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BEYOND THE WATERS: TOWARDS WATER RESOURCE MANAGEMENT IN PERU

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Beyond the waters: towards waterresource management in Peru *)

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1. Introduction

Although modern technology has contributed considerably to solving problems of water scarcity, in many areas of the world situations are shaping up in such a way that they will turn into problems or near-disasters in a number of years. The Sahel countries are an example where matters have gone too far, but it is relatively simple to list other situations where water problems have arisen already: the Brazilean Northeast, the city of Bogotá, and that of Quito - thinking of South America only - are examples indicative of what we have in mind.

Basically, these problems can be resolved, but the solutions must be considered the result of an extremely complex process of decision making. Partly, this is due to the circumstance that a number of effects of certain measures can only be observed in the long run (e.g. the effects on a riverbasin's ecology of diverting part of its waters to another watershed), partly this is caused by the long gestation period characteristic for major water management projects and partly this is related to the fact that the problems concern the interrelationships between natural resources, ecological conditions and demographic and economic phenomena.

This paper addresses itself to this problem as it has been tackled in the case of Peru, where problems are showing themselves. In Peru, the nature of the water problem very much depends on where one finds himself. As most readers will know, the coastal area of Peru would be a virtual desert if not so many irrigated lands would be found in this part of the country. They exist there by the grace of a number of rivers that come down the western slopes of the Andes into the Pacific (see map 1). Most of Peru's urban population is found there and their demand for urban uses (households, industry, etc.) is becoming an important competitor for agri-

*) The author is grateful for suggestions by Bert Helmsing, of the Institute of Social Studies and he expresses admiration for Koos van Wieringen's fine maps.

cultural uses in the nearby irrigated areas. In fact, the same holds in many places for agricultural and urban demand for land. In the Sierra, the situation is different, at least in that there exists as yet no competition between urban and rural water users. In many places, however, agricultural output could increase considerably if irrigation works were constructed, most of which would not have to be major ones. The eastern slopes of the Andes - especially the area called Ceja de Selva - have many areas with good deep soils and plenty of rainfall. Many of the tributaries of the Amazone river find their origins there and they bring an abundance of water to the third of Peru's natural zones: the Jungle or Selva.

Thus we see that water resource development and management problems in these three natural zones differ widely: on the Coast a shortage may eventually develop due to the growth of the population and of industrial activity, while water reserves in terms of water resources not yet tapped for either agricultural or urban uses become more and more scarce. In the Sierra, although water is available, it is not sufficiently developed as a means to improve people's living conditions, whereas in the Selva, there is an abundant supply but hardly any demand. Seen in this way, the water resource development problem in Peru requires for its solution a study of the long term distribution of the population. If migration from the Sierra to the Coast continues as it has done over the past 40 years, there is no doubt that the stage of a serious water problem will approach rapidly. Poverty in the areas of origin of these migrants contributes strongly to the causes of this migration, while their poverty is to a large extent explained by the small size of their land holdings and the backwardness of their agricultural production techniques.

This paper reports on an effort of water resource planning that has been going on since 1974. Because a very great number of aspects has to be dealt with when such a plan is made (and revised), it is necessary to limit this report to one aspect: the determination of demand for urban and agricultural uses.

In 1976 a document describing the methodology for a plan to develop Peru's water resources appeared.[1] It constitutes the result of an interesting effort of cooperation between various government organizations in Venezuela and Peru, that was financed by the two governments and the Organisation of American States while counting with the cooperation of the InterAmerican Centre for Integrated Water and Land Development. Major organizations on the Peruvian side were the National Planning Institute (INP), the National Office for Natural Resource Evaluation (ONERN), the Ministry of Agriculture and the Ministry of Public Health.

By then, various of these organizations had been working since 1972 on a number of aspects, such as rural water supply, water for irrigation, urban water supply, but very largely, these constituted isolated attempts, although INP was making efforts at coordinating them.

