**Trade-off between economic efficiency and contamination by Coffee Processing**

**A bioeconomic model at the watershed level in Honduras**

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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 lower cost.**

**Keyword : coffee, environment, water quality, mathematical programming, transport cost, spatial analysis, watershed, Honduras**

# INTRODUCTION

**Coffee is the most important export crop in Honduras. Up to 250,000 hectares are cultivated by 85,000 small-scale producers located in the Hillsides. 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 unsuitable for the production of the other major crops in Honduras. 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. This situation helps reducing poverty and has been a key factor in diffusing Central American civil wars in the seventies and eighties.**

**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 the 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 eutrofisation, 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 in direct relation of to the quantity of coffee processed and the processing technology (Jacquet, 1993).**

**Because coffee processing in Honduras is decentralized exporters are unable to guarantee a standardized product that meets the quality standards that the international market demands. Importers apply a price penalty of US $12.00 for each 16 Kg sack of Honduran coffee. Only a few Honduran cooperatives that can guarantee quality through centralized processing don't get this penalty.**

**To improve coffee quality the Honduran Coffee Institute (IHCafe) is promoting the idea of centralizing coffee processing in modern large 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. Ihcafe has approved five processing technologies that are 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 to centralized production.**

**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. The third section of this paper presents a minimum cost optimization model for a pareto superior system of centralized coffee processing. The fourth section presents the results of a spatially optimized linear programming model with a sensitivity analysis for added restrictions.**

## 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 Honduras over 90% of Honduran coffee is processed by individual small-scale farmers. Of the estimated 85000 Honduran coffee producers, 44000 process coffee themselves using inefficient traditional technology. They 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 than by efficiency. Because of bad management and corruption most of these plants failed, and only three plants are still processing.**

**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 streams are highly contaminated during the processing periods from December to April. Since processing plants do not include effluents control residues are emitted directly into the rivers and streams adjacent to the plant without any treatment (Jacquet 1993, González 1996; Pineda 1997; Echeverría 1998). 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, et al 1994, Osorio,1997). Furthermore, the contaminated water by coffee is twice as acidic as household wastewater.**

**The wastewater is less contaminating than the more gelatinous byproducts of depulping 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 et al.1998). 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 worsening the contamination (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 then 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).**

## INPROVING COFFEE PROCESSING

**IHCAFE's wants to improve the current system of coffee processing by introducing a network of environmentally controlled processing plants. This system of processing plants would: i) reduce water pollution; ii) reduce water consumption during processing; iii) improve the product quality ; and iv) facilitate improved export prices. 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, we estimate the minimum cost of the system and later we estimate the financial**

**incentives to each type of participant. This study does not address how this network of processing plants should be initiated nor who should own and operate these plants. We concentrate on the determination of the best location and the most appropriate type of plant.**

*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**

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

**In order to minimize:**

$$\sum_{i,f,p,r}(FC_i + VC_i + \sum_{p,e} TC^{\gamma} dis_{f,p,r} + \sum_{p,e} TC^{\phi} dis_{p,e,r})X_{i,p,r} \quad \textbf{(1)}$$

**With:**

| | | |
|---|---|---|
| $i$ | = | **plant type (1 to 5);** |
| **f** | = | **clusters of plantation (1 to 17);** |
| **p** | = | **processing plants location (1 to 7);** |
| **r** | = | **river segments (1 to 7) ;** |
| $FC_i$ | = | **Annualized fixed cost per quintal for each plant of type *i* in $;** |
| $TC^{\gamma}$ | = | **Transport cost per km per quintal of wet bean in $ ;** |
| $TC^{\phi}$ | = | **Transport cost per quintal per kilometer of dry bean in $;** |
| $VC_i$ | = | **Variable cost for each type of plant *i* in $;** |
| $dis_{f.p.r}$ | = | **Distance from the field to the plants in kilometers;** |
| $dis_{p,e.r}$ | = | **Distance from the plants to the buyer in kilometers;** |

**Subject to the following restrictions:**

$$\sum_{f} prod_{f,r} \leq \sum_{i,p} pros_i X_{i,p,r} \qquad \textbf{(2)}$$

**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;**

$$\sum dist_{f,p} \; X_{i,p,r} \leq 25 \qquad \textbf{(3)}$$

**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;**

$$WATER_r \geq \sum_{i,p} water_i X_{i,p,r} \qquad \textbf{(4)}$$

**Water consumed in coffee processing does not exceed the water available in the river during the peak period (which corresponds to the low flow periods);**

$$\sum_{i,p} cont_i \;\; X_{i,p,r} \leq Contm \quad WATER_r \qquad \textbf{(5)}$$

