

# Productive water decontamination: Colombia

## ABSTRACT

Water used in agriculture is traditionally considered waste that has to be discharged. Untreated, however, this polluted water threatens health and the environment. Conventional water treatment systems – highly specialized, costly and based on high inputs and energy – are beyond the means of most small- and medium-scale farmers in the developing world. As a result, water contaminated with sediments, pesticides, animal manure, fertilizers and other organic and inorganic matter is being dumped into streams, a practice which degrades water quality, limits its use downstream and causes a loss of valuable resources.

In Colombia, as in other developing countries, traditional technologies for wastewater decontamination were restricted to expensive septic tanks or oxidation lagoons, in which organic matter, nutrients and energy present in wastes were lost and rarely linked to waste re-use such as irrigation, fertilization or aquaculture. There was therefore an urgent need to develop simple, low-cost and practical waste management techniques, adapted to tropical conditions and the resources available.

An innovative example in Colombia has been the Productive Water Decontamination System, developed by the Centre for Research in Sustainable Systems of Agricultural Production (CIPAV Foundation). The aim is to reduce water and soil pollution caused by agriculture and convert the energy and nutrients contained in wastewater, such as biogas, compost and fertilizer, into elements that can be used in farms. The system is based on the idea that organic waste treatment and recycling can be more effectively carried out through biological processes involving the activity of micro-organisms such as bacteria, algae, fungi, plants and animals. The elements of the system are a low-cost biodigester, which is easy to install and operate, and aquatic plant channels complemented by fish polyculture ponds and associated crops. Wastewater passes through the biodigester and then to the aquatic plant channels and the fishpond. As wastewater passes through the system, pollutants are transformed into biogas, aquatic plant biomass, food crops and feed for fish. Aquatic plants are harvested and used periodically and the sediments accumulated in the bottom of channels are collected every four or six weeks to be used as fertilizer.

Since 1993, the system has been implemented in the Andean watersheds of the Valle del Cauca province of Colombia. Attention was focused primarily on tests at Los Sainos, a 150-hectare site in the upper portion of the watershed, where productive systems and households were polluting a stream used as a source of drinking water by most families in the area. Some inhabitants searched for water upstream in order to avoid the health problems caused by contaminated water. Conflicts between neighbours arose as unpolluted water became scarce and water transportation costs increased. Downstream, some people had to take water from different watersheds with less pollution. **CIPAV** worked with the landholders to diagnose the problems of water quality and access, analysing plant cover, agricultural and household activities and the size and distribution of human populations.

Once the productive decontamination system was implemented, there was a notable recovery of the watershed, a reduction in pollution and generation of income for farmers. Wastewater from farms and domestic activities was treated as a valuable resource containing energy, organic matter and nutrients that had to be extracted before water was returned to the environment. Decontamination was soon considered a productive and attractive activity by farmers, since they could obtain aquatic plants to feed animals and fertilize plants as well as obtain fish and crops, both as food and saleable goods. Above all, they could obtain biogas for energy, which was less labour-intensive or costly than using scarce firewood. An important incentive for the implementation of biodigesters was the possibility of replacing up to 70 percent of diesel motor fuel with biogas. This allowed medium- and large-scale farms to generate electricity or move machinery within the production units or in the neighbourhood. As a result, farming units were more efficient in the use of resources and had lower production costs, as they were less dependent on external inputs such as firewood, fossil fuels, fertilizer and formulated feeds.

Since the introduction of the system, landholders have become more aware of contamination and other adverse effects of agriculture on the environment and human health and the need to preserve and protect water as a natural resource. Streams have recovered their quality and can be used by more people. This means a lower incidence of water-related diseases and lower costs of water treatment for human consumption.

The Productive Water Decontamination System has since been successfully used in other localities to treat different kinds of agricultural residual water. While the system was being introduced and developed at **Los Sainos**, it was also tested at various medium-sized and large productive systems in the flat lowlands of Valle del Cauca, where it proved equally effective and efficient. Currently,

the system has been adopted by an estimated 37 percent of farms in the area, with the systems treating from between 70 to more than 30 000 litres of wastewater daily.

