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WATER RESOURCES OF CHILE: AN ECONOMIC MODEL

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The occasional note of petulance found within the pages that follow reflects the author's perplexity over the fact that Chile is an undeveloped economy but Chilians are not. Chile does not need foreigners to tell it what to do; Chile has economists, engineers, scholars, and scientists Moreover, these people are not isolated but move back and forth between the government and the universities. A single sojourn in Chile of eighteen months provides a snap-shot rather than a moving picture. For this reason the writer may inadequately appreciate the changes that are taking place or the rate at which change is occurring. The eighteen months in question, July 1964-December 1965, were especially interesting since they encompassed the election of a new government dedicated to social and economic reform.

The opinions expressed herein are solely the responsibility of the author; in several instances they run counter to those held by people with whom he has been closely associated.

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SETTING OF THE STUDY

Objectives of the study

The purposes of this study are first, to ascertain what is the
present state of water resource use, knowledge of water resources and
policies of water resource planning in Latin America; and, second, to
indicate how planning of water resource use can be related to national
economic planning. As a by-product it was hoped that the project would
serve as one of the needed bridges between engineers and physical scien-
tists on one side and economists and economic policy makers on the other
regarding the role of water in economic development.

Work already undertaken by CEPAL had shown that investment in water
resource projects--ranging from large multi-purpose dams to wells drilled
to meet the needs of a single user--accounted for a substantial share of
aggregate investment in most Latin American countries. Interest in water
resource planning has been high, since the pay-off in possible economies,
should such be revealed, might also be high. There has also been a
latent hope that a study of water resources might reveal opportunities
for economic development that hitherto had been overlooked.

It was quite clear from the beginning that, within the limits of
time and manpower that were available, the first objective could not be
accomplished for Latin America, but might be for one country. The second
and third objectives, since they are methodological, could also be met
by using a single country. The choice fell on Chile for several reasons:
it was close at hand, it had a long tradition of irrigated agriculture,

it had better hydrologic data than could be found elsewhere, except possibly in Mexico. In addition to the supply of raw data, other studies could be drawn upon. The first of a series of national water resource studies being carried on by CEPAL had dealt with Chile. The CEPAL study had stimulated several investigations by the Department of Planning in the Ministry of Public Works. There were, moreover, rumblings of possible changes in Chile's administrative organization, legal basis of water rights, and extension of planning into regional questions that encouraged the hope that a successful undertaking would find a receptive audience.

There is ample evidence that both national and international agencies are aware of the need for multiple purpose river basin development and in possession of the requisite skills to conduct whatever analysis might be necessary to accomplish the results. At the same time, and for the reasons suggested below, the several studies made within CEPAL and the Chilean government approached but never fulfilled the requirements of a systematic "model," no matter how rudimentally defined such a model might be. 1/

One reason for the deficiency is, of course, a lack of basic data. In the face of the fragmentary, uncertain, and often contradictory state of basic information regarding economic activity, techniques of water use, hydrologic measurements, and costs of developing water supplies, one might readily conclude that a comprehensive model of water resource

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1/ To the best of our knowledge, no other Latin American country has gone farther than Chile, and most have not gone as far.

use, no matter how primitive, is beyond the capacity of the analyst. For Chile, however, and possibly for other countries, a model can be constructed. The fact that it has not can be explained, perhaps, by

(1) failure to formulate optimizing or sub-optimizing criteria that would serve as the basis of a model;

(2) concentration of attention on river basin development, whereby each basin is treated as a micro-economy;

(3) the difficulty of making economic projections because

    (a) the historical record is short and subject to dis-continuous variations,

    (b) disaggregation of the economy into regional components has been given little attention;

(4) lack of governmental machinery to achieve the coordination needed for investigations of multiple uses served by a river system and for the planning, financing, and administration of such a system. Collaboration among the various Chilean water resource agencies is informal rather than formal, and extends only as far as each agency sees fit. 1/

There are many topics that should be included in a comprehensive report on the water resources of a country. This is not a comprehensive report. We grant little attention to matters of law and water rights, benefit-cost analysis of river basin projects, and administrative organization, nor do we dwell on past successes or failures of particular

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1/ After reading a preliminary version of this manuscript, Blair Bower, staff member of Resources for the Future, made the comments that additional factors to be considered are (1) failure to make explicit the problems of decision-making under conditions of uncertainty, (a subject to which Estevam Straus of the Instituto Latinoamericano de Planificacion has recently had under study) and (2) the difficulty of comparing the merits of investment in water resources with other forms of investment.

water resource projects. These questions are not wholly ignored; but having been treated, in more or less detail, in other studies already completed or currently under way, they are given only a passing nod except for the one or two instances in which our own investigation revealed information that had not previously appeared in print.

While this study is wholly concerned with Chile, it was the author's hope and the expectation of members of the Institute and CEPAL staff, that the results would have a high transfer value. Chile has served as a laboratory specimen. We hope to extend our studies to other countries until we are confident that we understand "Latin American" water resource problems. Since each Latin American country is sui generis, only the method of analysis can be transferred. But we cannot be sure of the transferability even of method until it has been accomplished, and this has not yet been done.

Order of presentation;

This report consists of three parts:

(1) a description of the economic model by which water requirements were projected to 1985,

(2) a discussion of the present state of water use and the state of information about water use from the point of view of what is required for the model, and

(3) results of the projections.

A Brief Word about the Geography of Chile

There is no reason why non-Chileans should be expected to have the knowledge of the geography of Chile that is necessary to understand its water resources, so let us hope that the publishers include a map showing provinces, mountains and major rivers. Chile is a beautiful country beloved by Chileans, but it is also a geographic curiosity. Its map, complete with provinces, looks like the spinal column of a man who has low-back trouble.

The climate of Chile ranges from very dry to very wet and from subtropical to polar. Continental Chile extends southward to 46 degrees; the rest is antartic to the south and insular far to the west. Climatic variation in going from east to west within continental Chile is extreme

enough for a _Santiaguino_ to pick an orange off a tree with one hand while holding a pair of binoculars in the other with which he can see the ski lift in operation at Farellones.

We have divided Chile into water resource regions, so bounded that watershed and political boundaries are coterminous or approximately so. A number of regions contain several independent streams; some regions only one. All rivers in Chile are relatively short; practically all of them flow from the Andes to the Pacific in a relatively straight line. [1]/

Continental Chile consists of twenty-five provinces and several dozen rivers, of which thirty-six carry significant quantities of water and, with one exception, have a usable record of flows. It is clear that water supplies can impose no constraint on the economies of the three archipelagic provinces of Chiloé, Aysén, and Magallanes. They and their rivers have been more or less ignored, although an occasional numerical value is assigned to them. Antartic Chile and insular Chile have been ignored completely.

What remains is eleven water resource regions, of which six are composed of a single province each (Tarapacá, Antofagasta, Atacama, Coquimbo, Santiago and Ñuble), two of two provinces (Aconcagua-Valparaíso and O'Higgins-Colchagua), one of three provinces (Valdivia, Osorno and Llanquihue), one of four provinces (Curicó, Talca, Maule and Linares), and one of five provinces (Concepción, Arauco, Bío-Bío, Malleco and

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1/ A few deviate from this pattern, but the deviation is inconsequential. For example, the Río Loa in Antofagasta forms a large U in the course of traversing the northern desert. In the south a river occasionally goes north and south (Río Petrohué).

Cautín). The similarity to a spinal column of the map of Chile is
heightened by its vertebral appearance when the provinces are shown
neatly stacked one on top of another. The three northernmost (Tarapacá,
Antòfagasta, and Atacama) and two southernmost (Aysén and Magallanes)
are relatively large. The remainder are comparatively small--on the
order of a county in New Mexico or Arizona.

The eleven water resource regions can be grouped into five larger
regions, as follows:

1. "Norte Grande" is the Chilean term applied to the two northernmost
provinces, Tarapacá and Antofagasta. They comprise one of the famous
desert areas of the world--a region whose aridity is challenged by few
other deserts. According to local residents, it "never rains." Ac-
cording to official statistics, average annual rainfall at Tocopilla,
for example, is three millimeters; at Antofagasta eleven millimeters.
However, years intervene between rainfalls. In the desert are oases
watered by streams that rise in the Andes. In some instances the oasis
is man-made and dependent upon aqueducts that carry water for a hundred
or so kilometers. Aqueducts supply urban and mining communities, not
irrigation. Farming takes place in the river valleys and accounts for,
at the very most, about one percent of the land area of the two provinces.
(Reported irrigated area in 1959 was 11,000 hectares; the provinces
measure about 90,000 square kilometers). The Province of Tarapacá, which
borders Perú, has two rivers whose flows have been measured, Lluta and
Lauca. No usable data were available for the Azapa.

The other province in the Norte Grande is Antofagasta which in the
past, was the main locale of Chile's external earnings, less so today.

Nitrate and now copper have been the main sources of Chile's foreign
exchange; and Antofagasta has been and remains the major source of both.
O'Higgins Province, South of Santiago is also a major copper center. In
the future Atacama may become important. In addition to mining, the
Norte Grande contains two manufacturing cities. Iquique and Arica in
Tarapacá are centers of Chile's fish meal industry; Arica is the center
of automobile and television assembly plants. The proximity of anchoveta
(a kind of sardine) in the waters of the Humboldt current may have
dictated the location of the fish meal industry in Iquique. Location of
the automobile industry in Arica is harder to justify. "No assembler
would have picked Arica of his own free will, but would obviously have
picked a spot in or near Santiago ---." [1] Should the economic require-
ments of the industry override the desire to foster the economy of Arica,
the industry would probably move south. Under these circumstances a
projection of urban activity of Arica is subject to considerable un-
certainty. Antofagasta has one measurable river, the Loa, which is also
the longest river in Chile. The open pit copper mine at Chuquicamata
is one of the world's largest. Beneficiation and smelting of copper are
carried on at several places within the province.

2. "Norte Chico" consists of the next two provinces, Atacama and Coquimbo,
each of which constitutes a separate water resource region. In Atacama
are the rivers Copiapó and Huasco. In Coquimbo are the rivers Elqui,

1/ Leland L. Johnson, Problems of Industrialization in Chile: Some
   Preliminary Observations, Memorandum RM-4794-AID, December 1965,
   The RAND Corporation, Santa Monica, p. 5.

Limarí, and Choapa. Both are transitional provinces between the desert
of the north and the mediterranean climate of the Central Valley. Both
are primarily agricultural regions, although there is some mining and
mineral processing. Atacama is likely to become a major copper producing
center in the future. The river valleys of the Elquí and Huasco are
famous for the grapes that go into pisco, a clear-as-water distillation
of grape juice. Fruits are grown. La Serena's chirimoyas command a
premium price in Santiago. Far up the narrow valley of the Elquí is
the town of Vicuña, where Gabriela Mistral, Chile's Nobel Laureate,
lived as a child.

3. The North Central Region: This geographic division contains two
water resource regions--Aconcagua-Valparaíso and Santiago--that form
the northern end of the Central Valley. The first region is composed
of the Río Aconcagua plus two smaller independent rivers, Petorca and
Ligua. Santiago province, which is a separate water resource region,
has approximately the same borders as the watershed of the Río Maipo.
In these provinces are the population center of Chile, the commercial,
financial and intellectual center, the seat of the national government,
the site of the 1966 ski Olympics, and one of the most famous summer
resorts and casinos of South America. In spite of the major urban con-
centrations around Santiago and Valparaíso-Viña del Mar, these regions
are major agricultural centers. The province of Santiago leads all
provinces in hectareage under irrigation, a fact that explains as well
as anything the reason for the city's dominance. Agriculture is sur-
prisingly diversified, ranging from fruits and vegetables to wheat,
barley, corn, rice, feed crops, and pasture. Fruits include oranges,

lemons and tuna (prickly pear), chirimoyas, avocados and olives, as well as vineyards and the usual temperate zone orchards.

Santiago is now a city of about two and half million people. Its untreated waste is discharged into the Mapocho, a tributary of the Maipo; the Mapocho carrying waste downstream from Santiago, is used for irrigation.

4. The Central Central Region: This consists of the water resource region composed of O'Higgins and Colchagua provinces, the region composed of the four provinces of Curicó, Talca, Maule, and Linares, the region consisting of the province of Ñuble, and the region consisting of the five provinces of Concepción, Arauco, Bío-Bío, Malleco and Cautín. O'Higgins and Colchagua together form the basin of the Rio Rapel. Curicó-Talca-Maule-Linares contains the Mataquito and Maule rivers. Ñuble has one river, the Itata. The Concepción-Cautín has four rivers, the Bío-Bío, Paicaví, Imperial and Toltén. Agriculture dominates. In addition, there are the major copper producing center at Sewell (in O'Higgins), light manufacturing (e.g. matches) in Talca and one or two other smaller communities, and the major industrial area--steel, textiles-- around Concepción.

The central central zone is the first part of Chile, going from north to south, in which the supply of water is great enough to warrant the removal of water scarcity from the list of obvious impediments to economic growth. We shall see that, viewed wholly in physical terms, projected requirements in the central central zone are only a small fraction of average annual runoff, but are great enough to create a need for some regulation. Water resources in the Concepción-Cautín region are largely unexploited, either for agriculture, industry, or

hydroelectric power. Irrigation is needed as far south as Cautín. Palm trees grow in Concepción (37 degrees south). It is the hope of the Chilean government that Concepción can become a major center of heavy industry. Paper mills have been established in this area and others are planned. The steel industry is growing.

5. The South Central Zone: This is the southern end of the central valley, a well-watered green landscape, consisting of the provinces of Valdivia, Osorno, and Llanquihue, which together comprise the last of the eleven water resource regions around which this report is built. Quite clearly water is no problem. Agriculture is unirrigated. The menace is too much, not too little, water. Present minimum flows are far in excess of foreseeable requirements unless dams are needed for hydroelectric power. Large power reserves remain untapped. Agriculture is mostly grains, forage, and pasture. Here are the lakes of Chile: Villarrica, Ranco, Llanquihue, and Todos los Santos, to name only a few. Here, also are important timber reserves. What we have named the "south central zone", because it is the southern extremity of the central valley, is frequently called "Sur Chico."

Puerto Montt, a seaport on Reloncavi Sound, in the Province of Llanquihue, is the mainland contact with the island of Chiloé and the archipelagic mainland of Chiloé, Aysén, and Magallanes provinces. From Puerto Montt southward are the fjords and channels by which one can navigate to the Straits of Magellan without entering the open sea except for one brief stretch.

6. The archipelago. The scenic grandeur of Chile's archipelago is unsurpassed. The growing desolation of the channel islands and the gleam of glaciers reaching down to the sea leave one unready for the view of

Punta Arenas and the forests and meadows of the surrounding countryside that border the Straits of Magellan. Here is the gateway to a region of magnificent craggy mountains, deep lakes and oak forests, and the only national park that Chile possesses. Within sight of Punta Arenas, lying low on the horizon is Tierra del Fuego, the source of Chile's petroleum supply. (Coal is found far to the north, near Concepción, where the steel mill is.) The rivers of the Sur Grande (Aysén and Magallanes) may some day be used for hydroelectric power. At present, and for the foreseeable future, they flow undisturbed to the sea.

Chapter II

THE PROJECTION MODEL

We assume, in effect, that each region is two points in space to
which all water supply and activity of that region is assigned, one
"upstream" and one "downstream". The "water supply" is the quantity of
surface water that is available, based upon the records of flow. In
many instances--how much is not known--the movement of underground water
becomes a part of the surface water record. A considerable quantity of
ground water, however, never appears in records of surface flow.

We shall not consider "normal" costs of water treatment and distribu-
tion as part of the "costs of water", since such costs are incurred with-
out reference to the quantity of water available, but rather in response
to the number of consumers and quality of water that is delivered. Were
there to be a significant deterioration in the quality of water or, if
at the extreme, fresh water had to be manufactured out of ocean water
water treatment costs would be relevant. The possibility of a desalina-
tion plant for Antofagasta was under study, but we shall not incorporate
desalination or especially high treatment costs in our analysis. In-
stead, we shall assume that industrial and municipal wastes are treated
to remove biochemical oxygen demanding substances, and that such treatment
will enable subsequent users to avoid unusual treatment costs.

What then will costs of water include? They will consist of (1)
the costs of regulating surface flow to achieve whatever pattern of flow
is necessary to satisfy the water requirements of the region, including
waste dilution flows to assure a designated amount of dissolved oxygen
in the river after receiving discharged wastes, subject to the limit

imposed by average annual flow as measured by the period of record, plus
(2) the costs of treating organic domestic and industrial wastes in order
to reduce the quantity of biochemical substances discharged into a river.[1]

The "costs of water", then, are a function of the underlying hydro-
logy and the sum of all uses to which the water is put. This makes a
"cost curve" for water different from a "cost curve" for, say, steel. The
cost of an ingot of steel is a function of the metallurgical composition,
production process, rate of production relative to capacity, and price
per unit of inputs. The use to which the steel is put is not a relevant
factor in fixing its cost. In the case of water, because of the possi-
bility of reuse, costs for one user can be, but are not necessarily, a
function of anterior uses to which the water has been put. Certain
costs, such as those incurred to regulate virgin flow at a designated
point on the river, can be ascertained independently of the uses to
which water is put. A "cost of regulation" schedule (or curve) indicates
the unit costs of successively higher degrees of regulation. One can
estimate how many "units" of regulation will be "bought" by estimating
the quantity of water that must flow by a particular point in space at
a particular point in time. But even a cost of regulation schedule is
not wholly determinate ex ante, since reservoirs of different sizes and
different costs can be added in different sequences, so that only one
arbitrarily selected sequence yields a cost curve for planning pur-
poses. [2]

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[1] Costs of waste treatment, see below, are based upon estimates pre-
pared for the United States and pertain to usual sewage treatment
processes. It was assumed that comparable processes would be used
in Chile.

[2] Subject to the statistical uncertainty of the underlying hydrology
and the additional uncertainty of the costs of certain engineering
features -- e.g. outlets -- until the use of a dam is established.

The cost of maintaining water quality is likewise a part of the cost of water with which we are concerned. In any market the "product" is defined to include specified quality characteristics; the same holds true for water. Quality can vary in a number of dimensions: chemical, physical, biological. These variations manifest themselves in the capacity of water to serve various duties. Unfortunately, we cannot encompass all quality dimensions in our analysis. We shall estimate the costs of treating wastes to remove decomposable organic substances and the costs of assuring a flow of high quality water to mix with the waste effluent after treatment. These estimates are subject to an unknown range of error for three reasons: (1) they are taken from computations made for the United States and reflect the waste-assimilating capacity of rivers in the Central Pacific Region (mostly California); (2) they contain an unknown error factor for the United States; (3) finally, until we know more about quality problems, now and foreseeable, of Chilean rivers, we cannot even be sure that dissolved oxygen and the assimilation of biodegradable substances are in fact the critical qualitative factors. Dissolved solids may turn out to be more important. Unfortunately there is no way of incorporating dissolved solids into our analysis, since the requisite data do not exist for Chile nor do they exist in such systematic form for the United States that a translation might be possible.

When we have estimated the costs of regulation and waste treatment for a projected pattern of economic activity we can ascertain three things: (1) whether projected water uses are compatible with physical supply, assuming "complete" regulation; [1] (2) the combination of waste treatment

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[1] Because we can never be sure of the future variability of stream flow, it would be more accurate to speak of "very high regulation."

and dilution flow that minimizes costs of water; (3) whether marginal costs of water vary substantially among regions and, therefore, whether this suggests a different regional distribution of water use or different assortment of goods and services produced.

Economists object to a "requirements approach" to the study of any economic good or service because such approach typically fails to take into account the possibility that implicit technical coefficients are subject to change if economic conditions warrant. We have taken cognizance of the possibility of technological improvement by using rates of water use for irrigation that reflect more economical usage 1/ than now prevails; but there is still a wide gap between theoretical plant requirements and the figures we have adopted for 1985. We have made no special attempt to project improved technology of water use for other activities. Our projections indicate that certain adjustments will inevitably be made in either the rate of water use per unit of product, the geographic distribution of activity, or the composition of the national bill of goods, especially as it is divided between water-related and non-water-related goods. These are, however, conclusions derived from the projections rather than assumptions adopted for the purpose of making the projections.

In order to ascertain the relationship between future demands for water and its availability, it is necessary to aggregate separate uses. The method of aggregation into what we call a "requirement" depends in part on assumed policies and objectives of the Chilean economy. For

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1/ Usage here refers to both gross and net measurements. See ch. VI, below, for more detailed discussion.

example, we must make an assumption regarding the standard of quality
that will be adopted for instream water, since there is no statement of
policy to which we can turn. Because we do not possess the information
needed to route water downstream from point to point, taking into account
both quantity and quality requirements, the possibilities of instream
and offstream multiple use, the natural recuperative powers of the stream
along with the benefits or damage of stream regulation, and the possi-
bilities of treatment at points of intake and discharge, we must sub-
stitute looser, rule-of-thumb concepts of water "requirements". Our
main task is to frame the concept of "requirement" in such a way that
it is parallel to a concept of ability to meet the requirement and what
it will cost.

A requirements approach does not ask whether the benefits of invest-
ment in water resources are equal to or more than the costs, even though
the analysis may yield information that can intuitively be used toward
that end. Generally speaking, a benefit/cost analysis is feasible for
marginal decisions, where most of the elements related to the decision
are given. Such would be, for example, the question of whether it is
worthwhile to invest in an irrigation system in a particular valley,
given the potential output and the expected market. The approach that
we have adopted starts with a national bill of goods and the quantity of
fresh water available in the form of measured surface runoff, and con-
cludes with a regional pattern of output that is consistent with speci-
fied outlays on water resources. By adopting a number of simplifying
assumptions we can supply tentative answers, within the limits of the
assumptions and the quality of the data to the following questions:

(1) What are the requirements for water if a reasonable extra-
polation of presently observed trends or presently known
plans are extended to 1985?

(2) To what extent will shortages of water prevent the consum-
mation of these plans?

(3) What will be the "critical costs" of supplying the implied
water requirements? By "critical costs" are meant those
costs that can be readily avoided by transferring an
activity from one region to another.

(4) What modifications in projected activity are likely to have
a significant effect on required outlays for water?

(5) What modifications in projected activity are likely to be
induced by rapidly rising marginal costs of water?

(6) How will the physical and economic limits of supply affect
the regional distribution of activity?

The simplifying assumptions that we must adopt are the following:

(1) Each water resource region is considered to be two points in
space between which all of the region's activity is divided,
an upstream point and a downstream point. The upstream point
consists of all of the region that is so far from the ocean
that water discharged from any industrial plant, mine, power
plant, city, or irrigation project can be used again. The
downstream point is all of the region located so close to the
sea that all fresh water discharged into a receiving body of
water is considered to be irrecoverable as fresh water, and
therefore considered to be lost, just as though it were evapo-
transpired. In mining, thermal power, and manufacturing it

is assumed that fresh water can be recirculated within the plant.

(2) The water requirement for a region is considered to be equal to the largest of:

(a) the sum of upstream losses (i.e. consumption by evaporation or transpiration) plus downstream intake, or

(b) the sum of synchronous intakes at all points that are so separated from each other that the water discharged by a user at any of these points will not affect the supply available to a user at any of these points, or

(c) the sum of losses plus waste dilution flows.

The amount of water "required" by any region depends not only upon the intake and losses of offstream activity but also upon the uses to which water in the stream is put, and, in a more complete model, on the balancing of intake costs against maintaining instream quality by waste treatment and dilution. Up to now the maintenance of instream quality, either to meet instream uses or to assure water of adequate quality to successive off-stream users, has received little attention in Chile. There has also been little attention directed to the quality of estuarine waters. The character of Chile's coast line is such that estuaries are small or non-existent, or are fed by flows that are so great that there has been no concern over adverse effects of upstream uses. Chile's concern over pollution has been so weak that there has not only been no thought of providing waste dilution flows after treatment, but its capital city, Santiago, does not yet have a waste treatment plant. Under these circumstances it appears unlikely that waste dilution requirements

will seriously compete against other demands for water within the next
twenty years.

The Chilean government possesses authority to prevent undue pollution
by an industrial plant, and presumably will use such authority to compel
treatment when necessary.   However, even high level treatment of organic
wastes will not remove dissolved solids from water. We have no informa-
tion on what dilution would be necessary to prevent an undesirable build-
up of salinity on the downstream side of a city of five million or so
people. In the absence of better information we have used a dissolved
oxygen criterion of water quality, with levels of treatment ranging
between zero and 90 percent removal of BOD. One measure of water require-
ment that we have used includes the flow needed, after mixing the treated
discharged liquor, to maintain dissolved oxygen in the stream at four
milligrams per liter, or approximately four parts of oxygen per million
parts of water. Water meeting this standard normally requires no special
treatment at points of intake and will support relatively high level
aquatic life. By adding all losses to the dilution requirement we are
implicitly assuming that the discharge of the river to the sea will be
at least equal to the waste dilution flow.

The other two measurements of water requirement are designed to
meet those circumstances where dilution flows are lower than the gross
requirement at any single point or lower than the gross requirement at
a group of independent points so situated that users at these points can-
not utilize the water discharged by other users whose intake we are count-
ing, or, in the limiting case, where no dilution flows are specified be-
cause no explicit account is taken of water quality.

In formulating these measures of requirement we take into account

the following uses: agriculture, manufacturing, mining, thermal power, and general municipal uses - domestic, commercial, civic and light manufacturing. We ignore possible instream uses such as fishing, water-based recreation, and hydroelectric power.

