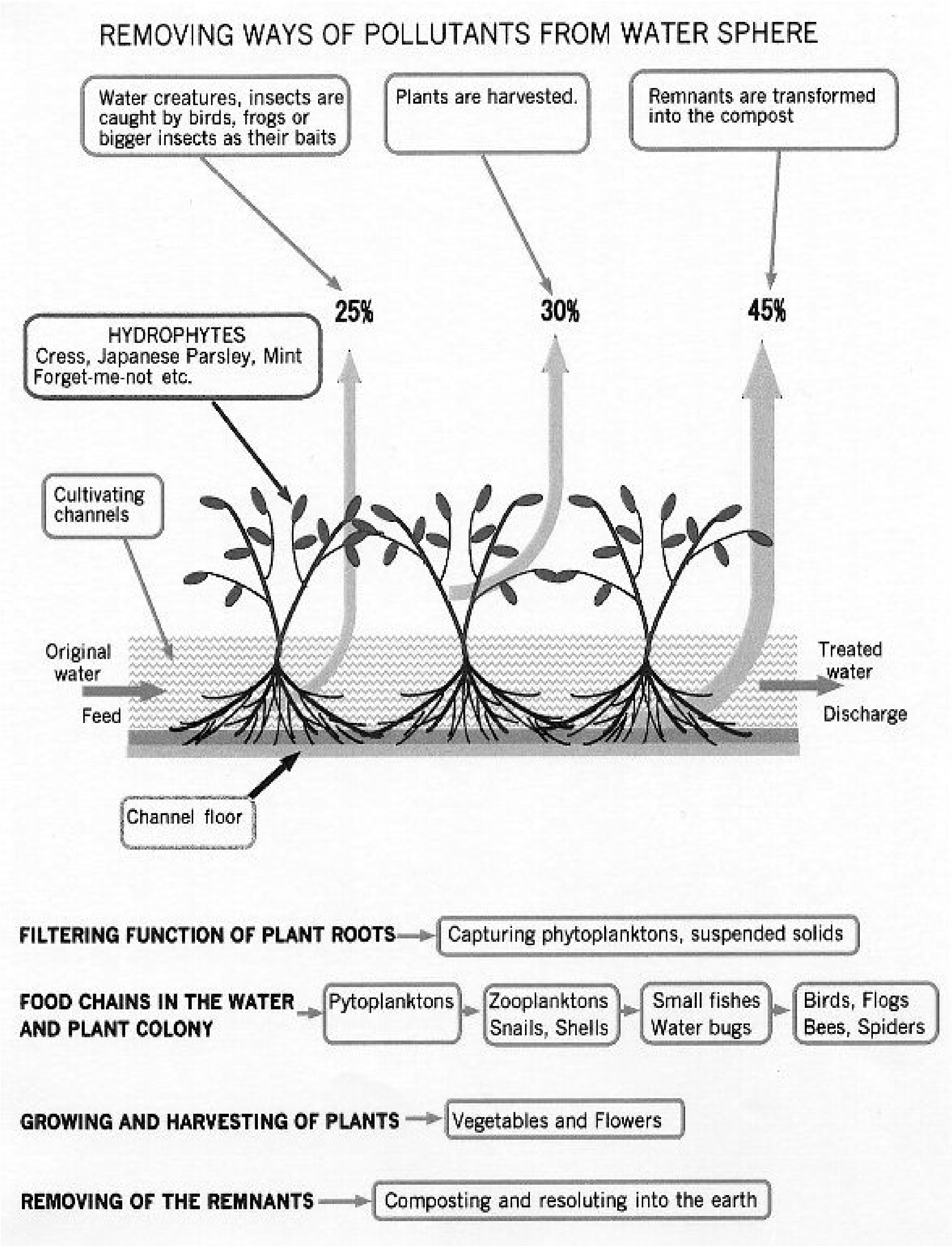


Fig. 8-3-2 Mechanism of nutrient remove in Bio Park

8-3-2 Performance of the System

(1) Purification of eutrophicated lakes and marshes

A. Some examples in Japan

In Japan, ten facilities across the country, including Tsuchiura Biopark shown in Photo 8-3-7 as the largest example, cultivate vegetables and flowers on lakesides and riversides removing nitrogen, phosphorous and turbidity from the water. These are then removed from the facilities by harvesting and consuming flowers and vegetables, and composting and utilizing the accumulating sludge. In recent years, the growth and proliferation of corbiculas has become a new means for extracting nutritive salts. Tsuchiura Biopark is a provisional facility made by building a provisional water supply plant and passages on existing concrete planes. One example of permanent facilities built from basics is Kibagata Biopark shown in Photo 8-3-8.

Photo 8-3-7 Tsuchiura Biopark

Photo 8-3-8 Kibagata Biopark

B. Purification performance

Tshuchiura Biopark has been operating for seven years, Kibagata Biopark for two years. Their average annual purification results are calculated as shown in Table 8-3-1.

Table8-3-1 Annual average purification records at temporary facility of Tsuchiura and permanent facility of Kibagata

Pollutants	Equipment	Influent	Effluent	Removal Rate	Removal Amount
COD	Tsuchiura	9.6 $mg\cdot l^{-1}$	8.3 $mg\cdot l^{-1}$	14%	4.3 $g\cdot(d\cdot m^{2})^{-1}$
	Kibagata	8.2 $mg\cdot l^{-1}$	5.6 $mg\cdot l^{-1}$	32%	7.8 $g\cdot(d\cdot m^{2})^{-1}$
SS	Tsuchiura	20.9 $mg\cdot l^{-1}$	9.6 $mg\cdot l^{-1}$	54%	50.0 $g\cdot(d\cdot m^{2})^{-1}$
	Kibagata	16.0 $mg\cdot l^{-1}$	3.3 $mg\cdot l^{-1}$	79%	38.1 $g\cdot(d\cdot m^{2})^{-1}$
T−N	Tsuchiura	3.7 $mg\cdot l^{-1}$	3.1 $mg\cdot l^{-1}$	15%	1.9 $g\cdot(d\cdot m^{2})^{-1}$
	Kibagata	1.7 $mg\cdot l^{-1}$	1.1 $mg\cdot l^{-1}$	36%	1.8 $g\cdot(d\cdot m^{2})^{-1}$
T−P	Tsuchiura	0.12 $mg\cdot l^{-1}$	0.09 $mg\cdot l^{-1}$	27%	0.16 $g\cdot(d\cdot m^{2})^{-1}$
	Kibagata	0.13 $mg\cdot l^{-1}$	0.07 $mg\cdot l^{-1}$	47%	0.18 $g\cdot(d\cdot m^{2})^{-1}$

C. Purification capacity and cost comparison

It is difficult to compare the technological efficiency of purification conducted in different conditions; however, one effective comparison of the capacity affecting the balance of pollutants in a water system is that of the removing speed. As the removing speed is proportional to the concentration of the primary water to be treated, purification efficiency will be clearly compared if the correlation straight lines relating to the speed of removing the primary-water concentration of each technology are denoted on the same diagram; then, the removing speed at which each technology treats primary water with a particular concentration will be known. There are few systems applicable to practical use that are capable of purifying eutrophicated lakes and marshes and removing nitrogen, phosphorous and so forth. The systems that do publish detailed comparable data consist of only a system that combines biomodules and the denitrification and phosphorous-removing devices, and a system that purifies polluted water in vegetation wetland. Data collected at the Tsuchiura and Kibagata bioparks are shown in Fig. 8-3-3~4 together with the data obtained at the Thai biopark. The biopark system is known to have better removal efficiency than other systems in the shown range of concentrations. In terms of cost, there are no large-scale systems put into practice that have the combination of biomodules + denitrification + phosphorous removal; therefore, it is only possible to compare the cost of Kibagata Biopark with the cost estimated in a trial design of a large-scale combined system. The cost of the facilities installation measured on the basis of pollutant removal capacity per gram of pollutants per day for the biomodule system is on average 12 times that of the biopark; electricity consumed to remove 1 g of pollutants for the biomodule system costs on average 10 times as much. Data variations in Fig. 8-3-3~4 show that the biopark system is not suitable for cases that require assured quality on the treated water or only a high removal percentage; it is suitable the cases that require as many pollutants as possible to be removed from the water.

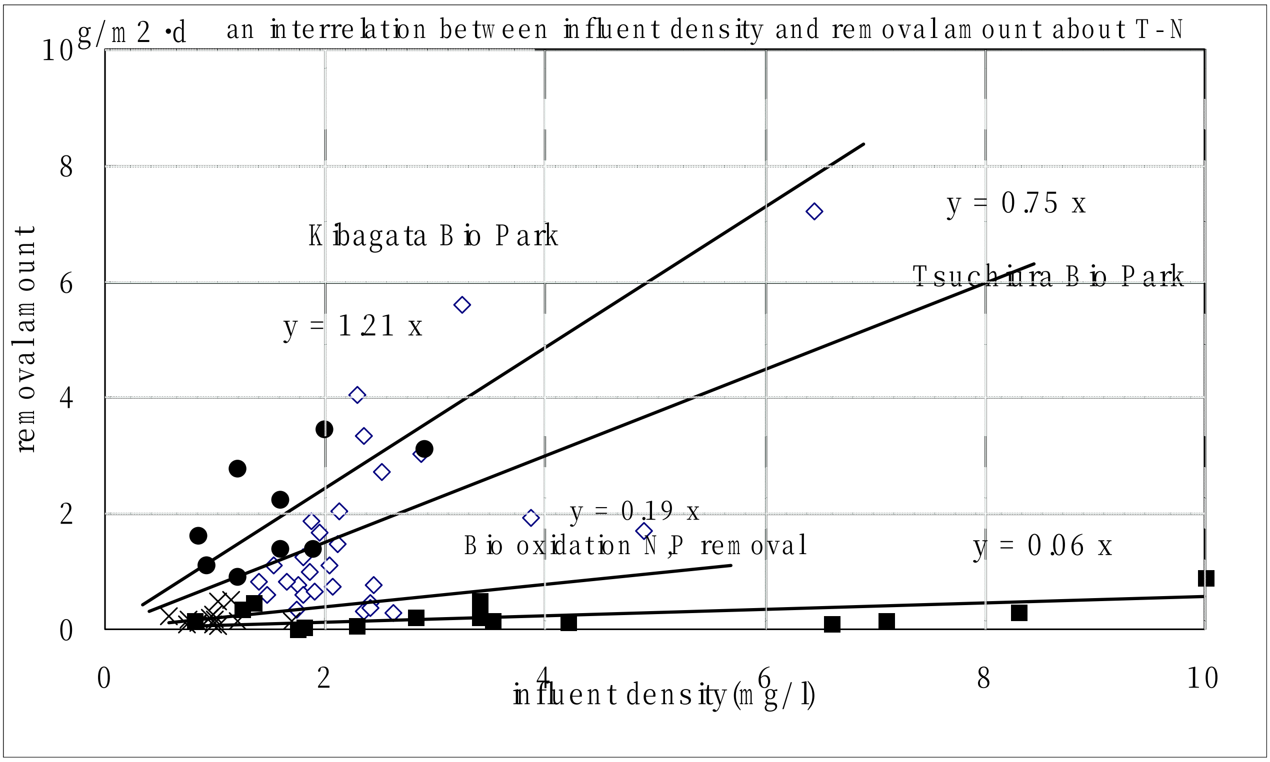
(2) Removing water-blooms

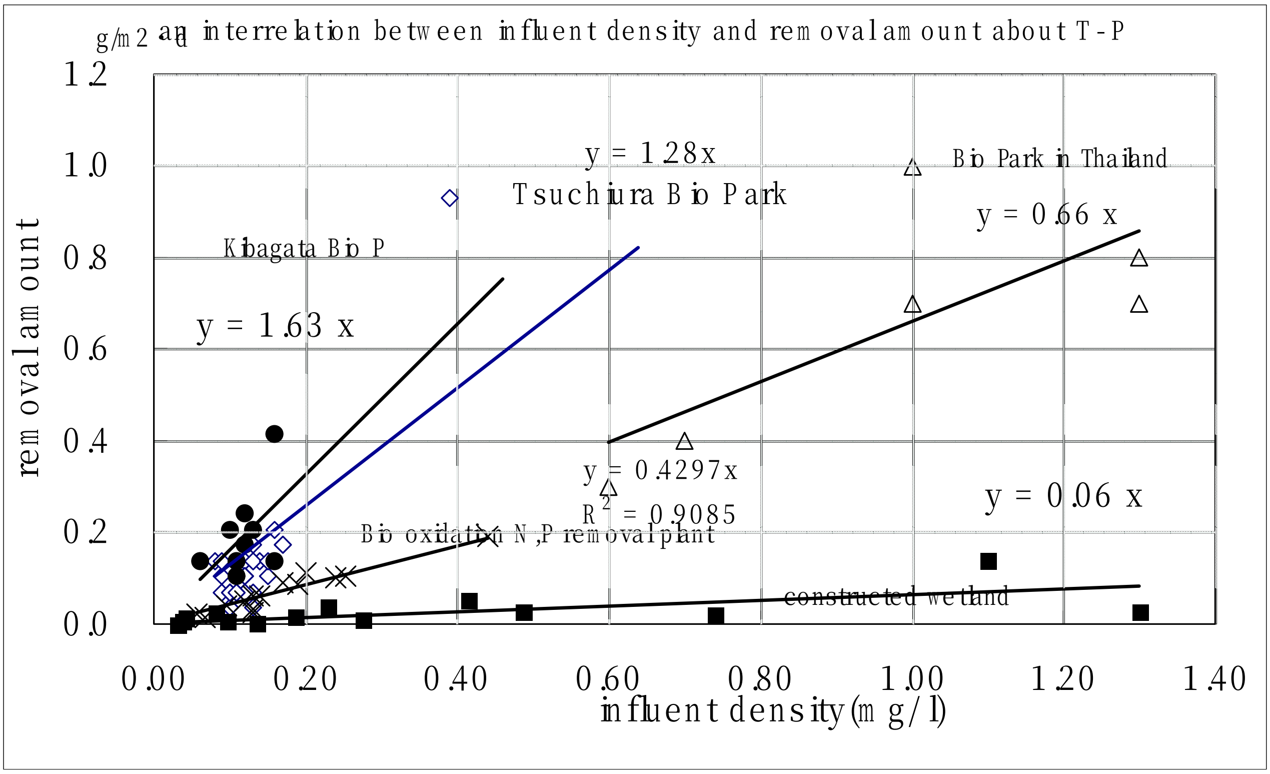
A. Mechanism of removing water-blooms

At a biopark, the ecosystem formed by rootstalk mats is densely inhabited by animals such as creeping-nektonic rotifers and aquatic earthworms that eat relatively dispersed water-blooms. Small snails such as *Physidae* or *radix japonicus* that normally eat biofilms devour water-blooms that are attached to rootstalk mats in large masses or dammed up afloat on water surfaces by stalks. Water-blooms are consumed by these actions, while at the same time microcystins are digested by these animals or decomposed by the action of microorganisms.

