Development of Minimum Cost, Incentive Based Plan for the Implementation of a Technology Standard for Coffee Processing in Honduras[1].

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ABSTRACT

In Honduras, traditional coffee processing is the cause of two problems: poor coffee quality and contaminated water. In this study we propose to replace traditional coffee processing plants with a network of improved ecological plants that would be optimally located in a sub-watershed. The method is an adaptation of a spatial integer linear programming that determines the optimal location and size of new coffee processing plants. We applied the method to a typical sub-watershed in the hillsides of western Honduras and show that coffee quality can be improved and contamination can be reduced substantially at a relatively low cost. We also calculated the incentive for small farmers to give up home processing. We find that the incentive is much lower than the premium that could be obtained from an improved coffee quality.

KEYWORDS: coffee, water quality, linear programming, spatial analysis, watershed management, Honduras.

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INTRODUCTION

Coffee is the most important export crop in Honduras. Up to 250,000 hectares are cultivated in 85,000 separate plots, mostly by small-scale producers in terrain between 700 and 1500 meters above sea level. Over 92% of producers plant less than 7 hectares and more than one third of Honduran farmers are involved in the production (Pineda, 1997). Because much of the coffee is grown on the hillsides in the upper watersheds, it utilizes land that would be economically and environmentally unsuitable for the production of other crops. Despite price fluctuations, and a price penalty imposed on Honduran exports for poor quality control, total cultivated area is expected to increase in the medium term (IHCafe). Coffee cultivation generates income in rural areas which reduces poverty and has been a key factor in maintaining rural social stability in Honduras.

Over 85% of the coffee produced in Honduras is grown in combination with tree species that provide shade to the plant. This traditional agroforestry system is considered to be environmentally friendly because: i) less chemical inputs are required than in modern intensive monoculture systems; ii) trees maintain soil quality and prevent erosion on the predominantly steep slopes of the upland areas where coffee is cultivated; iii) shade trees provide habitat for birds and thus support biodiversity conservation; and iv) trees provide valuable inputs into the household economy such as fruits, firewood, and lumber which reduce the stress on forested area. Indeed recent research has demonstrated that consumers are willing to pay a price premium for shade-grown coffee because of its environmentally favorable attributes (Kotchen et al 2000).

However, coffee cultivation does come at an environmental cost, especially in Honduras where post-harvest processing is done at the farm level, using water intensive technology and no environmental controls. In Honduras over 272,000 metric tons of pulp and 136,000 metric tons of mucilage are produced as waste in post-harvest processing. Currently this waste is dumped into the waterways of the upper watersheds without control or treatment. The concentration of organic matter dumped into these streams is sufficient to cause eutrofication, with the subsequent: i) loss of plant and fish life; ii) strong odors; iii) and increased population of mosquitoes and other harmful insects (Gonzalez et al, 1994). The level of pollution in these rivers and streams is directly related to the quantity of coffee processed and the processing technology (Jacquet, 1993).

Furthermore, because coffee processing in Honduras is decentralized, with individual farmers processing their own harvests, exporters are unable to guarantee a standardized product that meets the quality standards that the international market demands. This implies that a price penalty of US $12.00 for each 46 Kg sack of coffee has been applied

to Honduran exports in 2000. The few Honduran cooperatives that can guarantee quality through centralized processing do not receive this penalty[4].

Because of this the Honduran Coffee Institute (IHCafe) is promoting the installation of centralized coffee processing plants with pollution reducing technologies. These environmentally friendly processing technologies: i) recycle water; ii) accelerate the fermentation of the pulp; iii) modify the process of receiving and depulping husks; and iv) recycle any byproducts where possible. There are five processing technologies that have been approved by IHCafe as meeting environmental standards. The smaller processing plants are similar in size to those that are currently employed by individual farmers, but the larger plants are only appropriate for centralized processing.

This paper presents a minimum cost plan to implement centralized, pollution reducing coffee processing in the Rio Frío Basin in west-central Honduras. This plan is intended to reduce water pollution to acceptable standards as well as facilitate product quality control and improve the export price received by Honduran exports. The second section of this paper details the impact of coffee processing on water quality and product quality. The third section presents a minimum cost optimization model for a pareto superior system of centralized coffee processing. The application of this optimization model to a watershed in western Honduras is presented in the fourth section of the paper. The fifth section presents the results of a spatially optimized linear programming model with a sensitivity analysis for added restrictions. The sixth section of this paper calculates the financial incentive needed to guarantee producer and exporter cooperation with a system of centralized processing. The paper concludes with a comparison to the cost of implementing a system of centralized processing plants and the potential financial awards of presenting quality control via centralized processing.

THE PROBLEM

The coffee processing problem is specific to Honduras. Neighboring countries such as Guatemala, Salvador, Nicaragua and Costa Rica have centralized processing plants with effluent control and a more efficient use of scarce water. In contrast over 90% of Honduran coffee is processed by the individual small-scale farmer. Of the estimated 85,000 Honduran coffee producers, 44,000 process coffee themselves, mostly using inefficient traditional technology.

These small farmers do not have the financial capacity to improve their processing technologies, and banks are reluctant to lend to farmers with little collateral. The private sector has invested very little in coffee processing. Only a few dozen large producers have constructed modern processing plants (Pineda, 1998). Previous efforts from the government to improve coffee processing have failed. In the 1970s, IHCafe constructed 13 large processing plants but the choice of the location was motivated by politics more

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[4] The 2001 /2002 penalty was approximately $5.00 for each 46 Kg. sack of coffee. This penalty was waved for coffee exported by the Central Honduran Coffee Cooperative in 2002 because they had quality control and centralized processing.

than by efficiency. Because of bad management and corruption most of these plants failed, and only three plants are still processing.