The general methodology developed in 1974/75 on which the cited document reported stipulated that the national water resources development plan would have to fit within a long term development plan. This plan would have to have both spatial and sectoral dimensions, and naturally it would have to take into account population growth and tendencies of the national economy. In other words, for certain purposes, a definition of sectors became necessary, as well as definitions of regions, all in such a way that available data would serve the purpose of the water resource development plan. The fact that the water resources plan had to be integrated into the national long term plan not only underscores the recognition in Peru of the importance of the above mentioned interrelations, but also that effective water resource management needs to be compatible with other long term goals. Thus it became necessary to specify objectives of sectoral and regional character, while respecting national objectives and constraints. At the same time, whatever results that were to be produced should provide the possibility to determine the demand for water

1) Plan Nacional de Ordenamiento de los Recursos Hidraulicos, Republica del Perú, Bases Metodológicas, Caracas-Lima, 1976, pp. 258.

by watershed or sub-watershed, for both urban and rural purposes.

The basic idea underlying the methodology is that water-resource development is a sectoral activity and that it should be placed within the framework of the central box in figure 1. The long term macro plans

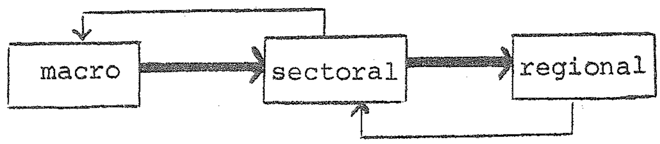

Figure 1: Three types of long term plans

would provide the initial framework for the sectoral plans (thick lined arrow), and these would in turn constitute the general objectives for regional plans. However, the more detailed information used to elaborate regional and sectoral plans can be expected to give rise to improvements in the sectoral and macro plans respectively (thin lined arrows). The water resources development plan would thus be a sectoral plan, that in its objectives and instruments would not only have to be consistent with those for other sectoral plans, but also with those of the macro and regional plans.

The water resources development plan proper was considered to have a demand side and a supply side. The demand side was to have a certain sectoral and regional specificity, because the various forms of demand require for their satisfaction specific types of supply.

The INP took upon itself to undertake the job of specifying demand. Together with ONERN and the Ministry of Agriculture it was able to identify 48 watersheds which in combination yielded eleven planning regions (see map 2). At the same time, a methodology was developed to estimate demand. The general outline of this methodology is as follows. On the basis of the long term intersectoral plan - which would provide preliminary totals for the labour force in agriculture and total output of this sector - a spatial breakdown according to watershed would be made, specifying for each of them employment in agriculture, land use, and demand for output, the latter being related - in a first instance - to a population forecast for the entire planning region in which a watershed is located.

The distribution of employment, income and demand over the national territory is based on a linear programming model, the general description of which will be the main subject of this paper. The results of this model were then to be used as inputs for the urban-regional model, which could answer the following question:"given total employment in agriculture in each region, given furthermore specific population growth objectives for each of the main urban centres for the 11 planning regions (including Metropolitan Lima) and total population growth in the country, which will be total employment (and population) in each region by city size?" Since population by region resulting from this model would not necessarily equal population numbers used in the distribution model, iterations were necessary to arrive at coherent results. Since demand schedules for agricultural products are different from region to region, given differences in income per capita and in eating habits, total output and employment in agriculture resulting from the second model would not necessarily coincide with those of the long term intersectoral model, also the latter would have to be included in an iterative process.

It seems fair to say, that the results that will be shown below,could not have been obtained if there had not been the combined efforts of a mathematician, an urban planner, various agronomists and economists and the gratuite cooperation a major computer company.

2. The production programme

2.1 General

Linear programming is in principle a relatively simple mathematical technique by which distribution problems (e.g. how many trucks, of what size, should be used to distribute the production of a factory in a given point to a number of sales outlets in a number of other points at given distances from the factory in such a way that total distribution cost is minimal and demand at each sales point is satisfied) can be solved. A linear programming model is characterized by the existence of some objective (a maximum benefit, or a minimum cost) that should be reached by the system that is taken into account. In the example that was just given, the system consists of total output of the factory, the demand at each sales point, the distances between the factory and the sales outlets, the loading capacity of each truck, the size and weight of each unit of output and the cost per km of transporting the output etc. and the relationships between all of these variables. In principle, there are many ways to solve the problem of our example: each of these constitutes a feasible solution. For each of these solutions we will e.g. find that a number of trucks of various sizes is required. However, each of these solutions implies a certain cost. A solution will be considered optimal if the objective is satisfied. The numbers and types of trucks will then have optimal values.