Adoption of the CIPAV system to treat wastewater from agriculture has social, environmental and economic benefits. In 1995, the system and its participatory research process won the Planeta Azul (Blue Planet) Ecology Award and it has been introduced into various tropical countries including Costa Rica, Honduras, Venezuela and Viet Nam. It is hoped that other countries will follow the example. Installation of the system is easy and can be carried out without specialized skills. The polyethylene tube used for biodigesters is produced in most countries, while the other materials and fittings are commonly available in local markets.

## INTRODUCTION

Water becomes an increasingly critical resource as growing populations demand more and various factors reduce its quantity and spoil its quality. Of the global 4 530 km<sup>3</sup> extracted annually from rivers and aquifers, an estimated 65 percent is destined for agriculture, 25 percent for industrial use and 8 percent for human consumption. A fraction of the water used in urban and industrial settings is returned to rivers in a poor condition due to contamination.

Water pollution from point and diffuse sources limits further use of the resource, especially for direct human consumption. Untreated municipal sewage and effluents from industry, food processing and intensive animal husbandry are the most significant sources of contamination.

Diffuse sources can be separated into atmospheric – mainly deposits of pollutants from fossil fuel combustion – and non-atmospheric – urban and agriculture runoff. At least 300 000 million cubic metres of wastewater and organic and inorganic residues are discharged annually into water bodies, causing a 40 percent reduction of primary productivity in rivers and oceans. Poor water quality affects human health, particularly in developing countries, where polluted waters cause severe health problems and high infant mortality.

Agricultural systems contribute significantly to water pollution, mainly through suspended and sedimentable solids, nutrients, biochemical oxygen demand (BOD) and pesticides. The predominant trend towards specialized production and monoculture relies heavily on imported inputs and hampers the use of by-products from each process. These systems **give** preference to short-term financial profits and do not consider natural resource degradation.

Water pollution caused by solids, nutrients and BOD implies environmental degradation and a **loss** of resources which are very important for developing countries, since production of chemical fertilizers **is** costly in energetic and

economic terms and loss of soil by erosion is difficult and expensive to remedy. It is, incidentally, an indirect way of measuring organic matter.

Integrated production systems are more efficient in the use of resources. More possibilities of recycling wastes within farming systems become available as wastes from one process become inputs for another.

The technological development of water decontamination systems originated in industrialized nations. Prevailing social and economic conditions, variations of light and annual temperature – and the fact that such systems were developed mainly by engineers – has meant that the results have often been irrelevant to countries' needs. Water decontamination systems have tended to be highly specialized processes, costly to build and maintain. In recent years they have been based on high input and energy levels. In addition, conventional waste-treatment systems are rarely linked to waste re-use such as irrigation, fertilization or aquaculture. Moreover, they generate neither income nor employment. There is therefore a need to develop or adapt simple, low-cost and practical waste-management techniques, suitable for tropical conditions and available resources.

Organic waste treatment and recycling can be more effectively carried out through biological processes involving the activity of micro-organisms such as bacteria, algae, fungi, plants and animals. By-products of these processes include biogas, compost, fertilizer and protein biomass.

This approach is applied in the Productive Water Decontamination System developed by CIPAV in Colombia, which uses elements such as the biodigester, aquatic plants and fish ponds to recycle wastes produced in other production subsystems and convert them into valuable products. CIPAV is implementing this system in some watersheds of the Andean region of Colombia. The process of investigating, implementing and evaluating the system with a rural community in the Valle del Cauca province of Colombia is described here.

### **PRE-INNOVATION**

As in most tropical Latin American and African countries, in Colombian Andean watersheds, the water used in livestock production, harvest processing, toilets and household activities is traditionally considered waste to be discharged. Conventional treatment systems are very expensive for small and medium scale farmers, so wastewater is mostly dumped **into** streams, causing deterioration of water quality, limiting its use downstream and causing a loss of valuable resources from farming units.

At Los Sainos, a 150-hectare watershed located in the municipality of El Dovio in southwestern Colombia, productive systems and households were

polluting a stream used as a source of drinking water by most families living in the area. Some inhabitants drew their water further upstream in order to avoid the health problems caused by contaminated water. Disagreements among neighbours arose as unpolluted water became scarce and the cost of transporting water increased. Downstream, some people had to take water from different watersheds with fewer pollution problems.

Deforestation to establish crops or pasture had caused further deterioration of the stream. It is estimated that contamination produced by households in the watershed amounted to 2 719 kg of BOD and 2 518 kg of total suspended solids (TSS) per year, either disposed in earthen holes or discharged into the stream.