Coffee Quality

Honduran coffee is of relatively poor quality because of inadequate processing. In general the individual farmer has no more than a manual de-pulping machine and a barrel for fermenting and washing. Medium and large producers can have more complete processing plants with some mechanization but the vast majority of the processors process small quantities. Some 93% of the producers harvest less than 100 quintals[5] and only 0.5% more than 500 quintals (Pineda, 1998).

Coffee processing can be dry or wet (Cleves,1995). In dry processing the fruit is dried initially and later the pulp is separated with a special machine. Dry processing is largely used for *robusta* coffee produced in Brazil and Africa. The robusta coffee has a strong taste because of the fermentation which leads to a price discount (OCI, 1998; Oseguera *et al.,*1997; Cleves,1995). In wet processing, the pulp is separated from the bean with water. This process is employed in México, Colombia, Central America, and the Caribbean and produces *arabica*. *Arabica* has a softer taste than robusta and wet processing is supposed to conserve arabica quality (IHCafe,1995; Oseguera *et al.,*1997).

Wet processing consists of bean collection, storage in a barrel without water, depulping, fermentation, washing, and drying. The washing of the beans after fermentation facilitates the classification of bean quality by flotation and the removal of lower quality beans. Furthermore, wet processing diminishes the bitterness and increases the acidity which usually leads to a better quality (Jaquet 1993). Most producers dry coffee before selling it at 30% humidity. The exporter then dries the beans again (Palma et al.1997). Three problems can alter quality during wet processing: i) it can be difficult to remove the pulp when the fruit is not mature; ii) immature beans produce bad taste; and iii) water used by farmers is usually contaminated by upstream processing plants (Bailly *et al.* ,1992).

Honduran farmers have had financial incentives to process coffee themselves. A 1995 IHCafe study showed that unprocessed wet beans were sold at 54 to 56% of international market prices. But processed *pergamino seco* was sold at 70% of international prices. The required investment needed for processing can reach 26% of the total revenues, which leaves the producer a return of only 44 to 46% of international prices. Incentives to sell to large plants are small because farmers do not expect to be treated fairly. According to IHCafe (1995) farmers need to deliver 286 Kg of wet beans in order to be paid for 245 Kg.

River Water Pollution

Although coffee quality is a concern, the main problem with decentralized coffee processing in Honduras is water pollution. In the coffee growing areas of Honduras

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[5] In Honduras a quintal is actually 46 Kg.

streams are highly contaminated during the processing periods from December to April. Since processing plants do not include effluent controls, residues are emitted directly into the rivers and streams adjacent to the plant without any treatment (Jaquet 1993, González 1996; Pineda 1997; Echeverría and Cleves 1995). Organic contamination of water is not benign. Mucilage reduces oxygen in water killing aerobic organisms such as fish, insects, and plants. This results in unpleasant odors, insect infestation, and downstream human health problems (González and Obando,1994; Osorio,1997). Furthermore, water contaminated by coffee is twice as acidic as household wastewater (see Table 1).

The wastewater is less contaminating than the more gelatinous byproducts of de-pulping. Pulp and mucilage with 62% of the weight of the product are the main pollutants (Orozco *et al.* 1992). One Kg. of dried coffee produces 2.5 Kg. of wet pulp and 12.4 Kg. of effluent (Echeverría and Cleves,1995). The byproducts are richer in pectins, sugar, and fatty acids. The pulp is more noxious when it is separated and transported through wet processing because it postpones the decomposition which worsens pollution (Cleves 1995).

In addition wet processing requires 40 liters of water for each kilo of processed coffee (Bailly et al. 1992). Around 40% of the water used during the process is wasted. This extraction of river water occurs during the dry summer months in Honduras when rainfall is not expected and rivers have their minimal flow. And it is precisely during these months when human consumption of water reaches its peak because of the immigration of migrant labor for the coffee harvest (Bailly *et al., 1992,* González, 1996).

Other environmental problems can be attributed to traditional coffee processing. Soils and water become acidic. Acidic soils become less fertile and acidic water has a negative effect on irrigated crops downstream (Blanco and Perera,1999, Salas *et al.* 1983). Organic sediments and acidity tend to damage hydraulic equipments downstream (Alfaro and Cardenas,1988). Also, water pollution of mountain streams and strong odors from coffee processing diminish the ability of the coffee processing areas to attract tourists. In addition consumption of fuelwood for drying coffee promotes deforestation (Blanco and Perera,1999).

Table 1: Water Quality in Honduras

Parameter	Potable Water	Untreated Wastewater	Coffee Processing Discharges
pH	7	6.5	3.7
ChOD mg/lt	2	500	15000
BOD mg/lt	2	250	9000
Soluble Solids mg/lt	0	500	3600
Total Solids mg/lt	500	800	12000
Source: SERNA 1995			

Optimizing Coffee Processing

IHCafe's wants to improve the current system of coffee processing by introducing a network of centralized, environmentally controlled processing plants. This system of centralized processing plants would: i) reduce water pollution; ii) reduce water consumption during processing; iii) improve the product quality and quality control; and iv) facilitate improved export prices. This system of processing plants could be implemented through the establishment and enforcement of an environmental policy that requires the use of prescribed technologies or instead regulates emissions levels to those that correspond to these certain technologies. This type of technology standard would be very similar to that which has established near universal use of the catalytic converter and unleaded fuel in US passenger vehicles (Field, 1995) .