If we retain a waste dilution flow in our measure of "requirement" we implicitly provide for some recreational (including fishing) uses and some power production. We have ignored hydroelectric power as a component of the "requirement" because, except for Rapel, the installations are upstream and, up to now at least, have been administered in such a way as to conflict as little as possible with other uses. It is quite possible that conflicts will increase; especially as relatively more power is produced from regulated flows and less from upstream run-of-the-river plants. The extent of these conflicts cannot be ascertained without information on the location of activities within a water resource region and information on the functioning of an electric grid system. By ignoring hydroelectric power we fail to account for those possibilities in which revenues can be earned to offset in whole or part the costs of regulation. We shall see that in terms of major decisions regarding water resources this omission is not critical. [1]

If all users of water, including municipal systems and irrigation projects, captured and reused all water that was not evaporated, transpired, or incorporated in the product, intake would be equal to what we

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[1] By ignoring hydroelectric power we may understate total expenditure on reservoir capacity. Up to now most hydro plants have been run of the river; the picture for the future is expected to change. See Chapter VII.

call "loss".[1] We have assumed that mines and thermal power plants re-
circulate all fresh water intake; whether these activities are located
upstream or downstream we consider their requirement to be measured by
"loss". Manufacturing activities - steel mills, oil refineries, pulp
and paper plants, and so forth, could, and in some cases do, recirculate
their fresh water. In this event intake is equal to loss. Where no re-
circulation is practiced and the point of use is downstream, the required
flow of the downstream point of use is equal to downstream intake plus
upstream loss. Such a computation may be equal to, more than, or less
than required flow as measured by losses plus waste dilution.

Another option in computing required flow based on a dilution re-
quirement would be to assume that downstream losses could be met out of
the dilution flow. In this case the flow requirement would be equal to
upstream losses (not total losses) plus waste dilution flows, provided
waste dilution flows exceeded downstream intake. In quantitative terms
a requirement stated in this way will not be greatly different in most
regions from a requirement expressed as total losses plus waste dilution.

There is no need to know the intraregional location of activity in
order to compute total losses, so long as "losses" are limited to evapo-
transpiration, incorporation in the product, and usual losses due to
inefficiency, etc. in irrigation projects. However, when we distinguish
between "upstream" and "downstream" points of discharge we must fix the
geographical position of each activity to correspond to these points. In
the case of municipal use the division was made by extrapolating the trend
of population. Manufacturing activities in the major water using indus-
tries, other than food, are so easily located that a reasonably exact

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[1] Agricultural losses also include water that soaks into the ground and,
for one reason or another, cannot be recovered. In another context,
we also classify as "loss" all waters discharged into salty or brackish
bodies of water.

distribution could be made. For food, the distribution of activity was cased on the distribution of population. (See Table II-1).

Mining and steam electric power were not infra-regionally distributed because:

(1) Losses are relative low.

(2) Recirculation is relatively easy if water supplies are scarce.

(3) Salt water can be used for cooling if recirculating equipment is too expensive.

Hence, requirements for these activities are measured by evapotranspiration losses, whether located upstream or downstream. Furthermore, they do not suffer pollution by organic, degradable substances for which a dilution flow is specified. Where pollution is a problem, such as disposition of acid wastes, the waste-carrying water is usually lagooned, and the water requirement appears as evaporation loss, (in which case intake is equal to loss).

There was no easy way to divide agricultural requirements between "upstream" and "downstream" except by using the 1955 Census of Agriculture, which gave the irrigated area of local units of government known as comunas. Comunas were designated as upstream or downstream by the technique known as al ojímetro with the use of a map.[1] The 1955 distribution was assumed to persist to 1985. In the basic model agricultural requirements were considered to be equal to "net use" upstream plus "gross use" downstream. The distribution of irrigated area between upstream and downstream points is given in Table II-2.

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[1] Translated as "eyeballing".

Table II-1

ASSUMED DISTRIBUTION OF MANUFACTURING AND URBAN POPULATION

BETWEEN DOWNSTREAM AND UPSTREAM POINTS OF WATER USE

	All Manufacturing, except Food and Beverages		Percentage Distribution of Urban Population and Food and Beverages	
	Coastal	Inland	Coastal	Inland
Tarapacá	x		88	12
Antofagasta	x		58	42
Atacama		x	14	86
Coquimbo	x		50	50
Aconcagua		x	3	97
Valparaíso	x		70	30
Santiago		x	2	98
O'Higgins		x	0	100
Colchagua		x	4	96
Curicó		x	1	99
Talca		x	0	100
Maule	x		30	70
Linares		x	0	100
Ñuble		x	1	99
Concepción	x		94	6
Arauco	x		39	61
Bío-Bío		x	0	100
Malleco		x	0	100
Cautín		x	2	98
Valdivia	x		58	42
Osorno		x	0	100
Llanquihue	x		70	30
Chiloé	x		85	15
Aysén	x		100	0
Magallanes	x		100	0

Table II-2

PERCENTAGE DISTRIBUTION OF IRRIGATED AREA

BETWEEN UPSTREAM & DOWNSTREAM POINTS [1]/

	Downstream	Upstream
Tarapacá	50	50
Antofagasta	0	100
Atacama	12	88
Coquimbo	19	81
Aconcagua	14	86
Valparaíso	10	90
Aconcagua-Valparaíso	12	88
Santiago	2	98
O'Higgins	0	100
Colchagua	1	99
O'Higgins-Colchagua	0.5	99.5
Curicó	3	97
Talca	1	99
Maule	100	0
Linares	0	100
Curicó-Linares	6	94
Ñuble	0	100
Concepción	3	97
Arauco	100	0
Bío-Bío	0	100
Malleco	0	100
Cautín	0	100
Concepción-Cautín	4	96

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[1]/ Source: Based on distribution of irrigated area by comuna
according to 1955 Census of Agriculture.

The need for defining "water requirements" in several alternative ways is brought on by the absence of well defined trends or policies, especially with respect to water quality and in-stream uses.[1] There is no information on the quality of estuarine and inland fisheries. Furthermore, it is impossible to ascertain whether the lack of data is a reflection of the fact that fisheries are in no danger, that deterioration in the foreseeable future has been brought to no one's attention, that deterioration is accepted with equanimity, or that it has been determined that the cost of preventing deterioration is greater than the benefits. There is some evidence that water supplies are being polluted by the discharge of untreated sewage. One is warned not to eat raw vegetables; the supermarkets feature strawberries with a cachet on the box indicating they are grown where the irrigation water is safe. These comments do not apply, of course, to water treatment plants which are being constructed to serve most of Chile's urban population.[2]

Projections of Population and Gross National Product

Projected water use depends upon the output of water related goods and services. We estimated future outputs by assuming that production would be determined by the change in demand, modified by an assumed change in imports or exports, and that changes in demand would be determined by

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[1] No account has been taken of possible increases in water losses attributable to soil conservation practices and reforestation.

[2] It has been alleged that infiltration of ground water pollutes water supply systems during periods of low pressure. The author was not able to verify or disprove the allegation.

changes in the size and income of the population. Changes in income were assumed to be measured by changes in gross national product.

We adopted two rates of annual growth of gross national product. The lower rate, 3.75 percent, is the average rate experienced during the period 1940-1963. The higher rate, 5.5 percent, is the rate around which current government planning is built. Projected demands for agriculture and manufacturing products were dependent upon the growth of GNP. Mining was projected at two levels, but independently of changes in population and income. (The output of most Chilean mineral products is not significantly affected by Chilean domestic demand. We did not examine the effect of mineral production on GNP). Steam-electric power was projected on the basis of the plans of ENDESA.[1] (The projected main source of power is hydroelectricity; thermal plants are expected to meet a relatively small portion of future demand).

For population growth, the rate that was adopted for elaboration of the models in detail was 2.43 per cent.[2] This corresponds to a middle rate. Summary comparisons were made using a low rate of 2.2 percent and a high of 2.6 percent.

Urban population was estimated for 1985 by extending Sadie's percentages, on the assumption that the percentage decline in rural population

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[1] The Chilean national electric power corporation.

[2] Estimated by Catholic University, Santiago. This figure coincides closely with an extension to 1985 of an estimate prepared by Professor Sadie, using cohort survival rates. (Poblacion y Mano de Obra de Chile, 1930-1975, Johannes L. Sadie, Centro Latinoamericano de Demografía (CELADE) Santiago, 1964.

would be the same for the decade 1975-85 as was projected for the five-year period 1970-75, namely 9 percent. This gave an urban population for 1985 equal to 73 percent of total. With the control totals of 13,902,400 for total and 10,843,900 for urban we distributed total and urban population among the provinces on the basis of the historical percentage (1940, 1952 and 1960) each province's population bore to the national total. The general rule followed was to add to or subtract from the 1960 percentage one-half of the change that occurred in the province's percent of total population between 1940 and 1960. In this way a trend, but dampened substantially, was followed. In several instances either the past figures seemed implausible or the results seemed unreasonable for the future and were modified intuitively. The final results were reconciled to 100 percent.[1]/

The medium rate of population growth, 2.43 percent, and the high rate of GNP growth, 5.5 percent, were the rates for which models were elaborated in greatest detail. In somewhat lesser detail projections were made using the medium rate of population growth and lower rate of growth of GNP. Projections using the lower rate of GNP growth are labeled "A" and those using the higher rate "B". "Medium A" refers to the combination of 2.43 percent for population and 3.75 percent for GNP. "Medium B"

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[1]/ The estimates of municipal water use that were incorporated into our measure of requirements were based upon a slightly different distribution and larger size of urban population in comparison with the figures indicated in Table II-4. The resulting over-statement is on the order of ten percent for the country as a whole and 20 percent for the province of Santiago. A reduction of municipal loss by 20 percent would reduce total losses in Santiago province by eight-tenths of one percent.

Table II-3

PROJECTIONS OF GROSS NATIONAL PRODUCT AND POPULATION

GROSS NATIONAL PRODUCT

Mil. E° (1960)

	A(3.75%)		B(5.5%)
1963		4,645	
1965		4,998	
1985	10,436		14,579

POPULATION

(thousands)

		Total	Urban
1965		8,601	5,028
1985			
	Low (2.2%)	13,289	10,365
	Medium (2.43%)	13,902	10,844
	High (2.6%)	14,372	11,210

Table II-4

PROJECTED POPULATION, MEDIUM GROWTH RATE, 1985 (THOUSANDS)

	Total	Urban	Rural
Tarapacá	236.3	227.7	8.6
Antofagasta	458.8	444.6	14.2
Atacama	208.5	184.3	24.2
Coquimbo	542.2	347.0	195.2
Aconcagua	236.3	173.5	62.8
Valparaíso	1,167.8	1,051.9	115.9
Santiago	4,991.0	4,912.3	78.7
O'Higgins	458.8	292.8	166.0
Colchagua	278.0	108.4	169.6
Curicó	180.7	97.6	83.1
Talca	375.4	195.2	180.2
Maule	139.0	65.1	73.9
Linares	292.0	130.1	161.9
Ñuble	486.6	238.6	248.0
Concepción	1,070.5	976.0	94.5
Arauco	166.8	65.1	101.7
Bío-Bío	305.9	141.0	164.9
Malleco	292.0	151.8	140.2
Cautín	625.6	281.9	343.7
Valdivia	472.7	249.4	223.3
Osorno	278.0	141.0	137.0
Llanquihue	319.8	162.7	157.1
Chiloé	111.2	43.4	67.8
Aysén	83.4	43.2	40.2
Magallanes	125.1	119.3	5.8
Grand Total	13,902.4	10,843.9	3,058.5

Table II-5

COMPARISON OF ALTERNATIVE VALUES FOR POPULATION, GROSS NATIONAL

PRODUCT, AND SELECTED INDUSTRIES IN 1985

BASED ON ALTERNATIVE RATES OF GROWTH

| | Index Number (Medium B = 100) | | | | | |
| | "A" | | | "B" | | |
	Low	Med.	High	Low	Med.	High
Gross National Product	72	72	72	100	100	100
Population	96	100	103	96	100	103
Manufacturing:						
Food	74	77	80	97	100	104
Pulp & Paper	58	62	63	96	100	104
Petroleum Refining	55	57	59	94	100	102
Steel	63	67	68	96	100	104
Agriculture	82	86	89	96	100	104

refers to the growth rates of 2.43 percent and 5.5 percent for population and GNP, respectively. The combination of a low population growth rate with each of the two GNP growth rates are designated "Low A" and "Low B", respectively. Similarly, we have "High A" and "High B".

The effects of the various combinations of population and GNP growth rates have been summarized in the form of index numbers resting on Medium B as equal to 100. Indexes of manufacturing and agricultural demand incorporate an income elasticity coefficient.

A Preview of the Results

If the water supplies of the country as a whole are compared with projected water requirements -- both measured as a specified regulated flow -- there is no foreseeable shortage. There is no foreseeable short- age even if we compare only the aggregate requirements and supplies of the provinces north of archipelagic Chile, even though these requirements amount to 99.7% of the national total (in 1985) and these supplies (average flow) account for only 40% of the national total. Projected requirements (1985, Medium B), for all provinces for Llanquihue to the northern boundary range between 31 and 34 billion cubic meters per year, depending upon the alternative used to measure requirements, whereas average flow for the same region is about 176 billion cubic meters annually. (Average flow of the three provinces south of Llanquihue amount to about 269,000 million cubic meters while projected requirements for 1985 range between 46 and 103 million cubic meters.)

Evapo-transpiration losses constitute the main projected requirement; and of these losses 98.5% consist of agricultural (irrigation) uses. Municipal losses account for 1% and mining, manufacturing, and steam-

electric power together account for the remaining one half of one percent. Relatively large changes in non-agricultural uses of water will have relatively small effects on the total water picture, although local conditions, especially in the north, will be affected by changes in non-agricultural use.

Taking the country from the province of Cautín to the northern boundary, there is comparatively little difference among the requirements for water when measured by the several alternatives that have been used. The lowest amount, 30.4 billion M^3 per year, covers evaporation-transpiration losses only. The highest amount, 34.1 billion M^3 per year covers evaporation and transpiration losses and provides for waste dilution of effluent after removing 90% of degradable organic material by treatment. Dilution is computed to yield four milligrams per liter of dissolved oxygen in the stream after the waste effluent mixes with the high quality dilution water.

Annual requirements according to the various measurements used are as follows (Cautín to the north):

	billions M^3/yr.
Evaporation-transpiration losses	30.4
Case I: evaporation-transpiration losses plus downstream municipal & agricultural intake	31.3
Case II: Case I plus mining intake instead of evaporation loss	31.6
Case III: evaporation-transpiration losses upstream; all intakes downstream	32.7
Evaporation-transpiration losses plus waste dilution to yield 4 mg/l dissolved oxygen in the stream after 90% removal of organic wastes 1/	34.1

1/ Only wastes discharged upstream are assumed to require dilution.

If water quality should become a major consideration and if treatment should fall short of 90% removal of biochemical oxygen demanding substances, water requirements for the same region (Cautín to the north) could rise substantially. At zero treatment, total required flows would be 61.7 billion M^3 per year to assure 4 mg/l of dissolved oxygen. With primary treatment (35% removal of BOD), required flows would be 50.8 billion M^3 per year. Estimated required flows, therefore, are apparently more responsive to decisions regarding water quality and waste treatment than to decisions regarding recirculation at the lower end of river basins.

When we sharpen the focus of our analysis to the northern half of the country, (the province of Santiago and all others to the north), the picture changes. Instead of a projected adequacy of supply with considerable room to spare the results of our calculations indicate serious shortage. Using Case I requirements (i.e. downstream municipal and agricultural intake plus evaporation-transpiration losses from all other uses), our estimates indicate a required annual flow of 8.8 billion cubic meters but an average available flow of 6.2 billion cubic meters. This means that if regulation were carried to the maximum possible degree supply would fall short of requirements by 30%.

The disparity between required flow and available flows is greater with the lesser degrees of recirculation implied by Cases II and III and with the need for maintaining a flow of high quality dilution water over and above projected evapo-transpiration losses. If the costs of regulating flow are taken into account by fixing an upper limit on expenditure per unit of regulated flow, the disparity increases even more.

It is reasonable to assume that any restriction on water supply will

be felt first in agriculture. For 1985, application of water per hectare
of land was assumed to reflect an improvement over present rates of water
use to a degree that further economies in water use would be beyond normal
expectation. For this reason, restrictions on water supply are likely to
mean a corresponding, more or less, restriction on irrigated hectareage.
Estimated irrigable land in the country including and to the north of the
province of Santiago is about 566,000 hectares. If all available water,
fully regulated, were used for irrigation, about 403,000 hectares could
be cultivated. If non-agricultural uses were first met in full, this
area would shrink to 373,000 hectares, (both estimates based on Case I.)
A comparison of projected total agricultural output, taking the restric-
tions imposed by water into account, with projected agricultural require-
ments as based upon growth in population, dietary needs, and envisaged
restriction of imports to a level corresponding with present experience,
indicates a required increase in output per hectare by somewhat more than
two times. Such improvement seems feasible. The question is whether the
necessary steps will be taken to bring it about.

There is little ground for fear that projected non-agricultural water
needs cannot be met, provided reasonable steps are taken to regulate
stream flow and recirculate water used for mining, power, and manufactur-
ing purposes.

Stream regulation, based upon surface storage, involves a capital
cost, but estimated future costs do not appear to be unreasonably high
unless regulation is carried to its theoretical physical limit. If the
annual cost per million cubic meters per year of flow assured 85% of the
time is equal to 8900 escudos in the province of Santiago (at 1964 prices,

which is equal to $3.42 per acre-foot at the 1964 official rate of
exchange), and less elsewhere by varying amounts, and if all non-agricul-
tural needs are met before allocating water to agriculture, irrigated
hectareage in the northern provinces would be about 311,500 hectares.
Total annual costs of regulation would be about 37.5 million escudos.
If non-agricultural uses were met by regulation of flow beyond the con-
straint of 8900 escudos per year per million cubic meters, but agricul-
ture was bound by this limit, irrigated hectareage would be about 343,000
hectares, and total annual costs would be about 47.2 million escudos.

The expansion of irrigated hectareage from 311,500 to 344,000 in
the northern provinces, (no problem is encountered in the provinces south
of Santiago since all projected requirements can be met at relatively low
marginal costs of regulated flow), would cost approximately 10 million
escudos per year. In comparison with prices that currently prevail in
Santiago, of agricultural products as well as water, such extension of
regulation seems unwarranted as of 1985. The marginal cost of water by
such extension would be about 333 escudos per hectare per year (which
translates to about $100 at 1964 exchange rates, or $45.45 per acre), or
almost 14 escudos per metric quintal of wheat (or wheat equivalent) for
water alone, compared with a 1964 wholesale price of wheat of about 21
escudos.

Cumulated capital costs of regulating stream flow up to the full
capacity of the stream or the level of projected 1985 demand, whichever
is lower, is estimated to be E^{o} 1.0 billion (1964 prices) for the country
as a whole. The equivalent annual cost would be E^{o} 84.0 million. A
marginal cost constraint, where agricultural needs are met only after

non-agricultural, would reduce capital costs by about E^o 569 million, or fifty-six percent. Putting it in reverse, the cost of going to the full physical limit, since it would only mean additional agriculture, would represent a very high cost per additional unit of crop (about E^o 31 per metric quintal of wheat equivalent).

The investigation turned up several side issues that were briefly explored. One dealt with the past experience of the Chilean government in financing irrigation projects. Whether Chile's experience with project selection is worse or better than the experience of other governments cannot be ascertained without more detailed comparisons. What is rather clear, however, is that the financial arrangements contemplated by law have been eroded by inflation. Another side issue, but central to the question of Chilean economic planning and progress, is the implied increase in productivity per hectare that is consistent with available land and water and Chilean agricultural output goals. The conclusion that output per hectare will have to more than double between now and 1985 is the signal for a specific technological effort, especially in light of the balance of payments difficulties experienced during the last few years. What constitutes the optimum agricultural policy, expressed in terms of domestic production, exports, and imports, had not been formulated at the time of this writing. An inter-regional agricultural model would constitute a major contribution to Chile's water resource planning tools.

Moving from the regulation of flow to meet evapo-transpiration needs to the question of water quality, three considerations must be taken into account: (1) the quality standard, (2) the level of waste treatment, and (3) the quantity of high quality water that is mixed with the effluent of

waste treatment plants. These three factors must be appropriately re-
lated to each other. For example, a low level of treatment and a large
dilution flow can serve to yield a designated in-stream quality equally
with a higher level of treatment and smaller dilution flow. Given cost
functions for regulation of flow and degrees of waste treatment there
is likely to be a combination of waste treatment and dilution flow that
minimizes total cost in each basin for a designated quality standard.
In a given basin, the range of possibilities may be limited by the avail-
able water supply; where supply is small the level of treatment may have
to be high in order to achieve a designated quality with a designated
output of waste-producing goods and services.

Although there is a deficiency of information regarding the incidence
of pollution, the costs of its abatement, and the relationships between
levels of treatment and required dilution flows, estimates were made with
the assistance of U.S. coefficients. Annual costs of treatment were
estimated at E^o 42.6 million escudos. The additional flows needed for
dilution were assumed to be used downstream for irrigation, in which
case the dilution flows could irrigate about 25,000 additional hectares
rather than go unused into the sea. The additional cost of stream regula-
tion, beyond the costs of Case I, marginal cost constraint, agriculture
in a residuary position, was estimated at E^Q 15.5 million annually.
Total annual costs of quality maintenance, based on an instream quality
standard of 4 mg/l of dissolved oxygen was, therefore, about E^o58.1
escudos. If collection costs of municipal systems are also taken into
account, costs of treatment, collection, and additional flow amounted
to E^o74.5 million escudos annually for the country as a whole. The

estimated costs of maintaining quality -- treatment, municipal collection, and additional flow to provide dilution -- came to about twice the costs of flow regulation within the limits of a marginal cost constraint, agriculture residuary. Of the quality-maintenance outlays, the annual costs of collection, some E^O 16 million per year, cannot be sidestepped without serious health consequences. The remaining E^O 58 million can be avoided in whole or in part by accepting a lower average in-stream quality standard or by relocating people and activity from regions in which water supplies must be treated highly and regulated at high marginal cost to regions in which natural minimum flows are so great that quality can be maintained with low level treatment and little or no additional flow regulation.

How do projected outlays compare with recent rates of investment for capital goods. In 1964, at 1961 prices, gross fixed investment at market prices was 75 million escudos.[1] At 1964 prices this would be about E^O 1,785 million. If streams are regulated in accordance with the marginal cost constraint, agriculture residuary, costs were estimated at E^O 37.5 million (1964 prices). If, in addition, stream quality of 4 mg/l of dissolved oxygen were to be assured, total annual costs would be about E^O 112.0 million, or about 6% of the 1964 level of investment. However, since estimated annual costs are for the level of investment required for assumed conditions of 1985, the required outlays for water should be compared with expected 1985 investment. If gross investment grows at the

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[1] ECLA, Statistical Bulletin for Latin America, Vol. III, No. 1, February 1966. Prices rose about 2.4 times between 1961 and the middle of 1964, based upon an unofficial consumer price index. The consumer price index and the wholesale price index tended to move together.

same rate as "Medium B" projections of GNP -- i.e. 5.5% per year -- by
1985 annual gross investment at constant prices should be three times
the level obtained in 1964, or about E° 5.4 billion. Annual capital
cost equivalents for water resource development would then amount to
roughly 2% of the gross investment budget. These costs exclude municipal
treatment and delivery costs as well as long distance supply lines,
manufacturing intake costs, to-the-farm and on-the-farm delivery costs,
and the like, which would be incurred in any case. In the absence of an
investment model, one cannot draw a firm conclusion regarding the overall
burden that investment in water resources would impose. There is no
reason, however, for assuming that it would be intolerably high.

Unfinished Business:[1]

The foregoing summary leaves untouched several important questions.
The need for an inter-regional agricultural production model has already
been mentioned. Among other topics inadequately treated in this study
are the supply of and disposition of ground water, storage requirements
for hydroelectric power and additional evaporation losses, possible
effects of nuclear power production, possible effects of desalination of
sea water or inland brackish waters, legal-economic-institutional changes,
urban capital costs for local treatment and distribution, costs of inter-
basin transfers of water, a host of financial questions such as the
appropriate interest rate for the computation of costs and benefits,
incidence of costs, benefit-cost comparisons, and the merits of expendi-
ture on water resource projects compared with other activities.

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[1] This section is based largely on comments made by Adolfo Dorfman,
Chief, Natural Resources & Energy Programme, Economic Commission
for Latin America, and Blair Bower, Research Associate, Resources
for the Future.

Ground water cannot be systematically incorporated into a study of water resource development until more is known of its occurrence and behavior. We have assumed that surface water measurements include the contribution made by ground water, an assumption that is reasonable for relatively large basins but not necessarily valid for small. By failing to go beyond this assumption we neglected the possibility of storing water in aquifers as an alternative to surface storage; we also ignored the possibility of withdrawing ground water in excess of the rate of recharge. Should ground water storage prove feasible, evaporation losses would be less than we assumed. Should mining of ground water be a possibility in various basins of the north, the near-term disparity between projected requirements and supplies would be less. The use of ground storage in lieu of surface storage might affect estimated costs of regulating flow. Also ignored was the possibility of constructing artificial underground reservoirs by use of nuclear explosives.

Although at this date the economic feasibility of large scale inter-basin transfers appears low, there is little information on which to base a firm conclusion. There is also little information on other methods of augmenting supply. At the time of writing the feasibility of using nuclear energy for production of power and desalination of sea-water was under study by the Chilean government electric power corporation, ENDESA. When data have been acquired regarding costs of desalted water (which at present are likely to be comparatively high), the possibility of releasing water to agriculture from non-agricultural uses, and the future place of agriculture of the northern provinces in the national picture, the place of desalination will be better understood. At the moment there is no reason

to expect a substantial augmentation of supplies from this source, but since technology may change materially in the near future, one can hardly reach a dogmatic conclusion. It is likely that ENDESA and other Chilean entities will continue their studies of possible applications of nuclear energy even if no power or desalination plants are constructed in the immediate future.