B. Japan’s examples and their effects

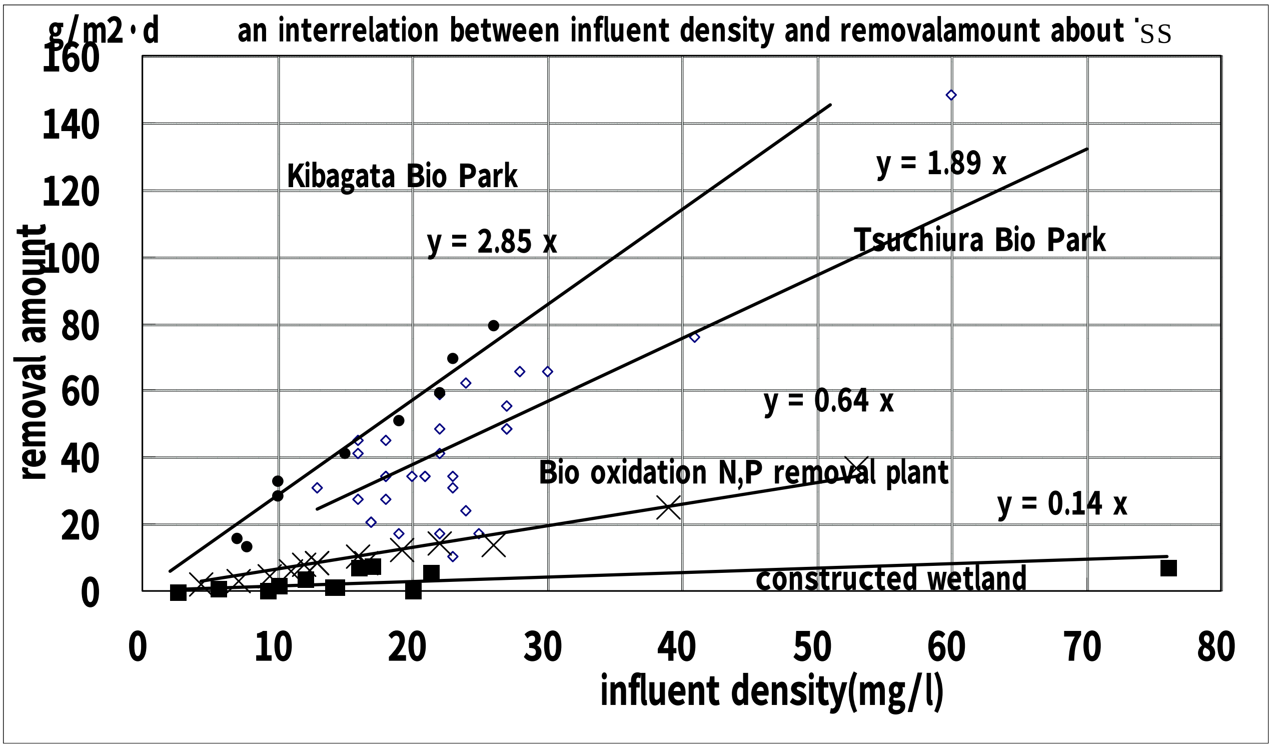
At Tsuchiura Biopark and Teganuma Experimental Biopark lake water containing water-blooms is supplied as the primary water to the biopark for treatment of the water-blooms. At Tsuchiura Biopark, the concentrations of SS, T-N and T-P rose when the water-blooms were mixed with the primary water, resulting in high removal percentages and removing speeds shown in Fig. 8-3-2. Based on the moisture content of the water-blooms assumed to be 98% from this SS-removing speed, the raw weight of the water-blooms to be removed is calculated as being 7.4 kg per m^2 per day.

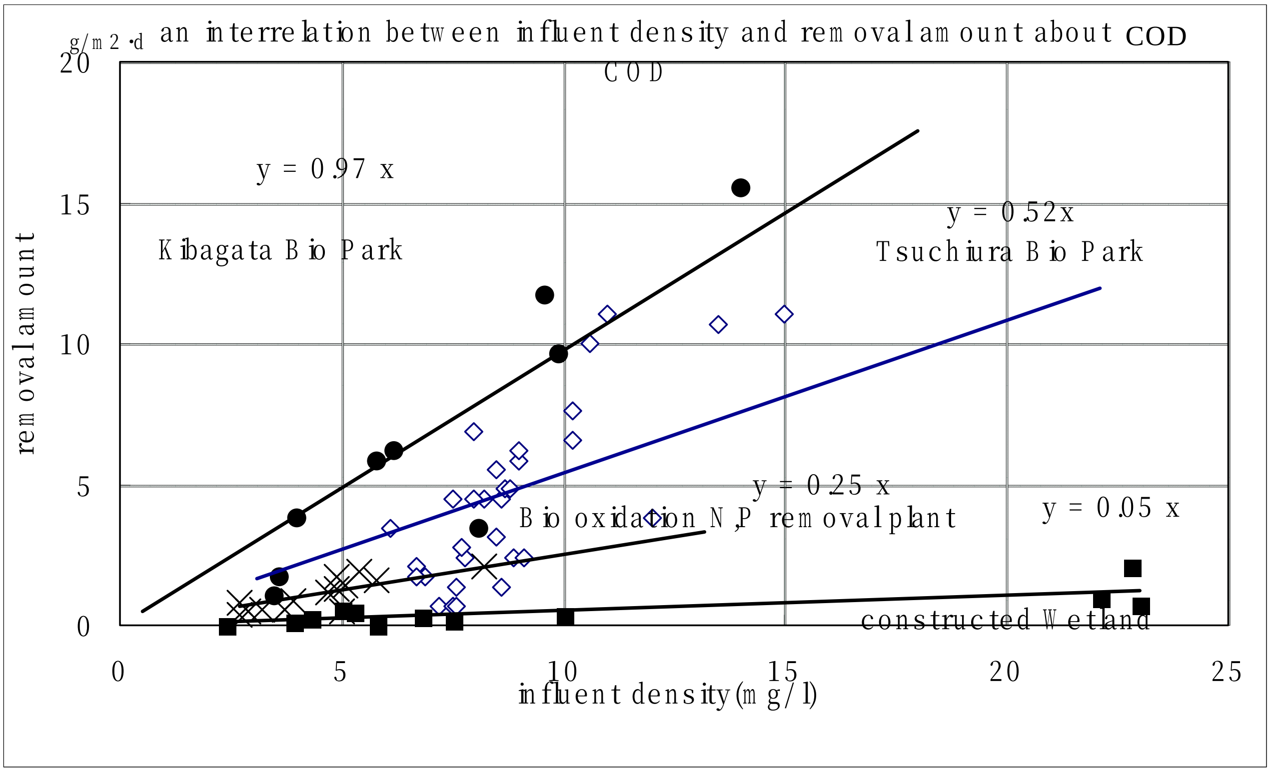




◇ : Tsuchiura , ● : Kibagata , × : Bio oxidation and NP removal, ■ : Constructed Wetland, △ : Thai AIT

Fig8-3-3 Interrelation between influent density and removal amount about T-N, T-P in Bio Park





◇ : Tsuchiura , ● : Kibagata , × : Bio oxidation and NP removal, ■ : Constructed Wetland,

Fig8-3-4 Interrelation between influent density and removal amount about SS, COD in Bio Park

Table8-3-2　Water purification performance on the Blue-green algae bloom at Tsuchiura Bio Park

Pollutants	Influent	Effluent	Removal Rate	Removal Amount
ＳＳ	５６mg·l^{-1}	１４mg·l^{-1}	７５%	１４８g·(d·m^{2})$^{-1}$
Ｔ－Ｎ	６．５mg·l^{-1}	３．５mg·l^{-1}	４６%	１０．６g·(d·m^{2})$^{-1}$
Ｔ－Ｐ	０．４１mg·l^{-1}	０．１５mg·l^{-1}	６４%	０．９３g·(d·m^{2})$^{-1}$

At Lake Tega, variations of microcystin concentrations checked on each isomer while the primary water containing water-blooms was being treated provided the results shown in Fig. 8-3-5. YR, which had a low concentration in the primary water, showed a concentration in the treated water below the detection limits; however, on LR, the removal rate was 76% with a removing speed of 3.84 mg/(d/m^2), and on RR, the rate was 68% with a speed of 7.14 mg/(d/m^2). All figures showed high removal efficiency.

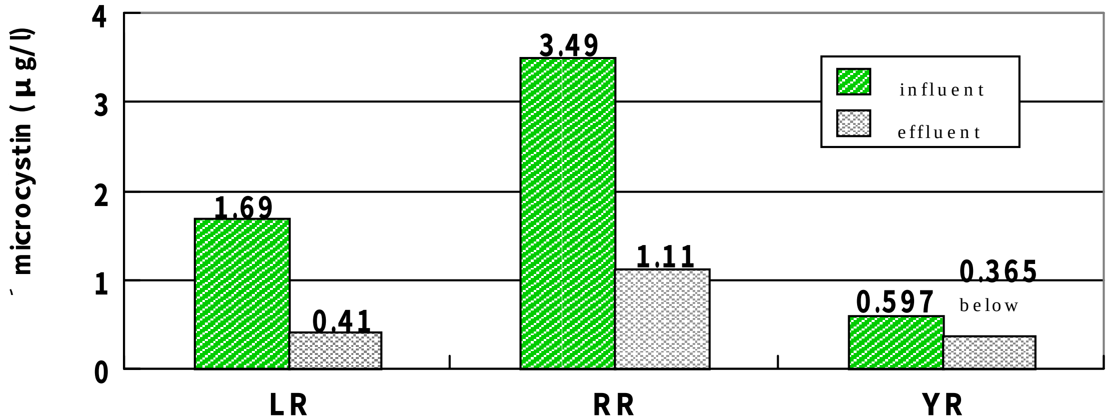


Fig8-3-5　Bio Park performance to reduce microsystin in Teganuma

(3) Purification of the treated sewage

A. Outline

The biopark method is applicable to the water treated as being below BOD20 mg/l (below 50 mg/l if swamp cabbage is used) in which plants can be cultivated. In Japan, at three settlement-wastewater treatment facilities, the final treatment by the biopark method is performed based on the experiment conducted in sewage disposal plants. One example is shown in Photo 8-3-5 (*Zantedeschia aethiopica* growing in treated sewage, directly after picking flowers) where *Zantedeschia aethiopica* is cultivated in the waterways, removing nitrogen and phosphorous, and producing flowers.

B. Purification results and revenues obtained

8. Aerated Circulation Purification

8-5-1 Principle of the aerated circulation purification system and its features

(1) Features of the aerated circulation system

In lakes, marsh, dams or impounding reservoirs when phosphorous and nitrogen are present in sufficient amounts (0.02 mg/l or more for phosphorous and 0.2 mg/l or more for nitrogen), primary production or phytoplankton production occurs, according to their concentrations and loads per area causing a number of obstacles to water utilization.

Phytoplanktons are roughly divided into three kinds of algae; blue-green algae, green algae and diatoms. Of the three, blue-green algae have many species that cause obstacles to water utilization: for instance, microcystis that produce toxic matter and Phormidium that produce musty odorants. These blue-green algae are sensitive to light intensity, and therefore are restrained by light. Because of this, blue-green algae are known to accumulate in surface layers as do the most representative microcystis; others are generated when the water becomes relatively transparent.

Consequently, as compared with diatoms and green algae, blue-green algae are more likely to be restrained from proliferating in weak light conditions. Promoting their circulation in a direction vertical to the lake-water will reduce the average light intensity and is therefore convenient for controlling harmful planktons that produce toxic water-blooms or musty odors.

On the other hand, lakes and marshes that have become heavily eutrophic in recent years are facing the problem of increasing soluble organic substances. Production of soluble organic substances by proliferating phytoplanktons and dissolution of dead phytoplanktons over a long time as putrefactive matter in the water are regarded responsible for such problems.

These organic substances are known to form carcinogenic trihalomethane by the action of chlorine, and therefore are regarded problematic in securing safe water. Prevention of their generation is an urgent necessity.

Apart from the above problems, massively generated phytoplanktons consume oxygen dissolved in the water when they die, and form anaerobic water masses; they accumulate on the lake-bottom and create anaerobic conditions in the depths. The anaerobic conditions of the lake-bottom cause various nutritive salts as well as heavy metals to re-elute. The aerated circulation method has a large capacity to supply oxygen to the bottom layer and at the same time it can cause the depths to become aerobic.

Why phytoplanktons need to be restrained can be summarized as follows. The aerated circulation method is theoretically effective for such restraint.

- It restrains the production of trace toxic materials
- It prevents fish gill disease and death
- It restrains anaerobic water mass formation
- It prevents promotion of nutritive salt regression
- It prevents the promotion of heavy metal elution due to anaerobic condition
- It restrains the ability to form trihalomethane due to increasing soluble organic substance

(2) Principle of the aerated circulation purification system

The principle of lake-water circulation by an aeration pipe (the intermittent air-lift pipe is called hereinafter “aeration pipe”) lies in density current formation process through jet formation by an air-bubble shot and a hauling mixture as described below. The lake-water circulation mechanism consists of the following prime mechanisms:

1) Compressed air is sent;

2) The air chamber located in the lower part of aeration pipe is filled with compressed air;

3) After it is filled, the air-bubble shot rises due to a siphon effect;

4) Simultaneously with the rise of the air-bubble shot, lake-water is hauled from the lower part;

5) The water mass inside the pipe is pushed up by formation of the next air-bubble shot and simultaneously the water mass of the lower layer is hauled;

6) Steps 4) and 5) are repeated intermittently;

7) The air-bubble shot forced from the pipe-head rises and simultaneously expands due to falling water pressure; the air-bubble shot is broken by the water resistance and rises as it bubbles;

8) Simultaneously, water inside the pipe is forced out, and joined by the water, it rises as a jet;

9) At this point, the jet hauls the surface-layer water, and because of the temperature of the lower-layer of water which has been sucked and temperature of the hauled water, a water mass less dense than the lower-layer water is formed and reaches the upper layers; and

10) This water-mass becomes a density-current and disperses a slightly lower even-density layer as a horizontal density-current.