Linear programming is also characterized by the use of restrictions and boundary conditions. Restrictions normally indicate the maximum to which certain resources can be used. In our water resource management problem, this was the case with for instance arable land available in each of the watersheds. Boundary conditions are of a slightly different nature: they can be imposed by the programmer. Thus, in reference again to the transport problem example, he might require that trucks can load not less than 1 tonne. The model, of which a general description is following in this section has used boundary conditions with respect to social objectives of development. The activity programme that results in terms of the production programme and the programme of government measures would thus ensure that these conditions are met.

Investment in water resource development cannot be looked at in isolation, especially not in a country like Peru where conditions vary so widely from region to region. To develop an irrigation system in a given watershed means that a certain crop mix is chosen, which in turn implies for instance certain transport costs, storage facilities, investments in agricultural equipment and government expenditure on extension services. In addition it will require investment in land and in physical infrastructure. Many of these costs differ from area to area and from crop to crop.

Therefore, the objective function of the linear programming model that was used to identify the most desirable distribution of investment in water resources required that the annual sum total at the end of the planning period (1990) of amortization of investments in land, in agricultural machinery and equipment and in storage as well as the current expenditure related to extension services, fertilizer use, transport costs between watersheds for internally produced products and between Lima and other watersheds for imported and exported products should be minimum.

To deal with the cost of the programme in this way did not mean that a series of other objectives were sacrificed. On the contrary. The situation in the country did not allow for considering a truly minimal cost programme. On the one hand, income per capita in rural areas was lagging behind that in urban areas with the result that migration towards coastal cities was increasing rapidly, while it was also becoming clear that the population of a great number of areas did not satisfy its basic needs in foods. On the other, the country became gradually a net food importer (beef, wheat), while its overall balance of payments was in disorder due to negative price movements for copper and zinc and the need to pay back development loans.

Therefore, for each watershed, normative demand for food figures were determined, so as to ensure that at least basic food needs would be met. Similarly, another boundary condition was introduced so as to ensure a considerable improvement in the distribution of income between regions. Whereas the data on overall income per capita differentials showed a relationship of more than 1 to 3 between the poorest and the richest regions[2], the figures for agricultural product per worker in

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2) R. Webb; Income Distribution in Peru, Washington, 1976.

in 1972 were considerably worse: putting the national average equal to 100, it was found that in the poorest region the index was equal to 35 while the highest figure stood at 383, almost eleven times higher.[3] The programme that was found feasible reduces these differences considerably, by requiring that in no region product per worker will be less than 60 per cent of the national average.

This implied, of course, that for each region specific measures would have to be elaborated. In some regions, the causes were to be found in the traditional production technology employed, so that extra attention by extension workers would be required, as well as additional distribution of fertilizers and better credit facilities. In other areas, these difficulties were compounded by extremely small holdings and the absence of irrigation facilities. The latter problem might be solved by water resource development, but the former could in some areas only be solved by migration of farmers to new land. Therefore, per watershed the size of a minimum family holding was determined, and indications of required migration of farmers became one of the results of the model.

Farming technology in Peru is distinguished in three types: "empirical", "semi-technical" and "technical". The "empirical" type refers to traditional farming, with few and low quality inputs. The "technical" type can be considered as modern farming and it is found especially on the Coast. The other type lies between "empirical" and "technical". For each of these levels it was possible to elaborate coefficients indicating the inputs of labour, equipment, fertilizers etc. per hectare, as well as the amount of produce per hectare. Also, it was possible to determine the cost in terms of extension service of bringing technology from one level to the next. Since the programme would have to produce at least an overall value of production equal to that of the intersectoral plan with at least the number of people employed indicated in this plan, a central problem arose in the elaboration of the