A number of interesting and broad topics related to national water resource planning demand the attention of experts in economic, legal, political and social spheres. Chile's metamorphosis from a rural to urban economy will induce changes in land tenure, laws regarding water rights, and intensive competition for capital. Each of these changes will affect economic feasibility considerations, as well as the physical characteristics of the supply of and demand for water. To some extent these changes were taken into account in the assumptions used for making the projections of water demand and supply, but a number of things were left unsaid. For example, irrigation coefficients resting upon an implicitly assumed higher level of efficiency in water use may not materialize unless the conditions of ownership and use of water are changed, funds are available to landowners for necessary capital improvements, and alternative techniques for raising agricultural output are fully exploited within economic limits. Questions relating to the implicit or explicit pricing of water and the ease with which water can be transferred from one use or user to another will have to be settled. Furthermore, the benefits that flow from the marginal dollar spent on water resource projects relative to the benefits of the marginal dollar spent elsewhere cannot be ascertained by a study of water resources only, or, in view of the special problems of the Chilean capital market growing out of inflation, controlled interest

rates, and the rationing of capital by the banking system, by study of the flow of investment funds in response to market processes.

Chilean and United Nation experts are aware of these untouched topics and steps have been taken to fill some of the gaps. It would be presumptuous to second guess the outcome of investigations now underway or to anticipate what policy recommendations might emerge.

Chapter III

AGRICULTURE: A GENERAL SURVEY

In order to appreciate the most vexing aspects of Chile's water resource use we must understand the problems of Chilean agriculture. The "problems" of Chilean agriculture stem from the fact that agricultural output has been stagnant over more than a decade. Total agricultural output, including forestry, amounted to 450 million escudos in 1950 at 1961 prices; output in 1962 was 448 million escudos.[1]

The failure of agricultural output to grow would not be prima facie evidence of economic distress were it not that Chile has had, and still has, an adequate average diet, a high rate of population growth, a relatively high income elasticity of demand for food, and a serious balance of payments problem. The lag in productivity of the agricultural sector has probably contributed to Chile's inflation and the low rate of growth of the economy as a whole.

Table III-1 shows the disproportionate rates of change in gross product, agricultural output, and population. Even in 1959, when gross agricultural output amounted to 536 million escudos (1961 prices), output per capita was below the level of 1950. The growth in per capita gross product and, by implication, in per capita income, coupled with growth in population, has contributed to a rising demand for food and fibers that has been met by an increase in imports to a much greater degree than by more domestic production. The strain that this has imposed on the Chilean economy is indicated by Chile's balance of payments.

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[1] Boletín Estadístico de América Latina, Vol. I, No. 1. Comisión Ecónomica para América Latina, Maciones Unidas, 1964, p. 44.

Table III-1

SELECTED ECONOMIC INDICATORS, CHILE, 1950 - 1962

(Money values in millions of 1961 escudos)

	1950	1959	1962	Percent change 1950-59	Percent change 1950-62
Agriculture and Forestry	450	536	448	+ 19.1	- 0.4
Gross domestic product	3,753	4,932	5,680	+ 31.4	+ 51.3
Population (1000's)	6,073	7,465	7,987	+ 22.9	+ 31.5

Source: Boletín Estadístico de América Latina, Vol. I., No. 1, pp. 17, 44, 45.

Between 1950 and 1963, total exports grew by 16 percent, but total im-
ports grew by 219 percent. Of imports, non-durable consumer goods
constituted 10 percent in 1950 and 16 percent in 1963, and rose, in
real terms, by 245 percent over the period 1950-1963. In 1950, total
exports exceeded imports by US$ 113.2 million; in 1963 imports exceeded
exports by $95 million.[1]

There are differences in the rates of growth of sub-classes of
agricultural output. Production of livestock has been the most notorious
example of agricultural stagnation. Output of crops grew at an annual
rate of 4.9 percent during the period 1950-1959 whereas output of live-
stock grew at an annual rate of 0.5 percent during the same period.[2] In
1959-60 the output of meat, milk, and wool amounted to 226 million esducos
out of total agricultural output of 593 million escudos.

Studies that have been made of Chilean agriculture attribute the
low rate of growth to many different causes, some of which explain not
only a low rate of growth but a low level of productivity per unit of
input as well. The evidence that supports various explanations is likely
to be somewhat impressionistic, since systematic measurements of land and
water use, complementary inputs, and yields, all related to each other,

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[1] In current dollars, Boletín, Vol. II, No. 1, pp. 200 and 202. Volume
II, No. 2, however, received after the above was written, shows an
export balance for 1964 of $17 million dollars.

[2] La Economía de Chile en el Período 1950-1963, Instituto de Economía,
Universidad de Chile, Santiago, 1963, p. 25.

have not yet been made. It is just as easy to demonstrate low outputs per unit of labor and per unit of capital as it is to show low outputs per hectare. Inadequate use of fertilizers, herbicides, insecticides, high quality seeds, and failure to employ proper genetic practices are deficiencies frequently cited. There is little doubt that unskilled labor is in oversupply and skilled labor capable of using, maintaining, and repairing farm machinery is in low supply.

Two proposed explanations are contradictory. One is that discriminatory price controls keep prices of milk, meat, and wheat disproportionately low in the face of persistent and severe inflation, thereby discouraging investment. Another is that the high concentration of ownership of land is coupled with a relatively weak desire to maximize income. Lack of credit; lack of research and extension facilities; lack of personnel with adequate technical education; lack of marketing, transportation, and storage facilities help explain the backward state of agriculture. So far as water resources problems are concerned these explanations ultimately focus on two parameters: the amount of land under irrigation and the amount of water required per unit of land.

A study of Chilean water resources planning can, perhaps, be begun with the year 1952. In December of that year appeared the IBRD-FAO mission report entitled The Agricultural Economy of Chile.[1] The mission

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[1] The mission consisted of Egbert de Vries, Chief; Paul F. Craig-Martin, Agriculture Economist; Grace W. Finne, Transport Economist; Paul H. Hohl, Agricultural Engineer; and W. Norman McLeod, Civil Engineer. The mission acknowledged the assistance of Dr. E.I. Kotok and other unnamed FAO technicians, and Professor Paul T. Ellsworth. This report, although its cognizance of water was largely limited to assertions regarding the necessity of irrigation in semi-arid and arid regions, laid the foundation for other reports and plans more

was asked to analyze agricultural problems and policies and "in consultation with the Government of Chile, to arrive at recommendations for a broad program of agricultural development...directed primarily at a program for the next five to seven years."

This statement meant that the mission's time horizon, from the point of view of water resource planning, would be brief indeed and would automatically exclude certain methods of analysis. The IBRD/FAO team concluded that agricultural output should increase and was capable of being increased by 3.12 percent per year during the eight year period of 1952-1960. This rate of increase was designed to offset an estimated growth in population of 23 percent during the corresponding period coupled with an increased per capita income of 18 percent.

As events turned out only the population increase was realized. The growth of national income was less than was assumed; measured by per capita gross product it rose only by 7 percent. And, as already shown, agricultural output in 1962 was no higher than the figure for 1950. Had

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1/ continued from page III-4.
directly related to water resource planning. However, since the IBRD/ FAO mission strongly influenced subsequent plans for agriculture and since the largest single use of Chile's water is in irrigation, the report's relevance goes far beyond the attention explicitly given to water resources.

The IBRD/FAO report made two notable contributions to water resource planning in Chile: first, the goals it set for Chilean agriculture have continued to influence plans made by Chilean government up to the present; second, the way in which it approached irrigation plans and requirements was followed by all subsequent planning reports of the Chilean government and international agencies.

the changes projected by the IBRD/FAO team been realized, imports of food-
stuffs would have fallen to the level of the 'forties. As it was, annual
agricultural imports in 1954 and 1955 [1] were double the level of the
annual average for the period 1940-44, measured in constant prices. In
1955 agricultural imports were $109 million; in 1960, $110 million.[2]
A high rate of importation has persisted to the present. In July 1965
restrictions were imposed on the consumption of beef in order to reduce
the drain on foreign exchange and stimulate the consumption of pork,
poultry, and, especially, fish.

Pattern of Land Use: Evasiveness of Facts

Far more changeable than the agricultural economy is the state of in-
formation regarding agricultural resources. La Agricultura Chilena [3] for
the period 1951-1955 shows the total of land in Classes I-IV (i.e. land
fit for cultivation) in the province of Antofagasta, as 1,000 hectares.[4]
The same figure is repeated in the CEPAL report as the total amount of
"irrigable land that requires irrigation."[5] In both documents the amount
of land actually irrigated is also shown as 1,000 hectares. On the other

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[1] Naciones Unidas, Los Recursos Hidráulicos de América Latina, I.Chile,
prepared by the Comisión Económica para América Latina. Mexico, 1960.
(This report will hereafter be referred to as CEPAL). See p. 69.

[2] La Agricultura Chilena, en el Quinquenio 1956-1960, Ministerio de
Agricultura, Table 181, after p. 212. It has been stated un-
officially that food imports will be $150 million in 1965.

[3] La Agricltura Chilena en el Quinquenio 1951-1955, Santiago, 1957.
La Agricultura Chilena en el Quinquenio 1956-1960, Santiago, 1963.
These are two quinquennial reports of the Ministry of Agriculture.

[4] Cuadro Anexo No. 3 between pp. 24 and 25.

[5] CEPAL, p. 69.

hand, the FAO report, El Riego en Chile,[1] in a table listing projects
under construction and projects under study, included projects designed
to improve the irrigation of some 3,000 hectares and to provide for the
new irrigation of some 2,100 hectares.[2]

Of more importance than the quantity of land in Antofagasta is the
amount of arable and irrigable land in the country as a whole. La
Agricultura Chilena en el Quinquenio 1951-1955,[3] indicated that land in
Classes I-IV amounted to 11,079,000 hectares, almost double the estimate
of 6.2 million hectares that had been made during the 1940's. CEPAL
adopted the estimate of 11 million hectares in classes I-IV and concluded
that of this amount 7,163,000 hectares constituted "irrigable land that
needs irrigation," i.e. all land in and to the north of the province of
Cautín in Classes I-II and II-III and 60 percent of the land in Classes
III-IV.[4] Pourtauborde's report, El Riego en Chile, which followed the
appearance of CEPAL's study by about two years, stated that 20,000,000
hectares "ought to be irrigated" of the 30,000,000 hectares that made up
Chile's agricultural area.[5] Pourtauborde apparently reached the figure
of 30,000,000 hectares for Chile's "agricultural area" by adding
20,000,000 hectares of land of Classes V and VI, temporary or permanent

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1/ FAO, #1622, November 1962, by Jean Pourtabourde.

2/ Pages 61-62.

3/ P. 24 and note to Graph 3.

4/ CEPAL, p. 69.

5/ Op. cit., p. 3.

pasture, to the total of 11,000,000 hectares in Classes I-IV.[1] How

he reached the estimate of 20,000,000 hectares that "ought to be irrigated"

cannot be ascertained.

Between 1957 and 1963, when the second quinquennial report appeared [2]

land in Classes I-VI shrank from 30,888,000 hectares to 21,637,060

hectares.

Measurements of "arable land," apparently were as unsettled as the

measurement of "agricultural land." In the first quinquennial report

"arable land"--i.e. the sum of classes I, II, and III--was given as

6,924,000 hectares, whereas the agricultural census showed only 5,514,000

hectares. The comment on this difference was as follows.[3]

"This area (i.e. arable area) is concluded in the soils classified

in classes I and II and III in the general scheme already seen, that is

to say, those cultivable without or with light limitations and which amount

to 6,924,000 hectares. Since the statistical sample of the Censo

Agropecuario of 1955 indicates only 5,514,000 hectares as current arable

area, one can say that there exists a margin of 1,410,000 hectares that

can be immediately brought into cultivation within class II and III whose

only limitations consists of the need for a longer (period of) rotation

with emphasis on artificial pasture. This margin of increase of arable

area amounts to an increase of 25.6 percent over the area now under cultiva-

tion."

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[1] See Agricultura Chilena en el Quinquenio 1951-1955, pp. 21-23 and
CEPAL, p. 68, for definition of land classes.

[2] P. 26.

[3] Op. cit. p. 28, my translation.

By the time of the second quinquennial report the Census's figure of 5.5 million hectares had won out and there was no further talk of 26 percent margin for expansion.

None of the foregoing figures are confirmed by the Instituto de Investigación de Recursos Naturales, which has been tabulating data gathered by the air photogrammetric survey.[1]

The photogrammetric survey indicates that the total amount of land in classes I-IV, whether dry or irrigated, is no more than 4.6 million acres, instead of the 11.1 million reported in the 1951-1955 quinquennial report. Even if we adjust for land that is in the two northernmost and two southernmost provinces, using the figures from the quinquennial report, we cannot add more than 230,000 hectares.

Within the past decade irrigated land has been censussed, estimates have been made by CORFO and Dirección de Riego, one independent investigator in the Ministry of Public Works has made his own estimate, and, most recently, the land has been mapped and photographed from the air. Between the highest and lowest quantity of "irrigated land" is a spread of 270,000 hectares. (See Table III-2). The same effect would be achieved by occasionally misplacing the province of Santiago.

The probable explanation for the low figure revealed by the census is in under-reporting by the farmers themselves; the high figures of CORFO and Riego are probably explained by their use of design area rather than area actually developed for irrigation. There is also the likelihood that

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[1] Tables released in 1965. Unfortunately the survey excludes the two northernmost and two southernmost provinces.

one agency may include all area under a ditch as "irrigated land" whereas another may ignore land that is irrigated infrequently.

As already noted the air photogrammetric survey throws into wild doubt previous estimates regarding total arable area and all estimates except Basso's regarding the area that can be described as "irrigated." Even more disconcerting than corrections being made in the global figures are the changes in figures for particular provinces. According to the first and second quinquennial reports the irrigated area of Maule is given as 40,000 hectares. An unpublished table prepared by CORFO gives the figures as 4,000 hectares. The Institute's tables show 540 hectares "irrigated" and 3,116.3 hectares as capable of "contingent irrigation" (riego eventual).[1]

Another instance is the province of Cautín. The first and second quinquennial reports show 32,000 hectares irrigated. A special report on irrigation projects prepared by Jorge Chavez S., Ing.,[2] lists three projects in Cautín province that were completed between the years 1944-1959 with a design area of 35,700 hectares of which only 7,913 hectares were effectively irrigated. The photogrammetric survey shows 4,016 hectares now irrigated, and 79,663 hectares as "riego eventual." There is no way of reconciling the difference between the Chavez figure and the photo-

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[1] The definitions adopted by the air photogrammetric project are as follows: "irrigated land" (Classes Ir-IVr, inclusive) consists of land in the descending order of quality from Class I through Class IV that is assured of water 85 percent of the time and in the years of deficiency has at least 70 percent of its supply. "Contingent irrigation" (riego eventual), shown as mixed classes, e.g. IIr-II, consists of two kinds of land: (1) land under a canal that because of unfavorable micro-relief is not irrigated; (2) land that lacks a security of water supply equal to that of "irrigated land."

[2] Chief of Studies Section, Department of Public Works, CORFO, Report is dated 7 October, 1963.

Table III-2

AMOUNT OF IRRIGATED LAND ACCORDING TO VARIOUS SOURCES

(1,000 hectares)

First Quinquennial Report	1,362.8
CORFO (unpublished)	1,375.9
Second Quinquennial Report	
(a) according to Dirección de Riego and CORFO (1960)	1,366.1
(b) according to 1955 Agricultural Census	1,097.9
Basso [1]	1,260,000
Instituto de Investigaciones de Recursos Naturales [2]	
"irrigated"	1,212,601
"contingent irrigation"	700,594

[1] Eduardo Basso S., _Inventario de Recursos Hidrológicos Superficiales de Chile_, Minesterio de Obras Publicas, Mayo de 1963, p. 34.

[2] Data taken from tables released by the Institute.

grammetric figure of land irrigated. Both presumably measure exactly the
same thing--land under effective irrigation at present. If anything, the
photogrammetric figure should be larger, since Mr. Chavez' figure of
7,913 hectares relates only to three Ministerio de Obras Públicas projects,
ignoring all others.

Comparable uncertainty affects other characteristics of land use. Both
quinquennial reports contain a table showing the distribution of arable
land by type of crop for the same year, 1955, but with different figures.
(See Table III-3). The differences may reflect changes in classification
more than in count. It is possible that part of the difficulty originates
in self-censussing and either because of unfamiliarity with the classi-
fication scheme or a desire to under-report certain types of land use,
the census loses accuracy. A new agricultural census is currently (1965)
under way, but its results will not be available for some time.

Within the inter-censal period of 1955-65, CORFO [1]/made estimates of
arable land among different crops. There presumably have been no signifi-
cant changes since 1955, as is shown by the figures for 1962-63:

	(1,000 hectares)
Annual crops	1,584.6
Vineyards and fruits	173.5
Cultivated and natural pasture and fallow	3,777.7
Total	5,535.3

Regardless of the uncertainty of the total amount of arable land
and its pattern of use, one conclusion seems reasonably credible: a large

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[1]/ Unpublished

Table III-3

DISTRIBUTION OF ARABLE LAND BY TYPE OF CROP, 1955

(1,000 hectares)

	First Quin. Report	Second Quin. Report
Annual Crops (grains, beans, vegetables, potatoes, industrial crops)	1,326.8	1,300.7
Vineyards	108.1	96.8
Fruits	45.7	83.2
Cultivated Pasture	454.0	487.4
Natural Pasture	2,998.3	2,909.9
Fallow	590.0	665.4
TOTAL	5,514.0	5,543.4

Table III-4

DISTRIBUTION OF IRRIGATED LAND BY MAJOR USE, 1959-60

		Hectares
Annuals (except vegetables)		489,187
Vegetables		63,650
Vineyards		48,300
Fruits and olives		57,600
Pasture, total		730,847
Cultivated	328,210	
Natural	402,637	
Total		1,389,584

Source: CORFO, Unpublished data.

fraction of arable land is used for pasture or is fallow and the area
devoted to high value crops--fruits, vegetables and vineyards--is rela-
tively small, amounting to about 250,000 hectares.

The low intensity of land use in Chile is even more striking when we
consider land under irrigation (see Table III-4).[1] More than half of all
irrigated land is devoted to pasture; a significant amount is devoted to
a use only slightly more rewarding, namely, wheat.[2]

Land Ownership: Sizes of Farms

The relatively large amount of land used for natural pasture probably
represents a dubious use of water as well as land. Apparently a combina-
tion of circumstances that include uncertainty of water supply, scarcity
of skilled labor, capital and marketing facilities and conditions of land
tenure keeps land out of cultivation. A study of land tenure reveals a
direct correlation between the size of the farm unit and the percent of
its arable land devoted to natural pasture.[3] According to CIDA, the
"sub-familiar" (very small unit) allocated 29.2 percent of its arable land
to natural pasture, while the large multi-family unit allocated 46.8 per-
cent.

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1/ Total irrigated area given by CORFO implies that some of the land
   irrigated in 1959 came from the 700,000 hectares classified as
   "contingent irrigation" by the air photogrammetric project.

2/ See below, discussion of water use.

3/ CIDA, Estudio Sobre la Tenencia de la Tierra en Chile, p. 113,
   preliminary draft, 1964. CIDA stands for Comité Interamericano
   de Desarrollo Agrícola--a combination of several international
   agencies.

The significance of CIDA's findings is somewhat obscured by the studies of the Department of Agricultural Economics which find the following percentages when farms are classified by size of total irrigated areas:

Size Class of Irrigated Area (has.)[1]	Percent in Natural Pasture
1 - 5	29.3
5 - 9	28.0
10 - 15	19.7
15 - 30	19.0
30 - 50	19.0
50 - 100	20.0
100 - 200	17.5
200 - 500	22.5

Information on the distribution of farm land among units of various sizes is given in Table III-5. Total irrigated land is underestimated and total arable land is overestimated in comparison with results of the air photogrammetric survey, but the relationships are not likely to be seriously in error.

The concentration of ownership of land under irrigation is somewhat less than the concentration of ownership of land in farms and somewhat more than the concentration of ownership of arable land. For example, 36 percent of farm units have less than 100 hectares of total land area, and account for 7.4 percent of total land in farms, 16.7 percent of irrigated land, and 20.9 percent of "arable" land. These figures do not reveal how ownership of unirrigated land in Classes I-IV is distributed and what would be the distribution of ownership that would result from bringing new land under irrigation.

1/ Second quinquennial report, pp. 50-51.

Table III-5

SIZE CLASS OF FARMS AND LAND USE

(hectares)

Size	Number	Average Area in Farm	Average Agricultural Area in Farm	Average Arable Area in Farm	Average Irrigated Area in Farm
Less than 1	28,246	0.3	0.2	0.2	0.1
1 - 9.9	47,381	4.4	3.9	3.0	0.9
10 - 99.9	53,766	34.1	30.8	18.7	2.6
100 - 499.9	15,240	214.2	195.8	101.7	21.8
500 - 999.9	3,076	683.1	624.8	250.6	58.5
1,000 - 4,999.9	2,554	2,009.1	1,771.2	539.7	105.1
5,000 and up	696	21,788.3	14,884.0	982.9	191.4
Country as a whole	150,959	183.6	143.2	36.7	7.3
Aggregates	150,959	27,712,300.9	21,637,060.8	5,543,380.7	1,097,984.9
Percent of total area in farms		100%	78.1%	20.0%	4.0%

Source: "La Agricultura chilena en el quinquenio 1956-60" Ministerio de Agricultura, 1963, p. 27.

The amount of land under irrigation in the largest size-class averages about 191 hectares in farms that average about 22,000 hectares in size. These are dimensions roughly equivalent to the large western United States cattle ranch owned by husband and wife, each of whom are entitled to irrigate 160 acres of land with water supplied by a federal irrigation project. As in the United States, the largest land holdings tend to be cattle or sheep ranches; and as indicated by the relationships between the amount of land in the farm (21,780 hectares) and arable land in the farm, (983 hectares), the largest holdings are spread over land of low agricultural productivity.

Type of management and proportion of irrigated area devoted to crops are related to the distribution of land by size of unit. On farms operated by the owner only 24 percent of irrigated land is not in crops; where owner and operator share control, 30 percent is not in crops; on absentee-owned farms managed by a salaried administrator the percentage is 43 percent.[1] CIDA also found an inverse correlation between size of farm unit and value of output per hectare and a direct correlation between size of farm unit and value of output per worker. The figures are given in Table III-6. Insofar as there seems to be a relatively large amount of unemployed and underemployed labor in the country, so that labor is not a constraint, these figures indicate that total agricultural output would fall with consolidation and rise with diffusion of land holdings, other things being equal. The critical point, however, is under what circumstances

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[1] Quoted by CIDA, op. cit., p. 112, from a CEPAL/FAO report, _Analysis of some Factors Inhibiting the Growth of Livestock and Livestock products_, 1953, pp. 44-45.

Table III-6

CENTRAL CHILE: COMPARATIVE PRODUCTIVITY BY SIZE OF FARM UNIT

| Size of Unit | Value of output in 1955 (1960 Escudos) | |
	Per Irrigated Hectare	Per Farm Worker
sub-family	904	332
family	453	506
medium	454	776
large	243	1,150
Total	283	835

Source: CIDA, op. cit., p. 116.

the desired changes in "other things" can be most easily accomplished.

Sample studies of farm income indicate that net income per hectare from artificial pasture is equal to or more than income from crops, but substantially less than income per hectare from vineyards. (Income comparisons between crops and artificial pasture on the one hand and fruits on the other, yield somewhat ambiguous results). The sample studies also suggest that farms that engage in milk production along with other activities earn a higher rate of income per hectare than farms that do not.[1] Unfortunately, the studies are fragmentary and do not fully isolate the various factors that bear upon productivity. Perhaps the most striking conclusion is that for a country that is almost as famous for its fruits and wines as for its copper and nitrate, the area devoted to orchards and vineyards is small, amounting to about 175,000 hectares, or only 2 percent of its arable land.

Output per Hectare for the Country as a Whole

There still remains the question of how output per hectare in Chile for any given crop compares with output in other countries. Comparisons of this sort are relatively complex and cannot be made without carefully framing all conditions within which the comparison is made. An attempt at constructing a summary comparison was made by M.I. Kendall [2] and adapted by L. Dudley Stamp, for international use. The technique yields a ranking of countries according to yield per hectare. Out of the twenty countries studied by Stamp Chile ranked as follows for the year 1946:

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[1] Second quinquennial report, pp. 49-58.

[2] Quoted in L. Dudley Stamp, Our Undeveloped World, Faber & Faber, London, 1953, page 92.

Wheat	11th
Rye	12th
Barley	8th
Oats	14th
Corn	11th
Potatoes	11th
Sugar Beets	no data
Beans	11th
Peas	14th

For all nine crops taken together, using Kendall's ranking coefficient, Chile was in the thirteenth place, followed by China, Argentina, Australia, and India, and preceded (from the top of the list downward) by Belgium, Denmark, Netherlands, Germany, Britain, Ireland, New Zealand, Egypt, Austria, France, Japan, Italy, United States, Canada and Spain.

Stamp supplied production data for Chile that could be compared with other countries for only one specific crop: oats. In 1951 the yield in Chile was 0.87 metric tons per hectare. The world average was 1.39; the highest reported was 3.09 (Denmark) and the lowest was 0.43 (Roumania). Stamp's data reveals, moreover, that in 1951, for the twenty-two countries compared, Chile ranked next to last (Roumania being last) in productivity per hectare, whereas in 1945-47 there were six countries with lower productivity than Chile's, and in 1934-38 there were nine. Yield per hectare declined in Chile from 1.01 metric tons per hectare in 1934-48 to 0.87 metric tons per hectare in 1951, while the world average moved from 1.19 metric tons to 1.39 metric tons.