A necessary condition for the success of this system is that all participants, farmers, processors, and exporters remain at least financially neutral to the new system. With the possibility of improved export prices, it is possible that a centralized system of environmentally controlled processing plants is pareto superior to the current system. In order to assess the financial feasibility of a centralized system, the minimum cost of the system is estimated. Later the financial incentives to each type of participant is estimated. This research does not address how this network of processing plants should be initiated nor who should own and operate these plants. The more specific problem is to determine the optimal location and type of plants.

THE MODEL

The problem is one of simultaneously determining the optimal size and location of the processing plants in a given sub-watershed given that they need to process all of the existing coffee production, meet environmental standards, and utilize limited water supplies. This problem can be easily solved by linear programming. Linear programming is a branch of mathematical programming which consists in maximizing or minimizing

an objective function under constraints. Much of the original development of linear programming, by Nobel laureate Leonid Kantorovitch and American George Dantzig dealt with transportation. Currently different types of mathematical programming are used to optimize distribution of goods and services, especially by large industries in developed countries. Integer programming is a subset of mathematical programming that consists in finding integer solutions when the output variables cannot be divided.

The model will find the minimum of the annualized fixed costs *FC*, variable costs *VC* of the plants, and transport costs *TC* in a sub watershed. The social planner's problem is to Select the decision variable

$$X_{i,p,r} \quad = \quad \text{plants of each type within each river segment;}$$

In order to minimize:

$$\sum_{i,f,p,r} (FC_i + VC_i + \sum_{p,f} TC^{\gamma} dis_{f,p} + \sum_p TC^{\varphi} dis_{p,e})X_{i,p,r} \tag{1}$$

With:

FC_i	=	Fixed cost for each plant of type i;
TC^{γ}	=	Transport cost per kilometer per quintal of wet bean;
TC^{ϕ}	=	Transport cost per quintal per kilometer of dry bean;
VC_i	=	Variable cost for each type of plant;
$dis_{f,p}$	=	Distance from the farm f to the plant location p in kilometers;
$dis_{p,e}$	=	Distance from the plant p to the buyer e in kilometers;
i	=	plant type (1 to 5);
f	=	farm location;
p	=	processing plants location (1 to 7 per river segment);
r	=	river segment (1 to 7);

Subject to the following restrictions:

$$\sum_f prod_{f,r} \le \sum_{i,p} pros_i X_{i,p,r} \tag{2}$$

In each river section the sum of coffee produced during the peak period is less than the processing capacity of the proposed plants in the river segment;

$$\sum dist_{f,p} \ X_{i,p} \le 25 \tag{3}$$

The distance between each coffee field and its corresponding plant is less than 25 kilometers, this allows for the processing to begin within five hours after harvest;

$$WATER_r \ge \sum_{i,p} water_i X_{i,p,r} \tag{4}$$

Water consumed in coffee processing does not exceed the water available in the river during low flow periods;

$$\sum_{i,p} cont_i \ X_{i,p,r} \leq Contm \quad WATER_r \tag{5}$$

The sum of effluents rejected by all plants is less than a predetermined maximum per cubic meter of water (in some simulations);

$$\sum_{i,p,r} inv_i \ X_{i,p,r} \leq Inv \tag{6}$$

Total investment is less than a predetermined maximum (in some simulations); and

$$INTEGER(X_{i,p,r}) \tag{7}$$

X has to be an integer variable.

With the use of the optimization software GAMS, the model was constructed for the Río Frio sub-watershed in Santa Barbara, Honduras. In this area recent studies of river flows and water quality complement the impressive data collected by IHCafe on farm locations, costs, and output.

METHODOLOGY

A recent study reports five different types of coffee processing technologies currently employed. These differ by their capacities from 25 to 5000 bags per year and their water requirement (Pineda, 1997a). The great majority of these are small-scale, with limited capital. These technologies rely on water power to reduce labor and utilize 40 liters of water for each kg of processed coffee (Pineda 1997a, Baily *et al.* 1992).

All of these technologies can be modified to conserve water and reduce water pollution. Thus IHCafe has proposed five types of regulated plants which feature water recycling, effluent treatment, composting of organic byproducts, rapid fermentation, improved de-pulping, and low energy use (see Figure 1, Table 2). (Urive *et al.,* 1997, Jaquet, 1993, Barrios, 1995).

Study Area

The Rio Frio watershed is located in the department of Santa Bárbara, within the boundaries of the municipality of San Nicolás in western Honduras. The watershed covers an area of 86 Km^2 between 550 and 1600 meters above sea level. Temperatures vary between 18°C and 26°C, humidity between 86 and 94%, annual rainfall between 2300 and 2700 mm, and there are an average of 120 a 160 days of rainfall each year. The topography is mountainous with slopes of 40 to 50% in average. Soil texture is clayish with good organic matter content. According to the Holdridge classification the vegetation corresponds to a Sub-humid Tropical forest. Overall these are good conditions for coffee.