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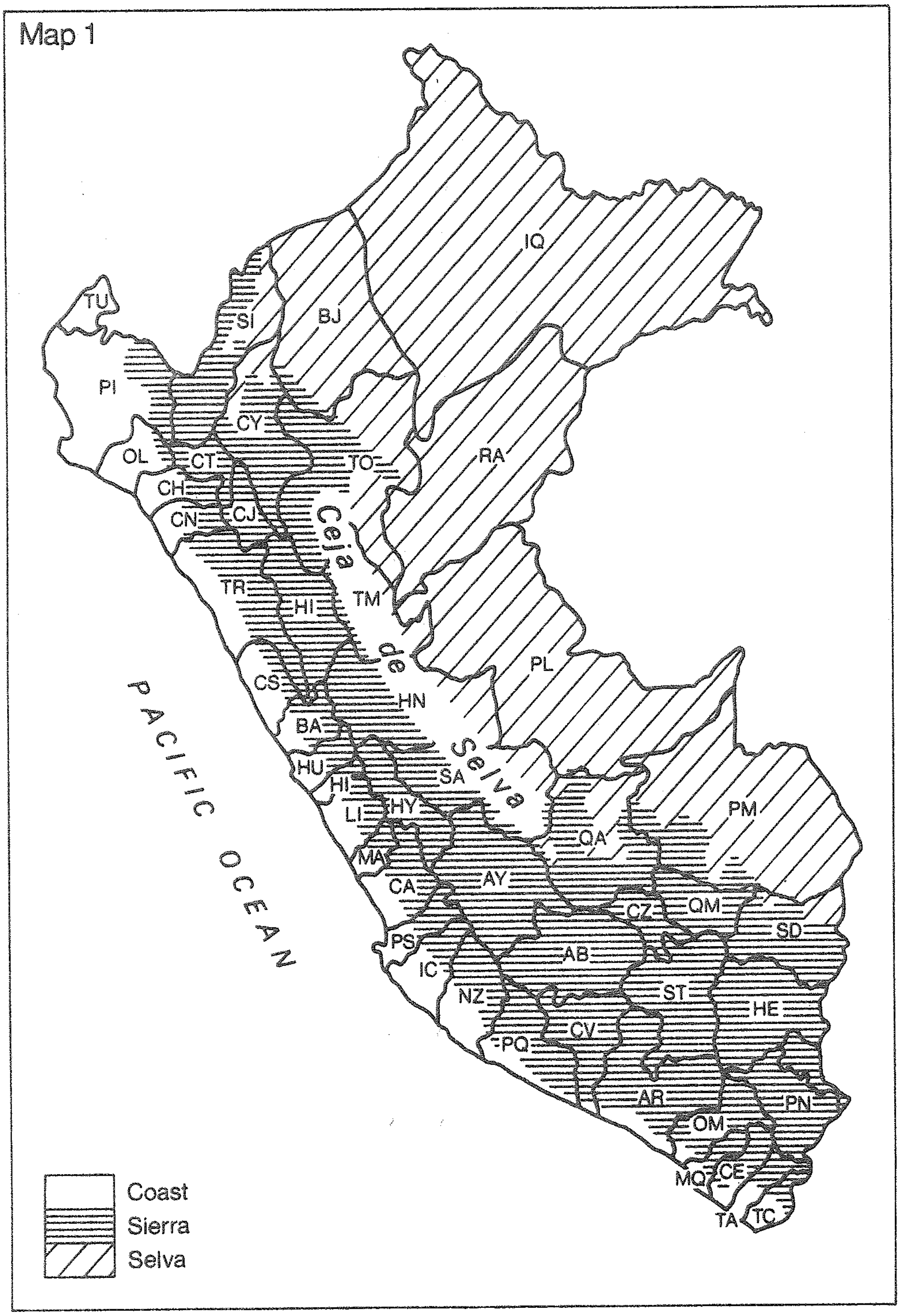
3) INP: Modelo Prospectivo, Informe al Horizonte 1990, p.228

Natural Regions of Peru



programme. With the need to increase product per worker in the majority of watersheds, the model selects in favour of labour extensive technologies (low input of labour per hectare) and high value added crops (high value added per hectare). High value added crops are especially those that allow the double or triple use of a hectare in a single year (maize and potatoes; vegetables; maize and soya). Low labour input technologies are generally either of the empirical type and therefore often also low value added (beans), or they become high cost (the combination of potatoes and yellow maize). The effect is that although the boundary condition concerning overall value of production can easily be met, this is not the case with that for overall employment. This is caused, it was found, especially by the income distribution requirement mentioned before and the need to keep the cost of the overall programme at a minimum.