If we compare Chile's yields for the year 1950-51 in tons per hectare, as reported by the second quinquennial report, with world average yields

as given by Stamp (taken from FAO's <u>Yearbook of Food and Agricultural</u> <u>Statistics</u>, no date, but presumably for a year between 1951 and 1953), we have the following:

	<u>Chile</u> (tons per hectare) <u>1950-51</u>	<u>World Average</u> <u>1951</u>
Wheat	1.15	1.15
Corn	1.43	1.58
Rice	1.72	1.62
Barley	1.56	1.26
Oats	0.91	1.39
Rye	0.58	1.35
Sugar beets (1953-54)	15.26	24.8
(1959-60)	28.02	

These figures indicate that Chile's output per hectare, for 1950-51, exceeded the world average for rice and barley, equalled the world average for wheat, and fell below the world average, in some cases by substantial proportions for corn, oats, rye and sugar beets. The Chilean figures for sugar beets are for 1953-54, the first year of record. Since the crop was introduced only in that year perhaps a comparison is not meaningful. Yield in 1959-60 amounted to 28.02 tons, somewhat above the world average.

The comparisons among yields conceal the varying proportions of total output, inside as well as outside Chile, that are produced on irrigated land and dry land, the relative productivity of which varies substantially.

What is the significance of knowing that in Chile the average output of wheat per hectare is about the same as that of the United States, when in Chile according to one source,[1] about one-third of wheat land (1959-60)

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[1] CORFO, <u>Programa de Desarrollo Agrícola</u>.

is irrigated, whereas in the United States very little is?

Statistics on productivity generally suffer from such deficiency of detail that most comparisons cannot readily be interpreted. For example, figures on comparative productivity per hectare (Table III-6) fail to indicate that the large unit is usually a livestock enterprise, whereas the productivity of smaller units reflects another type of agriculture. Without additional information one cannot infer that the large unit is relatively "unproductive," since the "low" productivity per hectare probably reflects dedication of irrigated land to production of cattle feed--a use that if not supplied would make impossible the exploitation of large areas of unirrigated grazing land. Questions of "efficiency of land use," moreover, cannot be examined independently of "efficiency" in the use of labor and capital. The figures reveal that while the output per unit of land varies inversely with size of unit, the opposite is true per unit of labor. No information is supplied regarding output per unit of investment.

Chapter IV

THE USE OF WATER FOR IRRIGATION

The main conclusions reached by investigators of Chilean irrigation
are that water is used with a prodigality that can only mean great waste.
Principal and secondary works are inadequate, antiquated, frequently in
poor condition, easily damaged by moving water, clogged with weeds, and
lined with thirsty trees. In many cases the land is not prepared for
irrigation; the technique of irrigation commonly used -- innundation --
is extremely wasteful; and there is little knowledge of current rates of
water use let alone optimum water requirements. The network of canals
reflects haphazard development over decades, maybe centuries: long,
parallel canals inhibit movement of men, animals and machinery, as well
as waste large quantities of water. Irrigating by turns, whereby ditches
are alternately dried and wetted, and a "turn" may mean 2 hours every ten
days, inhibits delivery of water rightfully claimed by the irrigator.
Irrigating only during the day coupled with absence of night-time storage
allows water to run unused to the sea.

The degree to which the faults of Chilean land use -- i.e. the
extensive use of natural pasture and fallow fields rather than cultivation
of crops, feeds, fruits and vineyards -- is a reflection of poor use of
water, and the degree to which poor use of water is a reflection of
problems facing agriculture in general are questions that demand investiga-
tion before a rational water resource policy can be developed. These
questions in turn, cannot be investigated without the acquisition of con-
siderable information and analysis at both the technical and budgetary
levels of farm operation. In the absence of such data our conclusions

are largely inferential, based upon scattered bits of information.

The 1952 IBRD-FAO report, in passages that have lost none of their relevance, described Chilean irrigation as follows:[1] "...Most of the water comes directly from the rivers, whose flow is not regulated in any way. Thus coarse silt, gravel and even small boulders cannot be prevented from entering the canals. When floods occur, the head of the canal may be washed away and irrigation interrupted. Most canals are not protected against erosion and the water level decreases gradually; difficulties experienced in serving the fringes of the irrigated zone increase... many small canals of great length were built by individual owners or small groups with consequent unnecessary losses of water. Further lack of attention to irrigation during the night and weekends, except in the North where water is so precious that storage tanks are being built, causes additional losses. In the Central Valley fields with excessive applications of water (even to the point where crops suffer) alternate with others which get water only in a haphazard way.

"...A conservative estimate puts the loss of water, i.e. the possibility of increasing the area under crops or artificial pasture, at 20 percent. In some places qualified observers put the loss at 40 percent. The main trouble is unequal application of the water over the fields due to failure to divide the fields into compartments; yields are depressed and where the flow of water is rapid, erosion threatens.

"...Improved use of irrigation water is largely a matter of giving information to the farmers.... in a number of cases, additional investments of a public character will be needed... ...underutilization (of land) is mainly a problem of the large farms and is found to a large degree on irrigated land. The mission found bad farm management by the

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[1] P. 176, ff.

owner, or more often by the mayordomo in his absence, among the reasons
for the large percentage of irrigable land lying fallow in the central
valley... On the peasant holdings land use is already rather intensive."

Somewhat surprisingly in view of the poor state of many existing
facilities and the low level of efficiency in the use of water the mission
recommended "early completion of the (irrigation) works under construction
as the best available means to provide for the larger part of the desired
new cultivable land and the construction of two additional schemes before
1960."[1] The total proposed irrigated acreage would provide 283,000 new
irrigated hectares. In addition, the mission recommended drainage of
about 300,000 hectares of non-irrigated land for pasture and truck farm-
ing. These recommendations, along with increased productivity of agricul-
ture in general were designed to raise output by 38.5 percent, during the
period 1952-60.

The mission dealt with many other aspects of farm management,
fertilizers, equipment, credit, marketing, transportation, and so forth.
In the mission's collective mind "the importance of irrigation in Chile
has been stressed throughout this report" (p. 278). In spite of such
stress, however, the treatment of irrigation was somewhat casual. At
no point did the report assess the relative merit of allocating avail-
able funds to the improvement of existing irrigation systems instead of
building new ones, or to increasing the land under cultivation within a
given system by increasing the efficiency of water use. One cannot
ascertain from the report the degree to which improper land use is a
property of land per se, or a property of the availability of water, and
if the latter, the ways in which its improvement would automatically be

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1/ Ibid p. 182.

reflected in better land use.

A later study on irrigation by Ralph M. Bell [1] made the following recommendations:

(1) Improved control and soil conservation practices, restriction of grazing accompanied by practices designed to encourage natural beneficial vegetation; forestation to protect the watersheds; river bank and canal erosion control.

(2) Increased storage of surface flow for irrigation and other uses such as hydroelectric power, fishing and recreation; provision of storage tanks to capture nocturnal flows.

(3) Surveys to determine optimum locations of principal irrigation intakes along the river; rearrangement of canals in order to maximize the number of hectares served per unit of length of canal--for both supply and drainage canals, taking into account the reuse of irrigation water.

(4) Better supervision of distribution of water--inspectors, measurements, etc. to ensure delivery of water according to ownership of rights; domestic production of devices to measure, control and distribute water; measurement of water use; instruction in amount and timing of irrigation.

(5) Acquisition of more complete information regarding present use and available supply of ground water.

(6) Study of soils and capacity of land under irrigation or planned for irrigation; determination of crops best suited for different soils

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[1] FAO, Report No. 379 to the Government of Chile on *Irrigation and Methods of Irrigation*. Rome, 1958, p. 8 ff.

(7) Substitution of ditch and furrow irrigation for inundation;
substitution of spray irrigation for gravity flows where soil
erosion threatens; transfer of water from poor lands to better
lands.

(8) Development of programs to awaken the interest of farmers in
progressive methods, use of equipment, improved techniques of
irrigation and education of workers; more adequate treatment of
irrigation problems and techniques in the university curriculum.

(9) Expansion of the collection of basic hydrologic and meteor-
ologic data, behaviour of soils under irrigation, and duty of
water.

The report pointed out that many of its proposals dealt with matters
about which the Departmento de Conservación de Recursos Agrícolas y
Forestales and the Departamento de Extensión Agrícola were cognizant and
at work.

Unlike the IBRD/FAO report Bell dealt with "reforms" of current
irrigation practices and emphasized the need for changes in techniques,
better knowledge of adaptability of soils and crops, and the need for
more complete information regarding water use. Bell issued a mild reproof
to the authors of the earlier report for not insisting "as they should
have on the need for giving greater importance to what happened with the
water once it reached the farm" 1/ and pointed out that improved use of
water could yield results that "could be spectacular" and could avoid
some construction projects. The author emphasized the need for 24-hour
irrigation seven days a week, which would be possible with improved land

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1/ P. 16.

preparation and irrigation by furrow instead of inundation. Bell esti-
mated that in addition to losses in canals leading to the farms, losses
on the farm were probably about 60 percent. If such losses could be
reduced from 60 to 40 percent, the total of irrigated acreage could be
increased by about 280,000 hectares. Furthermore, improved application
of water could raise yields about 10 percent according to a "conservative
calculation."[1] To achieve this would require an educational program,
more and better machinery, credit facilities, and technical supervision.
Bell concluded that the existing water supply with better management would
supply an increased output of 30 percent from irrigated land. Up to now
neither Bell's nor the IBRD/FAO recommendation has been followed.

Measures of Current Water Use

According to the CEPAL report on Chilean water resources the irriga-
tion input of water exceeds norms derived from applying coefficients for
California to the Blaney-Criddle formula by amounts that range between
20 percent and 106 percent. Norms based on Chilean investigations are
not available. Estimates of water requirements were computed for four
river basins. Unfortunately they provide no detail regarding crops, size
of farm, or other characteristics:

RATES OF WATER USE AND REQUIREMENTS FOR IRRIGATION [2]

(cubic meters/per hectare per year)

Basin	Current Rates	Needs According to Blaney-Criddle formula	Percent of use over needs
Río Elqui	14,200	11,850	20
Río Maule	21,200	10,300	106
Río Maipo	14,800	10,230	45
Río Itata	15,100	11,660	30

[1] P. 18.
[2] CEPAL, p. 68.

The authors point out that part of the excess water returns to the river by infiltration. They also repeat Bell's recommendation to measure flows in the canals, accumulate data on water use by type of crop and by zone, and conduct studies designed to fix optimum water requirements based on Chilean conditions.

A study written by Eduardo Basso S. [1] examined several estimates of water use by crop and broad region within Chile and in comparable regions abroad (mainly California, it appears). Wide differences among estimates are not explained. It is possible that in some cases the figures are observed measures of actual inputs, whereas in other cases they refer to requirements determined experimentally under idealized conditions. In some cases they may represent water requirements on the field, whereas in other cases, deliveries to the farm. The lack of data based on Chilean experience--whether observed on operating farms or experimentally determined under carefully controlled conditions--led Basso to base his efficiency norms on results collected in California. Out of a mass of conflicting statistics, Basso constructed a table that represented current use of water by region and crop, excluding the highest reported rates, since some level of improvement could be anticipated "without a change in the idiosyncrasy of the Chilean farm worker."[2] He then compared these figures with "optimum rates of irrigation, according to North American investigations (translated to Chilean conditions)." Basso indicated that the "optimum rates" would not be realized without a "gradual campaign of education" of the farmer. Thus, the first set of figures represent,

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[1] Inventario de Recursos Hidrológicos Superficiales de Chile, op. cit.

[2] pp. 40-41.

roughly, a picture of what all except the most prodigal farmers are already achieving, whereas the second set presumably represent a higher order of efficiency, but one that is reasonably attainable. The differences between the two sets of figures reveal a minimum practicable quantity of saving.

We can get a better idea of estimated waste by translating the unit values of Table IV-1 into aggregates. This is done in Table IV-2, using the irrigated areas and cropping patterns estimated for the country by CORFO for the year 1959-60.[1] Gross irrigation inputs for the country as a whole were estimated to be about 9.2 billion cubic meters for the year 1959-60. Of this total, zone II [2] accounted for 7.1 billion, cubic meters and zone III accounted for 1.6 billion cubic meters.

We can also estimate the amount of additional land that could be irrigated in each zone if water were used efficiently, assuming the same cropping pattern were retained:

    Zone I   - 13 percent or   1,456 hectares

    Zone II   - 45 percent or 476,119 hectares

    Zone III   - 45 percent or 115,079 hectares

    Zone IV   - 44 percent or   28,203 hectares
                                 _____

    Total, four zones   620,862 hectares

The potential total increase would raise the 1959-60 estimated

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[1] There are slight differences between the provinces that comprise the four zones of Table IV-2 and the provinces that comprise the regions to which Basso's coefficients apply, but these are of little consequence.

[2] Zone II consists of Atacama and all provinces to the South as far as and including Linares. Zone III consists of Maule, Ñuble, Concepción, Bío-Bío. Zone IV consisted of the provinces from Cautín to and including Llanquihue.

Table IV-1

IRRIGATION RATES CURRENTLY EXPERIENCED VS. OPTIMUM RATES a/

(M³/hectare/year)

Crop	Tarapacá and Antofagasta			Atacama to Coquimbo			Aconcagua to Linares			Ñuble to Malleco			South of Cautín		
	E	O	O/E	E	O	O/E	E	O	O/E	E	O	O/E	E	O	O/E
Pasture	11,000	10,500	95.5	10,500	10,500	100.0	9,000	5,700	63.3	8,500	5,500	64.7	7,400	5,500	74.3
Vegetables	9,300	6,000	64.5	9,000	7,500	83.3	6,200	5,000	80.6	6,000	4,500	75.0	6,000	4,000	66.7
Fruits	10,500	6,600	62.9	10,000	8,100	81.0	9,700	6,000	61.9	8,900	4,200	47.2	7,300	4,000	54.8
Cereals	3,000	3,000	100.0	3,000	3,000	100.0	2,800	2,300	82.1	2,300	2,300	100.0	1,800	1,800	100.0
Vineyards	-	-	-	10,000	10,000	100.0	9,700	9,700	100.0	-	-	-	-	-	-

E = experienced; O = optimum.

a/ Basso, op. cit., p. 41.

"Optimum" is not explicitly defined by Basso but presumably refers to a physical optimum on the assumption that water of satisfactory quality is available. To illustrate the range of data yielded by Chilean sources, we can give the estimates made by Fco. Javier Domínguez, Ing., as cited by Basso. Domínguez's estimates are ranges or averages for a region without distinction by type of crop:

Tarapacá - Antofagasta - 13,000 - 17,500 m³/hectare/year.
Atacama - Coquimbo   - 13,000 - 17,500
Aconcagua - Linares   - 10,000
Ñuble - Malleco   - 6,000
Cautín - Llanquihue   - 4,000

For the three regions between Tarapacá and Linares, the figures of Javier Domínguez are greater than any of those accepted by Basso as reflecting current experience. There is no way of knowing whose figures come closer to reality. In view of the prodigality of water use reported by Pourtauborde, Bell, and CEPAL, Domínguez's estimates might be the better, in which case we have substantially underestimated the potential total savings of water.

irrigated area by about 45 percent. These estimates do not take into account the fact that water is recovered for further use in areas in which it has been applied to excess. Therefore, the potential total increase in irrigated area with the same water supply is overstated.

In all of these estimates there is a large uncertain factor represented by the ignorance of the degree of security that can be assigned to the water supply of each hectare. All estimates of current water use contain an implicit assumption: that the water is there. We have no way of knowing how well each farm fared in a given year.

The estimates of Table IV-2 support the suspicion that a relatively large amount of water is used for low-yield production. About 70 percent of estimated water use went into pasture and about 14 percent went into annuals. Of the latter, a significant fraction went into wheat.[1] Unfortunately, we have no way of isolating the yield from irrigated land from all land devoted to a particular crop. Table IV-3 shows the value of output per hectare by crop. The fact that irrigated land cannot be separated from dry land is especially serious for pasture, since total area devoted to pasture is 3.2 million hectares, whereas only 731,000 were irrigated and undoubtedly have a higher yield than is indicated.[2]

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[1] In Zone II, for example, of 386,137 irrigated hectares devoted to annuals, 131,000 hectares were in wheat.

[2] Cultivated pasture supports 1.5 to 2 animal units per hectare per year whereas natural pasture maintains only 0.5 animal units. Of the 731,000 hectares of irrigated pasture, 328,000 were cultivated and the remainder natural.

Table IV-2

EXPERIENCED AND OPTIMUM WATER REQUIREMENTS BASED ON 1959-60
IRRIGATED AREA

| | | Irrigated Area a/ (has.) | Unit Water Use (Gross) | | Total Water Use | | "Waste": Current-Optimum m³/10⁶/yr. |
			Current b/ m³/Ha/yr.	Optimum b/ m³/Ha/yr.	Current m³/10⁶/yr.	Optimum	
Zone I	Annuals	-	3,000	3,000	-	-	-
	Vegetables	1,910	9,300	6,000	18	11	7
	Fruits & Olives	576	10,500	6,600	6	4	2
	Vineyards	-	-	-	-	-	-
	Pasture	8,714	11,000	10,500	96	91	5
	Total	11,200			120	106	14
Zone II	Annuals	386,137	2,800	2,300	1,081	888	193
	Vegetables	46,464	6,200	5,000	288	232	56
	Fruits & Olives	38,070	9,700	6,000	369	228	141
	Vineyards	46,851	9,700	9,700	454	454	0
	Pasture	540,521	9,000	5,700	4,865	3,081	1,784
	Total	1,058,043			7,057	4,883	2,174
Zone III	Annuals	88,668	2,300	2,300	204	204	0
	Vegetables	5,092	6,000	4,500	31	23	8
	Fruits & Olives	3,888	8,900	4,200	35	16	19
	Vineyards	1,449	-	-	-	-	-
	Pasture	156,634	8,500	5,500	1,331	861	470
	Total	255,731			1,601	1,104	497
Zone IV	Annuals	14,382	1,800	1,800	26	26	0
	Vegetables	10,184	6,000	4,000	61	41	20
	Fruits & Olives	15,066	7,300	4,000	110	60	50
	Vineyards	-	-	-	-	-	-
	Pasture	24,478	7,400	5,500	181	135	46
	Total	64,110			378	262	116
Total	Annuals	489,187			1,311	1,118	193
	Vegetables	63,650			398	307	91
	Fruits & Olives	57,600			520	308	212
	Vineyards	48,300			454	454	0
	Pasture	730,847			6,473	4,168	2,305
	Total	1,389,554			9,156	6,355	2,801

a/ CORFC, unpublished.
b/ Basso, p. 41.

Table IV-3

AVERAGE VALUE OF OUTPUT PER HECTARE, CHILE, 1959-60

SELECTED CROPS

	Cultivated Has.(1000)	Aggregate Market Value (E° 1000)	Market Value per Ha. E°
Wheat	887.6	79,643.4	89.7
Corn	74.7	11,876.1	159.0
Rice	40.0	9,124.6	228.1
Beans	93.2	21,674.6	232.6
Potatoes	86.3	50,550.2	585.7
Sugar Beets	18.6	8,311.1	446.8
Vegetables, including onions and garlic	63.7	36,881.6	579.0
Sunflower	51.1	5,398.3	105.6
Tobacco	3.1	1,599.9	516.1
Fruits	57.6	38,207.3	663.3
Vineyards	98.0	52,922.8	540.0
Pasture (total) 1/	3,217.8	245,153.4	76.2

Source: La Agricultura Chilena en el Quinquenio 1956-60, Ministerio de Agricultura, pp. 60-78. Hectares of vegetables, fruit, and pasture taken from unpublished CORFO sources.

1/ Aggregate market value includes all animal and poultry products. Includes natural and artificial pasture but fails to account for feed that might be supplied by crops.

Chapter V

EXPERIENCE WITH GOVERNMENT IRRIGATION PROJECTS

Virtually all new irrigation in Chile developed during the last

fifty years has been in the form of public projects. The present Dirección

do Riego has its antecedents in an agency created in 1914. According to

CEPAL [1] by the beginning of the present century about one million hectares

of land had been put under irrigation by privately financed works, mostly

in the form of canals and ditches. Works constructed by the State during

the last fifty years have added 362,751 hectares. [2]

We have little to say about the economic merit of private irrigation

projects. Presumably most of them were justified in the eyes of the farmers

who singly or in groups supplied the money, labor, and materials for their

construction. Private projects are usually administered by an associa-

tion whose members are owners of the land under irrigation who possess

rights to the use of water. Water rights, rights of way, equitable

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[1] Page 66.

[2] Villarroel & Horn, Rentabilidad de las Obras de Regadío en Explotación
Construidas por el Estado, Ministerio de Obras Públicas, June 1963,
p. 25. The figure given by Villarroel & Horn is the design area of
all projects for which data are available. The major exclusion is the
Canal San Carlos, in the vicinity of Santiago, which was built by the
government over a period of many years before Dirección de Riego was
created.

relations among association members, and legal powers of the association
were established by a series of laws culminating in a water code (1951)
which has had subsequent amendments and is now in the process of being
completely overhauled.[1] Separate laws cover the powers and responsi-
bilities of the Dirección de Riego and the procedures whereby public irriga-
tion projects are selected and financed.

The present deficiencies of irrigated agriculture in Chile are in the
main a reflection of the private projects since they account for most of
the irrigated land. Most major private works are at least fifty years old;
many go back to Chile's colonial period. Some, of course, are well designed
and efficiently managed.

In particular instances the distinction between "public" and "private"
has been lost, since the purpose of a number of public projects was to
improve or expand existing private systems.

There is no pretension on the part of Chilean officials that all is
well regarding the level of agricultural efficiency, the use of water by
irrigators, and the selection, construction, maintenance, and administra-
tion of all governmental irrigation projects. Critical studies of separate
irrigation projects have been made by Chilean experts and by foreign
authorities on invitation of the Chilean government.[2]

1/ See CEPAL and Villarroel & Horn for summaries of the laws regarding water.

2/ Such studies are (1) FAO Report #879, Irrigation and Methods of Irrigation,
by Ralph M. Bell, 1958; (2) FAO Report #1622, EL Riego en Chile, by Jean
Pourtauborde, 1962; (3) Rentabilidad de las Obras de Regadío en Explota-
ción Construidas por el Estado, by René Villarroel B. and Heinrich Horn
F., Ministry of Public Works (Dirección de Planeamiento), June 1963;
(4) Informe Preliminar, Jorge Chavez A., Chief of Studies, CORFO
(Departmento de Obras Civiles), October 1963.

The author is grateful to Eugenio Lobo, Ingeniero de la División de
Estudios, Departamento de Riego, for the generosity with which he made
his time available and shared his knowledge of the problems of irrigation
in Chile.

Pourtauborde's study identified and described ten projects in the

four northern provinces--Tarapacá, Antofagasta, Atacama, and Coquimbo--

that were already in operation, four projects under construction, and

nine projects under study. A brief sample of his comments illustrates

the problems that are encountered:

> Many of these projects are small. The caritaya reservoir
> irrigates 500 hectares. The irrigable area could be extended to
> 1,000 hectares if there were a "well cared for" network of canals
> and a supply of underground water of better quality than the
> mineralized surface waters now being used. The Canales Catiña,
> Pocoma, y Pachica, taking water from the Tarapacá are in such
> mediocre state that irrigation is "uncertain."

> Among the larger projects is Lautaro Reservoir constructed in
> 1938, with a capacity of 40,000,000 m3, designed to improve
> the irrigation of 7,800 hectares, add 2,100 hectares, and provide
> 85 percent certainty of water supply. The reservoir has failed
> to function as expected because the flow of the Copiapó was over-
> estimated. Design flow was based upon data covering a period of
> six years. In the one period that the reservoir was full (1940-42),
> leaks were observed through the alluvium on which the dam rested.
> Although the stability of the dam was not affected this has turned
> out to be an irrelevant virtue since the dam has been dry 90 per-
> cent of the time since its construction. Today it is virtually
> abandoned.

> By another project the meadows near the city of La Serena were
> drained and a network of irrigation canals fed by the Elqui River
> were built. The land was then divided into relatively small farm
> units (parcelas) and distributed to new settlers. The project has
> faced a continuous deficit of water owing to the older rights pos-
> essed by other landholders. Pourtauborde concluded that the project
> was quite imprudent, especially in view of the water requirements
> that had been incorporated into the initial plans, 16,000 to 22,000 m^3
> per hectare (5½ - 7½ acre-feet of water per acre). Those who hold
> prior rights apparently lay claim to excessive quantities of water.
> (Pourtauborde mentioned the quantity of 32,000 m3/ha rather off-
> handedly--the equivalent of 10½ acre-feet per acre). Apparently not
> all this water is used by the title holders; but those without legal
> rights cannot use it either. Pourtauborde thought that the project
> could be successful if (1) the flow of Elqui were regulated and
> (2) the water were distributed strictly on the basis of physical needs.

The "preliminary report" of Sr. Chavez (CORFO, 1963) dealt with a

different problem: the failure of a project to be completed after the

principal works have been built. In their present unfinished state these

presumably are projects that augment the supply of irrigable land at relatively low marginal costs. He examined twelve projects whose design area amounted to about 100,000 hectares, in order to ascertain why the secondary and on-the-farm elements had never been completed. The main works of nine had been finished at various dates extending back to 1944. Three were still under construction. Of the nine, 35 percent of the design area was being irrigated, on the average. One project, for which the major works had been completed in 1944, had reached 31 percent. Another, completed in 1959, had reached 6 percent. One project had reached 72 percent development, the highest of the twelve. Eleven were canals and one was a reservoir. The reservoir had been finished in 1953, but only 43 percent of the planned area was under irrigation in 1963. In contrast with Pourtauborde's report, which dealt with the north, Chavez's report was limited to projects in the southern part of the central valley.