The lack of awareness about the pollution being caused was linked to irrational use of water in productive processes. For example, rainwater that could have been collected for different purposes was squandered. Manure and wash-water from pigpens and stables were not considered valuable. In fact, stables and pigpens had been strategically built near to streams in order to facilitate water discharge. Contamination from livestock production was equivalent to 3 668 kg of BOD and 8 395 kg of TSS in the watershed. Coffee processing, which severely affects water streams during the harvest season, was another source of pollution. On the other hand, farmers had to buy all the fertilizers required for their crops or simply avoid using any. Since families depended heavily on firewood as fuel for cooking, wood extraction degraded the remaining forests and the streams protected by them. Larger production units used electric energy and propane gas to warm young animals, prepare feeds, move pumping engines and other functions.

The only decontamination systems available were septic tanks. Given their high cost, however, these could only be installed once external institutional subsidies became available. These systems were focused exclusively on pollution removal and showed no additional benefits that could make them attractive for farmers. Pollution-control programmes had to be subsidized or imposed by law.

### **INTRODUCING INNOVATION**

CIPAV's experience with the Productive Water Decontamination System began with research on each of the separate components. Continuous-flow biodigesters were installed mainly as a low-cost energy source for farms and to halt the environmental damage linked to firewood harvesting. Research on aquatic plants was aimed at reducing the need for costly commercial animal feeds. The incorporation of organic residues in fish polyculture ponds was studied as an option to make fish production more efficient in economic and biological terms. Taking Asian experiences as an example, these elements were linked so that each

is the most desirable of the gases produced. In rural areas, the most tangible benefit of biodigesters is the production of biogas, which replaces firewood, coal or electricity and can be easily obtained on the farm. Unlike fossil fuels, biodigestion generates no pollution during production or combustion. As an additional benefit, the organic matter in wastes is reduced by 40-60 percent without losing nutrient availability. Digestion increases the availability of nitrogen in organic wastes to above its usual range of 30-60 percent. Phosphate and potash contents are not decreased. Anaerobic digestion also helps to inactivate some pathogenic bacteria, viruses, protozoa and helminth ova in wastes. Biodigester effluents must be used with caution as a fertilizer for vegetables, however, since some pathogens might persist after washing.

The digestion process involves the following steps:

- polymer liquefaction or partitioning;
- formation of acids;
- formation of methane.

Extra-cellular hydrolytic enzymes produced by hydrolytic bacteria accomplish the first process. Acetogenic bacteria form acids, liberating CO<sub>2</sub> and H<sub>2</sub> in the process. Obligate anaerobic metanogenic bacteria release methane. Growth of these bacteria, which use acetic acid, methanol, carbon dioxide and hydrogen to produce methane, is generally slower than that of the bacteria involved in steps 1 and 2.

Different materials can be used to build biodigesters, provided they are completely waterproof. Some digesters are rigid, since they are made of cement or a metallic bell on top of a cement base. Although these materials are durable, they are too expensive for some farmers and the construction process is rather difficult. In contrast, plastic continuous-flow biodigesters, modified by CIPAV from a Taiwanese model, have a low cost and installation is easy. This design has proved efficient in gas production and the decontamination of pig unit wastewater. A 9 m<sup>3</sup> biodigester can produce enough biogas to use a 1.25cm heater for an average of 6.3 hours each day and to treat 600-800 litres of wastewater per day with good BOD and solid removal rates (Table 1).

Low-cost biodigesters have various advantages for rural families:

- workload is reduced, because there is no need to gather and prepare firewood;
- discomfort from smoke disappears, **an important benefit** for women;
- pressure on natural resources such as wood is reduced;
- water and soil pollution are diminished;
- families gain access to low-cost energy;
- facilities are easy to install and maintain.

TABLE 1  
Average decontamination in two plastic biodigesters in the municipality of Dagua (Valle del Cauca)  
(average of 4 samples/biodigester)

Site	BOD, (mg/l)	Suspended solids (mg/l)	Sedimentable solids (ml/10')	Nitrate (mgNO <sub>3</sub> /l)
Biodigester inlet	6 462.5	18 935.5	5 378	0.9
Biodigester outlet	570.8	8 311	2 426	0.69
Removal rate	91.17%	56.11%	54.89%	23.68%

Source: Pedraza *et al.* (1996).