2.2 Land

Three types of land use were distinguished: agriculture (including fodder crops), natural pastures and forestry. ONERN had prepared a land capability map for each watershed, indicating the crops that could technically be grown. For some crops, upper limits showing the maximum number of hectares that could be used for the various crops, were indicated. For each watershed, it was required that agricultural land would have at least the same surface at the end of the planning period, while for each area a maximum of land to be developed was fixed. In virtually all cases, this maximum was determined by agro-technological criteria. Inasfar as natural pastures are concerned, their area was required not to increase, that is to say, that in some cases it might be converted into irrigated land. The area of forest land under management of the Ministry of Agriculture was to remain at least equal, while possible increases were tied to a maximum imposed by land capability.

2.3 Labour

In view of what has been observed in section 2.1 employment in agriculture and forestry in a given watershed was tied to a maximum. In other words, larger than minimum family holdings were allowed in the model, while lower sizes were not. In addition, the total national labour force in agriculture was required to be at least equal to that resulting from the sectoral model. In order to ensure a modernizing agriculture, the number of people in a watershed working at the technological level "empirical" was not allowed to increase, while those working at the level "technical" were required to remain at least constant.

2.4 Demand for agricultural products

Two types of agricultural and forestry products have been distinguished: so-called industrial products (wood, sugar, wool, coffee, tea, etc.) and other products (including e.g. potatoes, beef, chicken, eggs, etc.). For industrial products, projections of demand were made based on the intersectoral plan and on other data. For both types of products (industrial and other) export demand projections were made on the basis of the generally accepted methods. For the other products, a different approach was taken. As indicated before, for each of the 25 agricultural and animal husbandry products a watershed-wise estimate was made of a balanced basic diet per person. These estimates have been elaborated with the help of a dietist and showed considerable divergence from area to area. The programme was required to make available at least this amount of food.

However, given the income differentials as between regions, it has to be expected that market demand will at least be higher in those areas where income is higher. Therefore, for each of the 48 watersheds and each of the 25 products estimates were made on the basis of income-elasticities for per capita demand. Since in all regions a majority of people consumed more than basic food needs, total demand per capita per watershed had to result in a figure above the minimum.

Since exports are given and the production of certain crops is limited either by natural conditions or by its costs, imports for all products, with the exception of wood, were allowed in the production programme.

Another element in bringing about a balance between supply and demand for agricultural products is transport. The model allows the movement of commodities from one watershed to another, the costs of transport being determined by the distance between main centres of watersheds and the nature of the product. The national total of transport costs is an element of the objective function.

2.5 Investment and other issues

In this paper - which attempts to focus on the main lines of thought behind the planning effort and not on the technical aspects of the linear programme - no attention will be paid to the problem of extension, of prices (these were kept constant) or to specific issues related to storage, fertilizers etc. However, some observations must be made concerning investment in land.

In Peru, investment in agricultural land on the Coast means investments in developing water resources. In many parts of the Sierra the same holds. Only in the Selva and in certain parts of the Sierra is land development a matter of mainly other infrastructure such as roads and other facilities. At the time the model was developed, a series of land development projects were under execution or had been contracted. Since the programme for the final year had to take into account these projects, the programme assumed that land availability by watershed included all this related new land. Production on these roughly 270.000 new hectares could, on the basis of experience, be assumed to have the highest level of technology. Investment in land under the programme would thus refer to new projects, at least, to projects to which the government had not tied itself already and which could be in production before 1990.

For each of the watersheds the per ha cost of developing suitable land could be determined, keeping in mind the indivisibilities characteristic for irrigation works. However, it turned out impossible at this stage to include the benefits of multipurpose projects. Investments per ha for each watershed for the development of new land were reduced to a current cost category by determining amortization and interest on the basis of a 50 year life time for irrigation works and a 10 year life time for roads. Similar operations were made for storage facilities.