The above mechanism of the lake-water is illustrated in Fig. 8-5-1. The state of the jet forced from the aeration pipe is shown in Photo 8-5-1. The diameter of the jet area on the water surface is 20 to 30 meters. Initially it was feared that boats would be in danger of capsizing in this jet area; however, the safety of rowboats was later confirmed.

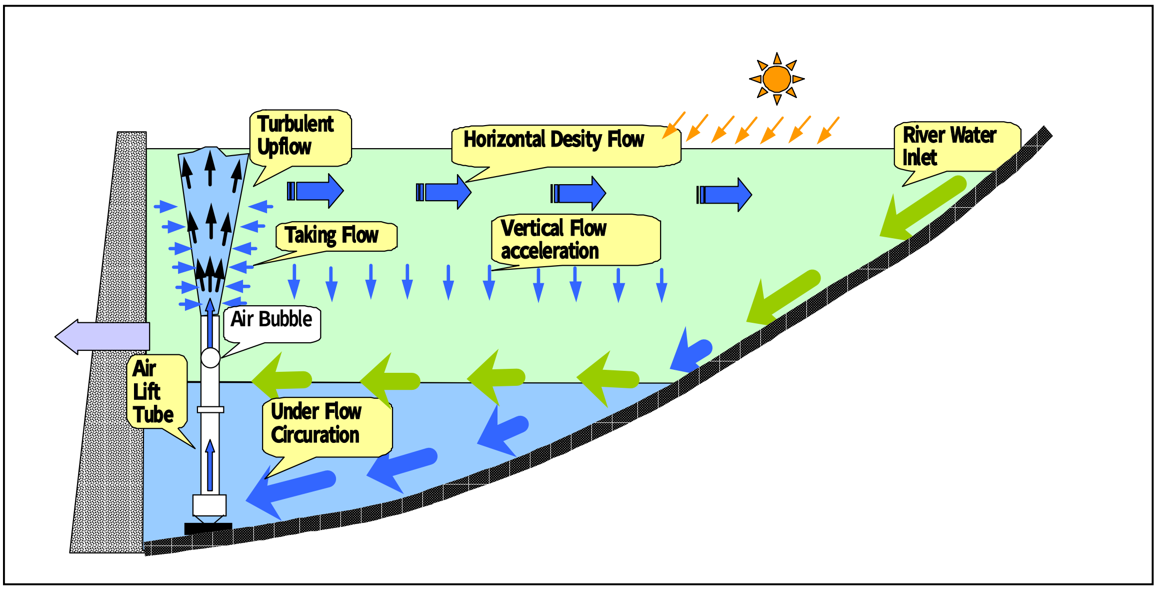


Fig 8-5-1 Fllow pattern of Air bubble gun system

Photo 8-5-1 State of jet by aeration pipe

8-5-2 Performance of the Aerated Circulation Purification System

The principles of phytoplankton proliferation restraint by lake-water circulation are the following:

- Light control effect
- Surface-layer water dilution effect
- Sedimentation promotion effect

Which is the greatest of the three effects depends upon the form of inflowing nutritive salts, hydraulic condition of the lake or impounding dam or types of generating phytoplanktons; however, in general, the “light control effect” is regarded as the greatest. Following is an explanation of the performance of the aerated circulation purification system relating to each of the above principles:

(1) Light control effect

The deeper the water from the water-surface, the greater the exponential decay of light intensity becomes due to the absorption of light energy by water and light- scattering by suspended particles. The light-reaching range (for phytoplankton production) is generally called the productive layer, and the water depth of 2 to 2.5 times the transparency is empirically regarded as this layer. The productive layer then gives the following approximate values depending upon the degree of eutrophication.

Nutritional state	Transparency (m)	Productive layer (m)
Hypertrophic lake	below 1 m	below 2 m
Eutrophicated lake	1 - 1.5 m	2 - 3 m
Mesotrophic lake	1.5 - 2 m	3 - 4 m
Oligotrophic lake	over 3 m	over 5 m

Thus, in eutrophicated lakes below the 3m-depth lies a layer where no light reaches (aphotic zone); if phytoplanktons circulate in this layer, the average light density will be reduced and restrain them from proliferating. The degree of such proliferation restraint will depend upon the targeted phytoplankton’s light properties (Fig.8-5-2).

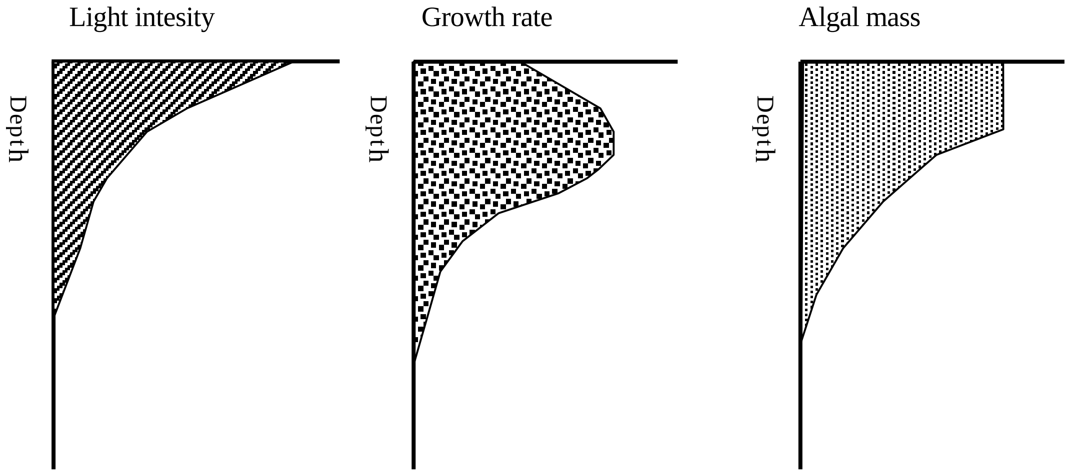


Fig 8-5-2　Relationship between light intensity,growth rate and algal mass

The relationship shown in Fig. 8-5-3 show the following pattern between mixed depths and algal concentrations. Further, Fig. 8-5-4 shows the pattern of relationship between depth and existing quantities shown, and this relationship restrains the proliferation of phytoplanktons by artificially providing greater mixed depth. The methods of giving greater depth are:

1) Aeration pipe (intermittent airlift pipe)
2) Continuous aeration (diffused air aeration)
3) Pump circulation method
4) Surface-layer water circulation method

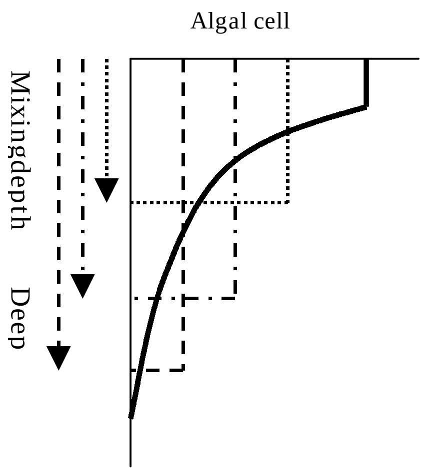


Fig 8-5-3 Mixing depth and algal cell no

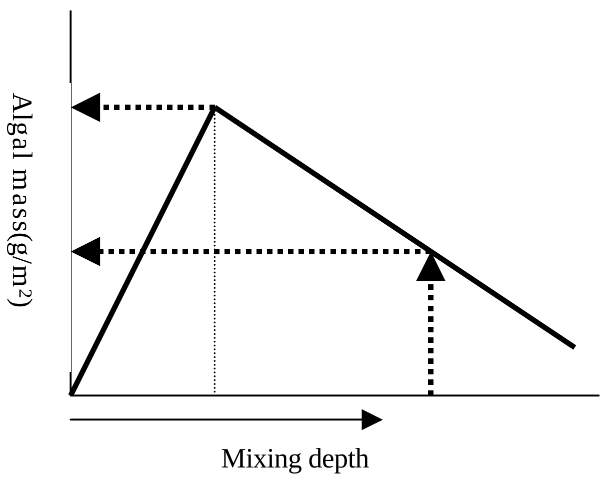


Fig 8-5-4 Mixing depth and Algal Mass

Generally, on lakes or marshes, the surface-layer water mixes at a depth of approximately 3 meters by wind-driven currents or free convection due to diurnal temperature change; therefore, unless the depth is twice this depth or greater than several meters, light-limiting will not be effective in most cases. Restraining phytoplanktons by lake-water circulation therefore will be effectively targeted only to lakes and marshes with a depth of more than several meters.

However, as shown above, the lake-water circulation method is effective not only for light-limiting but also for improving the DO of the bottom-layer water and promoting sedimentation by a vertical circulation current; therefore, it is important to properly design and plan in accordance with the quality of the water, topography and condition of phytoplankton generation in lakes and marshes targeted for improvement.

(2) Dilution effect of surface water

Lake-water circulation causes the dilution of the euphotic surface zone by lower-layer water scarcely populated with phytoplanktons. The depth being the same, the aerated circulation method causes the amount of circulation water to be proportional to the amount of the air sent, or the rated current of the compressor. The following approximate values have been calculated on the amount of circulated water in lakes which use the aeration pipe method:

Capacity per compressor 22 kw amount of pumped water 800,000 m^3/day

(N.B.) Pumped water includes the net pumped amount and hauled amount.

The dilution effect is calculated in the following manner where one aeration pipe is installed per km^2 of the lake area, the epilimnion being 3 m thick:

Dilution effect = amount of aerated circulation／volume of surface water

= (800,000 m^3／day x pipe) ／(1,000,000 m^2 x 3 m)

= 0.26／day

The above result indicates that 26% of the lake-water is changed per day. Supposing that without circulation, the surface-layer water is detained for 1 month on average; dilution will shorten such a detention period to 4 days or less.

(3) Effect of promoting sedimentation

As stated above, lake-water circulation leads to shortening the detention period of the epilimnion; however, as the water itself shifts to the lower layers as vertical circulation currents, even downflow currents are formed. The downflow currents promote sedimentation of suspended solids and the settling of immotile phytoplankton as well.

Similarly to the above example, the sedimentation promotion effect on the installation of one 22 KW aeration pipe per km^2 of the lake area is calculated in the following manner, provided, however, that the net pumped amount is used to calculate the downflow currents. The net pumped amount is 110,000 m^3/day.

Average downflow current speed = (net pumped amount)／(epilimnion)

= 110,000 m^3／day x pipe／1,000,000 m^2

= 0.11 m／day

For relatively slow sedimenting phytoplanktons such as microcystis, this sedimentation promotion effect varies greatly.

8-5-3. Plan and Design of the Aerated Circulation Purification System

(1) Way of thinking about planning and designing

The following six purposes are significant in artificial lake-water purification, corresponding to water features to be improved:

1) Restraining the proliferation of specific harmful phytoplanktons such as blue-green algae
2) Restraining proliferation by internal production (phytoplanktons)
3) Improving water quality stipulated in environmental standards such as COD
4) Improving the DO of bottom-layer water
5) Preventing elution of Mn, NH_4 —N etc.
6) Dilution and dispersion of toxic substances such as microcystins

Aeration pipes are applicable to the solution of all these problems as a concrete counter-measure system; however, as applicable principles vary according to each quality problem, the number of aeration pipes, aeration energy and amount of air that are required will be different.

This manual outlines planning and designing relating to 1), 2) and 4) of which the design method is generally disclosed, together with one design example. The basic planning and designing ideas for each three is described:

a. Restraining proliferation of specific harmful phytoplanktons such as blue-green algae

The following are the design conditions, based on the three principles—light-limiting, improvement of surface-layer water detention period and destratification—that are necessary for restraining proliferation of phytoplanktons that prevent water utilization.

a) Light limiting

Light-limiting conditions serve for designing the amounts of aeration and numbers of aeration pipes to necessary to maintain sufficient mixed depth based upon the relationship between the light intensity and production characteristics of the phytoplanktons (Fig. 8-5-3).

In this case, the necessary design factors are: 1) the number of harmful phytoplanktons to be controlled; 2) the necessary mixed depth; and 3) the amount of aeration to maintain the thermocline at the necessary mixed depth. For this purpose, the relationship between the mixed depth and the existing algal quantity needs to be obtained as shown in Fig. 8-5-4; however, it is usually difficult to clarify such a relationship in actual lakes or impounding dams; further, it is a different matter whether any formula obtained from laboratory experiment data on proliferation is applicable to actual lake conditions.

Therefore, in planning and designing aerated circulation that properly reflects light-limiting effects, planning and designing based on a forecast simulation of an ecological model is necessary.

b) Shortening the detention period of surface-layer water

The epilimnion is the upper part of the thermocline where vertical mixing progresses through free convection mixing caused by wind-driven currents and diurnal changes. This definition is usually applied as it can easily be observed, and also corresponds to the applicable principle.

By diluting the water of this epilimnion area with the lower-layer water, the amount of diluting water required for restraining the speed of proliferation can be calculated.

At normal concentrations of nutritive salts, phytoplanktons need from one week to ten days until they reach their maximum proliferation. Shortening the proliferation time to approximately one-third of this period will restrain their proliferation. The calculation, then, requires the amount of circulation water to be secured at a speed that enables the surface-layer water to be replaced in 2 to 3 days, provided, however that this dilution rate is higher than the speed of proliferation. The proliferation speed varies according to the type of phytoplanktons and the concentrations of the nutritive salts; therefore, the 2 to 3 days required for the dilution serve just as guidelines.

c) Destratification

Destratification is the state in which the temperature stratification is completely destroyed and mixed until the same vertical density is reached. Under conditions where the temperature stratification develops, the water mass with a lower specific gravity is on top of the density causing the center of gravity to be in the lower layer. The destratification is nothing other than increasing the potential energy until the overall density becomes even.
Therefore, injection of energy equal to the changing speed of potential energy by aeration forms the basis of design calculations for destratification.

d) Improving DO of the bottom-layer water

There are two methods to improve DO: dissolving directly oxygen into the water by the air-bubble aeration method, and advecting DO-rich surface-layer water into the lower layer for replenishment. The latter is more energy efficient. Therefore, the below-mentioned design method is described based on this latter method.