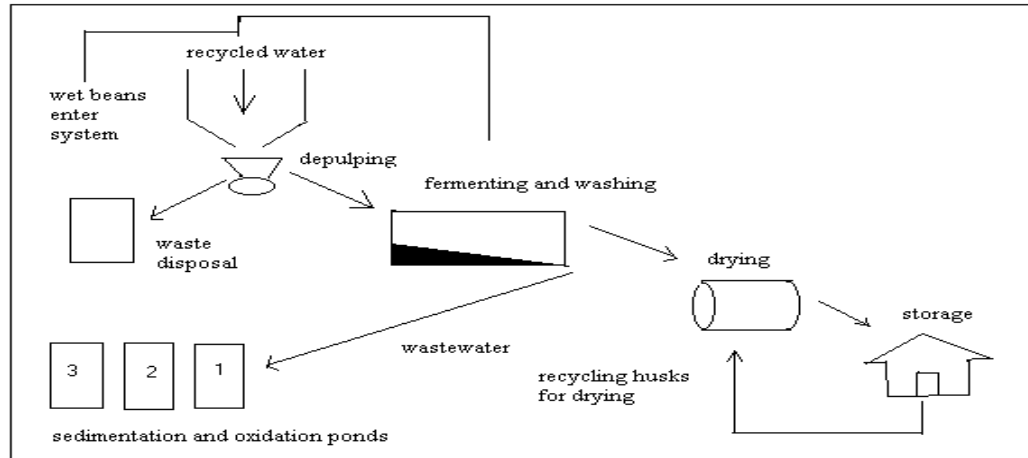Figure 1. Ecological coffee processing (Jaquet,1993)

Table 2:
Production and pollution attributes of five proposed coffee processing plants

| Plant Model	Fixed Cost $/quintal 10 year loan 28%	Effluents kg/quintal /year	Variable Cost $/ quintal	Annual Capacity in quintals	Water use, lt/quintal
1	21.88	171	3.18	25	507
2	12.31	171	3.18	100	501
3	10.94	171	2.34	500	300
4	12.31	151	0.99	1000	300
5	14.23	151	0.62	5000	300
Source: Pineda 1997a, 1997b					

Coffee plantations are located in the upper part of the watershed and represent the main economic activity of the watershed. Farmers also produce livestock, sugar cane, vegetables, maize, and beans. Around 1137 families produce coffee in the watershed but only 569 families reside in the watershed for the entire year. Around 40,000 quintals of *pergamino seco* coffee is grown on 2527 hectares, or 16 quintals per hectare.

Data

IHCafe has collected an impressive amount of data on coffee production and prices. It has also sponsored different studies on production costs, processing, transactions costs, as well as detailed studies on water use and water quality in the Rio Frio watershed (IHCafe 1995, 1999, 1999a, Jaquet 1993, Osorio1997, Palma et al, 1997, Pineda et al, 1998,

Pineda 1997a, 1997b). Production data for each farm was provided by the 1993 national and the 1992 IHCafe census. Interviews with local growers, middlemen, and extension agents were used to determine transportation costs, from the field to the processing plants and from the processing plants to the export depot. Also interviews were used to estimate the quantity of coffee sold illegally to buyers in other countries. Illegal exports were estimated to be 5700 quintals of coffee from nearly 190 producers. Conditions and costs of credit were obtained from local banks. The investment for the new plants requires a credit over 7 to 10 years at 28 % with 2 years of grace, and 5 to 8 years of capital reimbursement.

Figure 2: Possible Locations for Processing Plants.
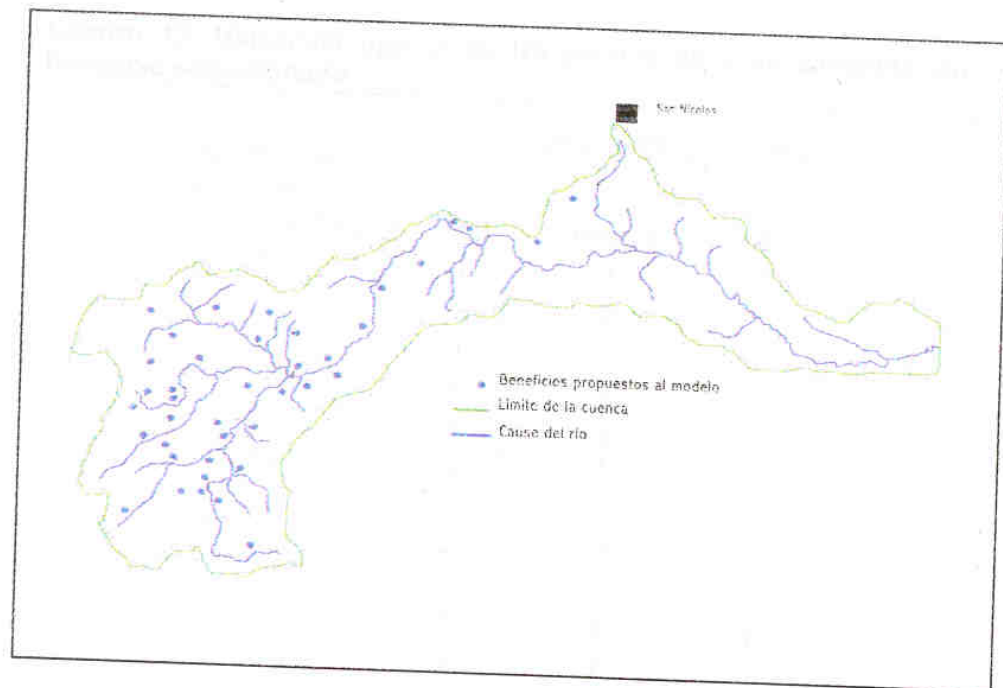
Maps from the National Forestry Corporation (COHDEFOR, 1997) were used to delineate the watershed. A digitized map from IGN (1991) was used to identify roads and rivers and a Geographic Information System from CIAT (1999) was used to estimate distances, between farms and possible plant sites and between plant sites and the export depot. These distances were validated during a tour of the watershed. Also, the final selection of potential locations for processing plants was done in consultation with local growers and extension agents in order to assure access to roads and water.