The current cost category was selected in order to obtain comparable elements in the objective function. Financing problems have thus not been considered, although total investment over the period 1979-1990 could be calculated.

3. Results

Some of the main results will be summarized in this section. Table 1 refers to demand for some major agricultural products.

Table 1 - Consumption per capita for main products, 1972 and 1990
(soles of 1972)

product	1972	1990	product	1972	1990
potatoes	360	589	sugar	217	238
rice	138	169	beef	226	504
banana	78	116	milk	383	692

Source: see footnote 3, p. 162

Obviously, living conditions would improve considerably if the programme were to be executed, and the interesting aspect is that none of these products would have to be imported. This is not the case with wheat, however. Whereas in 1972 wheat imports stood at 2,500 million soles, the 1990 figure would be 6,400 million soles of 1972, or roughly 2.5 times more. This is largely due to climatological conditions and to eating habits in the country. In fact, the programme advises against the production of wheat: although total output can increase, the area under wheat should be decreased, because more profitable crops can be grown on these lands. On the other hand, the results indicate that sugar is a very attractive crop: the total cost of the programme would decrease considerably if ecological conditions in areas like Arequipa, Huánuco, Tarapoto and Tingo María would permit.

Employment in agriculture would not increase much under the programme: less than 12.000 new jobs would be created in the period between 1972 and 1990. However, this is to a large extent due to changes in productivity. While in 1972 almost 70 per cent of all farmers were working at the lowest level of technology, by 1990 their number would go down to 24.8 per cent. The number of farmers working at the highest level would increase from 147,000 to 814,000.

It is clear that this would require a major effort on the part of the Ministry of Agriculture in terms of extension. By 1990, the budget for extension would have to be increased by 128.4 million soles for the Coastal area, by 311.3 million soles for the Sierra and by 126.9 million for the Selva region, all in soles of 1972. Thus, more than half of the increase would have to go to the Sierra, an area that has traditionally been neglected.

The increase in overall productivity of labour and the decrease in regional productivity differentials is accompanied by an important effort of land development. The programme shows that some 450,000 hectares of new land would be required. In view of the current Peruvian government policy, which favours development in the Selva, it is interesting to notice that the model selects against the Coast and strongly favours the Selva, where 390,000 has would have to be opened up. The remaining 60,000 has are located in the Sierra and constitute half of the available and as yet untilled land in this natural zone. Nevertheless, in most areas, expansion implies using the maximum of available land. It is understandable that the programme favours land in the Sierra: the cost of development is the lowest per hectare and the Sierra is centrally located.

Also the area managed by the forestry department is required to increase considerably: it should go up from 722,000 has in 1972 to 1,535,000 has in 1990.

Meanwhile, the programme implies a use of the country's land and waterresources that would lead to a more pronounced regional specialization. This can be observed in Table 2. The Sierra specializes in potatoes and wheat, at considerably

Table 2 - Hectares under main crops by natural zone, 1972,1990 (x 1000)

Natural zone	Potatoes		Rice		Cotton		Sugar		Wheat	
	'72	'90	'72	'90	'72	'90	'72	'90	'72	'90
Coast	6.7	-	69.3	50.4	124.8	151.7	132.3	191.1	2.7	-
Sierra	262.8	170.4	0.3	-	0.1	-	0.5	-	132.2	87.2
Selva	1.4	2.8	48.4	99.0	2.6	126.5	-	15.9	-	-
Total	270.9	173.2	118.0	149.4	127.5	278.2	132.8	207.0	134.9	87.2

Source: see footnote 3, p. 177

higher levels of productivity per hectare than in the past, while rice and cotton become typical products for the Coast and the Selva. However, the main crop for the Selva would become banana (plấtano) , a tree crop that would take full advantage of ecological conditions.

As observed before, the main areas that would have to be developed are located in the Ceja de Selva especially, in the watershed areas of Tarapoto (211,000 has), Tingo Maria (20,000 has), Huấnuco (87,400 has) and Puerto Maldonado (54,600 has).