To improve the DO of the bottom-layer water, securing water for oxygen supply is the basis of calculation which satisfies the following DO balance formula:

Necessary oxygen amount (O) = oxygen-consuming speed of bottom sludge (R_s)+ oxygen-consuming speed in the water (R_w)

Necessary circulation amount(Q) = necessary oxygen (O)／oxygen concentration of surface layer (C)

In the above formula, the most important design condition is the oxygen-consuming speed of the bottom sludge; in principle this must be obtained by measurement. In some actual lakes, variation in the existing DO that are obtained from values observed in the DO vertical distribution may be given as measured values of oxygen-consuming speed; however, it should be noted that the actual DO variations are the values under rate-determining conditions. Normally, DO variations are diffusion-controlled, and therefore, the oxygen-consuming speed of the bottom sludge, which is regulated by diffusion, may appear to be slower than the real speed. Care should be taken so as not to under-design.

(2) How to calculate for design

Here, the concrete design calculation method is shown based on the ideas mentioned above.

a. Light-limiting effect

Simulation-based design

Fig. 8-5-5 shows the light-limiting effect of the design flow based on an ecological simulation that is capable of handling plural phytoplanktons.

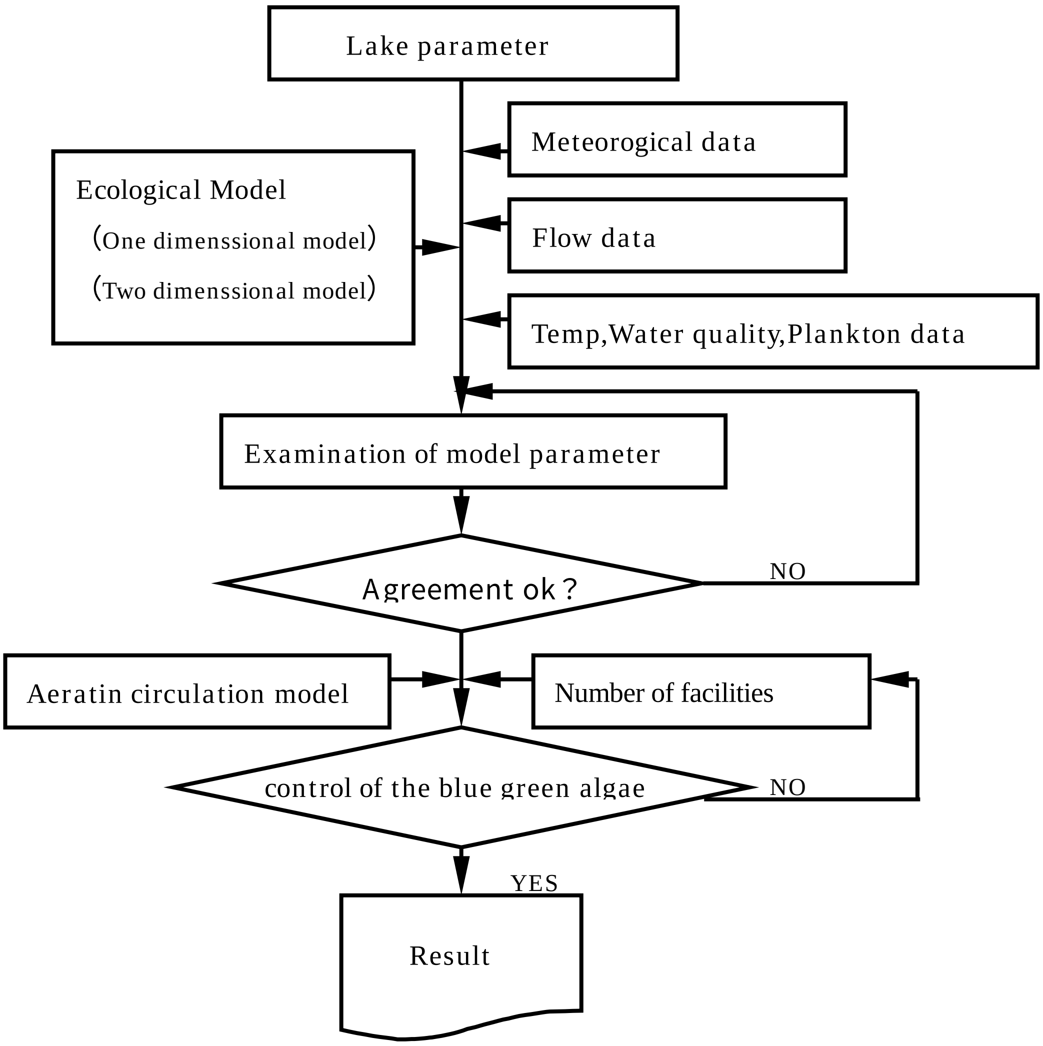


Figure 8-5-5 Optical limitation effect forecast calculation flow by aeration circulation

The formula for the proliferation speed of the ecological model is given by functional formulae on each limiting factor of water temperature, light and nutritive salts as shown below:

proliferation speed = f (water temperature)・f (light)・(nutritive salts)

This formula forecasts the effect that corresponds to 1) variation in light conditions, 2) variation in water temperature, and 3) variation in vertical advection that is caused by aerated circulation and determines the necessary specifications of aeration pipes.

[Design example]

The design of Kamafusa Dam (Tohoku District Development Bureau) is given below as a design example. Kamafusa Dam is a multipurpose dam having an effective pondage of 36 million cubic meters and a maximum depth of 27 meters.

Fig. 8-5-6 shows forecast calculations as of 1985 based on the installation of aeration pipes. The three 22 KW aeration pipes installed (equivalent to 12 single-type pipes) would result in almost completely restraining the Phormidium of blue-green algae. Under this plan, currently aeration pipes equivalent to 9 pipes are installed, and they have been able to restrain generation of “musty odor” almost perfectly except in years of unusual weather. The adequacy of the forecast has actually been verified.

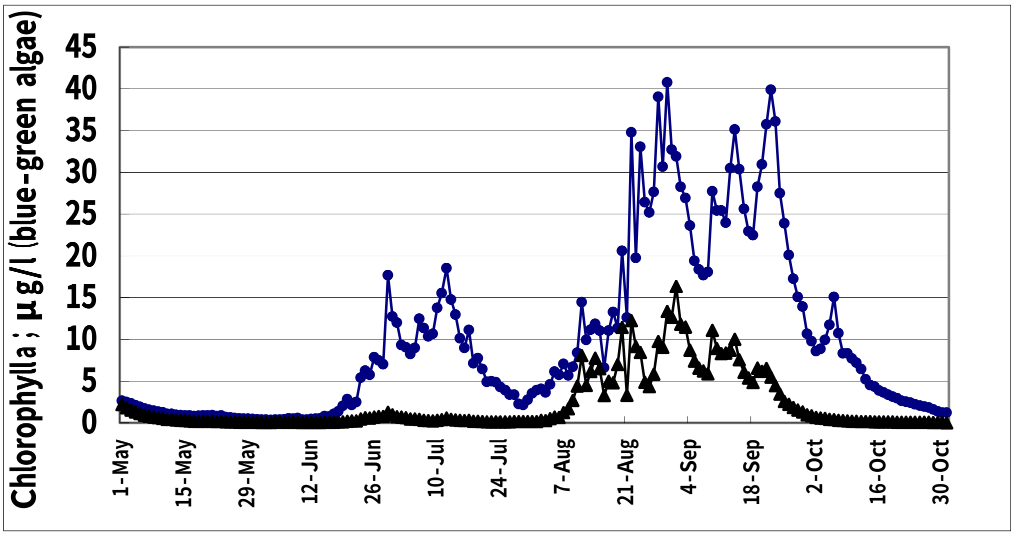


Figure 8-5-6 Effect of control of algae blue-green of aeration circulation of KAMAFUSA dam

b. Design to shorten the water layer detention period

Below are shown design calculation procedures to improve the detention period of the epilimnion.

a) Design variables

- Volume of epilimnion (depth at upper temperature stratification x lake area) ；V
- Set detention period ；T (days)

b) Design specifications

- Single type: output 7.5 KW, aeration pump up capacity；Q=25,000 m^3/day
- Dual type : output 22.5 KW, aeration pump up capacity；Q = 110,000 m^3/day
- Surface-layer water hauling rate ； α = 5 (measured coefficient)

c) Calculation of necessary aeration pipes

From conditions (1) and (2):

Number of necessary aeration pipes (N)

= (amount of epilimnion to be replaced／pump up capacity x (1+ α)

= (V／T) ／(Q x (1 + (1 + α))

d) Design example

Lake Sagami is taken as an example:

○Capacity of epilimnion (V) =lake area (2.58 km^2 x 3 m) = 7.74 x $10^6 m^3$

○Set detention period T = 2 days

○Aeration pipes required

N = (V／T) ／(Q x (1 + α))

7.74 x $10^6 m^3$／(110,000) x (1 + 5))

= 11.7 units 12 units

c. Design to improve DO of the bottom-layer water

For improving the DO of the bottom-layer water, the basis for the design calculations is to secure amounts of water for oxygen supply which satisfy the following DO balance formula:

Necessary oxygen amount (O) = oxygen-consuming speed of bottom sludge (R_S) + under-water oxygen-consuming speed (R_W)

Necessary circulation amount (Q) = necessary oxygen (O)／(oxygen concentration of surface layer C_u - oxygen concentration of lower layer C_d)

An example calculation on a lake having the described oxygen-consuming characteristics below is shown:
[Example]

Assuming that the lake area is 2.58 km^2, the surface-layer water DO(C_u) is 9 mg/1 and the lower-layer water DO(C_d) is zero, the design calculation is as follows:

1) Bottom sludge oxygen-consuming speed (R_S) = 120 mg/m^2 /day

2) Under-water oxygen-consuming speed (R_W) = 25 mg/m^2 /day

3) Necessary oxygen amount (O) = (120 + 25) x 10^{-6} x 2.58 x 10^6 = 374 (kg/day)

4) Necessary circulation amount $Q = O / (C_u - C_d)$

$= 374 \times 1000 / (9-0) = 41,600\ m^3/day$

5) Necessary aeration pipes = 41,600／25,000 2

One thing to be noted here is that the pumped water should be calculated not on the amount of water after hauling, but on the net amount pumped up from below the aeration pipes. The above example, on the assumed scale of Lake Sagami, indicates that 2 single-type pipes will be enough for improving the lower-layer DO.

(3) Installation plan of aeration pipes

There are two required aeration pipe installation plans; a plan for plane arrangement and a plan for the distances between the installed aeration pipes.

a. Plans for plane arrangement

For efficient aerated circulation by aeration pipes, the proper positioning of installation is important. Needless to say, the positioning depends upon what water qualities are to be improved; however, a basic key factor is the principle of the artificial circulation utilizing density current. That is to say, for the efficient generation of horizontal density current, the following are the necessary conditions:

- Pumping up the highest density water
- Causing such water to mix with the lowest density water of the surface layer

The first condition pumps up the highest density or heaviest water to cause a circulation current to be generated in the range that reaches the lowest layer; the latter causes horizontal density current and enables it to replace as much light as possible, and to improve the high-temperature surface-layer water.

Therefore, in principle, aeration pipe arrangement plans should start by installing aeration pipes in the deepest part of the lake or impounding dam; however, flat- bottomed lakes require other reasons for shortening the detention period such as the dissolution of dead water.

b. Distance between pipes installed

Air-bubble jet forced out of the aeration pipe top rises while hauling and mixing with the peripheral water to reach the surface. The area where this turbulence has sufficiently developed is called the “jet area.” When these jet areas overlap, low-temperature water masses mix with each other and are likely to form higher-density water. In these circumstances, these formed masses are lower in temperature than the surrounding water, and submerge to lower layers; no horizontal circulation is caused and energy is lost.

For this reason, the distance between the installed aeration pipes needs to be set at least greater than the diameter of the air-bubble jet areas. As the diameter of these jet areas is between 20 and 30 meters, preferably the pipes are safely separated 50 to 70 meters apart.

8-5-4. Examples of Measures

(1) Examples at Kamafusa impounding dam

Kamafusa Dam is where for the first time in Japan full-scale blue-green algae restraining measures by aeration pipes were applied to a large-scale impounding dam. At this multipurpose dam with a total pondage of 45.3 million cubic meters and a lake surface of 3.7 km^2, in and after 1975, the Phormidium of blue-green algae was producing a musty odor, causing much harm to primary tap water, and therefore required activated carbon to be injected for purification treatment. Based on an applicable principle, aeration pipes were introduced. At present, five 7.5 KW pipes and one 22 KW pipe are at work. The musty odor at the dam is specified as “2MIB.”

Photo 8-5-2 The position of aeration pipesin Kamafusa dam

As shown in Photo 8-5-2, Kamafusa Dam was built along the deepest part of an ex-river course considering the circulation effect. The aerated circulation devices were installed in September 1984, and, as shown in Fig. 8-5-7 after that year Phormidium was drastically reduced and the musty odor “2MIB” decreased to under 5ng/l.