The Rio Frio sub-watershed can be divided into 7 river sections (see Figure 3). Data on water availability is based on measurement of the stream flows by Pineda *et al.(*1998). Outflows are measured at seven points of the watershed. Stream flow is 2.5 m^3 /s at he end of the rainy season but goes to 1.4 m^3 /s in December and January the beginning of the processing time. At the end of the dry season the streamflow is down to 0.4 m^3/s.

Since the streamflows are measured at the outlet of each river section, the measured streamflow is net of all water consumed in the river section.

Water is withdrawn from the river segments to be used in coffee processing and human consumption. Almost all of the water used in coffee processing is not consumed but is returned directly to the river in polluted effluent. Some of the water used in human consumption is also returned to the river. All of these return flows are measured in the streamflow at the end of each river segment. For purposes of establishing a water consumption constraint, human consumption is assumed to be constant. Also water diverted from the river segments for use in coffee processing is considered to be returned to the river, so that the measured streamflows at the end of each river segment are considered to be the water available for coffee processing.

Figure 2: Daily water availability in the Río Frío from October 1997 to May 1998.
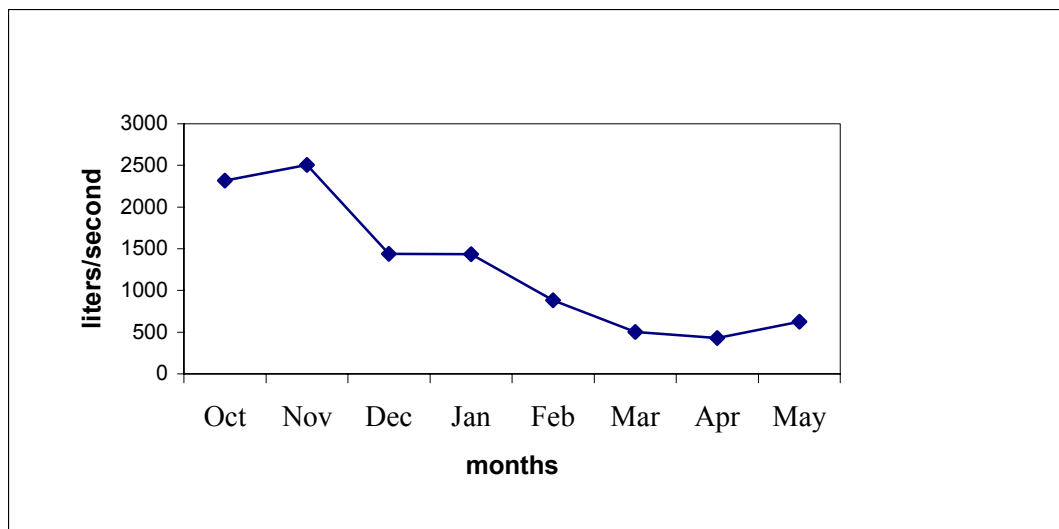
Harvested unprocessed coffee cannot be stored for long periods. The initial stages of processing should begin within five hours of the harvest. This implies that processing plants need to be relatively close to the plantations. Also the processing capacity needs to be sufficient to receive all of the coffee harvested during any day. Thus the aggregate output during the peak period determines all the estimates for the processing, such as: i) size of the installation; ii) type of plant to construct; and iii) demand for water . In the sub-watershed 70% of the production is harvested in 30 days. During this period all fixed inputs and variable inputs are fully employed in harvesting and processing. This implies that processing capacity much be sufficient to receive 1381 quintals per day.

Figure 3. Río Frío watershed and subwatersheds where the stream flows were measured

microwatershed boundaries

stream flows

flow meters

contaminated water flows

farm locations
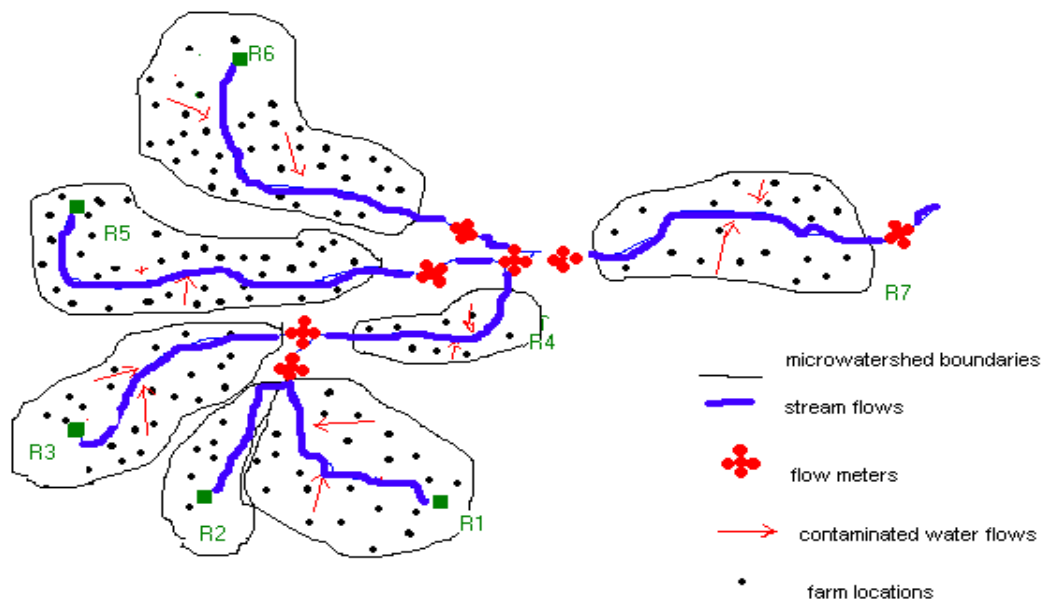
Unit variables costs per plant (see Table 3) are different because of economies of scale. Water is not recycled in plant models 1 and 2, which implies no recycling costs but a greater use of water (Table 2). Harvest cost per bag is US$11.49, independent of the size of the farm. Transport of wet beans to the processing plant was estimated at $0.62 per kilometer per quintal. Transport of dry beans on better roads is less expensive and is estimated as US$ 0.05 per kilometer per quintal.