Among the three works still in progress, all were canals. One had been started ten years before the date of the study, and had reaches 4 percent of planned development. Another had been started three years before, but had not yet served new land. The third had been underway eight years and served 33 percent of the planned area. CORFO tried to ascertain by questionnaire the reasons why complementary facilities had not been built along with the mother canals and why there had been such undue delay in completion of the three works still under way.

Responses to the questionnaires yielded the following answers:

"economic" (farmers' lack of funds)   - 52%

lack of technical advice   - 48%

poor distribution of water   - 33%

lack of secondary canals   - 57%

inadequate rate (allowed?) of irrigation - 3%

works are under construction   - 3%

poor quality of land   - 5%

lack of land preparation   - 16%

Since some of the categories are not mutually exclusive--e.g. lack of secondary canals and land preparation may be attributable to lack of economic resources--the responses yield a somewhat fuzzy picture. Nonetheless, the first four reasons are reasonably clear.

The responses from proprietors of farms dependent upon the three principal works still under construction were limited to two reasons:

"economic" (farmers' lack of funds)   - 59%

lack of technical assistance   - 65%

Chavez made the parenthetical observation that in addition to the data collected by the questionnaire, it was evident that appropriate techniques of irrigated agriculture either were little known or ignored in "almost all" of the works that were visited. This suggested to him the need for further investigation of the relationship between the small difference in yields between irrigated and dry land in the zones studied and the incentive to invest in irrigation works.

In commenting on various specific projects Sr. Chavez made the following additional observations:

(1) Canal Allipén suffered from a poor distribution of water because the secondary and tertiary canals had been poorly

placed when the land was still mostly forest. The more the land was cleared the more obvious it became that the canals were in the wrong places. Furthermore, for most of the project area the soils are thin.

(2) Canal Duqueco Cuel is in the final stages of completion but delays in bringing the land under cultivation are already apparent. There are no plans for secondary canals and future irrigators are largely ignorant of their respective areas and assigned shares of water. The Ministry of Public Works is constructing a new roll of irrigators since the one that exists was put together in a hurry and mingled the zone of Duqueco Cuel with that of Canal Laja.

(3) Canal Bío-Bío Sur, second stage, Canal Quillaileo, and Canal Coreo, still under construction, all serve areas of poor soils.

(4) Tutuvén Reservoirs, (43 percent of design area is under irrigation), was completed in 1953. The project suffers from poor topography, making canals difficult and expensive to construct. Furthermore, the farmers of the zone, accustomed to sheep raising and vineyards are apathetic to the advantages of irrigation. At least 25 percent of the area is unirrigated solely because the farmers lack interest.

Chavez's "preliminary memorandum" of October 1963 has not yet been replaced by a definitive document. An official of Dirección de Riego indicated that when the final report appears it will be less critical and will show more land under irrigation. This opinion is not supported by the results of the air photogrammetric survey. We have already referred to the uncertainty over the extent of irrigated land in Maule province.

According to Chavez's report, Tutuvén now supplies water for the effective irrigation of 920 hectares out of a design area of 2,160 hectares. The air photogrammetric survey shows 540 hectares being irrigated, in Maule province, the region supplied by Tutuvén. In other words, less rather than more land is under irrigation than Sr. Chavez indicates. In Cautín province the photogrammetric survey shows a total of 4,016 hectares as irrigated, whereas Sr. Chavez indicates a total of 7,913 hectares for three projects. If the air photogrammetric measurements are accurate, Sr. Chavez's preliminary evaluation has been too liberal rather than too restricted.

The severely critical study of René Villarroel B. and Heinrich Horn F.[1] is a disconcerting contribution to Chilean self-evaluation. The authors analyze forty-seven projects of Dirección de Riego that supply water to a new land equivalent of 362,751 hectares and account for more than 95 percent of the area served by all projects built by the agency. All types of works are included: canals, reservoirs, drainage systems, and pumping facilities.

Each project was appraised on the basis of a comparison between the added output resulting from irrigation and the added costs of production-- on-the-farm and project costs. Of a total of 47 projects, nineteen showed losses. Another seventeen experienced net yields on capital invested of less than 8 percent. Since CORFO loans, on constant values, were considered by the authors to be at 8 percent, earnings below this level were described as yielding less than the expected marginal yield on capital. Therefore, by varying degrees, 36 out of 47 projects, failed to meet a

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[1] Op. cit.

test of economic efficiency.[1]

Projects that performed poorly were those for which yields were low
rather than costs high. The authors concluded that poor performance was
the result of a poor choice of crops, inept use of water, lack of technical
assistance, and lack of necessary agricultural credit facilities. .

The main criticism directed toward the Villarroel and Horn analysis
by Dirección de Riego officials is that it underestimates additional pro-
ductivity attributable to government projects. Since Villarroel and Horn
did not have "before" and "after" data on production from land specifi-
cally a part of governmental projects, they estimated the effect of a
project as equal to the output of an average irrigated hectare in the area
minus the output of an average dry hectare, based on the census of agri-
culture in each comuna. The effect of this measurement was two-fold:
(1) it overestimated output on unirrigated land because the authors' sample
included land more favorably situated than the land that was put under
irrigation; (2) it underestimated output on irrigated land, because by
using the communal average it failed to reflect the fact that irrigators
on land served by government projects had a higher degree of security of
water supply, and therefore a crop mix of higher value, than irrigators
on non-project land. In other instances the authors overestimated pro-
ductivity by ignoring the fact that some projects were only modifications
of existing irrigation systems and brought little if any new land under

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[1] Allen Kneese commented that, "It might be a comfort to Chilean readers
to know that most federal U.S. projects will not stand the test of a
realistic rate of interest either."

irrigation; yet the authors assigned to such project the difference in output between irrigated and non-irrigated land.

What makes the Villarroel and Horn study difficult to evaluate in spite of the obvious weakness in their method of analysis is the fact that its results are partly corroborated by the investigation of Jorge Chavez and the further fact that there are no official (or unofficial) studies that make it possible to dispute Villarroel's and Horn's conclusions.

If subsequent investigation should support Villarroel's and Horn's conclusions, of the 362,751 hectares (new equivalent) served by public irrigation projects, about half, or 178,772 hectares, are within projects that cannot be justified by economic criteria. Total investment, i.e. capital costs plus the costs incurred by the state during the trial period of operation ("costos de explotación"), for all projects amounted to 116 million escudos (in 1962 escudos, which at the 1962 rate of exchange was approximately $116 million dollars), of which projects that could not be justified in economic terms amounted to 70 million escudos, or 60 percent.

Since Villarroel and Horn computed investment costs per hectare on the basis of project design area, they underestimated costs by the ratio of design area to area actually under irrigation. On the basis of the reports of Pourtauborde on projects in the four northern provinces and Chavez on projects in the southern part of the central valley we can estimate that of a design area of 78,082 hectares only 35,403 hectares[1] are effectively irrigated. For these projects, therefore, Villarroel's

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[1] A figure that is still too high according to the air photogrammetric survey.

and Horn's costs per unit of land are approximately half the amount that
they "actually" are. A modification of their computations, however,
converts only two projects from "economic" to "uneconomic". All others
whose costs would be raised were already classified as uneconomic.[1]

It is possible that detailed studies of other regions would reveal
additional differences between design area and area actually irrigated.
The difference of about 200,000 hectares between the air photogrammetric
survey's total of effectively irrigated land and the CORFO-RIEGO estimate
based on design area of public projects plus land irrigated by private
works suggests such a likelihood.

One scarcely knows what credibility can be attached to the conclusions
of Villarroel and Horn regarding economic merit. So long as the best we
can achieve is an opaque view of reality, there is a strong temptation
to seize upon any "fact" and make the most of it. One should be reluctant
in the present case to do so. On the other hand, past procedures in the
selection of projects support their conclusions. First of all, one might
question the criteria for project selection that are employed by Dirección
de Riego. Second, one might question whether the criteria and priorities
established by Riego are in fact followed.

Among the criteria used for the selection of projects has been the
objective of stimulating the production of wheat and meat.[2] This

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1/ According to Villarroel and Horn an "uneconomic" project is one for
which the net increase in production (i.e. after netting out on-the-
farm costs and current project costs) is equal to or more than 8% of
project investment.

2/ The next few paragraphs are based upon conversations with various
people within the Chilean government and foreign technical aid
missions.

meant emphasis on projects in the southern part of the central valley, the area with which Sr. Chavez was concerned. Furthermore, wheat and livestock production _per se_ are relatively low yield crops per hectare, even if reasonable levels of efficiency are attained in land and water use. In addition, the ranking of projects in order of desirability by Riego usually included engineering characteristics such as the quality of foundations and the ratio of earth moved to water impounded. There was no ranking on the basis of comprehensive benefit/cost ratios.[1]

The record shows that projects are usually under construction for many years, occasionally decades. We can infer that this reflects an obligation to distribute a relatively small budget among many claims for attention. On occasion procedures apparently are followed in letting contracts that result in an increase in costs beyond those originally contemplated. Special problems created by prolonged inflation, delay in payments to contractors, and delays in securing authorization of needed imports have raised costs. The professional staff of Dirección de Riego is far too small for the responsibilities thrust upon them, and there is a deficiency of basic data regarding hydrology, geology, soils, and other technical matters bearing upon the physical productivity of a project.

The accompanying Table V-1 indicates the rate at which new land has been brought under irrigation during the past four decades. The most

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[1] Apart from the way in which Riego makes its proposals is the way in which decisions might be made at higher levels. If decisions are made in Chile the way they are in the United States, it would not be surprising to see political pressures dominate: benefits to special interest groups, the need to cope with local pockets of unemployment, and the need to distribute governmental largesse among many competing political units.

Table V-1

NEW & NEW-EQUIVALENT LAND PLACED UNDER IRRIGATION

BY DIRECCIÓN DE RIEGO

Year

Year		Year	
1919	4,000	1950	8,280
1924	500	51	12,420
25	-	52	-
26	-	53	17,745
27	-	54	-
28	-	55	300
29	-	56	2,980
1930	63,600	57	-
31	22,250	58	111,137
32	6,500	59	2,400
33	400	1960	1,909
34	5,500	61	743
35	9,750	62	2,600
36	0	63	1,500
37	1,450	64	18,000
38	0	65	10,600
39	5,800		
1940	-		
41	-		
42	-		
43	-		
44	-		
45	-		
46	10,862		
47	10,560		
48	160		
49	8,500		

Sources: Villarroel and Horn, for years 1919-1961. Hectareage is overstated for various years because (1) design area is used, (2) some projects modify existing projects.

Michael Nelson, Chile-California Program, for 1962-65.

productive period, if we exclude Embalse Laguna del Maule, was the decade ending 1934, during which approximately 100,000 hectares (new equivalent) were added. In the thirty years that followed another 116,000 hectares were added (about 3,000 hectares per year), plus controlling the flow out of Laguna del Maule, which added approximately an equal amount.

Plans of Dirección de Riego for the period 1965-73 call for putting about 425,000 hectares of new land under irrigation plus improving the water supply for 700,000 hectares. Should the Chile-California Program proceed with full development of the Maule River basin, these figures would be augmented by 120,000 hectares of new land plus 150,000 with improved water supply. The consummation of such a program would not only mean that the average annual increase in irrigated land would surpass anything experienced in the past, but by 1973 Chile would be irrigating all land in Classes I, II, III from Cautín to the north, plus all land now under irrigation. This reaches the limit of irrigation without terracing the mountains as the Incas once did.[1]

One cannot help but wonder how realistic are plans for putting some 90,000 hectares under irrigation each year [2] in view of the recent record. Even without the Chile-California project the planned rate at which irrigated land would be augmented each year is 70,000 hectares. The government's basis for optimism rests on the expectation of polishing off

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[1] Data on future plans taken from material prepared by Dr. Michael Nelson for the Chile-California program.

[2] 546,000 new hectares plus the "new equivalent" of the improved water supply to 850,000 hectares, counting 3 hectares improved as equal to one new, or, rounding, 640,000 new equivalent in nine years.

a number of projects that have been under construction or study for
many years -- amounting to some 1.2 million hectares,[1] exclusive of the
Chile-California Program. In addition to questioning the capacity of the
government to accomplish its projected rate of construction, one might
question its wisdom in view of the uncertain state of information re-
garding land resources,[2] water resources, including ground water,[3] and
the pressure that is likely to develop against available water resources
in the foreseeable future.[4]

A Note on the Significance of the State of Data

A lament over the state of data in Latin America is a stale recital
of the commonplace. Why then be preoccupied with the obvious? The answer

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[1] CEPAL, p. 72.

[2] A deficiency that the air photogrammetric project is intended to remedy.

[3] A deficiency that can hardly be corrected between now and 1973 when
one considers the short period of record for most rivers in Chile.
In the hydrologic report prepared by the Centro de Planeamiento of
the University of Chile (see below), of the eighteen major rivers
between the province of Cautín (the southern limit of irrigation)
and the northern boundary of the country, twelve had a period of
record that was thirteen years or less. The longest period of
record, that of the Elqui River, was thirty-four years. The next
longest, twenty-five years, was for the Rapel. Six rivers had a
period of record less than ten years. If we assume that all rivers
will be carefully gauged from now on, by 1973 thirteen will still
have a period of record less than twenty-five years, and the average
for all rivers of the country will rise from twelve to twenty-one
years. Furthermore, existing measurements contain an unknown error
by virtue of the fact that knowledge of ground water is severely
limited, no record is kept of diversions into irrigation canals,
and there are no measurements of return flow from irrigation
diversions.

[4] See below.

lies in the fact that what may be obvious to an insider appears inexplicable to an outsider. Chile's own experts are fully aware of the need for better information. Moreover, the Chilean engineer and scientist are not newcomers to the scene. They have themselves repeatedly pointed out the need for appropriate data collection and the uncertainties and risks that must be borne in the absence of reliable information.[1] Why, then, has it not been until very recently that a serious attack on the data problem was begun? A reasonable inference in the face of these conditions is that those responsible for making decisions have not felt that the quality of decisions would be materially enhanced if better information were available. This, in turn, implies that decisions were based on criteria other than those which the economist and engineer consider relevant. If this inference is justified, another may follow hard upon its heels, namely that economic and engineering studies serve to stimulate a dialogue among economists and engineers but have little connection with decisions made by those in authority. Recent interest in better data may signal a change.[2]

The Costs of Water:

From the study on "Rentabilidad" we can extract an unexpected by-

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[1] See below, Chapter VII, discussion of paper presented by Raul Saez to the Latin American Seminar on Electric Energy.

[2] The strength of the current movement toward more and better information will depend upon the insistence of the scientists and engineers themselves that data collection agencies are adequately staffed and follow appropriate procedures. For this to happen, at least, according to one Chilean scientist there will have to be a departure from the prevalent point of view that scientists do not occupy themselves with problems of census-taking and other routine measurements.

product. On the assumption of a fifty-year life (residual value zero), and an interest rate of 8 percent, we can assume that the annual cost of water is approximately equal to 8.17 percent of the capital cost of public works plus the charges for current operation and maintenance. (This assumes that all costs are incurred in the first year, that depreciation is charged on a straight line basis, and interest is charged only on the unpaid balance. The appropriate life span of a structure such as a canal, when properly maintained, might be indefinite, but there is always a possibility of a shift in land use, hence a fifty year economic life is reasonable for both reservoirs and canals. There is also the question of whether additional capital on-the-farm costs should not be construed as a part of the "cost of water". We shall, however, exclude these, in order to compute the "cost of water delivered to the farm".)

For the current input of water per hectare, as already noted, we have conflicting estimates. For example, water requirements for vegetables, (less than for pasture, fruits, and vineyards, but more than for cereals) given by Basso, in cubic meters per hectare per year, are as follows:[1]

Zone	M^3/ha/yr
Tarapacá and Antofagasta	9,300
Atacama and Coquimbo	9,000
Aconcagua to Linares	6,200
Ñuble to Malleco	6,000
Cautín to Aysén	6,000

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[1] See Table IV-1. Since Basso's estimates of current use are conservative relative to other estimates such as Dominguez', the "true" cost of water might be lower.

CEPAL computed water needs by river basin, according to the Blaney-Criddle formula, weighted by crop, as follows:[1]

Loa   -   7,500 m^3/ha

Elqui   - 11,850 m^3/ha, including 35 percent loss in canals

Aconcagua   -· 9,564 m^3/ha, including 25 percent loss

Maipo and Mapocho -   9,902 m^3/ha, including 25 percent loss

Rapel   - 10,156 m^3/ha, including 25 percent loss

Maule   - 10,230 m^3/ha, including 25 percent loss

Itata   - 12,320 m^3/ha, including 25 percent loss

Bío-Bío   - 10,438 m^3/ha, including 25 percent loss

CEPAL also estimated current water use, apparently at the intake of the canal rather than at the point of delivery to the farm, for four basins, as follows:

Río Elqui   -   14,200 m^3/ha

Maipo   -   21,200 m^3/ha

Maule   -   14,800 m^3/ha

Itata   -   15,100 m^3/ha

These represent quantities that range between 20 and 106 percent of required amounts, but include inevitable canal losses estimated at 25 percent of farm requirements. In view of the frequently expressed opinion that water is used excessively by the average irrigator who possesses superior rights and has the water, we might assume that current use is 20 percent above requirements as computed by formula. The estimated current rates of use on the farm, for the eight basins studied by CEPAL, rounded,

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1/ CEPAL, p. 68 for Elqui; Aneto III for the others.

would therefore be:

Loa	-	9,000 m³/ha
Elqui	-	14,400 m³/ha
Aconcagua	-	12,000 m³/ha
Maipo-Mapocho	-	12,000 m³/ha
Rapel	-	12,000 m³/ha
Maule	-	12,000 m³/ha
Itata	-	14,400 m³/ha
Bío-Bío	-	12,000 m³/ha

Because of differences in elevation of irrigated lands and variations in micro-climates of various stations, these figures do not correspond to what one would normally expect in going from north to south. We might just as well adopt a uniform value for all basins--say 12,000 m³/ha. This figure should err, if at all, on the low side of consumption. Conversion of annual 1962 escudo costs per hectare into 1962 dollars per acre foot of annual supply (85 percent security) yields the following:[1]

Reservoirs, weighted average, excluding
Laguna del Maule (a natural lake re-
quiring only regulation of the outlet).......$5.93

Canals.......................................$4.30

If we assume that both reservoir and canals had to be built for a single project, the averages indicate that the annual equivalent capital cost of irrigation water have been on the order of $10.00 per acre-foot--a

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[1] Conversions based on assumptions that 1 hectare used 12,000 m³ of water per year, or 4.4 acre-foot per acre, and that E°1.1 = $1. Annual costs were assumed to be equal to 8.17 percent of capital costs. Projects consist of forty-seven projects, less Embalse del Maule, studied by Villarroel and Horn (see Table 3.2 - 2, op. cit.)

figure not unreasonably high in view of the fact that virtually all costs have been assigned to irrigation. The charges levied against farmers, however, have fallen far short of the costs.

Villarroel and Horn estimate that on-the-farm capital costs of water distributing structures and land preparation fall between E^o500 per hectare (at 1952 prices) in Tarapaca and Antofagasta (where all costs of land preparation must be incurred by new irrigated land, since in the absence of irrigation the land has virtually no use) and E^o100 per hectare in the South, where only the water distributing facilities have to be added. The added cost in dollars per acre foot range from $5 in the North to $1 in the South (at 1962 rates of exchange.)

As noted elsewhere, Villarroel and Horn estimate capital costs per hectare on the basis of design area of the project, rather than actual area under irrigation. They therefore understate cost per hectare where less than the design area is actually under irrigation. Projects that have fallen short of design size in the four northern provinces have generally done so because of inadequate water supply and poor quality of soil. Thus, Caritaya Reservoir designed to hold 42 million cubic meters has never had more than 10,000,000.[1] Embalse Lautaro has been empty ninety percent of the time. Recoleta Reservoir was built, only to find that the basin failed to supply enough water. A supplementary feeder canal was then constructed to supplement the water supply.[2] Cogotí Reservoir was designed for 12,000 hectares but has never had enough water for more than 4,650 hectares.[3]

1/ Villarroel & Horn, p. 15.

2/ Ibid. p. 16.

3/ FAO. #1622. p. 22.

The water supply for Culimo Reservoir is 30 percent less than anticipated.[1]
Water yield was overestimated for the Casablanca Reservoirs, as a conse-
quence of which, the authors say, "utilization of the reservoir is low"--
but how low and by how many hectares irrigated area falls below design area
they do not say.[2]

Since these projects in the North are unsatisfactory because of
deficient water supply, it is reasonable to correct the cost per hectare by
the factor: $\frac{\text{design hectares}}{\text{hectares actually irrigated}}$. We can make this correction
for five reservoirs. Costs rise from fifty to a hundred and fifty percent.

	Cost of Water	
	Design Cost	Cost based on Estimated Irrigated Area
Caritaya	$ 8 per AF	$20 per AF
Lautaro	$11 per AF	[3]
La Laguna	$ 4 per AF	$ 6 per AF
Recoleta	$ 7 per AF	$11 per AF
Cogotí	$ 7 per AF	$18 per AF

The unsatisfactory projects in the South have their fault not in the
deficiency of water supplied by the main structures, but by inadequate
development of on-the-farm or other secondary structures. It does not seem
reasonable, therefore, to adjust the "cost of water" to agree with the area
actually under irrigation except, perhaps, for the Tutuvén Reservoir. Sr.
Chavez points out that one reason for the failure of the Tutuvén to reach
design size is the high cost of derived canals. It is of this area that
he adds, however, that "25 percent of the total area is not irrigated only

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[1] Villarroel and Horn, p. 16
[2] Ibid., p. 17.
[3] Lautaro has been dry most of the time.

because the farmers lack interest".[1] On the basis of design size, the
cost of water would be about $7.50 per acre foot. If we use the photo-
grammetric survey area, the cost would be five times greater.

It should also be noted that reservoirs built up to now are compara-
tively small. The largest--Cogotí-- was designed to hold 150,000,000
cubic meters, or about 120,000 acre feet. Recoleta, was designed for
100,000,000 m^3, or about 80,000 acre feet. Bullileo was designed for
50,000 acre feet. The remaining seven are smaller.

There are, apparently, a number of reservoir sites that can retain
much larger bodies of water. The dam now being built on the Rapel, for
example, will provide a reservoir of 680,000,000 m^3 and Paloma, designed
to supplement Recoleta and Cogotí, was designed to hold 740,000,000 m^3.

A possibility recently come to light under the aegis of the Chile-
California program is a dam on the Maule River just before it debauches
into the central valley. This would be the first truly multi-purpose as
well as largest water resource project ever undertaken in Chile. The
reservoir would hold 1,500 million cubic meters (twice the size of the
largest now under construction) and have an installed capacity of 500,000
KW (100,000 KW more than the largest plant now under consideration). Should
it be built with all costs of the dam assigned to power (which would, on
the basis of very preliminary estimates, still make it a feasible power
project), capital costs of the canals would be about E^{o}500 per hectare
(based on very rough estimates), or in the neighbourhood of $1.25 per acre
foot of water (assuming four acre feet of water per year per acre and the

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[1] Chavez, op. cit., p. 7

current official exchange rate of $E^{o}4 = \$1$.) Marginal costs of water for one of the major agricultural areas of the country are, therefore, estimated at still a relatively low level when financed on a multi-purpose basis. The water resources of the Maule have received more attention recently than other basins because of the Chile-California Programme. Whether other basins would reveal equivalent opportunities of water resource development if subjected to the same scrutiny is an interesting speculation.

Payments for Water Use:[1]

Three laws have controlled the construction and repayment of virtually all governmental irrigation projects: Law #4445 of 1928, Law #9662 of 1950, and Law #14536 of 1960.

Law #4445 of 1928:

Salient provisions are as follows. The project must have the approval of 33 percent of the irrigators potentially affected. After a trial period known as explotación provisional the works are turned over to an association of irrigators who begin repayment. Total debt charged irrigators cannot

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[1] This section is a slightly condensed version of a report written by Manuel Agosín on the basis of a study of official records of the Dirección de Riego. The sample was intended to include all projects whose costs were three million escudos or more (1962 prices). For one--Chacabuco Canal--there were no data; for two others there was no repayment record because they had not yet been completed. The remaining eight projects were then supplemented by two others which although not of large size were the only ones completed under later legislation. The eight projects were Lautaro, Bullileo, Recoleta, and Cogotí Reservoirs and Maule, Laja, Melado and Recoleta Canals. The two more recent projects are Quillón Canal and El Noviciado mechanical irrigation system. Cost data were taken from Villarroel

exceed 120 percent of the original planned cost. Although the period of explotación provisional is supposed to be no more than three years it can be extended; for most projects the period has been extended. During the first three years of the trial period the irrigators are assessed progressively larger amounts in order to cover administration costs. These assessments are 1/2 percent, 1 percent, and 1 1/2 percent respectively, of the value of each irrigator's share. (A share is a prorata quantity of water based upon the amount of land to be irrigated). After the third year the assessment remains at 1 1/2 percent. Assessments are usually less than the costs of administration, the deficit being a subsidy by the government to the irrigators. Repayment is by level payments over 36 1/2 years including a 5 percent interest charge on the unpaid balance.