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

$$\sum_{i,p,r} inv_i \ X_{i,p,r} \leq Inv \qquad \textbf{(6)}$$

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

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

**X is an integer variable.**

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

*New plants with environmental control*

**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 depulping, and low energy use (Urive et al., 1997, Jacquet, 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. 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 bags per hectare.**

**The Rio Frio subwatershed can be divided into 7 river sections (see Map). Data on water availability is based on measurement of the stream flows by Pineda et al.(1998). This provides data on water availability in the Río Frío from October 1997 to May 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.**

**Figure 1**

**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. This is a fair assumption because the principle activity in the sub watershed is coffee production and this activity is assumed to be constant in most of the model's simulations. 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.**

**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 peak period determines all the estimates for the processing: Size of the installation; type of plant to construct; 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.**

## SIMULATION RESULTS

**We ran different scenarios to get a better estimate of the sensitivity of the model to external factors. We changed the upper limit of the investment, different contaminant discharge limits, different water volume and different coffee production. The result of the first simulation is shown in Figure 2. 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 2**

**We ran an alternative 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.**

**The centralized processing system increases transportation costs, because wet beans are heavier and cost more to transport than dry beans. 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.**

## CONCLUSIONS AND OBSERVATIONS

**This study addressed coffee processing as a social planner's problem, with a optimal solution based on transport 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 explored.**

**A necessary condition for the sucessful 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 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 institutional setting of the coffee processing also needs to be determined. 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.**

**If plant locations are determined by the market the current tool will loose of its relevance. In case the location will be determined by a consensus between farmers organizations and the**

**private sector such tool will be useful to take a more informed decision. IHCAFE the Honduran institute of coffee wants the model to be applied to whole Honduras.**

**To minimize the cost of transport and processing within the watershed it would require an investment of $660,000. The transport cost would be of $138,000. The model proposes to reduce the plants from 1137 to 8 plants.The optimal number of plant of type 1 is 8 and plants of the type 2 is 7. The economic incentive to stop processing in the farm is $5.73 by bag per year. The premium for a better quality coffee is $17 which is much higher. The processing can be cost effective. It will be possible to increase the production in the area especially with new types of plants. The stream flow in the stream during the processing period is still sufficient. The project can run even if the**

**current volume of water is divided by two.**

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**Figure 1. Río Frío watershed and subwatersheds where the stream flows were measured**

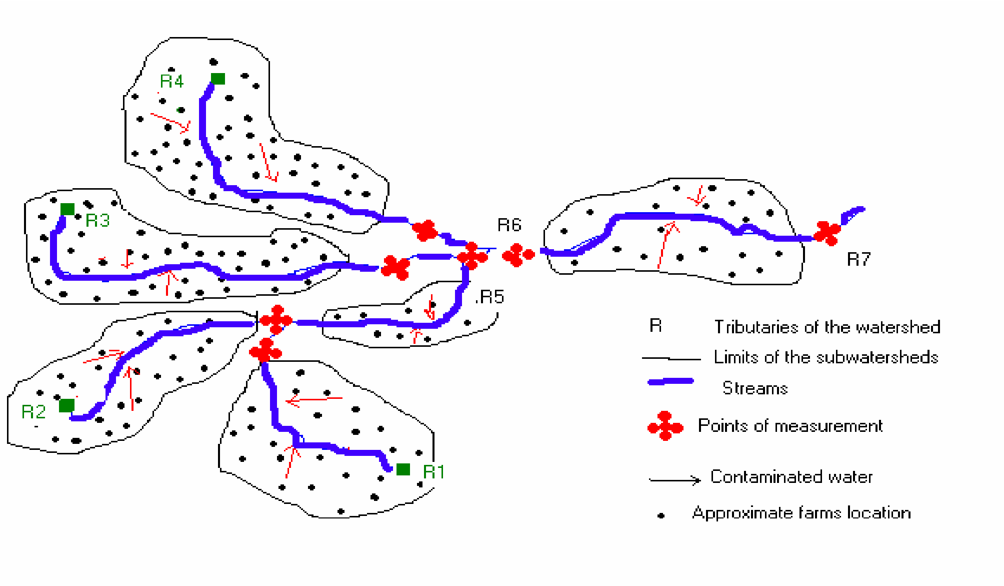


**Figure 2: Base Simulation Results, Location and Type of Plant**