Table 3.   Processing and transport costs per quintal US $

| Activity/Model	M1	M2	M3	M4	M5
Harvest	11.49	11.49	11.49	11.49	11.49
Within Farm Transport/ km	0.62	0.62	0.62	0.62	0.62
Transport to Plant/km	0.05	0.05	0.05	0.05	0.05
Transport to Exporter/Km	0.04	0.04	0.04	0.04	0.04
De-pulping	0.20	0.23	0.13	0.23	0.15
Washing	0.79	0.79	0.58	0	0
Recycling	0	0	0.84	0.17	0.03
Drying	0.90	0.82	0.78	0.58	0.43
Sub total for Processing	**3.18**	**3.18**	**2.34**	**0.99**	**0.62**

Source: Pineda 1997a, 1997b

SIMULATION RESULTS

Given 5 types of processing plants and 49 different plant locations, 245 possible combinations of processing plants are possible. GAMS was used to solve the cost

minimization model. The results of the main simulation are shown in Figure 4. Eight large Model 5 plants and seven small Model 2 plants meet the capacity constraints and minimize costs. A total initial investment of $667,000 is required to construct these plants.   These plants have a peak period capacity of 40,700 quintals of beans.

Figure 4: Base Simulation Results, Location and Type of Plant
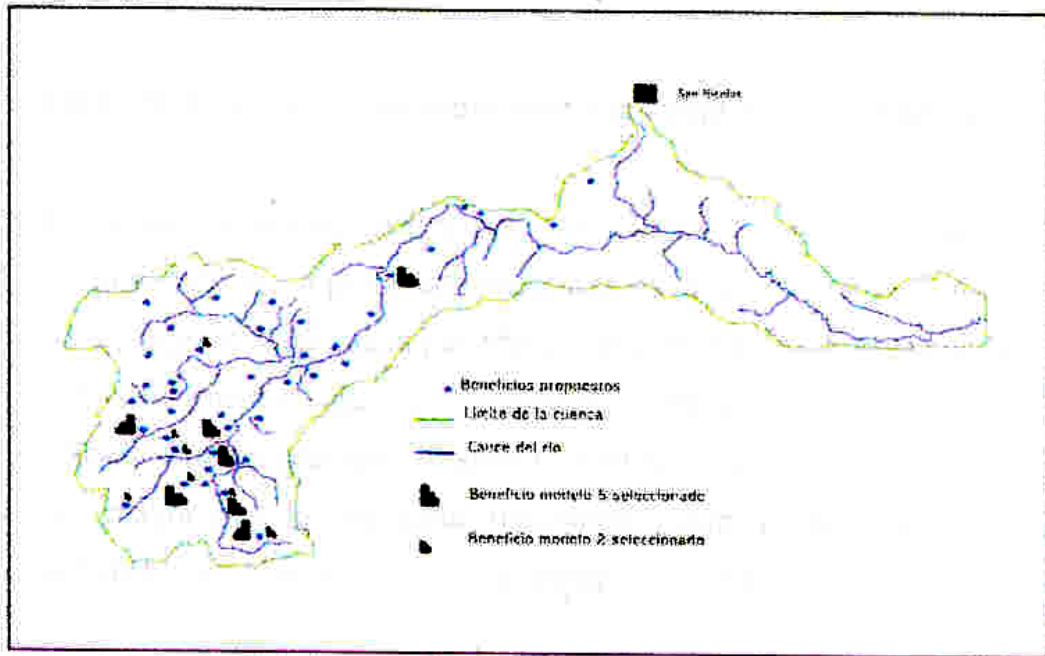
A second simulation analyzed the sensitivity of this optimized solution to a reduction in the initial investment. This second simulation solved the cost minimization model with an additional constraint of an initial investment less than or equal to $534,000. The results of this simulation are presented in Figure 5.