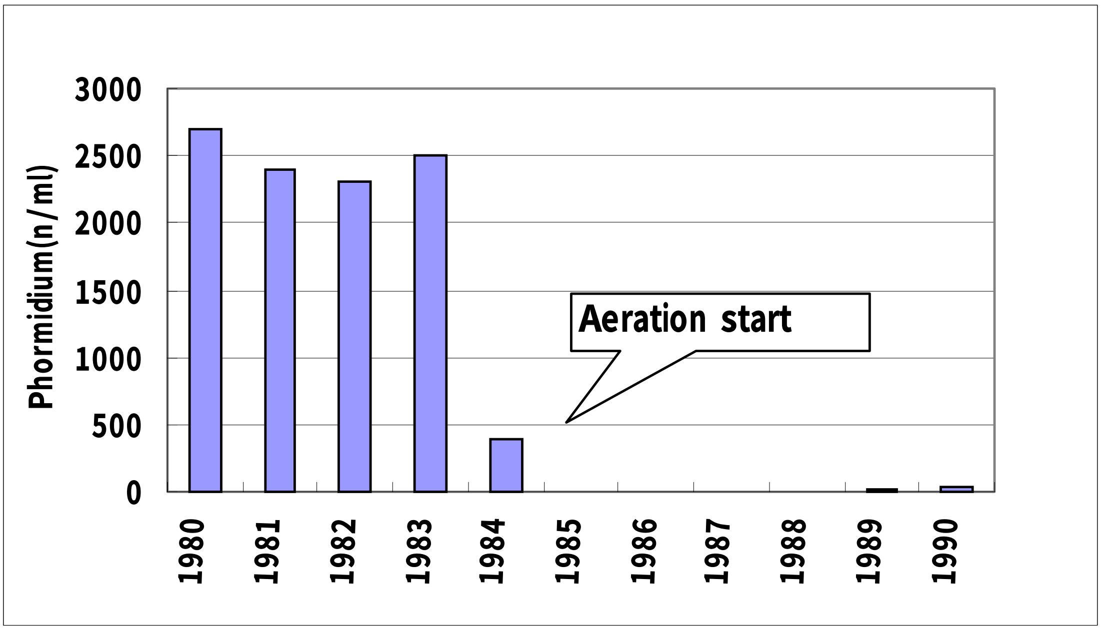


Fig 8-5-7 Effect of *Phormidium* control by aeration circulation in KAMAFUSA Reservoir

(2) Examples of Lake Sagami and Lake Tsukui

The lakes Sagami and Tsukui, with a pondage of 63.2 million cubic meters and 62.3 cubic meters respectively, are multipurpose impounding dams that supply primary tap water and electric power. The two older dams became significantly eutrophic around 1965 as shown in Photo 8-5-3, and every year large amounts of “water-blooms” were generated, urgently requiring implementation of full-scale measures to be. A full-scale investigation started in 1989, and aeration pipes were introduced at Lake Sagami between 1991 and 1993. At Lake Tsukui also, air-blow aerated circulation devices were introduced later in parallel with aerating the upper layers to good effect. The secular changes of microcystis in the peak years are as shown in Fig. 8-5-6. The microcystis drastically decreased due to the installed aeration pipes.

Photo 8-5-3 Water-blooms at Lake Sagami

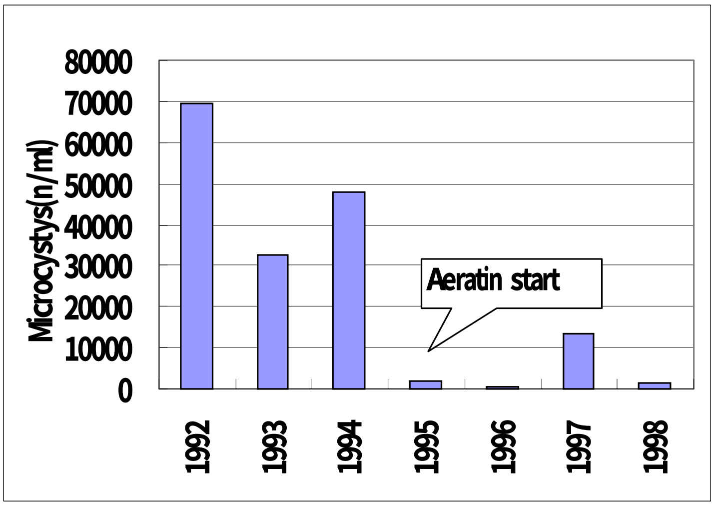


Fig 8-5-8 Effect of *Microcystys* control by aeration in Lake Sagami

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8-6. Lagoon Purification

8-6-1 Principle of the system and its features

The lagoon purification or the oxidation pond process is a treatment method that detains wastewater in a pond, maintains an aerobic condition using the oxygen generated by algal photosynthesis and dissolved from the air, causing bacteria to degrade organic substances contained in the wastewater. Due to its low construction and maintenance costs and very easy control, this lagoon process is widely used overseas for treating domestic sewage and industrial wastewater of various sorts; however, it requires a large space due to its long detention period, often gives rise to mosquitoes and odors but requires only a little rainfall. These are few examples put to use in Japan. This process consists of the facultative pond process or the high rate lagoon process, of which usually the former is used. The facultative pond has an effective depth of 1.5 to 1.8 meters, and usually operates at a depth between 0.9 and 1.2 meters. As photosynthesis does not take place deeper than 0.9 meters, a shallow pond is more effective. However, if the pond is too shallow, aquatic plants are likely to flourish, and in summertime, the temperature may rise too high; therefore, it should be at least 0.7 meters deep. The pond bottom is preferably made of the soil not easily permeated by water. The lagoon purification causes bacteria to decompose organic substances utilizing the oxygen generated by photosynthesis; therefore, bacteria and algae are directly involved in purification. In the pond, bacteria and algae are coexistent (Fig. 8-6-1).

Table 8-6-1 Types of oxidation pond

	Water depth(m)	Detention period(d)	BOD load ($g/m^2/d$)
Facultative pond	0.7 ~ 1.5	10 ~ 50	2 ~ 6
High-rate pond	0.2 ~ 0.3	2 ~ 6	10 ~ 30

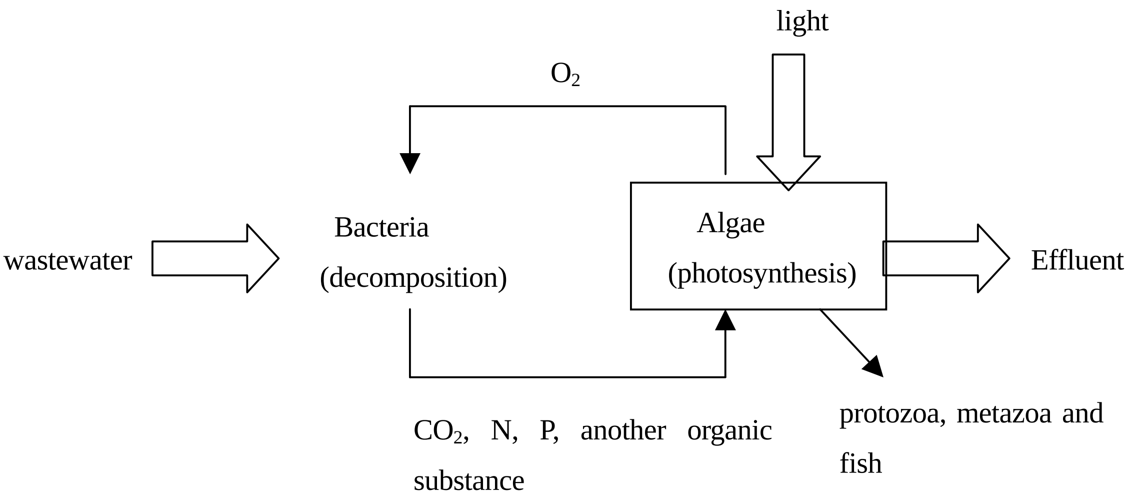

Fig. 8-6-1 Co-existence of bacteria and algae in lagoon

The bacteria decompose organic substances contained in the inflowing water using the oxygen produced by algae. Thus, produced inorganic substances serve as nutrients for the algae. Produced algae serve as food for protozoans, metazoans and fish. Purification efficiency in the pond improves significantly if the algae are collected; therefore, coagulating sedimentation or floatation in the outflowing water to remove algae will greatly improve the quality of the treated water. Multistage treatment having three or more ponds connected in a series provides discharged water with a low algal concentration if it allows fish to proliferate in the last pond. Proliferating fish are taken out of the pond from time to time. The algae that appear frequently in the ponds are green algae such as *Chrolella, Chlamydomonas* and *Scenedesmu*s and blue-green algae such as *Oscillatoria* and *Phormidium.* Likewise appear protozoans: they are *Flagellata* such as *Bodo* and *Oikomonas, Ciliata* such as *Cyclidium* and *Vorticella*. Metazoans are also reported to appear: they are *Rotifera* such as *Brachionus, Keratella, Colurella, Lepadella* and *Lecane or Cladocera* such as *Moina, Daphnia* and *Alona.* These protozoans and metazoans play a role in capturing, consuming and removing bacteria and algae; and further serve as food for fish.

8-6-2 Performance of the System

The most important manipulating factor in the lagoon process is the BOD load. The facultative pond is operated at a BOD load of 2 to 6g/m^2/d and the high-rate lagoon at a BOD load of 10 to 30g/m^2/d. Plural ponds are connected in a series to enhance the removal rate of proliferated bacteria and algae and obtain good-quality treated water. As the oxygen produced by photosynthesis is greater than the oxygen transferred from the water surface, sufficient algal proliferation is required to maintain an aerobic condition. When oxygen production is deficient in wintertime, artificial aeration is performed. The oxygen production at the oxidation pond is 0 to 0.6 g O_2/m^2/h with an approximate respiration speed of 0.1 to 0.23 g O_2 /m^2/h. At the pond, the dissolved oxygen is subject to heavy fluctuations that are at the highest in the afternoon and the lowest in the early morning. The BOD removal rate is heavily dependent upon temperature, being high in summertime and low in

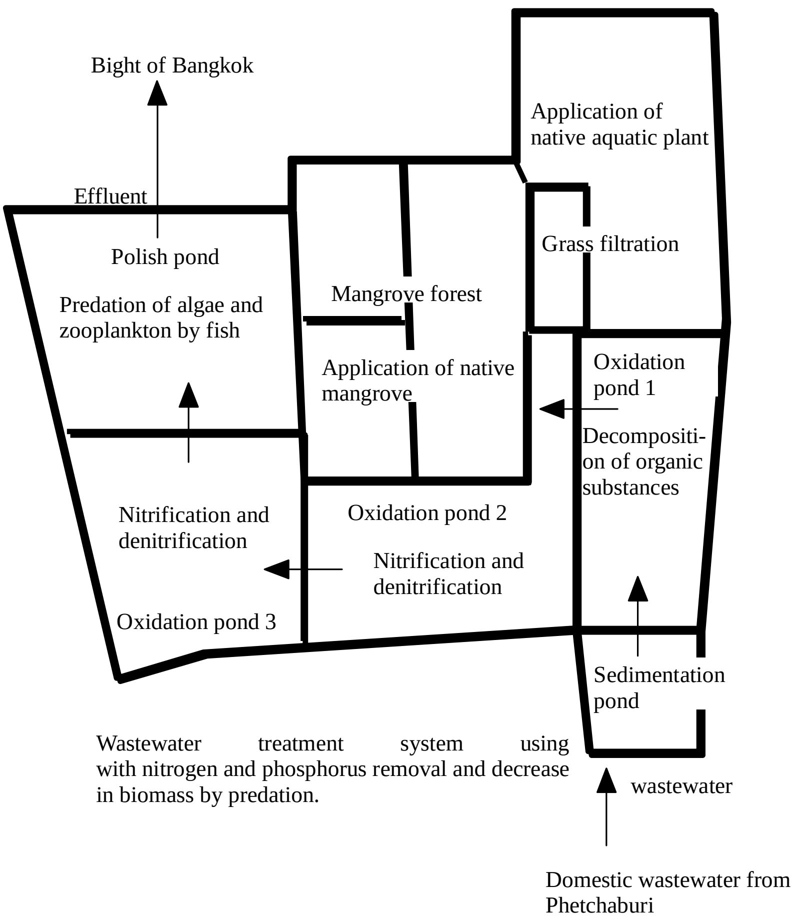

Fig.8-6-2Wastewater treatment facility constructed at Phetchaburi for the King's wintertime. The annual average removal rate is mostly around 80% and in summertime it may reach 98%.

Tropical regions such as Thailand have a temperate climate throughout the year and have vast land available in provincial cities so the lagoon process is regarded effective. The results of an investigation conducted at an oxidation pond at work in Phetchaburi, Thailand, are given below. The treatment flow at the facilities is shown in Fig. 8-6-2 and the capacity and depth of each pond in Table 8-6-2. The facilities are constructed with a designed gray water capacity of 10,000 m^3/day and a BOD of 200 mg/l; however, the actual amount of gray water (average) that inflowed each day was 1731 m^3/day while the inflowing water contained a BOD of 200 mg/l, a T-N of 22 mg/l and a T-P of 3.77 mg/l. The water quality at the outlet of each pond is as shown in Table 8-6-3.

Table 8-6-2 The volumes and depths of each lagoon constructed at Phetchaburi for the King's project

	Depth (m)	Area (m^2)	Volume (m^3)
Sedimentation pond	2.3	10217	23499
Oxidation pond 1	2	30408	60816
Oxidation pond 2	1.9	34898	66306
Oxidation pond 3	1.8	35424	63763
Polish pond	1.7	43132	73324

Table8-6-3 Treatment characteristics of lagoon constructed at Phetchaburi for the King's project

	BOD	T-N	T-P
Wastewater	145	22.0	3.77
Sedimentation pomd	45	19.5	3.48
Oxidation pond 1	31	11.8	3.09
Oxidation pond 2	21	7.5	1.37
Oxidation pond 3	12	6.8	0.71
Polish pond	14	6.1	0.51
Removal（%）	90	72	86

A system that utilizes ecoengineering which removes nitrogen and phosphorous and reduces biomasses through food chains. The overall removal rate obtained from the water qualities in the final pond is 90% of BOD, 72% of T-N and 86% of T-P. These reveal excellent treatment ability. The BOD removal rate at the sedimentation pond was calculated as 16.9g/m^2/d, which shows a removal rate three times higher than the rate so far reported in the oxidation pond. It shows how organisms are active and how the system is suitable for tropical regions. A great variety of algae, protozoans and metazoans are observed in the oxidation ponds. It is presumed that the food chains composed of these organisms have been so active that such high removal rates are possible. The microalgae that appeared at the facilities are 19 genera and 22 species (Table 8-6-4).

Especially biota peculiar to oxidation ponds such as *Pandorina morum, Eudorina elegans* and *Phacus caudatu*s were observed. Also observed were 10 genera and 10 species of microanimals: they are *protozoans ciliatas Vorticella sp., Paramecium sp., Zoothanium sp., Acineta sp.; protozoans Flagellatas Ocicomonas sp.; metazoans Flagellata Brachionus sp., Keratella sp, Philodina sp., Cephalodella sp.* and *metazoans Crustacea Cyclops sp.* It is inferred that these microanimals function as high-level predators, promote minimalization of organic substances and enable stable and highly activated purification. Photo 8-6-1 shows how residential wastewater is treated at an oxidation pond at Petchaburi.