Law #9662 of 1950

Under Law #9662, irrigators are supposed to pay full monetary costs of the works and engineering studies as fixed when construction is completed. The period of preliminary administration is extended to four years; irrigators pay 1 percent the first year, 2 percent the second year, and 3 percent the third and fourth years. If there is any difference between payments and costs of administration it is paid by irrigators together

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(Continuation of footnote [1]/, page V-22)
and Horn's Rentabilidad (op. cit.). Repayment data came from records of Dirección de Riego. The information is, more accurately, not a record of repayment but of amounts charged the irrigators. Actual payments are about 75 percent of amounts billed. (Interview with Luis Larroucau V., Ing., Head Departamento de Explotación, Dirección de Riego.)

All payments and costs were converted to 1962 escudos, a year in which the estimated parity rate was approximately $E^{o}1 = US\$ 1$.

with and in the same conditions as the principal. The debt is repaid
starting from the fifth year after the beginning of the preliminary
administration period. The interest rate on the unpaid balance is 1
percent the fifth year, 3 percent the sixth year and 5 percent the seventh
year and after. The amortization period is 30 years.

Law #14536 of 1960

This law introduced substantial changes. Investments and payments are
to be readjusted annually by the wholesale price index published by
Dirección de Estadística y Censos. It restored the limit of 120 percent
of the budgeted cost for the debt. The interest rate on the unpaid balance
is 5 percent and the amortization period is 30 years. Other conditions
were not modified.

Most works, because of their long construction period, are affected
by more than one law. There is no single criteria to follow in determining
what law applies to a project whose construction period extends over two
laws, but usually--especially when the work has been constructed under Laws
#9662 and #14536-- the investment is divided and each portion is reimbursed
according to the law under which the investments were made. Sometimes a
project is recontracted with the irrigators. In some cases when a unit
was begun under Law #4445 and finished under Law #9662, so that parts could
not be prorated to each law, applicable features were taken from both laws
and fitted to meet the interest of the irrigators. Most of the works in
our sample are of this type.

Under Law #4445, the debt to be reimbursed was settled before the works
were built, and repayment began after preliminary administration. Under
Law #9662 the debt was set at the completion of the work and irrigators had

to pay full money costs. In both cases, especially under the earlier law, inflation lightened substantially the weight of the fixed money debt. If the costs had been paid in full the year that irrigators began repayment, the state would have already lost a large amount. Table V-2 shows the periods of construction and preliminary administration and Table V-3 compares costs incurred by the government and value of debts assumed by irrigators the year reimbursement began, in escudos of December 1962.[1]

Charges to irrigators of works completed under Law #4445 covered only 36 percent of their money costs. If these debts had been paid in full during the first year of repayment, because of inflation between the beginning of construction and the end of "preliminary administration", only 6 percent of real costs would have been covered. As to the two newer works (affected by Law #9662), the law provides for a debt equal to money costs. But if the debt had been paid when repayment began, the state would have recovered only 13 percent of the real costs of resources invested in these works. The long period of repayment further reduces its real value. Sometimes the materials used to prepare the invoices are more expensive than the amounts paid. The Departamento de Explotación of Dirección de Riego has estimated the cost of these materials as one-half escudo per invoice, without considering the labor costs involved, while in many instances the yearly payment of irrigators is considerably lower than this amount.[2]

1/ Cost figures present some irregularities: (1) for Recoleta Dam and Canal it was not possible to distinguish between construction and preliminary administration costs; (2) in many cases, preliminary administration costs include costs of complementary works, which should more accurately be considered as construction costs; (3) costs of project studies are not available.

2/ Information furnished by Sr. Larroucau.

Table V-2

CONSTRUCTION AND PRELIMINARY ADMINISTRATION PERIODS

	Construction	Preliminary Administration
Lautaro Reservoir	1929-46	1946-50
Bullileo Reservoir	1929-49	1949-53
Cogotí Reservoir	1928-46	1947-50
Laja Canal	1916-30	-
Maule Canal	1916-30	1931-50
Melado Canal	1916-32	1933-53
Recoleta Reservoir	1929-40	1940-50
Recoleta Feeding Canal	1942-49	1949-53
"El Noviciado" Mechanic Irrigation System	1953-55	1956-59
Quillón Canal	1951-59	1960-63

Table V-3

COSTS AND IRRIGATOR DEBTS, SELECTED IRRIGATION PROJECTS

	Construction costs (in E^o of each year)	Debt for construction costs (in E^o of each year)	Construction costs (in E^o of December 1962)	Year in which debt reimbursement began	Debt for construction in E^o of December 1962 a/
Works under 4445:					
Lautaro Reservoir	17,655	4,000	3,550,807	1950	114,000
Bullileo Reservoir	80,463	30,125	8,408,211	1953	430,486
Cogotí Reservoir b/		29,443		1951	641,563
New Shares b/	105,347	8,226	10,699,025	1954	74,939
Huana Canal b/		771		1954	7,024
Laja Canal	10,210	6,013	3,908,054	1935	1,018,602
Maule Canal	20,639	14,763	8,270,551	1949	493,084
Melado Canal	31,320	11,027	11,113,081	1949	368,636
Recoleta Reservoir	30,229	14,617	6,643,687	1951	318,504
Recoleta Feeding Canal	94,388c/	22,544d/	4,751,438	1953	322,154
Subtotal	390,251	141,529	57,344,854		3,788,992
Works under 9662:					
"El Noviciado" Mechanic Irrigation System	40,116	42,772	293,846	1960	55,176
Quillón Canal	278,540	292,533	1,260,538	1964	149,484
Subtotal	318,656	335,305	1,554,384		204,660
Total	708,907	476,834	58,899,238		3,993,652

a/ Amount that would have been reimbursed in E^o as of 1962 if irrigators had paid the full debt the year repayment began.

b/ Cogotí Reservoir, New Shares, and Huana Canal are sub-divisions of the same project; costs should be interpreted as applying to a single project.

c/ Includes preliminary administration costs of the reservoir and the canal.

d/ Includes debt for difference between payments and preliminary administration costs.

Table V-4 compares what the state has charged irrigators with what should have been paid to offset the decline in value of the escudo. "Service of Debt A" is included in order to complement Table V-3. "Service of Debt A" indicates what irrigators would have paid in escudos of constant value (E^o of Dec. 1962) in order to meet the contractual obligation fixed by the state, even though this amount was less than full real costs. "Service of the Debt B" shows the quantities the irrigators would have paid up to 1964, in escudos of December 1962, if they had been paying full costs. We have assumed that preliminary administration costs should have been repaid the same year the government spent the money, since if there had been no preliminary administration period, the irrigators would have had to assume responsibility.

The situation is not too dissimilar if we consider separately the works constructed before and after 1950. The strikingly different ratios of "Service of Debt A" to "Service of Debt B" can be explained by the fact that the debts or works finished after 1950 are fairly recent.

The joint effects of inflation and rules fixing the liability of irrigators meant that irrigators paid 3 percent of total real costs under laws that ostensibly call for full reimbursement. The estimated subsidy for the sample group of projects is about 53 million escudos of December 1962 (about $53 million US).

Most of the subsidy has gone to a relatively small number of large landowners.[1]

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[1] Analysis based upon distribution of shares to water taken from 1965 payment records. Each share is a unit related to a unit of land into which total irrigable land of the project is divided. Usually the unit of land is one hectare, and the share is its prorata allotment of water.

Table V-4

: AND PAYMENTS

Amounts charged up to 1964 (in E° of each year)		Amounts charged up to 1964 (in E° of December 1962)		Payments that should have been made up to 1964 (in escudos of December 1962)		
Preliminary Administration	Construction	Preliminary Administration	Construction	Preliminary Administration	Service of Debt A a/	Service of Debt B b/
120	3,098	4,404	25,608	31,289	102,600	3,195,720
2,877	19,185	44,444	51,752	99,768	234,121	5,549,418
838	22,958	26,576	116,406	106,863	567,581	8,345,246
-	10,477	-	463,848	-	1,833,480	7,034,490
18,066	9,702	233,736	59,278	1,682,861	342,829	10,335,167
3,390	13,730	358,837	112,172	1,364,438	458,568	7,691,612
	22,317		233,439		461,049	8,318,020
25,291	101,467	668,047	1,062,503	3,285,219	4,050,228	50,469,673
25,069	11,292	27,104	10,571	182,631	14,568	77,576
57,555	19,307	44,334	9,866	559,523	9,866	83,196
82,624	30,599	71,438	20,437	742,154	24,434	160,772
107,915	132,066	739,485	1,082,940	4,027,373	4,074,662	50,630,445

real value of the debt fixed by the state the year reimbursement began.

paid full real costs.

not available separately. Construction costs include preliminary
for preliminary administration.

Information was available on distribution of shares by size of
holdings for seven projects. (See Table V-5). El Noviciado was the only
project that benefitted mostly the small farmer. In the remaining projects
the small irrigators in the aggregate constituted a minority interest of
shares, and sometimes a very small minority at that, although accounting
for the largest number of holdings.

There is no reason to suspect that our sample was in any way unusual.
A comparable study should be made of all projects, supplemented by in-
formation and analysis of payments actually made by irrigators. It would
be interesting to know whether those who fail to pay are among the large
landowners or the small.

Table V-5

PERCENTAGE DISTRIBUTION OF LAND BY SIZE CLASS OF HOLDINGS IN SELECTED GOVERNMENT
IRRIGATION PROJECTS

| | Size class (hectares) | | | | | | | |
| | .1 - 50 | | 50.1 - 200 | | 200.1 - 1,000 | | Over 1,000 | |
	Irri-gators	Irriga-ted land	Irri-gators	Irriga-ted land	Irri-gators	Irriga-ted land	Irri gators	Irriga-ted land
Recoleta Reservoir and Feeding Canal a/	86.0	22.3	4.5	7.5	8.7	55.1	.8	15.1
Bullileo Reservoir b/	32.0	3.3	25.4	9.9	33.3	42.8	9.3	44.0
Lautaro Reservoir	82.4	25.1	12.2	27.5	4.8	33.8	.6	13.6
Melado Canal c/	70.9	14.6	23.7	31.9	4.5	31.4	.9	22.1
Cogotí Reservoir	81.0	27.0	15.7	32.9	2.9	30.8	.4	9.3
El Noviciado Mechanic Irrigation System	100.0	100.0	-	-	-	-	-	-
Quillon Canal	94.8	48.3	4.0	28.3	1.2	23.4	-	-

a/ Intervals for Recoleta Dam are: 1. .1 - 66 2. 66.1 - 200 3. 200.1 - 1,050 4. Over 1,050

b/ Intervals for Bullileo Dam are: 1. .1 - 75 2. 75.1 - 225 3. 225.1 - 1,050 4. Over 1,050

c/ Intervals for Melado Canal are: 1. .1 - 45 2. 45.1 - 225 3. 225.1 - 1,050 4. Over 1,050

Chapter VI

PROJECTION OF AGRICULTURAL WATER USE

The dominant use of water in Chile is for irrigated agriculture. A clear understanding of the agricultural economy - prospective demands and prices of outputs, production functions, and prices of inputs used by the agricultural industry - are essential for rational planning of water resources. Very little information is available. Accordingly, our estimates of agricultural water use are based upon the following assumptions:

1. Agricultural output will respond to changes in domestic demand with an additional response to changes in import policy.

2. Irrigated and dry land production will share proportionately in any projected change in production subject to land and water limitations.

3. Increases in demand will be met first by bringing available new land into use; if land and water resources are limited, projected deficits in new production will be met by increases in output per hectare.

We tested two methods of projecting demand and found that they yielded approximately the same results. By one method per capita consumption of agricultural products was projected on the basis of an average coefficient of income elasticity of demand equal to .45, and the results adjusted to take population change into account.[1]

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[1] Based upon income elasticity coefficients for separate products supplied by the Center for Economic Research, Catholic University.

The other method consisted of establishing a relationship between aggregate consumption of agricultural products and per capita gross national product from historial data, excluding products not producible in Chile, and projecting that relationship to 1985, coupled with projected population charge.[1]

The implicit elasticity of demand for agricultural products as a whole of the second model coincided exactly with the weighted average elasticity of demand used in the first method.[2]

The overall demand for agricultural products, assuming an average income elasticity of demand of .45 and an average annual increase in population of 2.43 percent, would grow by 86 percent if GNP grows at the rate of 3.75 percent per year, (the growth rate experienced in recent decades) or by 118 percent if GNP grows at 5.5 percent per year, the goal of the Chilean government.

Mr. Holsen's estimates, based on the relationship between changes in per capita consumption of agricultural products and per capita GNP as observed between the period 1941-1958, and based upon a population growth rate of 2.5% and a per capita GNP growth rate of 2%, yielded a total increase in consumption amounting to 157% over the 1958 level, or an annual rate of increase slightly less than is implied by a growth of 118% in 21 years.

Thus, so far as demand for agricultural products is concerned, there is reason to believe that the next two decades should see an approximate

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[1] This model was constructed by John Holsen, Economic Adviser, U.S. AID Mission in Chile.

[2] This weighted average was computed for the seven most important agricultural products, measured by money value, which altogether comprised 80 percent of the total market value of output.

doubling of total demand - a little less if GNP grows at the historical
rate, a little more if it grows in accordance with present plans. If
the path of growth moves at the lower rate there will still be a dietary
deficiency in terms of FAO standards unless imports per capita rise. One
objective of present government planning, however, is to eliminate the need
for importing the foods and fibers that Chile can produce: wheat, meat,
oils, and other temperate climate products. Total imports of agricultural
products currently amount to approximately $150,000,000,[1] of which some-
thing more than half, (about $82 million per year during the period 1961-63)
are import substitutable.

If we accept Chilean plans as a basis of estimating output,[2] therefore,
we should add to the growth of total demand another $85 million, or about
14 percent of the 1960 level of production. Hence, even if per capita
incomes should grow at the low rate of 1.29 percent per year,[3] planned

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[1] Statistics of the Departamento de Economía Agraria for August 1964 in
    the possession of Mr. Holsen indicate that imports during 1961-63
    averaged $137 million; the current rate of importation is somewhat
    higher, according to preliminary estimates. Of total imports, during
    1961-63, about $82 million consisted of cereals, sugar, tobacco, meat,
    milk, wool, hides, and edible oils, all of which are produced in Chile.

[2] We make no attempt to evaluate the merits of Chile's objective of
    eliminating the importation of foods and fibers which they are "capable"
    of producing at home. "Capability" is, of course, a concept that is
    meaningful only within the context of comparative advantage and balance
    of payments restrictions. The feeling that Chile should produce its
    non-tropical agricultural "requirements" probably stems from the
    assumption that it could do so without strain (i.e. without unduly
    high marginal costs) if the agricultural sector were functioning at a
    reasonable level of efficiency. However, this assumption should itself
    be examined, (see below, Ch. XVI, on implied increases in output per
    hectare), even though it may seem plausible.

[3] On the assumption that growth in per capita income is the same as the
    growth in per capita GNP.

production would have to double in order to meet current Chilean objectives.

Estimates made of the projected increase in demand translated, product by product and province by province, into required land under irrigation,[1] based upon the joint effects of income elasticity of demand, projected increase in family income, and change in size of population, yielded a requirement for 2.6 million hectares of irrigated land under the assumption of the low rate of increase in GNP, and 3.0 million hectares at the high rate, without taking into account the reduction of imports or elimination of existing dietary deficiencies.[2]

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[1] On the assumption that irrigated land would increase in the same proportion as the projected increase in demand for products now produced on irrigated land. Estimates made by the Center for Economic Research, Catholic University, unpublished.

[2] An implied rise in per capita income would presumably afford a better diet. The dietary deficiency has not been translated into a fraction of total agricultural output, although this could be done with the data that are available. For specific food classes, average per capita dietary deficiencies were noted to be as follows as of 1961. (Because of the very unequal distribution of income in Chile, and the possibility that the well-off eat too much, the average deficiency may understate the degree of undernourishment that actually must be overcome.)

Food	Percent by Which Available Per Capita Supply Falls Short (-) or Exceeds (+) Minimum Requirement
Milk, all forms except butter	-42%
Eggs	-13%
Legumes	-28%
Potatoes	-42%
Vegetables	-20%
Fruits	-28%
Sugar	+107%
Cereals	+17%
Meat	+ 8%
Fish	-75%
Butter, oil and animal fat	+ 5%

Source: See page VI-5

We shall assume that at the low rate of income growth half of the
dietary deficiency will be eliminated, and at the high rate of income
growth, all. To the low rate of projected increase in demand we can add
another 15 percent [1] in needed additional output to account for dietary
deficiency plus another 15 percent to account for what is needed to
eliminate the import deficit. Total demand would then be about 115 percent
above present levels at the low rate of income growth. Even if we ignored
land requirements for elimination of dietary deficiencies and present im-
ports, the requirements for irrigated land would be 2,644,000 in 1985 at
the low rate of GNP growth (3.75 percent) and 3,039,000 at the higher rate
(5.5 percent). Assuming that these requirements are distributed in pro-
portion to present irrigated hectareage results in the distributions given
in Table VI-1.

Land presently under irrigation, as noted previously, is not a precisely
established figure. The photogrammetric survey classified 1,204,862
hectares as land "irrigated" and 708,332 hectares as land of mixed character,

Source: (Continued from page VI-4). CORFO, Programa nacional de desarrollo
economico, 1961-1970, p. 78. Hansen, Baeza, and Parker,
Proyecciones de la Demanda de Agua y su Repartición Geográfica
para los Próximos 20 Años, Ministerio de Obras Públicas, Santiago,
1962, pp. 116-117, converted the dietary requirements into a
weighted average of .55 hectares per inhabitant and concluded that
instead of an expansion in irrigated area of about 809,000
hectares (by 1982), as revealed by governmental plans, the expan-
sion should be greater by about 678,600 hectares. Since he as-
sumed that 1,400,000 hectares were already under irrigation, the
additional required hectareage over the expansion already planned
amounted to 678,600/2,209,000, or thirty-three percent.

1/ In recognition of the 12½ percent increase in per capita demand that
will remove roughly one-half of the dietary deficiency.

Table VI-1

IRRIGABLE HECTAREAGE REQUIRED ON BASIS OF PROJECTED DEMAND, 1985

	Growth in GNP	
	3.75%	5.5%
Tarapacá	21,930	24,101
Antofagasta	8,478	9,542
Atacama	40,369	46,220
Coquimbo	198,580	235,014
Aconcagua	143,794	167,365
Valparaíso	91,284	106,960
Santiago	407,169	474,418
O'Higgins	316,636	368 762
Colchagua	151,517	173,453
Curicó	129,952	149,607
Talca	255,551	291,722
Maule	4 902	5,783
Linares	269,797	301,532
Ñuble	209,184	235,923
Concepción	137,142	139,373
Arauco	1,383	1,592
Bío-Bío	138,384	155,903
Malleco	34,139	91,133
Cautín	33,792	39,467
TOTAL	2,643,991	3,038,880

either because of low security of water supply or problems of micro-relief. CORFO estimated the amount of land under irrigation as being in the neighborhood of 1,400,000 hectares. A figure somewhere between 1.2 and 1.9 million hectares is the measure of land under irrigation in a "normal" year. In a relatively wet year the amount would approach 1.9 million; in a relatively dry year, 1.2 million.

It is reasonable to assume a greater relative growth in cultivated irrigated land than cultivated dry land within the limits of land and water availability. If productivity per unit of land is to increase, more fertilizer, better seed, better weed control, and better methods of cultivation must be adopted. The increased investment per hectare that higher yields demand is likely to be placed on irrigated rather than dry land, because of the greater assurance of an adequate supply of water.[1] Unfortunately Chile cannot expand output simply by putting dry land under irrigation. There is neither enough land nor enough water to allow irrigated areas to expand in proportion to the expected increase in required production. For this reason a first approximation to the demand for water for agriculture can be made by assuming that all irrigable land will be irrigated in 1985.

We have taken as a measure of "all irrigable land" the total area of the following three groups of land capability classes in all provinces extending northward from Cautín.[2]

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[1] This point is made by John Holsen.

[2] Based upon the air photogrammetric survey. Tables prepared by the Instituto de Investigación de Recursos Naturales, Miguel Ruiz-Tagle P., Executive Director. The survey excludes the two northernmost provinces. For these we have adopted estimates prepared by other agencies.

a) all land classified as Ir, IIr, IIIr, IVr - i.e. land already
   under irrigation with relatively secure water supply; about
   1.2 million hectares.

b) all land in mixed irrigated-dry classes; about 700,000 hectares.

c) all land in classes I, II, III, (dry, arable); about 540,000
   hectares.

The total of these groups is 2.5 million hectares, exclusive of land
in the two northernmost provinces.[1] A figure of 2.5 million hectares
is likely to be an overstatement, but the magnitude of overstatement
cannot yet be ascertained.[2] At a guess the overstatement is equal to
40 percent of the land in Class III which would be about 200,000 hectares.
Ruiz-Tagle has expressed an off-hand opinion that total irrigable land
is in the neighborhood of 2.0 million hectares. Plans of the Dirección
de Riego for expansion of irrigation call for 546,000 hectares of "new"
irrigated land and 855,000 hectares of "improved" irrigation,[3] which
would imply 2.5 million hectares of irrigable land. We have, in our model,
adopted the figure of 2.5 million hectares,[4] as shown in Table VI-2.

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[1] Irrigable land in the provinces of Tarapacá and Antofagasta was
    estimated at 13,400 hectares by the Centro de Investigaciones
    Económicas of the Catholic University.

[2] The Instituto de Investigación de Recursos Naturales is now attempt-
    ing to measure the quantity of irrigable land without being dis-
    tracted by the question of whether water is or is not available.

[3] Table prepared by Michael Nelson, Economic Adviser in Regional
    Planning, Chile-California Program.

[4] This is a much smaller figure than has previously been used. For
    example, the CEPAL report estimated that "total irrigable land" that
    "required irrigation" amounted to 7.2 million hectares, op. cit.
    pp. 68-69.

Table VI-2

IRRIGABLE LAND THAT REQUIRES IRRIGATION

	Hectares
Tarapacá	10,773
Antofagasta	2,626
Atacama	27,288
Coquimbo	113,023
Aconcagua	63,092
Valparaíso	65,549
Santiago	283,852
O'Higgins	170,280
Colchagua	152,114
Curicó	88,644
Talca	193,936
Maule	31,378
Linares	244,499
Ñuble	260,413
Concepción	65,956
Aruco	29,187
Bío-Bío	142,756
Malleco	259,140
Cautín	302,921
TOTAL	2,507,429

An increase in irrigated area to 2.5 million hectares implies that irrigated hectareage will grow by approximately 66 percent. This growth is at the expense of land now being put to other use - mostly natural pasture or dry land cultivation - except in the northernmost provinces, where production from dry land is zero. We have no data on the net change in total production that should be expected as land is transferred from dry to irrigated, nor do we have enough data to estimate by how much productivity per irrigated hectare and per dry hectare must increase in order to meet projected goals. On the basis of indirect evidence we have constructed estimates of both. (See below).

Water requirements for irrigation were computed in the following manner. The so-called "tasa de riego" (rates of irrigation) estimated by Professor Patricio Carmona,[1] measured the water requirement at the head of the "field" for six classes of crops and five zones. (See Table VI-3). This figure gave us neither the "diversion requirement" nor the "net consumption", since the _tasa de riego_ was estimated to exceed the plant's evapotranspiration requirements by about 30 percent, but failed to include losses on the farm to the field and losses from the point of storage or diversion to the farm. In order to compute net and gross requirements we followed the practice of the U.S. Department of Agriculture in their estimates of water requirements for irrigated farming in California, based on technology of water use expected in 1980.[2] Present

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1/ Professor of Irrigation, Catholic University, Santiago.

2/ Land and Water Potentials and Future Requirements for Water, Committee Print #12, U.S. Senate Select Committee on National Water Resources, Washington, 1960, pp. 17-18 and p. 67.

Table VI-3

"TASA DE RIEGO"

(Thousands of cubic meters per hectare per year)

Crop	ZONE				
	Tarapacá & Antofagasta	Atacama & Coquimbo	Aconcagua- Linares	Ñuble Malleco	Cautín & South
Cereals	6.0	5.5	5.0	2.3	-
Vegetables	10.0	10.0	10.0	6.0	5.0
Fruits	12.0	10.0	9.0	8.9	5.0
Vineyards	-	12.0	9.0	-	-
Pasture	15.0	12.0	11.0	8.5	5.0
Rice	-	-	17.0	-	-

Source: Professor Patricio Carmona, prepared for the Center for Economic Research, Catholic University.

water use in Chile is considered to be extravagant. Professor Carmona's "tasas" are designed to be conservative in the implied improvement in efficiency, but are clearly below estimates of current rates of water use. There are no estimates for Chile of diversion requirements or net losses.

Gross (or "diversion") requirements were computed by applying the following adjustments to Professor Carmona's "tasas":

"tasa" ÷ 1.3 = plant requirement

plant requirement ÷ .55 = water required for delivery to the farm.

water required for delivery to the farm ÷ .55 = diversion requirement

(diversion requirement-plant requirement) ÷ 2 = amount of water recovered for subsequent use.

diversion requirement-amount of water recovered for subsequent use = net loss.

By applying these computations to Carmona's "tasas de riego", weighting each crop class by the relative importance of estimated hectare-age devoted to each according to CORFO's 1958-59 estimated output,[1] we were able to compute average gross and net water requirements per hectare by zone.[2] The figure for a zone was then assigned to all provinces in that zone. (Table VI-6).

Since pasture requires more water than most other crops, a shortage of water might result in a greater reduction of pasture than other crops. Should Chilean farmers raise average output per hectare, the use of irrigated _natural_ pasture would be reduced to a negligible quantity, since

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1/ Based on data prepared by Maciej Zaleski. See Table VI-4.