Figure 5: Results of Simulation with Reduced Initial Investment
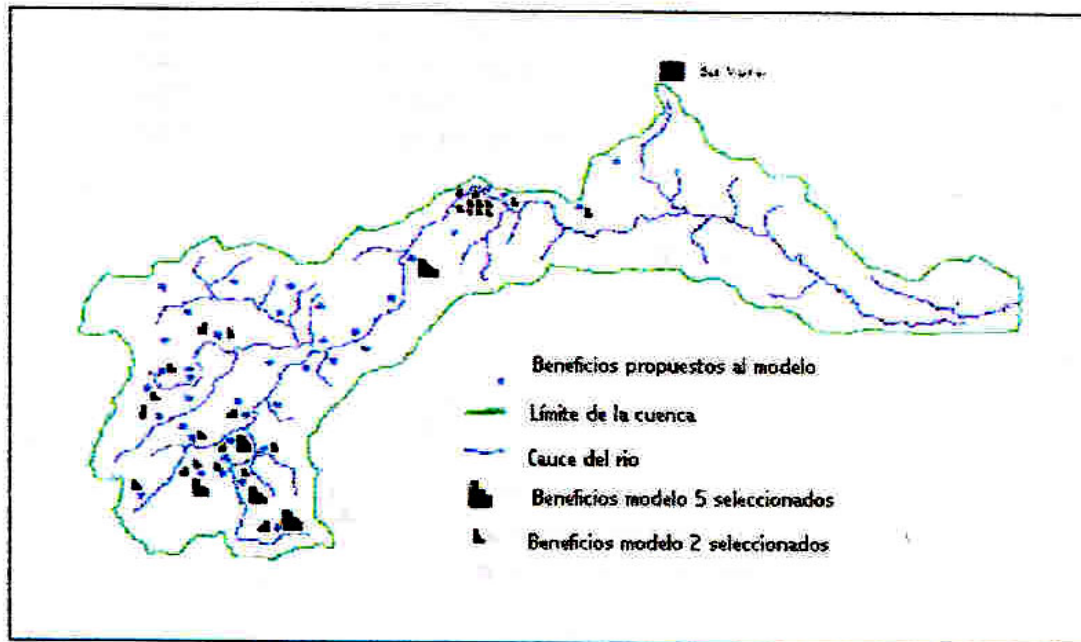
With the reduced initial investment, the cost minimization model produces 26 of the small Type 2 plants and 6 Type 5 plants. These plants can process 32,600 quintals of coffee during a 30 day period. Therefore only 80% of the harvest can be processed by these plants in the thirty day harvest period. This capacity shortage could imply either: 1) extended hours of operation in the processing plants; 2) extending the harvest period beyond the thirty day peak season; and/or 3) supplementing the centrally processed coffee with traditional processing that is without environmental controls and perhaps would be illegally processed. This third option could produce a quantity of coffee that is processed outside of the central processing system and is considered to be substandard coffee for household or local consumption. Because effluent reduction in Type 2 plants is not as complete as that in the larger Type 5 plants, the environmental improvement in this simulation will be less than in the original solution.

As noted data on water flows was taken from a 1997/1998 study, which can be considered to be a normal year for rainfall and water availability. An extended time series of water levels in this area is not available. However, water scarcity due to unusually dry years would greatly affect the coffee processing system. Figure 6 presents results of a simulation with 50% reduced water availability. With reduced water, the cost minimization model presents 4 Type 4 processing plants and 8 Type 5 plants. These processing plants utilize recycled water. The thirty day capacity of these plants is 44,000 quintals.

Figure 6: Simulation Results with a 50% Reduction in Water Availability.
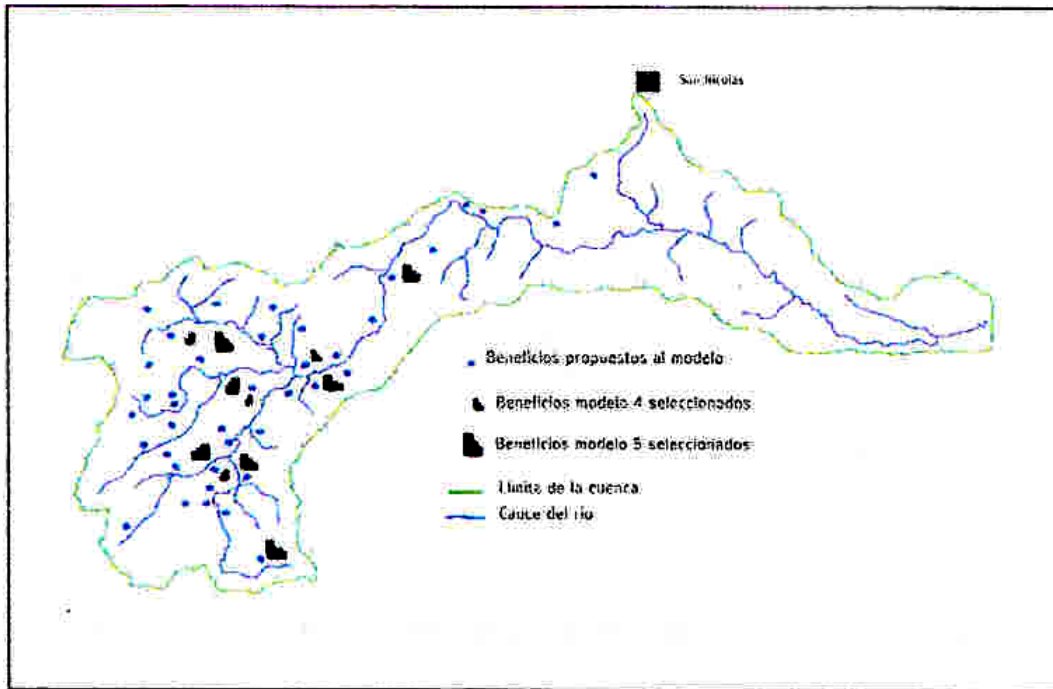
FINANCIAL INCENTIVES

A necessary condition for the success of a centralized system of processing is the presence of financial incentives for all of the participants in the coffee producing and marketing system. The centralized processing system with environmental controls will certainly produce benefits to all residents of coffee producing watersheds, including those in downstream zones where coffee is not produced. However, in order to gain their cooperation, farmers, processors, transporters, and middlemen need to be at least financially neutral between the current system and the proposed changes. Farmers will need to receive a price for unprocessed wet beans that compensates them for the loss of the value added that they receive from their own processing enterprises. And the new processing plants need to receive a price that covers all of their costs. The good news is that the new centralized processing system should allow for improved coffee prices on the international market.