Table 8-6-4 Algae observed in lagoon constructed at Phetchaburi for the King's project

Cyanobacteria	
Oscillatoria sp.	*Anabaenopsis* sp.
Merismopedia punctata	
Green algae	
Coelastrum microporum	*Scenedesmus acuminatus*
Chlorella sp.	*Scenedesmus quadricauda*
Pandorina morum	*Tetraedron trigonum*
Ankistrodesmus falcatus	*Pediastrum duplex*
Eudorina elegans	*Botryococcus braunii*
Phacus caudatus	*Chroococcum* sp.
Scenedesmus sp.	*Tetraedron minimum*
Scenedesmus bicaudatus	*Golenkinia radiata*
Diatoms	
Navicula sp.	

Photo 8-6-1 An oxidation pond at Petchaburi

8-6-3 Ripple Effect of the System

In developing countries including Thailand pollution of water areas is becoming apparent because of wastewater deriving from activated industries and population increase. Rivers, lakes, marsh and reservoirs located in densely populated areas have been suffering heavy pollution. Residential wastewater is great majority of pollutant load, which indicates serious sanitary problems. Lakes and marsh that play an important part as drinking water supply sources are also becoming increasingly eutrophic. Water-blooms that contain microcystin, in the WHO (World Health Organization) guideline items on drinking water, have unusually been proliferating. Therefore, establishing and reinforcing counter-measures against toxic water-blooms is very important position for the remediation of water environments in every country including developing countries. However, measures against eutrophication that fit the conditions of each country are delayed, including those applicable to pollution sources and direct purification. The lagoon process utilizes solar energy and no motorized power, and is energy- and cost-saving and highly practicable. The process further enables fishing the fish that proliferate in the pond, and thus changes residential wastewater into fish-producing water. Instituting the lagoon process and building the basis for its diffusion will be of great effect in water reservoir areas in developing countries where improvement of water qualities is very necessary.

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8-7 Submerged Plant-based Purification

8-7-1 Principle of the system and its features

The aquatic plant-based purification method positively utilizes aquatic plants for purification. Included in this aquatic plant-based purification are principally the method that utilizes emerging plants such as reeds, water rice and *Typha angustada,* and the method that utilizes free-floating plants such as water hyacinths and duckweed. The submerged plant-based purification method here presented is features the utilization of submerged plants, not widely-used emerging or free-floating plants, for direct purification of water areas. In some cases, according to the particularities of the water area to which the method is applied, floating-leaved plants are used in combination with submerged plants. The definition "submerged plants" applies collectively to plants that unfold their leaves and photosynthesize under water; it is not a taxonomic definition. The submerged plants unfold their leaves usually only under water; however, some of them stand above water surface and develop air leaves. Among the submerged plants most popularly known are members of *Hydrocharis asiatica* such as *Vallisneria asiatoca, Hydrilla verticillata* and *Ottelia alismoides*, and members of *Potamogeton distinctus* such as *Potamogeton malaianus, Potamogeton crispu, Potamogeton oxyphyllus* and *Potamogeton maackianus.* The floating-leaved plants that are widely used in combination with these plants are *Potamogeton distinctus, Nymphoides peltata, Nuphar japonicum* and *Trapa japonica.*

The principal members of submerged plants are given in Table 8-7-1, and the members of the floating-leaved plants used in combination, in Table 8-7-2. Some of the submerged plants such as *Potamogeton malaianus* can subsist, even in an environment where water has dried up showing the bottom sediment, by stretching air leaves. Attention should be paid as the forms of under-water leaves and air leaves are significantly different. The submerged plant-based purification method has a basic principle of causing plants to absorb nutritive salts and likewise microorganisms such as organisms attached to the plant surface to effect purification, in just the same way as purification by utilizing emerging plants or free-floating plants. Some of the features of using submerged plants is that although artificially planted, they do not flourish above surface and present no notable difference to the landscape; they provide greater surface area than emerging plants; they contribute habitats, as submerged structures, to large crustaceans such as water fleas and small fish; and they are not moved by wind or waves as are free-floating plants.

Table 8-7-1 Submerged plants utilizable for submerged plant-based purification

Family	Japanese vernacular name	Nomenclature
Isoetaceae	mizunira	*Isoetes japonica*
Hydrocharitaceae	yanagisubuta	*Blyxa japonica*
	ookanadamo	*Egeria densa*
	kokanadamo	*Elodea nuttallii*
	kuromo	*Hydrilla verticillata*
	mizuoobako	*Ottelia alismoides*
	kougaimo	*Vallisneria denseserrulata*
	sekishoumo	*Vallisneria asoatoka*
Potamogetonaceae	sasabamo	*Potamogeton malaianus*
	ebimo	*Potamogeton crispu*
	sennninmo	*Potamogeton maackianus*
	yanagimo	*Potamogeton oxyphyllus*
	itomo	*Potamogeton pusillus*
	ryuunohigemo	*Potamogeton pectinatus*
Najadaceae	ibaramo	*Najas marina*
	torigemo	*Najas minor*
	hossumo	*Najas graminea*
Ranunculaceae	baikamo	*Ranunculus nipponicus var.*
Ceratophyllaceae	matumo	*submerses*
Droseraceae	mujinamo	*Ceratophyllum demersum*
Haloragaceae	hozakinofusamo	*Aldrovanda vesiculosa*
	fusamo	*Myriophyllum spicatum*
	tachimo	*Myriophyllum verticillatum*
	suginamo	*Myriophyllum ussuriense*
Hippuridaceae	kikumo	*Hippuris vulgaris*

Lentibulariaceae *	tanukimo	*Limnophila sessiliflora*
Characeae	shajikumo	*Utricularia vulgaris*
Nitellaceae	hurasukomo	*Chara braunii*
		Nitella japonica

* Although a free-floating plant, it often sticks to the bottom sediment; close to a submerged plant.

Table 8-7-2 Floating-leaved plant used in combination with submerged plants for submerged plant-based purification

Family	Japanese vernacular name	Nomenclature
Potamogetonaceae	ohirumusiro	*Potamogeton natansa*
	hutohirumusiro	*Potamogeton fryeri*
	hirumusiro	*Potamogeton distinctus*
Menyanthaceae	asaza	*Nymphoides peltata*
	kagabuta	*Nymphoides indica*
Trapaceae	hishi	*Trapa japonica*
	onibishi	*Trapa natans var. japonica*
	himebishi	*Trapa incisa*
Onagraceae	mizukinbai	*Ludwigia peploides*
Nymphaeaceae	kouhone	*Nuphar japonicum*
	himekouhone	*Nuphar subintegerrimum*
	junsai	*Brasenia scherberi*
	onibasu	*Eurya ferox*
Nelumbonaceae	hitujigusa	*Nymphaea tetragona*
Marsileaceae	hasu	*Nelumbo nucifera*
	tenjisou	*Marsilea quadrifolia*

8-7-2 Performance of the System

One of the features of the submerged plant-based purification is the great improvement in transparency. Photo 8-7-1 shows a landscape at the lake Xuan Wu Hu, Nanjing City, Province of Jiangsu, China where submerged plant-based purification is in a demonstration test. In a water area enclosed by liner sheets, submerged plants such as *Egeria densa* and *Myriophyllum spicatum*, and floating-leaved plants such as water chestnuts are cultivated. It is clearly seen that transparency is 20 cm in the targeted water area while it is 80 cm where submerged plants are cultivated.

Contributing to maintaining high transparency are attached organisms such as *Vorticellae* that are attached to roots and stalks of aquatic plants, and free-floating organisms such as water fleas that inhabit the habitats created by leaves and stalks. Photo 8-7-2 shows magnified sections where the submerged plant *Myriophyllum spicatum* grows in the

Photo 8-7-1 Landscape of submerged plant-basedpurification test (China)

Photo 8-7-2 Cultivated submerged plant and attached biomembrane

submerged plant-based purification area. Attached organisms (periphyton) are observed to from around leaves. These periphytons are composed of attached protozoans such as *Vorticellae, Stentors* and *Suctorias;* attached *Rotifera* such as *Melicertoida* and attached diatoms. They feel slimy to the touch. They are the same kind as those formed on the surfaces of submerged pebbles or wooden stakes. Also, the stalks of submerged plants and floating-leaved plants that are present under water form new niches. In these habitats, filter-feeding floating organisms (planktons) such as water fleas and *Rotifera* exist in large numbers seeking escape from plankton eaters. Due to their predatory activity, free-floating plants are filtered and high transparency is achieved.

Fig. 8-7-1 shows the relationship between existing amounts of plankton and transparency. The figure indicates that the area that is densely inhabited by filter-feeding plankton such as water fleas, high transparency is achieved. Fig. 8-7-2 indicates the relationship between the existing quantity of periphytons and plankton. It shows the close relationship between the number of existing plankton and that of existing periphytons. In other words, the figure indicates that in the water areas where aquatic plants live, they play an important role in physical structure. Free-floating plants that

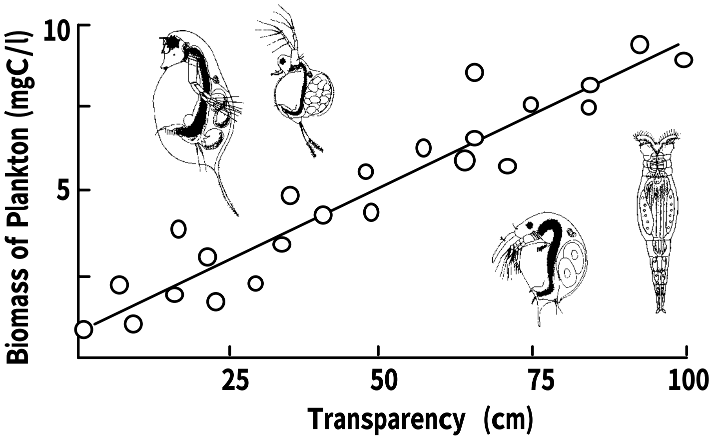

Fig 8-7-1 Relationship between existing quantity of plankton and transparency

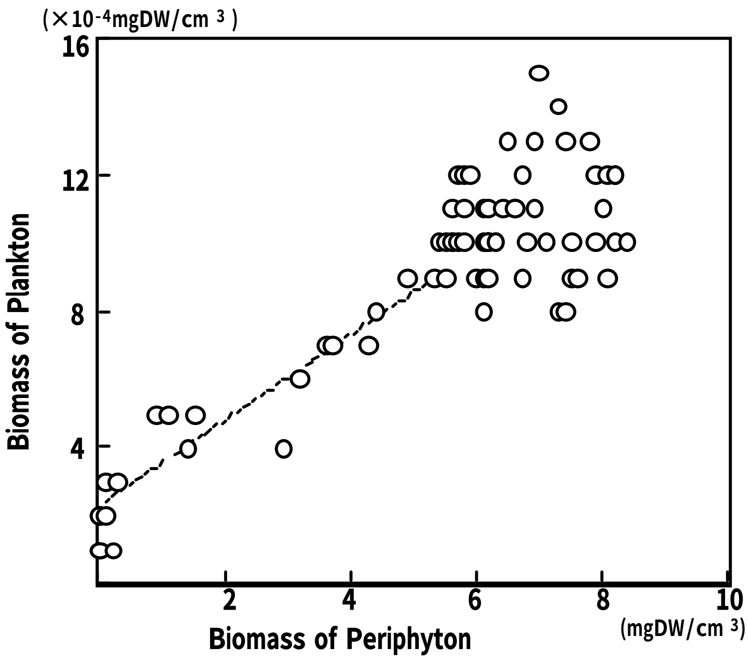

Fig.8-7-2 Relationship between existing quantity of plankton and of periphyton

contribute to water purification are free-floating microalgae such as blue-green algae and green-algae and flocks composed of bacteria and fungi. Algae absorb dissolved nitrogen and phosphorous and proliferate. The high activity of periphytons and plankton that eat the algae means that soluble inorganic nutritive salts are shifting from microalgae to periphytons and plankton. Also, in the submerged plant-based purification system, snails such as *Radix japonicus* and *Physidae* that eat periphyton and planktons, and large crustaceans such as shrimps and young fish coexist; further, *Amphibia* such as tadpoles and dragonfly nymphs, aquatic insects that eat these microanimals, birds such as ducks and herons and large-size carnivorous fish, are all involved in building a system which removes pollutants from the water area to the outside system through ecological food chains.