TABLE 2  
Aquatic plant production in ponds fertilized with wastewater

	Yield (tonnes/ha/year)			
	<i>Lemna</i>	<i>Azolla</i>	<i>Water hyacinth</i>	<i>Salvinia</i>
Fresh matter	521	569	2 190	691
Dry matter	16.95	34.2	131.4	27.6
Nitrogen	6.1	9.6	13.4	6.08

Source: Chara (1995); Dominguez *et al.* (1995).

**Aquatic plants.** Aquatic plants are the next important step in water purification. They grow very well in organic-loaded water, including biodigester effluent, and create an appropriate environment for micro-organisms that decompose organic matter and make minerals available for plants. The high productivity of these widely distributed plants and their spontaneous proliferation on slow water bodies cause difficulties for navigation, irrigation and the production of rice and fish.

Although the problem is global, it is more pronounced in tropical and subtropical waters, which allow the lavish growth of these species. Considered as a crop, however, aquatic plants have various advantages, since they are highly productive and require no ploughing, fertilizers or seeds. They can be successfully used as food, feed, soil additives, fuel or in wastewater treatment. Generally, aquatic plants are more productive than conventional terrestrial crops and since they grow in wastewater, they do not compete with crops for water, land or nutrients. Fresh weight, dry weight and protein production recorded for some aquatic plant species in Colombia and Cuba are given in Table 2.

**Animal nutrition.** Aquatic plants have traditionally been used as animal feed in many tropical and subtropical countries, especially in Asia. It is currently accepted that these plants can be used to feed different farm animals, including fish, which consume them in natural environments. The dry-matter content of these plants is between 5-15 percent compared with 10-30 percent reported

TABLE 3  
Proximal analysis of aquatic plants cultivated in wastewater in the Cauca Valley, Colombia

	Water hyacinth ( <i>Eichhornia crassipes</i> )	Lemna ( <i>Lemna</i> sp.)
Original humidity (%)	85	96.7
Dry matter (%)	15	33
Crude protein (%)	10.2	36
Crude fat %	15.5	4.4
Fibre (%)	11.78	10.7
Ash (%)	13.6	8.46

Source: Pedraza *et al.* (1996)

TABLE 4  
Functions of aquatic plants

Plant parts	Function
Roots and/or stems	Provide a surface for bacterial growth in the water column Media for filtration and absorption of solids
Stems and/or leaves	Prevent growth of suspended algae Reduce the effect of wind on water Reduce gas transfer between the atmosphere and water Transfer oxygen from leaves to root surfaces

Source: Stowell *et al.* (1980).

for different terrestrial species. Their chemical composition is highly affected by the aquatic environment in which they grow. Raw protein content is equivalent to 10-36 percent of the dry weight, higher than that recorded for terrestrial plants, especially Lemna sp. At least 80 percent of the nitrogen in water hyacinth (*Eichhornia crassipes*), Pistia striatotes and hydrilla (*Hydrilla verticillata*) is found in proteins. Mineral content is between 8-60 percent of the dry weight, although a proportion is contributed by sediments stuck to roots. Although they are richer in iron, calcium and sodium, the amounts of phosphorus, magnesium, sulphur, manganese, copper and zinc are similar to those recorded for terrestrial species. Table 3 provides figures from a proximal analysis of aquatic plants.

It must be noted that some aquatic plants have higher concentrations of carotenes and xantophylls than terrestrial species and that high concentrations of toxic substances in the water can cause high concentrations in the plants.

**Use as organic fertilizer.** Aquatic plants are good sources of organic fertilizer since many have considerable levels of nitrogen, phosphorus and potassium. Besides their nutrient contribution, they improve soil structure and increase water retention capacity, which is very important in sandy, lateritic and heavy clay

**TABLE 5**  
Decontamination of pigpen residual water with hyacinth (*Eichhorniacrassipes*) and lemna (*Lemnasp.*) (average from five samples)

Sampling site	BOD, <i>mg/l</i>	Suspended solids <i>mg/l</i>	Sedimentablesolids <i>ml/l 10'</i>	Nitrate <i>mg NO/l</i>
Biodigester inlet	8 900	38 208	825	69
Eichhornia channel inlet	1 100	5 418	135	0.40
Eichhornia channel outlet	375	164.5	0.55	0.64
Lemna pond outlet	95	89	< 0.1	0.30

Source: Pedraza (1997).