2/ Columns headed "Rates I" in Table VI-5.

Table VI-4

PERCENTAGE DISTRIBUTION OF IRRIGATED LAND BY MAJOR CLASS OF CROP

I. 1958-59 Crop Mix

Crop	Tarapacá & Antofagasta	Atacama-Linares	Maule-Bío-Bío	Arauco & Malleco [1]
Cereals	-	36.5	34.7	22.4
Vegetables	17.1	4.4	2.0	16.0
Fruits	5.1	3.6	1.5	23.5
Vineyards	..	4.4	0.6	-
Artificial pasture	57.5	23.7	27.1	2.0
Natural pasture	20.3	27.4	34.1	36.1

II. 1958-59 Crop mix after eliminating natural pasture

Crop	Tarapacá & Antofagasta	Atacama-Linares	Maule-Bío-Bío	Arauco & Malleco
Cereals	-	46.8	50.0	28.9
Vegetables	25.0	5.6	2.9	20.7
Fruits	7.4	4.6	2.2	30.4
Vineyards	-	5.6	0.8	-
Artificial pasture	67.6	37.4	44.1	20.0

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[1] In Cautín province the "tasa de riego" was 5,000 cubic meters per hectare per year for all crops. The regional division is slightly different from that used in Table VI-3, but this does not introduce a significant error.

Source: Tables prepared by Maciej Zaleski from data in CORFO files.

Table VI-5

COMPUTATION OF DIVERSION AND NET LOSSES FROM IRRIGATION BASED

ON "TASAS DE RIEGO"

(thousands of cubic meters per hectare per year)

RATES I

Zone	Weighted Average "Tasa de Riego"	Plant Use	Farm Require- ment	Gross Use	Gross Plant Use	Gross Plant Use ÷ 2	Net Use
Tarapacá & Antofagasta	14.0	10.8	19.6	35.6	24.8	12.4	23.2
Atacama- Linares	9.1	7.0	12.7	23.1	16.1	8.1	15.1
Maule-Bío Bío	6.3	4.8	8.7	15.8	11.0	5.5	10.3
Arauco & Malleco	6.8	5.2	9.5	17.3	12.1	6.1	11.3
Cautín	5.0	3.8	6.9	12.5	8.7	4.4	8.2

RATES II

Zone	Weighted Average "Tasa de Riego"	Plant Use	Farm Require- ment	Gross Use	Gross Plant Use	Gross Plant Use ÷ 2	Net Use
Tarapacá & Antofagasta	13.5	10.4	18.9	34.4	24.0	12.0	22.4
Atacama- Linares	8.5	6.5	11.8	21.5	15.0	7.5	14.0
Maule-Bío Bío	5.3	4.1	7.5	13.6	9.5	4.8	8.9
Arauco & Malleco	6.3	4.8	8.7	15.8	11.0	5.5	10.3
Cautín	5.0	3.8	6.9	12.5	8.7	4.4	8.2

Table VI-6

RATES OF WATER USE PER HECTARE PER YEAR

(Thousand M^3)

	Rates I		Rates II	
	Gross	Net	Gross	Net
Tarapacá	35.6	23.2	34.4	22.4
Antofagasta	35.6	23.2	34.4	22.4
Atacama	23.1	15.1	21.5	14.0
Coquimbo	23.1	15.1	21.5	14.0
Aconcagua	23.1	15.1	21.5	14.0
Valparaíso	23.1	15.1	21.5	14.0
Santiago	23.1	15.1	21.5	14.0
O'Higgins	23.1	15.1	21.5	14.0
Colchagua	23.1	15.1	21.5	14.0
Curicó	23.1	15.1	21.5	14.0
Talca	23.1	15.1	21.5	14.0
Maule	15.8	10.3	13.6	8.9
Linares	23.1	15.1	21.5	14.0
Ñuble	15.8	10.3	13.6	8.9
Concepción	15.8	10.3	13.6	8.9
Arauco	17.3	11.3	15.8	10.3
Bío Bío	15.8	10.3	13.6	8.9
Malleco	17.3	11.3	15.8	10.3
Cautín	12.5	8.2	12.5	8.2

its productivity is much lower than that of artificial pasture. In order
to show what effects such changes might have on water requirements, re-
vised gross and net rates per hectare [1] were estimated on the assumption
that 1958-59 product mix was modified by eliminating natural pasture and
dividing it equally between artificial pasture on the one hand and all
other crops on the other. This change in product mix would reduce gross
water requirements per hectare by amounts ranging between zero and four-
teen percent; about 7 percent in the central part of the central valley.
Total water requirements for agriculture were computed by multiplying
irrigable hectareage by the diversion and net requirements per hectare.
The results are given in Table VI-7.

By computing irrigation requirements on the basis of total irrigable
land we are assuming that the area under irrigation in any province be-
tween Cautín and Tarapacá is a function of total national demand subject
to land and water constraints, and not a function of local or provincial
demand. This assumption conforms reasonably well to the present situation
and is likely to be even more applicable in the future.

In addition to irrigation we have included an estimate of water re-
quirements for livestock.[2] The requirements are very small in compari-
son with irrigation. (See Table VI-8). We have assumed that water in-
take by livestock is equal to water loss - i.e. we have given no credit
for return flow. Also, we have assumed that livestock use was divided
evenly over the year, and did not conform to the seasonal pattern set

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[1] See Rates II, Tables VI-5 and VI-6.

[2] Estimate prepared by the Center for Economic Research, Catholic
University.

Table VI-7

AGRICULTURE (IRRIGATION) DIVERSION REQUIREMENTS

AND NET LOSS FOR IRRIGABLE HECTAREAGE

(Thousand cubic meters per year)

	RATES I 1958-59 mix		RATES II 1958-59 mix after eliminating natural pasture	
	Diversion	Net Loss	Diversion	Net Loss
Tarapacá	383,519	249,934	370,591	241,315
Antofagasta	93,486	60,923	90,334	58,822
Atacama	630,353	412,049	586,692	382,032
Coquimbo	2,610,831	1,706,647	2,429,995	1,582,322
Aconcagua	1,457,452	952,689	1,356,478	883,288
Valparaíso	1,514,182	989,790	1,409,304	917,686
Santiago	6,556,981	4,286,165	6,102,818	3,973,928
O'Higgins	3,933,468	2,571,228	3,661,020	2,383,920
Colchagua	3,513,833	2,296,921	3,270,451	2,129,596
Curicó	2,047,676	1,338,524	1,905,846	1,241,016
Talca	4,479,922	2,928,434	4,169,624	2,715,104
Maule	495,772	323,193	426,741	279,264
Linares	5,647,927	3,691,935	5,256,729	3,422,986
Ñuble	4,114,557	2,682,275	3,541,644	2,317,694
Concepción	1,042,105	679,347	897,002	587,008
Arauco	504,935	329,813	461,155	300,626
Bío Bío	2,255,545	1,470,387	1,941,482	1,270,528
Malleco	4,483,122	2,928,282	4,094,412	2,669,142
Cautín	3,786,513	2,483,952	3,786,513	2,483,952
TOTAL	49,552,179	32,382,488	45,758,831	29,840,229

Table VI-8

REQUIREMENTS FOR THE WATERING OF LIVESTOCK, 1985

(Thousand cubic meters per year)

Tarapacá	731
Antofagasta	412
Atacama	946
Coquimbo	8,031
Aconcagua)	
Valparaíso)	5,214
Santiago	9,345
O'Higgins)	
Colchagua)	8,691
Curicó)	
Talca)	13,312
Maule)	
Linares)	
Ñuble)	4,065
Concepción)	
Arauco)	
Bío Bío)	33,150
Malleco)	
Cautín)	
Valdivia)	
Osorno)	28,739
Llanquihue)	
Chiloé	4,652
Aysén	3,338
Magallanes	22,827
TOTAL	148,503

Source: Center for Economic Research, Catholic University.

by irrigation.

Because of the wide swing in water use from season to season, and the fact that in some basins the natural variation in flow coincided with needs whereas in others followed almost an inverse pattern, the quantity of required storage could not be computed directly as a function of required minimum flows. Total water requirements were computed separately for each month on the assumption that all uses except irrigation were evenly spread out over the year. The seasonal distribution used for irrigation is given in Table VI-9.

Production from Dry and Irrigated Land

If we could estimate how Chile's agricultural output was presently divided between irrigated and dry land, and could estimate the possibilities of expanding land under cultivation - irrigated and dry, we could estimate the increase in output per hectare required to meet Chile's production goals.[1]

Villarroel and Horn's study, "Rentabilidad",[2] contains estimated weighted average productivities of irrigated and dry land converted into units of "wheat equivalent", which is the yield of each product in metric quintales[3] per hectare multiplied by the ratio of the price of the product over the price of wheat. Villarroel and Horn computed weighted average

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[1] We must also keep in mind the fact that Chile's internal price relationships have been subjected to controls, and that changes in such relationships will affect aggregate value of output either directly or by inducing a change in product mix, or both.

[2] See Table on page 39, op. cit., and related discussion.

[3] One metric quintale is equal to 100 kilos in Chile. (Its size is not uniform in all countries.) The abbreviated designation is "qqm".

Table VI-9

MONTHLY DISTRIBUTION OF IRRIGATION REQUIREMENTS

(Percentage of annual total)

Province	January	February	March	April	May	June	July	August	September	October	November	December
Tarapacá	15.8	10.2	8.2	2.7	2.3	1.1	-	5.8	9.1	10.4	15.0	19.4
Antofagasta	15.1	9.3	7.4	4.3	4.2	2.8	-	5.6	9.1	10.3	13.9	18.0
Atacama	13.8	8.8	6.7	3.3	5.4	2.1	-	7.0	10.5	12.2	12.8	17.4
Coquimbo	13.6	8.8	6.4	3.9	5.4	.8		7.4	11.3	12.7	12.9	16.8
Aconcagua-Valparaíso	14.8	12.6	7.8	4.5	.5	.1	-	5.6	9.1	12.9	17.3	14.8
Santiago	15.6	14.3	10.6	7.4	1.5	.7	.6	2.7	7.3	10.4	13.9	15.0
O'Higgins-Colchagua	12.6	18.4	16.7	7.5	6.1	-	-	-	1.8	7.1	12.7	17.1
Curicó-Linares	16.5	15.1	8.0	5.4	-	-	-	1.7	8.4	11.9	16.3	16.7
Ñuble	13.6	12.3	10.5	7.1	-	-	-	2.4	9.3	13.3	18.2	13.3
Concepción-Cautín	16.7	14.5	9.0	5.9	-	-	-	2.1	9.5	13.9	15.8	12.6

Source: Basso, op. cit., p. 52.

yields in this way for each irrigation project and adjacent dry land, based upon census data of hectares seeded and yields in each comuna. The objections raised above to the productivity measurements of Villarroel and Horn and the use of such measurements in determining the added productivity of land put under irrigation by the Dirección de Riego, do not apply to the use we are now making of their computations.[1]

Because Villarroel and Horn made no measurements for provinces south of Cautín, except for one small project in Aysén, we assumed that productivity on unirrigated land in the provinces of Valdivia, Osorno, and Llanquihue was the same as in the four provinces to the north. The same productivity was assigned to Chiloé, Aysén, and Magallanes as Villarroel and Horn computed for the comunas adjacent to the Canal Chile Chico in Aysén. The average for a zone was then assigned to each province in that zone. The resulting productivity measurements are shown in Table VI-10. They reflect not only the yield in physical terms but the prices that prevail for the crops that are grown. For this reason a change in crop mix or a change in price relationships among agricultural products can affect the productivity coefficient.

Productivity estimates reflect a difference of 100:1 between irrigated and dry land in the north (where the only dry land that can be used are the Andean slopes for seasonal grazing) and a difference of about 2.3:1 in the provinces at the southern limits of irrigated agriculture. In the six provinces centered around Santiago the ratio is approximately 5:1.

By applying the Villarroel and Horn productivity coefficients to land

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[1] The objection was that their measurements were comuna averages of all dry and irrigated land, respectively, and failed to give due regard to the differences in productivity of land specifically selected for the Dirección de Riego projects.

Table VI-10

ESTIMATED PRODUCTIVITY OF IRRIGATED AND DRY LAND

EXPRESSED IN METRIC QUINTALES OF WHEAT EQUIVALENTS [1]

	Irrigated	Dry
Tarapacá	50.0	0.5
Antofagasta	50.0	0.5'
Atacama	50.0	0.5
Coquimbo	30.0	2.0
Aconcagua	22.5	4.6
Valparaíso	22.5	4.6
Santiago	22.5	4.6
O'Higgins	22.5	4.6
Colchagua	22.5	4.6
Curicó	22.5	4.6
Talca	17.5	5.0
Maule	17.5	5.0
Linares	17.5	5.0
Ñuble	17.5	5.0
Concepción	17.5	5.0
Arauco	15.0	6.6
Bío Bío	15.0	6.6
Malleco	15.0	6.6
Cautín	15.0	6.6
Valdivia		6.6
Osorno		6.6
Llanquihue		6.6
Chiloé		3.0
Aysén		3.0
Magallanes		3.0

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[1] Adapted from Villarroel and Horn, Rentabilidad, op. cit.
    pp. 39-40.

reported under cultivation in 1959, under the assumption that this figure
is about the same today, we acquire some appreciation of the land con-
straint and the implied productivity changes that must be achieved in
order to reach 1985 goals. Unfortunately, the accuracy of the basic
measurements again comes into question, and our answer varies substan-
tially depending upon which source is used.

According to CORFO's estimates of land under cultivation,[1] a total
of 1,389,084 hectares were irrigated in 1959. This land produced
29,700,000 metric quintales of wheat equivalent, calculated with the use
of Villarroel and Horn's coefficients. If all irrigable land is put under
irrigation in 1985, the yield will be 49,000,000 metric quintales of wheat
equivalent (see Table VI-11) at the productivity rates that now prevail.
In other words, given no change in output per hectare, product mix, and
price relationships, total production from irrigated land can increase by
about 60 percent.

Since, except in the north, the expansion of land under irrigation
will take place at the expense of dry land now under cultivation, the net
increase in agricultural output is less. Total potential output from dry
land after expending irrigable hectareage to its maximum depends, of
course, on the quantity of arable land. If we assume that CORFO's total
of "dry land under cultivation" in 1958-59 is equal to the total amount
of unirrigated land in classes I-IV, the total amount of such land is
about 4.1 million hectares, distributed among the provinces as shown in
Table VI-12 (column headed "dry land before reduction"). Multiplying
dry land under cultivation by Villarroel and Horn's production

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Table VI-11

ESTIMATED PRODUCTION FROM IRRIGATED LAND

	Hectares irrigated 1959 a/	Produc- tivity b/ qqm W./Ha	Production qqm WE 1959 (1) x (2)	Hectares Irrigable (1985) c/	Production in 1985 qqm WE (2) x (4)
	(1)	(2)	(3)	(4)	(5)
Tarapacá	7,000	50.0	350,000	10,773	538,650
Antofagasta	4,200	50.0	210,000	2,626 d/	131,300
Atacama	26,081	50.0	1,304,050	27,288	1,364,400
Coquimbo	107,081	30.0	3,212,430	113,023	3,390,690
Aconcagua	38,181	22.5	814,073	63,092	1,419,570
Valparaíso	53,881	22.5	1,212,323	65,549	1,474,853
Santiago	228,412	22.5	5,139,270	283,852	6,386,670
O'Higgins	143,529	22.5	3,229,403	170,280	3,831,300
Colchagua	106,281	22.5	2,391,323	152,114	3,422,565
Curicó	79,885	22.5	1,797,413	88,644	1,994,490
Talca	125,881	17.5	2,202,918	193,936	3,393,880
Maule	41,181	17.5	720,668	31,378 d/	549,115
Linares	148,831	17.5	2,604,543	244,499	4,278,733
Ñuble	100,000	17.5	1,750,000	260,415	4,557,263
Concepción	31,900	17.5	558,250	65,956	1,154,230
Arauco	5,000	15.0	75,000	29,187	437,805
Bío-Bío	82,650	15.0	1,239,750	142,756	2,141,340
Malleco	23,900	15.0	358,500	259,140	3,887,100
Cautín	35,210	15.0	528,150	302,921	4,543,815
Valdivia					
Osorno					
Llanquihue					
Chiloé					
Aysén					
Magallanes					
TOTAL	1,389,084		29,698,064	2,507,429	48,897,769

a/ Tables prepared by Maciej Zaleski from CORFO files.

b/ From Rentabilidad.

c/ Equal to all land now irrigated, plus mixed classes, plus classes I, II, III of dry land, based on Tables of Instituto de Investigación de Recursos Naturales.

d/ Something is wrong, but what?

Table VI-12

ESTIMATED PRODUCTION FROM DRY LAND

	Reduction in Dry land (Hectares)	Productivity dry land qqm WE/ha [a]	Dry land Before [b] Reduction (Hectares)	Production Before Reduction (qqm WE)	Dry land After Reduction (Hectares)	Production After Reduction (qqm WE)	Air photo non-irrigated land after expansion of irrigated [c] area (has)	Air photo Production from dry land (qqm WE)
Tarapacá	3,773	.5	-	-	-	-	-	-
Antofagasta	-	.5	-	-	-	-	-	-
Atacama	1,207	.5	9,919	4,960	8,712	4,356	9	5
Coquimbo	5,942	2.0	32,919	65,838	26,977	53,954	6,533	13,066
Aconcagua	26,911	4.6	26,819	123,367	-	-	4,065	18,699
Valparaíso	11,668	4.6	34,119	156,947	22,451	103,275	17,933	82,492
Santiago	55,440	4.6	61,538	283,305	6,148	28,281	58,844	270,682
O'Higgins	26,751	4.6	18,471 d/	84,967	-	-	1,740	8,004
Colchagua	45,833	4.6	115,719	532,307	69,836	321,476	60,224	277,030
Curicó	8,759	4.6	28,115	129,329	19,356	89,038	9,251	42,555
Talca	68,055	5.0	91,119	455,595	23,064	115,320	18,342	91,710
Maule	-	5.0	110,819	554,095	110,819	554,095	51,615	258,075
Linares	95,668	5.0	128,169	640,845	32,501	162,505	16,347	81,735
Ñuble	160,415	5.0	421,000	2,105,000	260,585	1,302,925	195,784	978,920
Concepción	34,056	5.0	125,100	625,500	91,044	455,220	30,619	153,095
Arauco	24,187	6.6	196,000	1,293,600	171,813	1,133,966	46,623	307,712
Bío-Bío	60,106	6.6	195,350	1,289,310	135,244	892,610	170,345	1,124,277
Malleco	235,240	6.6	442,100	2,917,860	206,860	1,365,276	103,815	685,179
Cautín	267,711	6.6	692,790	4,572,414	425,079	2,805,521	329,964	2,177,762
Valdivia	-	6.6	502,000	3,313,200	502,000	3,313,200	367,273	2,424,002
Osorno	-	6.6	345,000	2,277,000	345,000	2,277,000	352,205	2,324,553
Llanquihue	-	6.6	195,000	1,287,000	195,000	1,287,000	231,953	1,530,890
Chiloé	-	3.0	97,000	291,000	97,000	291,000	53,122	159,366
Aysén	-	3.0	23,500	70,500	23,500	70,500	23,500 d/	70,500
Magallanes	-	3.0	235,000	705,000	235,000	705,000	235,000 d/	705,000
Total	1,131,722		4,127,616	23,778,939	3,008,039	17,331,518	2,385,106	13,735,309

a/ Rentabilidad. b/ Zaleski-CORFO. c/ All of Class IV in Cautín and above, classes I-IV, south of Cautín. d/ Something is wrong, but what?

coefficients an estimated 1958-59 output of 23.8 million metric quintales of wheat equivalent. Total output in terms of Villarroel and Horn's unit, therefore, was about 53.5 million metric quintales of wheat equivalent. Projected agricultural output without taking land or water constraints into account in 1985, when expressed in wheat equivalent, would be somewhere between 97 million and 120 million metric quintales, depending upon the assumed growth path and foreign trade policy within the range of behaviour discussed above. A doubling of output over the present (1959-60) level of production is a minimum estimate of projected requirements.

Projected output, based on CORFO's land figures would be equal to 48.9 million metric quintales of wheat equivalent from irrigated land and 17.3 million metric quintales of wheat equivalent from dry land, a drop of 6.5 million quintales in dry land production in order to achieve a 19.2 million metric quintales increase in irrigated production. It should be noted that these estimates do not take into account the availability of water.

If we use the figures on land capability released by the Instituto de Investigación de Recursos Naturales, projected potential output is less. The air photogrammetric survey shows only 2,951,266 hectares of dry land in classes I-IV, exclusive of land that is in the mixed, dry-irrigated classes, compared with CORFO's figure of 4.1 million hectares of "dry land under cultivation".[1] Since we cannot clearly distinguish between land that was _actually irrigated_ and land that was not by studying the

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[1] The two quantities need not coincide, but they presumably are designed to measure the same thing. CORFO's figure includes arable land used for natural pasture.

photogrammetric survey's figures on land capability, we have estimated total arable dry land in 1985 as being equal to the sum of land in Class IV in all provinces plus land in classes I-III in provinces south of Cautín. (All land in mixed classes and all land in classes I-III in provinces in and north of Cautín were assumed to be land potentially irrigable in 1985). The photogrammetric survey yields a total of 2,385,106 hectares of dry arable land after expansion of irrigated area, in comparison with the figure of 3,008,039 based on CORFO's data. Applying the productivity coefficients to the photogrammetric survey's figure yields a potential output of 13.8 million metric quintales of wheat equivalent, or a total, including production from irrigated land, of 63.7 million metric quintales.[1]

If water constraints were taken into account estimated production would presumably be different. At the moment, however, we shall assume that all irrigable land is irrigated, all arable land is cultivated, and crop mix, prices and productivity are as implied by Villarroel and Horn's coefficients. The estimates indicate that if the air photogrammetric survey is accurate, output can reach 63 million metric quintales. Since projected requirements are about 1.8 to 2.25 the current level of output, or from 97 to 120 million metric quintales of wheat equivalent, an average increase in output per hectare of from 50 percent to 100 percent is implied. When water constraints are taken into account the implied required increase in productivity will be greater.

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[1] We cannot estimate the net change in output over current production on the basis of photogrammetric survey figures because we have no way of knowing how much of some 700,000 hectares of land in mixed classes was irrigated and how much was dry. This information should be available sometime in the future.

Chapter VII

MINING AND ELECTRIC POWER

Mining contributes to Chile on the order of 6 percent of its national income, 4 percent of "gross geographic product," and 85 percent of its income from exports. A few large producers dominate the industry--copper and nitrates being the principal minerals. Some oil and gas in the far south, coal in the central zone, iron, and small amounts of gold, manganese, molybdenum, sulfur, and calcium complete the picture.

Production of coal, which is concentrated around Concepción, and oil and gas, on the island of Tierra del Fuego, create no foreseeable problems of water supply, conflicting demands, or serious threat of pollution. The story is different, however, for copper and nitrate, all of which come from regions of serious water shortage. One large copper mine, Braden's (Kennecott) El Teniente, is in the central zone on the headwaters of a tributary of the Rapel. There is a little production of copper in the north central zone and the southern part of the Norte Chico divided among a number of small mines. The bulk of production is in the Norte Grande. Chuquicamata, Chile's largest copper mine, is a huge open pit in the province of Antofagasta. Not far away are the major nitrate deposits.

In recent years Chile has produced in the neighborhood of 10-15 percent of the world's copper. In 1963 production was 604,000 long tons of refined copper of which 84 percent came from the "Gran Mineria"--the mines of Anaconda in Antofagasta and Atacama and Kennecott in O'Higgins.

Within the last few months the Chilean Congress has been debating an agreement negotiated between the executive branch and the two major companies on a plan for expanding output, increasing total investment,

and transferring to the Chilean Government a share of financial and administrative responsibility. Since Chilean ores are both extensive and relatively rich,[1] a substantial expansion of the industry, with or without a corresponding expansion in the world market, appears to be reasonable.

Two projections of future output were made.[2] The lower assumed an industrial rate of growth equal to the historical average, but allowed small producers to grow more rapidly than large. Total output would rise from 604,000 tons to 1,222,000 tons in 1985. Output of the Gran Minería would fall from 84 percent to 75 percent. The higher projection assumed that the agreements now under discussion would be adopted, and that total production would be 2,000,000 tons by 1985 of which about 75 percent would come from the Gran Minería. The growing relative share of small and medium producers means that mining demands for water will grow in Coquimbo, Aconcagua, Valparaíso and Santiago as well as in the provinces dominated by Anaconda and Kennecott.

Output of nitrates has ranged in recent years, between a million and a million and a half tons per year, with no clear trend. In 1963 production was 1,144,600 tons. The ten-year plan of CORFO assumed a moderate increase over the 1960 low to a level of production in 1970 that would still be less than output of the 1950's. If CORFO's assumed rate of growth is extended to 1985 output would be 1,600,000 tons. This level of production was used for both the low and high economic projections.

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[1] According to Hansen, <u>Proyecciones de la demanda de agua en Chile</u>, Chuquicamata possesses the greatest single body of ore in the world. CEPAL says that Chilean costs of production are among the lowest in the world. An engineer for Kennecott said that their ores in Chile are about 1.8 percent copper, compared with less than 1 percent in the United States.

[2] By Catholic University.