In order to ensure the participation of the producer, the farm price of unprocessed beans should be greater than the farm price of processed beans less the variable processing costs. Fixed investments in decentralized processing are, for this analysis considered to be sunk costs that are not to be recovered. This implies that:

$$P_f^\gamma \geq \frac{P_f^\varphi Q^\varphi - VC_f}{Q^\gamma} \quad \forall f \tag{8}$$

where:

VC_f	=	variable cost of on-farm processing;
P_f^ϕ, Q^ϕ	=	farm price and quantity of quintal sacks of dry beans; and
P_f^γ, Q^γ	=	farm price and quantity of quintal sacks of wet beans.

Each coffee processing plant will need to: 1) pay farmers for their unprocessed beans; 2) cover their fixed and variable costs of processing; and 3) cover the transport costs from the farm to the plant and from the plant to the export depot. Thus the price that the processor receives from the exporter should conform to:

$$P_p^\varphi \geq \frac{P_f^\gamma Q^\gamma + TC^\gamma \, dis_{f,p} + TC^\varphi \, dis_{p,e} + VC_i Q^\varphi + FC_i}{Q^\varphi} \forall_p \forall i \tag{9}$$

where:

P_p^ϕ = quintal price of processed beans delivered to export depot.

Given that all producers and processors should receive financial rewards that would sustain their activities; the financial analysis utilizes data from the most costly option or least advantageous alternative. Thus in equation (8), data representing the in-farm processing plant with the highest variable costs is used. This corresponds to the smallest scale processing system used in the 92% of farms with less then 7 has. Data for equation (9) represents the greatest farm to processing plant distance, as well as the most costly processing plant that has emerged from the simulations, Type 2. The use of these parameters ensures the analysis of a Pareto Superior situation, where all farmers are at least better off, and all processors will have a positive return on there investments.

Table 4: Financial Analysis of Returns to Farmers and Processors

	Item	Source or Formula	$
a	2000 Variable Processing Costs Plant Type 1	Pineda 1997a	16.67
b	2000 Harvest Costs	Pineda 1997a	12.11
c	2000 International Price	IHCafe	75.00
d	2000 Penalty to Honduran Exports	IHCafe	12.00
e	2000 Farm Price for Processed Beans	local interviews	56.67
f	2000 Intermediary Cost	c-d-e	6.33
g	2000 Returns to Plant and Management	e-a-b	27.89
h	Necessary Farm Price for Unprocessed Beans	g+b	40.00
i	Transport Cost for Unprocessed Beans 25 km	local interviews	1.25
j	Transport Cost for Processed Beans to Depot	local interviews	2.80
k	Fixed Cost of Processing Plant Type 2	Pineda 1997a	12.31
l	Variable Cost of Processing Plant Type 2	Pineda 1997a	3.18
m	Necessary Depot Price for Exporter-Processor	h+i+j+k+l	59.54
n	Necessary Export Price	m+f	65.87
o	Necessary Incentive if $12.00 Penalty Remains	-(c-d-n)	2.87
p	Financial Gain to Sector if Penalty is Avoided	c-n	9.13

As shown in Table 4, a Pareto superior solution is feasible if the $12.00 per quintal price penalty is eliminated. This can be attained through improved product quality and quality control. With this improved price, all farmers in the sub watershed maintain their profit margin and all processors can cover their costs.

If the penalty is not removed a $2.87 per quintal incentive is required to improve river water quality, and maintain all current producers.
 A lesser incentive would be needed for farmers who have lower transport costs or other advantages.
If penalty is removed a benefit to the coffee sector of at least $9.13 per quintal would be realized[6].

CONCLUSIONS AND OBSERVATIONS

A necessary condition for the successful implementation of a centralized coffee processing system with environmental controls is sufficient financial incentive for all of the participants. Hopefully the increased costs of pollution mitigation can be covered by

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[6] This implies that the $5.00 price penalty that was implemented in 2001/2002 has been sufficient to cover the additional costs of centralized coffee processing and allow for a Pareto superior proposal.

an increase in the export price that producers receive. If this is so then a Pareto Superior solution is reached, and Honduras can improve its river water quality without risking the viability of small-scale coffee production.

The solution of the cost-minimization problem features two types of processing plants, Type 2 and Type 5. An initial investment of $667,000 is required to construct the required plants. When the initial capital invested in the system is constrained, the capacity of the resulting plants to adequately process peak period harvests is threatened. When a water scarcity constraint is proposed, Type 4 and Type 5 plants which recycle water are selected.

This research presents coffee processing as a social planner's problem, with an optimal solution based on transportation and processing costs. This addresses one of many necessary conditions for the success of centralized processing. Although the coffee growers in the Rio Frio watershed informally expressed their support for centralized processing, and although this has been identified by IHCafe as a priority, not enough is known about the impacts of the loss of coffee processing on the household production system. Further research on the role of coffee processing within the household, and the alternative uses for household labor and capital should be further explored.

The proposed plan does not address the organization of the coffee processing system. Certainly the state can impose, and perhaps enforce, a technology standard for coffee processing. However, it is doubtful that the state will take charge of administrating new plants. There is a tradition of coffee cooperatives and these might be capable of operating the processing plants. Or private sector investors might enter into this enterprise. Also, coffee processing could be a concessionary system or a full competitive one. Development banks, such as the Central American Development Bank or the Inter-American Development Bank may be interested in financing this system.

If processing plant locations are to be determined by decentralized actors responding to market signals, this cost minimizing approach would loose much of its relevance. If location decisions will be determined by a consensus between farmers organizations and the private sector such tool will be useful to take a more informed decision. For this reason, IHCafe has shown interest in the development of this cost minimization model for all of Honduras.

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