**TABLE 6**  
Decontamination of sow unit residual water with water hyacinth (*Eichhorniacrassipes*)

Sampling site	BOD, <i>(mg/l)</i>	Suspended solids <i>(mg/l)</i>	Sedimentablesolids <i>(ml/l 10')</i>	Nitrate <i>(mg N O/l)</i>
Eichhornia channel inlet	1 350	2 854	50	1.3
Eichhornia channel outlet	35	175	< 0.1	0.22
Removal rate	97.4%	93.8%	99.9%	83.07%

Source: Pedraza et al. (1996)

soils, which are widely distributed in tropical countries. If the aquatic plants are directly placed on top of the soil, irrigation and weed control requirements of crops are reduced. Water plants can also be transformed into organic fertilizers through composting or vermi-compost production.

Given their high water content, the production sites of crops, compost or vermi-compost should be close to water channels to avoid transportation costs.

**Use in wastewater decontamination.** Contrary to common opinion, aquatic plants themselves do not perform much water treatment. Their function is to provide an environment for species that do improve water quality (Table 4). This treatment is very similar to conventional techniques. The main removal mechanisms are physical sedimentation and bacterial metabolic activity, as in the case of activated sludge and slow filtering systems.

A significant reduction of BOD<sub>5</sub>, nitrogen, phosphorus and heavy metal contents is achieved through the combined effect of bacterial activity, sedimentation of slowly flowing solids and chemical reactions. Plants absorb dissolved materials and incorporate them into their own structure, extracting pollutants from water and thus causing less environmental harm. An additional benefit is obtained through their harvest and use, since nitrates, ammonia compounds, phosphates and organic compounds extracted from wastewater are nutrients frequently required by agricultural systems. These, particularly nitrogen and ammonia, are

costly to extract from an energy and financial point of view. Such costs imply foreign currency for developing nations and farmers.

Aquatic plant production is a practical and environmentally friendly way of purifying municipal wastes and wastewater from industry, pig production and dairy units, with low operational costs and no sophisticated technology requirements for implementation. Removal of 91 percent BODs, 98 percent of suspended solids and all sedimentable solids was recorded in a decontamination system established on a small farm to depurate residual water from six to eight pigs in the southwest of Colombia (Table 5). This system has two 3 m<sup>3</sup> biodigesters, three water hyacinth channels with a total area of 13 m<sup>2</sup> and a 28 m<sup>2</sup> pond covered with lemna plants.

At a larger-scale system, a 17 m<sup>3</sup> biodigester and 130 m<sup>2</sup> of water hyacinth were used to treat residual water from 80 sows. Reduction of 97 percent BODs, 93.8 percent suspended solids and 99.9 percent of total solids were recorded in the water plant section (Table 6).

**Fish polyculture.** The association of fish with different feeding habits is one of the most important practices to use the available pond food effectively and thus increase fish yield.

Although algae cells grow profusely in nutrient-rich water, their small size of less than 10 μm is a limitation for available harvesting techniques. This can be solved using phytoplankton-feeding fish that harvest this protein-rich biomass – more than 50 percent of protein on a dry-matter basis. Pollutants are decomposed by bacteria and converted into biomass by plankton, which is consumed by fish. These, in turn, can be harvested as a nutritive and high-value product. Fish control algal and bacterial growth, contributing to water quality improvement. In a wastewater-fed pond at equilibrium, feed for fish is produced by algae, wastes are decomposed by bacteria and foraging activity of fish prevents plankton overgrowth and mortality by excessive oxygen consumption during the night.

Fish density is an important factor, since at high densities there will be more nutrient uptake and hence more decontamination but less fish growth: at low densities, individual fish growth will be maximized but nutrient uptake will be lower. In waste-fed ponds, care should be taken to maintain adequate levels of dissolved oxygen and ammonia.

In a fish polyculture established as a part of a decontamination system evaluated in 1995, fish production was equivalent to 2 741 kg/ha/year. Polyculture was composed of Nile tilapia (*Oreochromis niloticus*), cachama (*Colossoma macropomum*) and bocachico (*Prochilodus reticulatus*). The fishpond was fed with effluent from an aquatic plant pond where the wastewater from a dairy

stable was treated. Fish were also fed with bore (*Alocasia macrorrhiza*) leaves and azolla.