The results of the linear programming effort thus are of threefold nature: (i) they indicate where which number of hectares should be in production by 1990 if the various objectives are to be met; (ii) they indicate where the government should take which specific measures to these ends, both in terms of investment and current expenditure, and (iii) they indicate where Peru's rural population would be living. Therefore, the model also provides the basis for estimates of demand for water in rural areas by 1990.

4. Urban demand for water

The agricultural employment figures resulting from the linear programming model could be turned into total normative rural employment estimates by watershed on the basis of general data for well-developed rural areas in Peru. They were then summed by planning region and provided an input into the urban-regional model that was to provide data on urban population by planning region and city size.

The eleven planning regions are shown in map 2 and the results of the normative projection are given in Table 3. It will be noticed that for most regions the rural population would decrease under the programme, a result that seems in line with the tendency in most Latin American countries. However, in the areas of land settlement like Selvatico Norte, Huancayo, Pucallpa and Iquitos, sometimes considerable increases would have to take place.

Table 3 - Rural and Urban Population by Planning Region, 1972 and 1990
(1000 of persons)

Planning Region	1972		1990		Percentage change	
	Rural	Urban	Rural	Urban	Rural	Urban
Piura	484.2	445.7	446.1	950.0	- 7.9	+ 113.1
Chiclayo	838.0	416.4	1,460.0	1,460.0	- 1.0	+ 250.6
Selvatico Norte	155.0	111.9	430.0	430.0	+145.0	+ 284.3
Trujillo	757.4	678.5	1,785.0	1,785.0	- 26.8	+ 163.1
Huánuco	1,165.0	431.3	1,165.0	1,165.0	- 15.1	+ 170.1
Ica	315.2	230.9	617.5	617.5	- 30.7	+ 167.4
Huancayo	830.4	266.3	1,070.0	1,070.0	+ 12.4	+ 301.8
Arequipa	1,703.8	793.9	2,470.0	2,470.0	- 22.8	+ 211.1
Pucallpa	63.5	73.3	410.0	410.0	+ 20.5	+ 459.3
Iquitos	142.5	129.9	545.0	545.0	+ 16.1	+ 319.6
Metropolitan Area	42.4	3,254.6	6,500.0	6,500.0	- 71.9	+ 99.7
Totals	6,705.4	6,832.8	5,920.4	17,402.5	- 11.7	+ 154.7

Source: See footnote 3, p. 278

The total rate of increase of population over the period 1972-1990 has been estimated at approximately 3.1 per cent per annum in line with official estimates. Urban population growth would be considerably higher: about 5.3 per cent. In most of the planning regions, the increase would be faster, however, this being due to the relatively low rate of growth that has been projected for the Metropolitan Area of Lima (3.9 per cent).

Of the total urban population more than 66 per cent would be living in centres over 100,000 inhabitants. However, in order to considerably improve access to services for the rural population, the number of centres between 5,000 and 20,000 would have to go up by by 237 from 1980. In these small urban centres almost two million people would have to be living by the year 1990. It is clear that these new centres would have to emerge especially in the areas of new land settlement.

With the results for the urban-regional model (which was largely based on urban economic base theory and normative estimates with regard to services activities in the various types of cities) it became possible to provide demand estimates for urban water by region and by city. Since each city could be identified also with respect to the nearest watershed, the population estimates provided valuable inputs for the water resource development plan.

5. Conclusions

The rural and urban water demand estimates resulting from the two models will have to be confronted with the supply that is or can be made available in each watershed. Cost estimates for the development of water resources for urban uses will have to be made for each of the regions and ways must be found to bring supply and demand in balance by 1990. It is well possible that bottlenecks on the supply side would require changes in the demand side.

Water being such a precious resource and its management therefore so important, this deserves the kind of complex studies that have been made in Peru. Now that the investments in the various methodologies and models have been made, adjustments on the demand side can easily be determined, whenever new problems emerge on the supply side. This requires, however, that data collection continues and that institutional cooperation remains intact. This, in turn, requires job stability for the people skilled in these intricate activities.

Planning Regions in Peru