The submerged plants that play the leading part in this system have difficulty growing in an environment which lacks a sufficient amount of light for photosynthesis; therefore, they cannot be well utilized eutrophically in a significant way, and therefore contribute little to water transparency. This limits their use. Nevertheless, Photo 8-7-3 shows a submerged plant that has successfully adapted itself to a given environment as have *Potamogeton malaianus* in the lake Tai Hu in China; even in such a poor transparency conditions, the plant can grow its stalk more than five meters long to unfold its leaves on the water surface to photosynthesize. At lake Tai Hu, such plant communities are present in patches, and it has been confirmed that each of them functions as an ideal habitat for protozoans, *Rotifera*, water fleas, shell-fish, aquatic insects and young fish. The water purification characteristics of this system can be divided into the absorption and removal of inorganic nutritive salts by growing the submerged plants themselves, and the part played by aquatic plants as under-water physical structures. Fig. 8-7-3 shows results of a small-scale experiment using a hydrosphere where string-like contact materials were used as dummy submerged plants that neither absorb nor remove inorganic nutritive salts. The results show that in the hydrosphere where aquatic plants are present, the concentrations of organic substances and inorganic nutritive salts decreases by approximately 20% more in an experiment with no fish, and 30% more with an ecosystem involving fish than in the world with dummy submerged plants. The results suggest that, apart from the absorbing effect of aquatic plants themselves, the plants creates

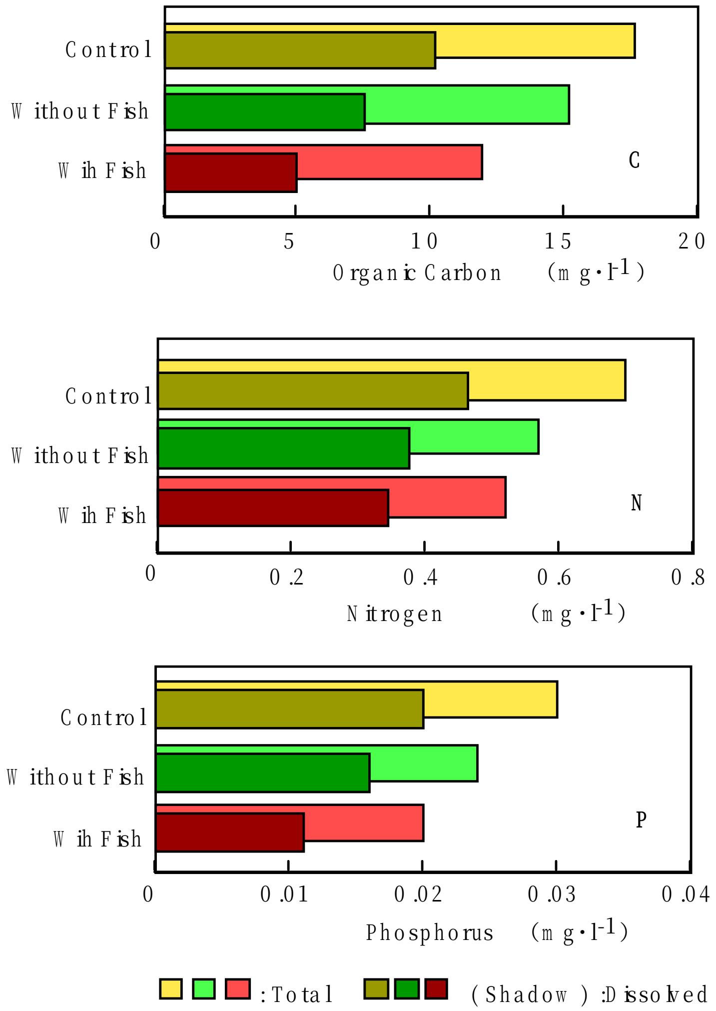

Fig.8-7-3 Comparison of water purification abilities in case of packed with artificial submergent

habitats allowing various animals to exist in larger quantities and that they greatly purify the water in a complex manner. In the actual submerged plant-based purification, a complex food web is formed by various organisms such as shell-fish, large fish, amphibians, reptiles, insects and birds besides small fish used in this experiment, and they keep the ecosystem stable. Once a stable ecosystem has been built, it has a buffering effect against environmental change and exercises its low-cost, sustainable water-purifying quality.

Photo 8-7-3 *Potamogeton malaianus* stretching stalks up to surface in search of light

8-7-3 Method of Applying the System

There are many types of submerged plants. Some, like *Potamogeton malaianus*, flourish in summer and die in winter; some, like *Potamogetn crispu*, flourish in winter to die in summer; and some, like *Egeria densa*, flourish throughout the year. The type that flourishes all through the year is easier to apply; however, there are types that let their leaves or stalks die when the season comes, yet form turions and store nutrients in their underground stalks; they allow nutritive salts to elute at a limited rate even when their leaves and stalks die. The most important thing in applying submerged plant-based purification is to understand the properties of the plant to be selected and select plants suitable to the water area.

Evidently, in applying this submerged-plant purification, plants will have difficulty growing if planted directly where their growth is difficult. It is necessary to choose adaptable plants from the native species of the same water area, and give them preliminary breeding, or the so-called “culture for adaptation” to the water environment. In this adaptation work, an important point is not to cultivate or reproduce control plants taken from distant places even though they belong to the same species. It is important to culture the stumps of the species growing native in the subject water area, cultivate, reproduce and divide them, and then plant them as regional genetic information of the species should be respected; the regional particularities are an important property. Yet, settling aquatic plants in a water area that has extremely poor transparency is a difficult task. In such a case, the purpose may be accomplished by using auxiliary contact materials. Photo 8-7-4 shows a string-like contact material that is placed in places difficult for cultivating submerged plants; the materials work as dummy submerged plants in such places. The material is made of braids of fine polypropylene plastic yarn woven into rings and is quite strong. The photographed material is 6 cm in diameter.

Photo 8-7-4 String-like contact materials utilizable as dummy submerged plants

Contact materials have been developed in a wide variety of materials, diameters and structures. During the period following the planting, submerged plants are subject to damage from various organisms such as crayfish and the tadpoles of bullfrogs; therefore, a method has been designed to protect the plants from enemies by weaving a float into the braids or placing string-like contact materials having a float in the upper part as dummy submerged plants and planting real plants between them; thus, the plants will be protected from enemies at the initial stage of planting. Another idea being studied is building string-like contact materials of biodegradable plastic as dummy submerged plants, which decays of itself to disappear after protecting the submerged plant in its initial stage, and shifts in a natural way to the community of planted submerged plants.

When this system is applied in deep water, dangling string-like contact materials from an artificial floating island is also being tried as an irregular application. This method does not use submerged plants; however, it makes the structure invisible above the water by positioning a floating island, which dangles string-like contact materials, under water fixed with an anchor; by broad definition, this is regarded as submerged plant-based purification. Photo 8-7-5 shows an assembled artificial module with dangling string-like contact materials. Anchoring this module under water and connecting plural modules will create new niches under water. A defect of this irregular use is that it does not cause plants to absorb and remove inorganic nutritive salts. However, it has been confirmed that conferva such as pond scum has adapted to flourish in the upper part of the water near the floating island; it causes water birds such as coots that selectively eat conferva to fly over and greatly contribute to removing inorganic nutritive salts from the ecosystem.


Photo 8-7-5 Artificial floating island utilizing string-like contact materials as dummy submerged plants

The mass balance attributable to water-purifying characteristics of the submerged plant-based purification, confirmed so far, varies according to the scale or type of the composed ecosystem. However, generally, the amount of pollutants absorbed and removed by plants and the amount removed by the work of animals are almost equal. The water-purifying characteristics of the submerged plant-based system are shown in Fig. 8-7-4.

In other words, the submerged plant-based purification system uses to the utmost the ecological food web and causes a great variety of animals to participate in it. For instance: (1) the bottom sediment is oxidized by rootstalks of the submerged plants enabling freshwater clams to settle; clams eat phytoplanktons, which decrease in quantity causing the transparency to improve. (2) submerged plant communities protect young fish from their carnivorous predators and contribute to maintaining the existing quantity of small-size plankton-eating fish. It enables the phytoplankton→zooplankton→ plankton-eating small-size fish→carnivorous fish food chain to operate. (3) the system attracts aquatic insects such as dragonfly nymphs nymph and giant water bugs that eat small fish fly and settle down. The emergence and flight of the insects builds a system of removal toward the outside, which operates as follows: phytoplankton → zooplankton → small-size plankton-eating fish → carnivorous aquatic insect → emergence to the outside system. (4) tadpoles inhabit the system, eat plankton and detritus, and when grown up they move to the land; thus building a system of removal toward the outside. (5) plankton-eating fish increase in quantity and cause plankton and periphytons to renew earlier, be more active in proliferation, and thus increase their ability to purify. (6) organisms such as shrimps, fish and shell-fish that serve for fishery increase in their existing numbers; fishing professionally, humans are positioned on top of this ecosystem. Thus, the cycle of the continuous pollutant-removing system is promoted. Through all these routes, it is clear that dissolved organic substances and inorganic nutritive salts are removed from the system.

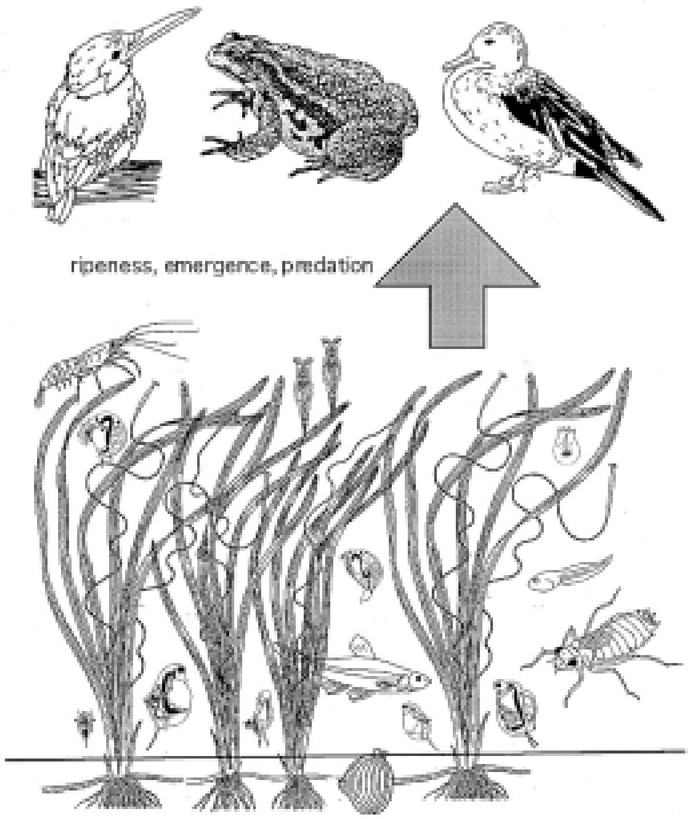

Fig.8-7-4 Total effects of ecosystem created with submergent

Thus, a submerged plant-based purification method utilizes the ecosystem to the maximum, producing no significant changes in the landscape; further, it is a low-cost, easy-to-maintain environmental ecological engineering method. Though the system is applicable to limited water areas, these defects will be corrected over numerous applications. The system will then be given increasing attention.

8-8 Resident-Participation Measures relating to the Kitchen

8-8-1 Principle and features

In public water areas suffering from water pollution, the main pollutants mostly derive from residential wastewater. So the real problem is lack of awareness of the problem on the part of residents responsible. It is necessary, more than anything, that each resident make an effort not to discharge polluted water.

In our country, the quality of water in rivers, lakes and marsh and sea areas have shown some improvement due to regulations on plant effluents, etc.; however, the environmental standards (living environment items) have accomplished no more than 70%. Approximately 50% of the pollutants flowing into these water areas derive from untreated discharged gray water; therefore, reducing the gray water load is essential in improving water quality in public water areas. Gray water is residential wastewater excluding human waste, from kitchens, laundries, bathrooms and so forth, and the greater part of the pollutant load comes from wastewater from kitchen cooking (Fig.8-8-1).

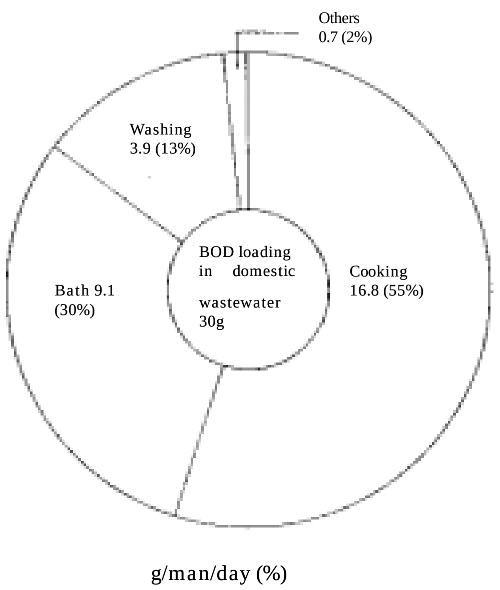

Fig.1 Ingredient ratio of domestic wastewater

The primary units of load from household wastewater, or the amount of pollutants discharged per person per day, were calculated from past measurements as follows: BOD that indicates pollution by organic substances is 27g/person/day; of total nitrogen and phosphorous responsible for eutrophication and contained in nutritive salts are 1.3 g/person/day for T-N and 0.3 g/person/day for T-P. Nitrogen and phosphorous, especially, have a particular situation. In closed water areas, algae proliferate; then internal algal reproduction increases COD in the hydrosphere. Therefore, even if inflowing COD is reduced, the situation results in progressive pollution. In view of this, not to mention the reduction of organic substances, it becomes essential that treatment facilities be diffused for the treatment of gray water from individual households that is currently discharged untreated and for wastewater treated without removing nitrogen and phosphorous. At the same time, measures aimed at reducing loads imposed by kitchens are particularly important. Such measures will help to reduce residential pollutants that are currently discharged untreated, as well as pollutant loads on the treatment facilities. In this section, measures taken against kitchen wastewater and the effects of these measures based upon experimental study are explained.

8-8-2 Effect of Reducing Pollutant Loads by anti-Kitchen Waste Measures

Table 8-8-1 shows pollutant load calculated of BOD, nitrogen and phosphorous on the basis of primary units and each respective condition: the load on the total amount of wastewater obtained after washing pre-boiled rice of 720 ml four times using water of 4500 ml in total and the load on the first time washing water; , on the total wastewater after boiling spaghetti and noodles and buckwheat noodles using hot water of 1,000 ml per person; regarding Chinese noodles and Japanese hotchpotch, on the wastewater equivalent to a glass of soup (180 ml) each; and regarding old cooking oil, on a spoonful (15 ml) of the oil remaining in the pan in the form of slurry.

Table 8-8-1 Pollutant load generated by Cooking

Specimen	BOD concentration (mg/l)	Nitrogen concent. (mg/l)	Phospho. concent. (mg/l)	Discharge Amount (ml)	BOD (g)	Nitrog (mg)	Phospho (mg)
Rice washing w.	2,400	29	7.8	4,500	10.8	130	35
(First washing)	11,100	111	32	700	7.8	78	22
Spaghetti	5,400	55	17	1,000	5.4	55	17
Noodles	1,030	22	6.3	1,000	1.0	22	6.3
Fish (unprepared)	1,300	60	13	2,000	2.6	120	26
Chinese noodle	26,000	1,180	290	180	4.7	210	52
Soy bean soup	37,000	—	—	180	6.7	—	—
Corn cream soup	126,000	1,300	210	180	22.7	230	38
Hotchpotch	95,000	4,200	970	180	17.1	760	175
Soup stock	1,730	210	82	180	0.3	38	15
Pumpkin soup	87,000	5,200	830	15	1.3	78	12.5
Potato & beef	52,000	—	—	15	0.8	—	—
Meat sauce	150,000	2,400	370	15	2.3	36	5.6
Old oil	1,670,000	1,400	30	15	25.0	21	0.5
Detergent (liq)	200,000	3,200	10	7.5	1.5	24	0.1

Noodle boiling water: 1000 m/l to boil each of spaghetti 100 g, noodles 250 g & buckwheat noodles 170 g

Fish preparation: 1medium-size horse mackerel

Discharged water measuring guide: a glassful (180 ml), a spoonful (15 ml)

The Environment Agency made the proposal shown in Table 8-8-2 as -kitchen waste measures that can be put into practice in each household. Of these proposed pollutant-reducing measures, the initial wiping effect and the use of a triangular corner were reviewed.