**Associated terrestrial crops.** In conventional decontamination systems, areas adjacent to ponds or water channels are not productive. If plants are allowed to grow around these facilities, however, they can use the nutrients captured by aquatic plants as well as the sediments periodically extracted from the channels. Integration of terrestrial crops to embankments has the following advantages:

- additional income is obtained from crops planted on dikes;
- sediments extracted from the bottom of the channels are easily applied to crops, thus reducing the cost of organic fertilizer;
- enriched water from ponds and channels available for crop irrigation contributes additional nutrients;
- pond and channel water with high mineral content is directly obtained through the roots, except when plants are small and are watered;
- fruits and vegetables can be used as food for fishes;
- plants strengthen the dikes, improving their water-retention capacity.

In general, plants with non-invasive and moisture-tolerant root systems can be planted on the embankments. Crops most commonly planted in decontamination systems in Colombia are plantain (*Musa paradisiaca*), papaya (*Carica papaya*), bore (*Alocasia macrorrhiza*), sugar cane (*Saccharum officinarum*) and nacedero tree (*Trichanthera gigantea*). The latter is a native tree used for forage production in Colombia. Under local conditions, it produces about 10 tonnes of dry matter per ha/year with 18 percent of protein.

**Practical aspects of the system.** Installation of the system is easy and can be carried out without specialized skills. Polyethylene tube used for low-cost biodigesters is produced in most countries. Other materials and fittings are commonly available in local markets. Polyethylene tube diameter ranges from 0.8- 1.25 m; 2.4 m diameter tube is suitable for bigger farms. Daily maintenance of the biodigester is limited to supplying the wash-water from pigpens and stables. If well protected from animals and solar radiation, the plastic lasts an average of five years, although it has been known to last up to nine years. The size of the biodigester must be adjusted to the amount of wastewater produced daily. In general terms, a 3 m<sup>3</sup> biodigester is enough for three to six pigs producing between 150 and 300 litres of residual water each day.

Aquatic plants can be placed directly on dug channels, unless the soil is too permeable. In this case, the channels must be covered with cement or a mud-and-cement mixture. Their length must allow the retention of wastes for at least two weeks. For example, the daily purification of 100 litres of wastewater requires 1.5 m<sup>3</sup> of channel volume (10 m length x 0.4 m x 0.4 m). The only maintenance

TABLE 7  
Economic analysis of three wastewater decontaminationsystems (US\$, 7997)

	Biodigester: hyacinth - lemna - nacedero tree	Biodigester: hyacinth - lemna - plantain - papaya - fish culture	Septic tank
NPV .of total costs	876.6	1184.1	277
NPV of gross profits	1145.3	2112.6	0
NPV of net Profit	268.7	928.5	(-277)
IRR* (10years)	42	98	0

\* NPV = Net Present Value calculated in 10 years at 15 percent discount rate.

\*\* IRR = Internal Rate of Return.

Source: Pedraza *et al.* (1998).

activities required are harvesting of aquatic plants as channels fill up and removal of sediment from the first channel every four to six weeks. Sediments can be applied to crops, while plants can be directly used to feed animals or as green manure.

**Environmental-economic analysis.** The productive decontamination system developed by CIPAV has proved to be very effective in the treatment of wastewater from agriculture and it offers social, environmental and economic benefits.

An environmental/economic evaluation of the system confirmed its economic and environmental advantages. A system installed at a small farm to treat the wastewater from 4-6 pigs, associated with production of plantain, papaya and fish, can generate:

- annual profit of US\$266;
- savings in firewood of US\$2.24/week;
- electricity savings of US\$15/month;
- savings on artificial feed – US\$15.6 per pig/year.

Moreover, the system reduces BOD5 from 5 900 ppm down to 148 ppm, equivalent to 97 percent less.

Table 7 shows the environmental-economic analysis of two productive decontamination systems compared with a septic tank globally recommended for rural dwellings. Although the initial investment for a septic tank is lower, it produces no revenues, while productive decontamination systems generate net profits that can encourage farmers to implement them. This is particularly important in developing countries, where environmental laws are becoming more severe. Thanks to its profitability, this kind of decontamination system can be promoted through small credits provided by banks or local environmental agencies.

## POST-INNOVATION

Since its introduction, the Productive Water Decontamination System has been implemented on 37 percent of the farms, especially those in the upper portion of the watershed. Wastewater from farms and domestic activities has begun to be considered a valuable resource containing energy, organic matter and nutrients that must be trapped before the water is returned to the environment. Manure and wastewater from animal production and water from toilets are treated in decontamination systems to retain the energy and nutrients within the farms.

With the systems installed so far, it is estimated that the annual contamination of the watershed has been reduced from 6 388 to 4 318 kg of BOD<sub>5</sub> and from 10 913 to 7 181 kg of TSS. Farmers now consider decontamination a productive and attractive activity because they can obtain biogas, which means less work or expense than obtaining firewood for cooking and lower costs from running engines. Aquatic plants feed animals and fertilize plants; fish and crops serve as food or saleable goods. So far, biodigesters have allowed the annual replacement of 19.7 tonnes of firewood, with additional benefits for forests in the watershed. For farmers, biogas has proved to be the most important product of the system.

Water hyacinth (*Eichhornia crassipes*) produced in channels is being applied to some crops and *Lemna* sp. is used to feed animals, mainly pigs and poultry. The protein content in *Lemna* sp. cultivated in decontamination channels reaches 40 percent on a dry-matter basis, permitting the annual replacement of about 480 kg of formulated feeds in the watershed.

Relationships established between parts of the system and other activities within the farms contribute to more integrated production. Farming units on which the system was implemented are more efficient in the use of resources and have lower production costs, because they are less dependent on external inputs. As an additional result of the process, farmers have become more aware of contamination and other adverse effects of agriculture on the environment and human health. Local people have reduced the use of pesticides and detergents and have installed rainwater-collecting devices.

Water streams have recovered their quality and can be used by more people downstream. This means a lower incidence of water-related diseases and lower costs of water treatment for human consumption.

A total forest cover of 25 ha has been recovered in the watershed, which represents 18 percent of the total area. This has contributed to the recovery of the physicochemical and biological characteristics of the water along 1.5 km of the stream.

As a result of the community-level processes generated through water decon-

tamination, local farmers have become more concerned about their methods of production and about the forest cover that protects the stream. They have started cooperative protection and reforestation activities in the upper parts of the watershed and the stream margins.

### LESSONS LEARNED

In Colombia, as in other developing countries, water-pollution taxes are being created or reinforced. Polluters have to pay for contaminating water sources. In order to tackle this situation, it is necessary to invest in costly decontamination systems that add to the expenses of productive processes. However, the Productive Water Decontamination System installed so far in Colombia has demonstrated that adequate treatment of pollutants can generate revenue, leading to the possibility that such a system could be financed with commercial bank credits.

As a strategy to spread this innovation among small landholders, CIPAV invested the money from the Blue Planet award in a special Small Initiatives for Water fund. Two other Colombian NGOs – Red de Reservas Naturales de la Sociedad Civil and Asociacion para el Desarrollo Campesino (ADC) – contributed to the fund. Up to July 1998, 70 percent of the interest from this fund had been used to finance 35 proposals, of which 51 percent were decontamination systems and 40 percent were aimed at protecting springs and streams. The remaining 30 percent of the interest had been used to recapitalize the fund. Farmers must submit a written proposal and budget with their contribution, which is generally human resources, and the amount solicited to the fund. A committee, on which farmers are represented, selects the proposals to be financed and evaluates their results once implemented. This has stimulated the installation of decontamination systems by low-resource small farmers, who sometimes need individual support to cover expenses.

Large entrepreneurial farmers finance the system with their own resources or through commercial credit, thanks to the income that can be generated through the system. Experience has revealed that large farmers are mainly interested in replacing the electrical power required in their productive units by biogas. In most cases, they are not motivated by the benefits from other components of the system and thus the process remains incomplete, although the taxes imposed by environmental authorities have forced some of them to install the complete system.

Due to the cost of energy and the possibility of replacing it directly by biogas, biodigesters are the most appreciated element of the system. Lemna production in aquatic plant channels is also important for farmers, because it can directly replace commercial feeds. The implementation process of a simple system in which changes in water quality can be clearly observed allows people

to understand the process and become more aware regarding the rational use of water. From this point of view, the system can be used as a strategy for environmental education. All members of the family can become involved in management of the system.

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