Measured figures indicate that oil, sauce, mayonnaise and dressing attached to used crockery and utensils have very high primary pollutant load values, and therefore, wiping utensils and dishes will greatly help reduce the load. Table 8-8-3 shows how much the load is reduced by wiping. It shows that the detergent used to wash cooking utensils after they are wiped using a rubber spatula and paper have a load reduced from 1/3 to 1/6 of BOD and from ½ to 1/3 of nitrogen.

Table 8-2-2 In-kitchen pollutant load reducing measures

a) Measures in the kitchen 1) Control cooking refuse. ・ Cook just enough, have no leftovers. ・ Use triangular corner + filter paper to collect food left over. ・ Use fine strainers to collect solids and food left over. ・ Do not dump rice washing water; spray it on plants and in the garden. ・ Wipe sauce, mayonnaise, dressing, etc. left on the dishes after each meal with kitchen paper; then wash them. ・ Do not dump soy bean soup or soup stock. ・ Do not dump beer or other alcohol. 2) Properly dispose of used oil ・ Use up cooking oil each time you cook. ・ When dumping used oil, don't dump it as it is. Use a commercial oil solidifier or absorb it with newspaper. ・ Wipe used oil attached to the frying pan, then wash it. 3) Properly dispose of collected materials ・ Frequently collect cookery refuse or leftovers in a triangular corner, dump it or bury it underground. b) Laundry Use the proper amount and type of detergent. c) Bath Use used water for laundry or other things.

Table 8-8-3 Pollutant load reduction by taking in-kitchen measures

Menu	Things washed	How wiped	Water ( )	Amount of pollution			
				SS	BOD	T-N	T-P
Hamburger French potato Seafood salad White stew Boiled rice	Large dish (4 + 1) Medium dish (4), Soup dish(4), Large spoon, Frying pan, Rice bowl Chopsticks, Pan (soup), Bowl, Rice cooker	Wipe dish and pan with rubber spatula, then wash	25	6.3	0.3	0.25	0.048
		Washed without wiping	35	11.2	1.8	0.81	0.158
Pork cutlet Cabbage Boiled seaweed Taro and radish soup Boiled rice	Dish (4) Rice bowl (4) Wok (1) Soup pan (1)	Wiped Wok and dish With paper, then washed	30	1.8	13.5	0.27	0.033
		Washed without wiping	30	21.9	38.4	0.42	0.072

When cleared table for 4 persons.

8-8-3 Promoting domestic wastewater measures

In our country, measures against residential wastewater have so far been aimed principally at the installation of sewerage systems, and septic tanks as measures against pollution sources; however, sole dependence on development of such treatment system on the basis of "area" will require a long period of time before treatment facilities come into wide use; and further, reduction of pollutant loads, even though reduced, will not ensure stable qualities of discharged water below 10 mg/l of BOD, 10 mg/l of nitrogen and 1 mg/l of phosphorous. Therefore, it is necessary to systematically promote domestic wastewater measures; namely, proper measures for sewage treatment and effluent load reduction by taking in-kitchen measures.

In these circumstances, in 1988 the Environment Agency drew up "Guidelines for Promotion of Residential Wastewater Treatment," which were partially amended in June 1990 to incorporate measures for residential wastewater into Water Pollution Control Law. The chief points of the amendment were: 1) definition of government responsibilities and the people involved in measures for residential wastewater (Table 8-8-4), 2) well-planned and coordinated promotion of residential wastewater treatment (Fig.8-8-2), 3) installation and diffusion of residential wastewater treatment facilities, and 4) promotion of awareness and education among the residents. The indication of targeted residential wastewater treatment areas will be made as part of the planned and coordinated promotion of these measures. The municipalities appointed by governors as targeted regions shall draw up "residential wastewater treatment measures promotion plans," through which they shall carry out the measures. As of January 30, 1999, forty prefectures, 171 regions and 414 municipalities are appointed as target areas.

Table 8-8-4 Responsibilities on residential wastewater treatment

Municipalities	・Promotion of installation of residential wastewater treatment facilities ・Fostering staffs in charge of education promotion ・Execution of other measures relating to residential wastewater
Prefectures	・Implementation of wide-area measures ・General coordination of measures drawn up by municipalities
Government	・Propagation of knowledge ・Technical and financial help to local public bodies
People	・Disposal of cookery refuse and used oil; proper use of detergent ・Cooperation with national government and local public bodies

8-8-4. Improvement of Water Environments Through Resident-Participating Residential Wastewater Treatment

For the effective promotion of residential wastewater treatment measures, people need opportunities that raise their awareness about water pollution. For this, it is essential to have people experience reborn nature, purified water or recycled natural resources. Then, utilization of "Ecoengineering," which includes the use of natural energy and plants, will be of great help as it enables residents to enjoy creating and maintaining a biotope. It will also help to purify water and make people more environment-conscious.

At Funabashi City, Chiba Pref., citizens are participating in a project aimed at purifying the Kanasugi River which coexists with a biopark (ecological space) at the uppermost part of the river where some 200 families live in a residential area. Fig. 8-8-3 shows what the facilities of the biopark and how it operates to purify the water. At Kanasugi balancing reservoir No.1 (3,181 m^2, covered with three concrete planes) a waterway (55 cm wide and 15 cm deep) runs through its central part, and the flowing sewage is purified at a purifying section (50 m long) within the waterway where contact materials made of carbon fiber (50 cm x 2) are installed at 40 points; then, the treated water is pumped up at a speed of 1.7L per second to the biotope purifying pond (636.8 m^2, with average depth of 5 cm where wild rice, watercress, parsley and water feather are cultivated) which is partitioned by concrete planes within the balancing reservoir.

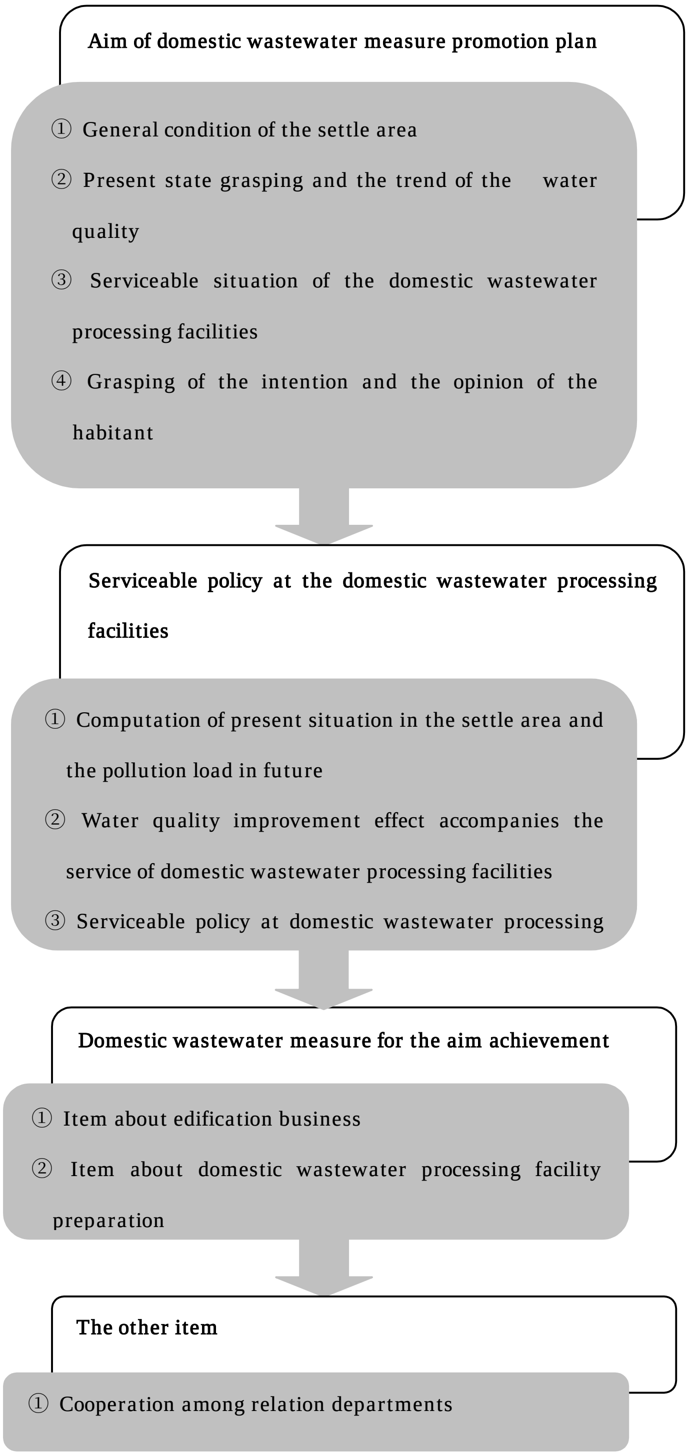

Figure 8-8-2 Flow of the domestic wastewater measure promotion plan

The confirmed purification result is a quality under 5 mg/l of BOD against 30 mg/l before purification. Also, an effect has been seen in the recovery of habitats of organisms. A great variety of birds, fish and insects have recovered their habitats in the biotope including areas downstream of the river. Further, plants that have flourished thanks to purification are being successfully collected as good-quality compost that finds use in green areas or as gardening fertilizer. The biotope also contributes to the improvement of living environments and landscapes; odors have been reduced by purification; unused space is now covered with greenery and the living environment of the neighboring areas has also been improved. Thus, efforts towards purification by this method have been made in conjunction with public works of Funabashi City as a local public body with ample citizen participation; businesses and administration have also cooperated. Such activities have successfully produced diverse environmental improvements other than water purification, leading citizens' interest in putting in-kitchen measures into practice and building the biotope; and therefore, the biotope facilities were constructed and are being operated at a much lower cost than normal river purification facilities. All this is an effect of residential wastewater treatment with active citizen participating. Fig. 8-8-4 is a conceptual picture showing the role shared by citizens, the administration and the resulting effects.

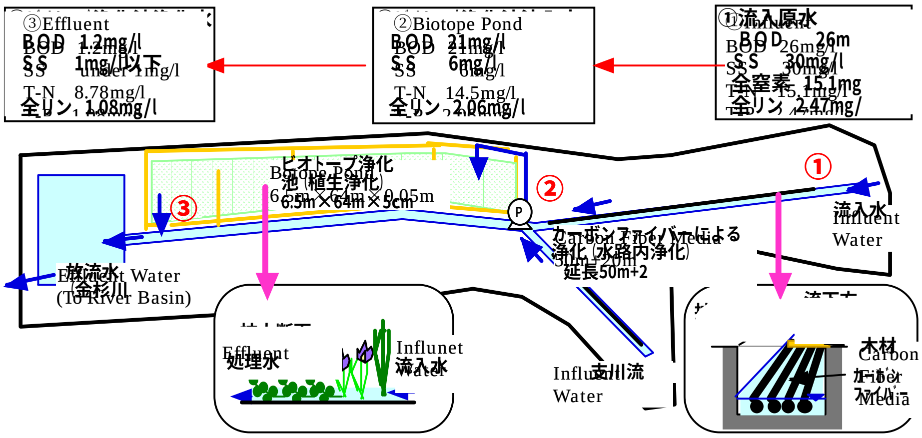

Fig. 8-8- 3 Overview and the purification effect of "water purification facilities with ecological engineering (Funabashi City) "

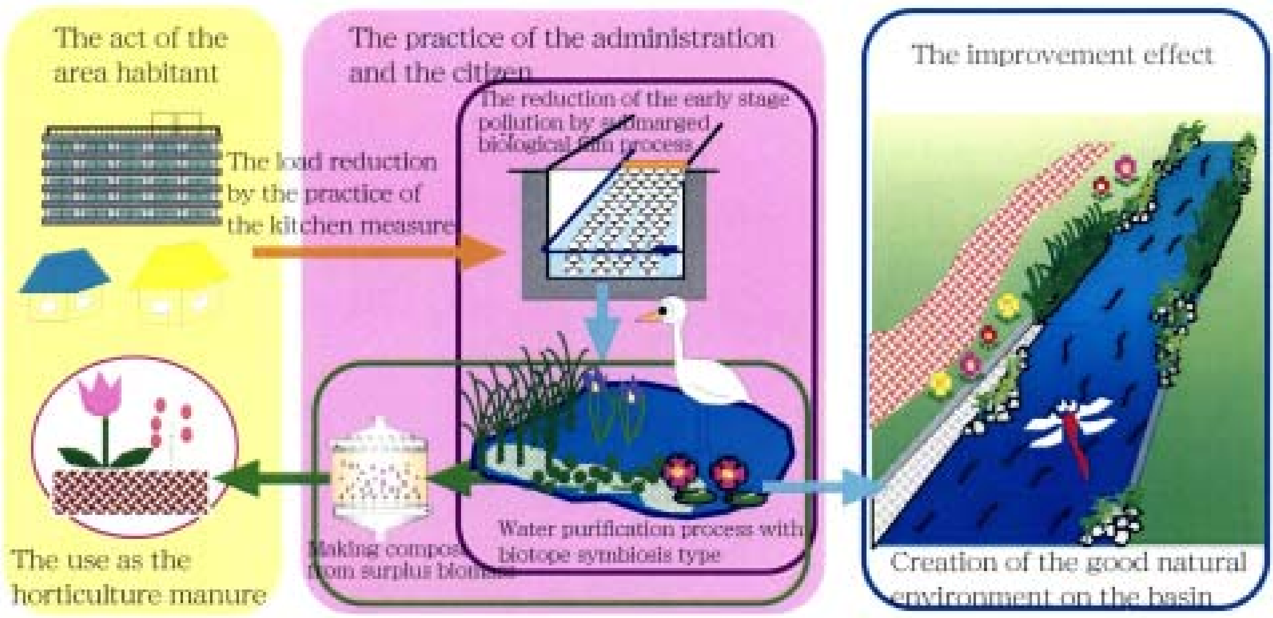

Fig. 8-8-4 The concept of the role share of the domestic wastewater measure and environment improvement effect by the citizen and the administration

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