Estimates of water use were made by CEPAL and Hansen based on data supplied by the companies and coefficients taken from technical literature. The amount of water used per ton of refined ore depends on the method of beneficiation that is used, the type of ore, and the degree of recirculation. A flotation process is used for copper sulfide ores; a leaching process is used for copper oxide ores. Unit rates of gross use were estimated as follows:

Copper[1]

Chuquicamata: (Antofagasta)	Oxide ores--.5 m^3 per ton of ore sulfide ores --1.0 m^3 per ton of ore or 91.5 m^3 per ton of refined copper. Since the bulk of reserves are sulfide, this coefficient is used for projections.
El Teniente: (O'Higgins)	Same as Chuquicamata, sulfide ores, but with higher degree of recirculation: 83 m^3 per ton of refined ore.
Potrerillos: El Salvador: (Atacama)	No data. Estimated at 3.75 m^3 per ton of ore treated or 415 m^3 per ton of refined copper.
Medium Mines:	No data. Estimated at 3 m^3 per ton of ore treated. Leaching process estimated to require an intake of 500 lts. per ton of ore treated.
Small Mines:	No data.

Nitrates[2]

Blackish Water of Loa and Salvador Rivers	Pedro de Valdivia and María Elena Mines: Current use 180 lts./second or 15,500 m^3/day. Expected total use after construction of 40 evaporation tanks--25,000 m^3/day.

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[1] and [2] CEPAL, Hansen, op. cit.

Table VII-1

COPPER PRODUCTION AND WATER REQUIREMENTS 1/

	Production (1000 tons)			Water requirements (1000 M^3/yr)2/		
	1963	1985		1963	1985	
		Low	High		Low	High
Tarapacá	a/	a/	4	b/	b/	160
Antofagasta	304.3	592	775	27,029	51,652	67,550
Atacama	107.7	220	437	38,391	72,035	166,326
Coquimbo	10.9	33	74	2,761	7,564	20,898
Aconcagua	17.6	54	188	807	2,477	14,168
Valparaíso	3.3	10	22	1,108	3,402	72,992
Santiago	15.5	48	76	3,925	12,050	19,294
O'Higgins	144.4	264	429	12,006	21,927	35,607
Total	603.7	1,221	2,005	86,027	171,107	396,995

a/ less than 500 tons

b/ less than 500 M^3

1/ Source: Catholic University

2/ Assumed to be intake

Table VII-2

NITRATE PRODUCTION AND WATER REQUIREMENTS [1]

	Production (1000 tons)		Water Use (1000 m^3/ year)	
	1963	1985	1963	1985
Tarapacá	118.3	164	890	1,230
Antofagasta	1,026.3	1,436	7,290	10,765
Total	1,144.6	1,600	8,180	11,995

[1] Source: Catholic University

Table VII-3

PROJECTED WATER USE IN THERMAL ELECTRIC POWER

(1000 M$^{3/}$yr.)

| | | INTAKE 1985 | | | |
| | | Multiple of Increase over 1965 | | | |
	1965	Medium A	Medium B	Medium A	Medium B
Tarapacá	110	5.79	5.79	637	637
Copper					
Others					
Antofagasta	246,071	3.08	4.02	756,816	988,910
Copper	177,171	2.02	3.33	357,885	589,979
Others	68,900	5.79	5.79	398,931	398,931
Atacama	2,806	3.53	4.31	9,898	12,104
Copper	1,684	2.02	3.33	3,402	5,608
Others	1,122	5.79	5.79	6,496	6,496
Coquimbo	8,885	1.39	1.39	12,350	12,350
Valparaíso	93,253	1.39	1.39	129,622	129,622
Santiago	56,293	1.39	1.39	78,247	78,247
Linares	1,421	1.39	1.39	1,975	1,975
Concepción	1,403	1.39	1.39	1,950	1,950
Bío-Bío	7,771	1.39	1.39	10,802	10,802
Llanquihue	553	1.39	1.39	769	769
Chiloé	1	1.39	1.39	1	1
Aysén	1	1.39	1.39	1	1
Magellanes	1,354	1.39	1.39	1,882	1,882

Source: Center for Economic Investigation, Catholic University.

Fresh Water   for domestic water supply and boiler feed. Current use is 4,500 m^3/day. No future increase is anticipated.

Tables VII-1 and VII-2 show projections of production and water use (intake) as estimated by Catholic University. Since no information was supplied on quantities of water recoverable for further use, a loss rate of 15 percent of intake was assumed. (See alternative computation of losses on the assumption that all intake is lost, Chapter XI.)

Electric Power

The use of water by steam-electric plants was estimated directly from data on current water use.[1] For the provinces below Atacama the rate of increase in production from thermal power projected by ENDESA [2] was applied to current intake. In the three northern provinces, where most of the thermal power is produced by the mining companies, 1965 intake was divided between the power plants of the mining companies and all others on the basis of capacity. Water use by mining company plants was projected at the two alternative rates of growth used for the mining industry; other plants were projected at the rate of growth projected by ENDESA for power production in the country as a whole--thermal and hydro--on the assumption that hydro would supply a negligible share of increased power in the far north.

Losses were estimated at being equal to 0.42 percent of intake, reflecting the experience of the Central Pacific and Southern Pacific regions of the United States (approximately equivalent to the state of California).

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[1] Supplied by the Center for Economic Research, Catholic University

[2] Empresa Nacional de Electricidad, S.A., the Chilean national power corporation.

The loss rate for the United States is a measure of fresh water losses and, therefore, is affected by the use of ocean water as well as by the degree of recirculation that is practiced. However, a relatively large error in the coefficient is not likely to result in a significant difference in total of water requirements measured as losses, because under the most adverse conditions loss rates are a very small fraction of intake unless recirculation reaches a high level.

The accompanying table shows that projected water use by thermal plants other than mining in Tarapacá, Antofagasta and Atacama is 5.79 times current use. Power produced by the mines is estimated to increase by lesser amounts. South of Atacama, where the interconnected hydro and thermal grid exists, projected increase of thermal power water use only 1.39 times present use. Within the area covered by the inter-connected grid most of the new capacity is scheduled to come from hydroelectric plants.

ENDESA, which will be responsible for virtually all future public utility power additions within the country, plans to increase its hydroelectric capacity within the interconnected grid area (La Serena to Puerto Montt) from 537 MW to about 1900 MW in 1978.[1] According to earlier plans reported by CEPAL.[2] ENDESA had expected to add about 1255 MW by 1973 and another 2744 MW by 1990 according to the following regional distribution:

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[1] Table prepared by Michael Nelson, Chile-California Program

[2] CEPAL, P.77. CEPAL gives two figures for expected additional hydro capacity: 1,254,600 kw. (p.77) and 1,124,600 kw. (p.83).

Installed capacity (100 kw)

	1957	Added by 1973	Added between 1973 and 1990
Norte Grande	1.4	9.0	-
Norte Chico	21.8	30.0	6.0
Chile Central	464.9	1,156.0	1,268.0
Sur Chico	25.2	59.6	1,470.0
Sur Grande	0.2	-	-
Total	513.5	1,254.6	2,744.0

Total capacity of 4,512 MW in 1990 represents 14 percent of the country's gross potential of 31,880 MW, figured at average flow.

Eighty percent of existing hydro capacity, and even more of produced energy, is run-of-the-river. Of 1.1 million kw. of new capacity under construction or under study 50 to 60 percent is to be regulated. (One project, Antuco on the Río Laja is shown to be both run-of-the-river and regulated).

An expansion in hydroelectric power installations in the Central Zone will complete with efforts to provide a higher degree of regularity in the supply of water for irrigation. In the Central Zone the rivers follow a glacial regimen, which means higher flows in the summer than in winter. If hydro installations are run-of-the-river, and if they are above the sites of irrigation, the two uses are neutral with respect to each other. If, however, the hydro installation is dependent upon a reservoir of such size that either season or annual flows are regularized, the uses will be competitive. For hydro, the main releases from a reservoir will be in the winter; summer flows will be stored. Irrigators of course, need the water in spring and summer.

For the year 1990, installations utilizing 2,000 kw. of capacity out
of a gross potential of 14,085,000 kw is projected for the Sur Grande.
The explanation for such vast under-use is the distance over which power
would have to be transmitted. From the Río Baker, say, which has itself
two-thirds of the gross potential of the sum of all rivers from the
Aconcagua to and including the Toltén, to Puerto Montt, the southernmost
city of the Central Valley, is roughly 450 miles. This does not exceed
the distance over which power is being sent in other countries, but
apparently topography and climate do not yet justify use of this source
of energy in the near-term plans of Chile. ENDESA conceives of the
hydroelectric resources of the south as a reserve for future exploitation.

The price of electric power per KWH is about the same in Chile as in
the United States.[1] The average cost of Chilean hydroelectric plants
built in the past was US$ 214 per kw which compares with the less expensive
of the hydro plants under construction or consideration in the 1950's
in the United States;[2] the average costs of plants being planned or under
construction is US$ 139 per kw.[3] Fixed costs of ENDESA's plants are
computed on the basis of 8 percent interest and 50 year depreciation.[4]

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[1] Estudios sobre la electricidad en América Latina, Naciones Unidas,
Mexico, 1962, Vol. I, p. 380

[2] Bonneville (211): Added capacity TVA (266).
Computed from data on amounts allocated to electric power and
installed capacity, Task Force Report on Water Resources and Power,
Vol. II, Commission on Organization of the Executive Branch of the
Government, June 1955, pp. 423, 428, 453, 458, 555, 562, 262.

[3] Estudios Vol. I. p. 419. However in this table escudos were converted
into dollars at the parity rate of 1.314 escudos per dollar. Elsewhere
in this same document the official conversion rate of $E^o = \$ .95$ was
used. The latter rate would raise the dollar equivalent by about
25 percent.

[4] Op. cit. p. 407.

There are no data on the capital costs of steam plants already in use in Chile, but it is estimated that two new plants with a combined capacity of 200,000 kw will cost $ 185 per kw. The steam plants will require an outlay of foreign exchange to cover 66 percent of the costs of construction, whereas only 30 percent of the construction costs of hydro plants will be paid in foreign exchange. Operating costs of hydro plants are lower than operating costs of steam plants. Based on these figures it is reasonable to anticipate a growth of hydroelectric relative to steam even though the hydro must be transmitted over greater distances. According to data prepared for the Seminario Latinoamericano de Energía Eléctrica,[1] for plants "under construction and projected," costs of transmission are included in the costs of generation but an additional cost of $ 32 per kw., on the average has to be added for interconnection. The cost advantage of hydro plants persists after taking interconnection costs into account. Except for one peaking plant with a construction cost of $ 162 per kw. and a plant factor of 26 percent, the cost per KWH of new hydropower should be no more than current costs, which range between 6.9 and 8.0 mills. In at least three plants the costs should be between four and six mills per KWH.

One cannot infer that Chilean investment in hydroelectric power is economically justified merely because capital costs are as low or lower than current capital costs in the United States.[2] The need for power

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[1] Op. cit. pp. 388, 390

[2] Plant factors are relatively high in Chile. Of those in operation, the largest has a plant factor of 65.4 percent. The lowest plant factor is 40 percent. Of thirteen being constructed or still in the planning stage, three are expected to have a plant factor between 24 and 30 percent. Five will have plant factors of more than 60 percent. Op. cit. p. 418.

is not a fact revealed solely by the cost of power. There is evidence, however,[1] that future capacity is planned to meet an anticipated growth in power use; rarely have facilities been constructed in the expectation that their availability would stimulate a demand. ENDESA's plans do, however, take into account any developmental programmes of CORFO or other governmental or private activities.

Of the hydro installations in operation, under construction, or planned, only one, Rapel is downstream, large and dependent upon a relatively large reservoir. Fourteen installations are far enough downstream to offer some competition with other uses of water.[2] The installed capacity of twelve of these amounts to a total of 26,000 KW. Rapel will have 350,000 KW; no data are available for one. According to ENDESA engineers, Rapel should offer no competition with irrigation because of the limited amount of land capable of being irrigated. Water from the reservoir will be used to irrigate some new land to replace that which will be inundated by the lake behind the dam.

In a paper presented to the Latin American Seminar on Electric Energy, Raúl Saez, Manager of ENDESA, discussed various problems relating to the expansion of capacity, the choice of prime mover, and location of plants. Among the items with which he dealt were price policies applicable to fuels; imports, export, and exchange rate policies as they related to fuels; the lack of stability in policies that has impeded adoption of a rational energy program; rates charged the user of electric energy; the

[1] Conversations with ENDESA officials.

[2] Based on a map prepared by CEPAL from data supplied by ENDESA. See Estudios Vol. 1, pp. 164-167.

financing of new investment and criteria for justifying and selecting
new projects, whether hydro or fuel.[1] He pointed out that Latin America
faced three basic scarcities: trustworthy data, technically competent
personnel, and financial resources. Consequently it was impossible to
overcome simultaneously the absolute lack of electric service in some
areas and the growing deficiency in other areas. The problem of priority
in new investment was much more complex for public power enterprises than
for private, since the latter needed only to consider profitability,
whereas the former had to take into account a much wider range of factors
relating to economic development within both regional and national
perspectives. Saez emphasized the difficulties encountered in planning
for the future that were created by lack of data, data needed to estimate
future demand for power as well as data regarding the resources with
which to meet the demand. "We know, moreover, of a case in which the
decision to develop electric service for one zone rather than for another,
was in part fundamentally based on the better state of basic information
of consumption and resources."[2] The Central Sauzal was given priority
because it had better hydrologic data than other projects of equal size
built later.

In some cases priority was based upon the need to mesh an additional
supply of power with other economic plans--such as development of a
particular region or industry. In other cases priority rested upon an
implicit or explicit scale of benefits, relative degrees of "urgency"
such as the existence of power rationing, or distinctions between "productive"
and "consumptive" uses.[3]

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[1] Op. cit. "Criterios Económicos para la Selección y Desarrollo de
Centrales y Sistemas Eléctricos," pp. 257-299.'

[2] Saez, op. cit. p. 266. The author noted that ENDESA's decision to
give priority to the Pilmaiquén system over others of greater
"economic urgency" was based in part on this consideration.

[3] Ibid.

Another point touched upon by Saez was the choice between a few large plants coupled with an extensive distribution system and a large number of smaller plants serving smaller areas. A completely interconnected system has much merit in Chile because of the variety of river regimens. In the North high flows come in the summer from snow and ice melt with clearly marked low flows in the winter. Further south the regimen is mixed, since the winter trough is partly offset by rains. In the south, flows are relatively constant all year round, regulated by many natural lakes. However, because of the high cost of high voltage lines, ENDESA, at least momentarily, is following a system of constructing separate plants for each region. Only two "modest" interconnections have been made, one of 110 KV and 105 kilometers in length and another of 150 KV. and 242 kilometers. At present, and in the foreseeable future, interconnections are being made mainly within the central zone, between latitudes 27° and 42° among ENDESA's plants, other public utility plants, and industrial self-suppliers, and among hydro and thermal plants. This "preponderantly hydroelectric system" uses thermal power to supply the deficit of energy during the winter and in dry years.[1] The plans of ENDESA rest, not upon study of separate generating plants, but upon analysis of alternative systems of hydro run-of-the-river, hydro with regulating reservoirs, and thermal power plants. Hydro plants within a region are interconnected to make full use of complementary hydrologic regimens and to reduce to a minimum the deficit to be supplied by thermal power, taking into account transmission losses.

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[1] Renato E. Salazar and Carlos Croxatto, "Métodos Empleados por la Empresa Nacional de Eléctricidad S.A. para la Selección de Alternativas de Abastecimiento Electrico en el Sistema Interconectado de la Zona Central de Chile," Estudios, Vol. II, p. 167.

Multiple Purpose Projects

There are very few multiple purpose projects in use, under construction, or under consideration in Chile. The main reason given by ENDESA is the unfavorable topography whereby costs of reservoir construction in the Andean valleys is "extraordinarily expensive."[1] Of thirteen projects for which we have information, six have daily regulating ponds, five have larger reservoirs for seasonal regulation, and two have capacity for inter-annual regulation. In the lake country and beyond, to the south, natural regulation and the natural regimen of the rivers eliminate the need for artificial storage. For a number of hydro projects, e.g. Lago Laja, Canutillar, Pullinque, and Pilmaiquén, natural lakes are controlled at relatively low cost. There are a limited number of sites for production of power within the coastal cordillera close to the sea. Such are Rapel and Cabimbao. Here, again, because of terrain, the possibilities of multiple purpose reservoirs are limited.[2] No detailed studies were available that indicated the costs, benefits, and range of possibilities that had been considered and discarded in the process of making the final choice.[3]

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[1] Bennet, et. al. Estudio, Vol. II, p. 327.

[2] The small irrigation project of Rapel was noted above.

[3] Chilean experience is not unique. Note the following comment in a slightly different context, by Fox and Herfindahl regarding Corps of Engineer projects in the United States. "Ordinarily it is impossible to tell whether the size of a project is correct, however, since data on the costs and benefits of marginal increments usually are not given in project reports." Irving K. Fox and Orris C. Herfindahl, "Attainment of Efficiency in Satisfying Demands for Water Resources," Proceedings, American Economic Association, May 1964, p. 1201.

A large multiple purpose dam at Colbún in the Maule basin has
recently come under scrutiny as a result of investigations carried on by
the Chile-California Program. On the basis of very preliminary studies
it has been ascertained that a dam could be erected with a capacity of
1,500 million cubic meters of water, which would support installed
capacity of 208 MW, serve 70,000 hectares of new irrigated land and
supplement the water supply of an additional 30,000 hectares. In addition,
return flows would support 20,000 hectares and other land would have
the security of its water supplies raised from 85 percent to 98 percent.
Since Colbún could reregulate water from Laguna del Maule now reserved
for irrigation an additional 192,000 KW of capacity could be installed,
bringing the total for this project to about 400,000 KW. As has been
said, Colbún would be, if subsequent studies prove its merit, the largest
project yet undertaken in Chile, the only major case in which a reservoir
was used for reregulation, and the only multi-purpose project (recreation
would also be important) of any consequence.[1]

Except for reservoirs designed to supply daily regulation, ENDESA
at present produces no power from reservoirs that were artifically
constructed[2] but will soon do so at Rapel, the reservoir-plant under
construction. Seven other projects using artificial storage are under
study: Cabimbao, Guaquirilo, Melado, Colbún, Porvenir, Ralco, and
Collipulli. Total capacity is about 8,000 million M^3, of which Ralco Grande
accounts for 4,100 million M^3. As we shall see later, estimates of
storage capacity to meet offstream needs by 1985 in the same part of
the country as these projects are located range between 8,500 and 22,000
million cubic meters. One might anticipate, therefore, a more intense
effort than has been made up to now to plan dual or multiple purpose projects.

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[1] Preliminary reports made available by Michael Nelson, Chile-California
Program.

[2] Cipreses, Abanico and Pilmaiquén use water of natural lakes.

We shall have little further to say about hydroelectric power production. Without detailed systems studies one cannot anticipate how effectively storage for power will serve other uses. To the extent that regulatory storage can be used for power production the costs of water allocated to non-power uses can be reduced. To that extent, therefore, a cost constraint on non-power users will be less binding than we have assumed in a later chapter. If, however, reservoir capacity is competitive among uses, so that reregulation is necessary, our estimates of reservoir capacity to meet offstream uses are not overstated.

ENDESA has no plans at present for the production of hydroelectric power from regulated storage for any basins to the north of Santiago. Since projected requirements call for about 1,650 million cubic meters of storage capacity, the possibility of multiple purpose uses should be fully explored. In this part of the country--i.e. Santiago northward-primary dedication of water to power production is probably unwise, but an allocation of costs and water on an incremental basis may justify hydroelectric installations.

Chapter VIII

MANUFACTURING USES OF WATER

Chile's manufactures include "practically all the ... non-durable consumer goods needed by the domestic market, ... (and) substantial production of intermediate goods (pulp and paper, rubber, petroleum and coal products, non-metallic mineral products and basic metal products)... The metal and metal-transforming industries are less developed..."[1]

Our analysis of industrial uses of water has been directed mainly to the five major water using and polluting industries: food, pulp and paper, chemicals, petroleum refining, and iron and steel production. All others have been aggregated into a single group.

The deficiency of data regarding the present state of affairs in the uses of water by manufacturing matches, if not surpasses, the deficiencies in other spheres. In four industries we acquired information directly from the companies themselves. In other instances it was necessary to estimate water requirements by a chain of inferences. There is practically no information on waste loads, level of waste treatment, and adverse effects of waste loads.

Published information regarding industrial water intake in Chile is found in the CEPAL study and a study of the Dirección de Planeamiento del Ministerio de Obras Públicas written by Norman Hansen, Ing., with the collaboration of H. Baeza and J. Parker B.[2] The CEPAL study preceded and was used by Hansen, and so the findings tend to be intertwined. Both studies estimated water requirements--current and future-- by relying upon a relatively small amount of specific information supplied by Chilean

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1/ Unofficial statement, Instituto Latinoamericano de Planaficacion, March 1966.
2/ Op. cit.

manufacturers supplemented by coefficients taken from other countries, notably the United States.

As Hansen points out "there are no official statistics regarding the quantities of water used by industry in Chile" nor is there "an official organization charged specifically with the problem of industrial water supply". While the Dirección de Riego "indeed intervenes in the grant of water rights, this work, although necessary, is totally inadequate since it neither defines a clear policy to follow nor accomplishes any form of hydraulic planning", (p. 17) nor, Hansen might have added, does it gather information on industrial uses of water.

The distribution of manufacturing activity among industries and provinces can be ascertained for the year 1956 from "Industrias Año 1956".[1] In 1956 the value of manufacturing output amounted to 407 billion pesos in 1956 prices, (this would be approximately 1.1 billion escudos at 1962 prices, and therefore, roughly equal to US\$ 1.1 billion at the official 1962 exchange rate. As Tables VIII-1 and VIII-2 show, most manufacturing output was concentrated in a few industries located in a few provinces. Of the twenty-five provinces, fourteen accounted for 5.6 percent of total market value. At the other extreme, three provinces accounted for 83.8 percent of which one, Santiago, accounted for 52.9 percent. These three provinces, Valparaíso, Concepción, and Santiago, all border on the ocean, but whereas the cities of Valparaíso and Concepción are themselves located on the coast, the city of Santiago is in the interior, a circumstance that makes the problem of present and future pollution in the Maipo and Mapocho Rivers especially acute. Food, textiles, and basic metals accounted for

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[1] Dirección de Estadística y Censos, Chile

53 percent of total manufacturing value. Even though manufacturing is only in its infancy there is no reason to expect a radical alteration in either geographic or industrial concentrations unless some presently unanticipated factor intervenes.[1]

Manufacturing: Projections of Output

Manufacturing output was projected for the country as a whole and then allocated to provinces, and in some cases to cities. The methods that were used for making the projections and provincial distributions fall into two distinct categories:

(1) Projections based upon plans of the enterprises themselves or of CORFO or of ODEPLAN (the National Planning Office) for expansions of output in the future;

(2) Estimates of future production based on the assumption that output would meet projected demand computed on the basis of estimated growth in population, income per capita, and income-elasticity of demand. Where appropriate, an estimated foreign trade balance was also taken into account.

Where income elasticities were used the following assumptions were adopted:

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[1] After the above was written the following table was unofficially pre-pared by the Instituto Latinoamericano de Planificación. (See Table VIII - 1(n).) According to the new table, between 1956 and 1964 the relative importance of consumer goods (mainly non-durable) fell from 62.5% to 50.3% of the total market value of manufacturing industries,) intermediate goods (pulp and paper, rubber manufactures, chemicals, etc.) rose from 28.7% to 35.2% to total market value, and metal products and machinery industries rose from 8.8% to 14.6% of total market value.

Since projections were based on industry plans as of 1965, the new figures in Table VIII-1(n) do not affect the figures for estimated outputs in 1985.

(Footnote continued)   Table VIII - 1(n)

CHILE: STRUCTURE OF PRODUCTION OF THE FACTORY SECTOR OF MANUFACTURING
(Percentage distribution of Market Value)

Industrial branches according to the United Nations standard international trade classification	Existing situation (1964) a/
TRADITIONAL INDUSTRIES (Principally producers of consumer goods, especially non-durable)	50.3
Food	18.1
Beverages	2.8
Tobacco	1.1
Textiles	14.4
Clothing and footwear	8.0
Furniture and fittings	1.4
Leather and leather manufactures	0.9
Printed matter	3.6
INTERMEDIATE INDUSTRIES (Principally producers of intermediate goods)	35.2
Pulp, paper and manufactures thereof	3.4
Rubber manufactures	2.1
Chemicals	6.6
Petroleum and coal products	4.8
Non-metallic mineral manufactures	6.6
Basic metal manufactures	11.7
METAL AND METAL TRANSFORMING INDUSTRIES (Principally producers of durable consumer goods and capital goods)	14.6
Metal manufactures	
Machinery	
Electrical machinery and equipment	13.3
Transport equipment	
Miscellaneous	1.3
TOTAL	100.0

a/ The factory (non-artisan) sector of industry is defined as including
establishments that employ five workers or more. Based on the figures
for value in the 1957 Industrial Census, adjusted to bring them up to
date to 1964 according to the Industrial Production Index of the Depart-
ment of Statistics and Censuses.

Table VIII-1

MANUFACTURING, PERCENTAGE DISTRIBUTION OF MARKET VALUE

AMONG INDUSTRY CLASSES, CHILE, 1956

Industry	Percent of Total
Food	25.3
Beverages	3.0
Tobacco	2.8
Textiles	17.2
Shoes & Clothing	5.8
Furniture & Wood Prod.	3.8
Paper & Cellulose	2.9
Printing & Publishing	2.2
Hides & Leather	2.4
Rubber Products	1.2
Chemical Products	7.4
Petroleum Refining & Coal Products	2.4
Cement, Clay, Glass, etc.	4.6
Basic Metals	10.2
Metal manufactures, machinery, etc.	8.8
	100.0

Total market value, 1956 pesos, 407,093,267,000.-

Source: Dirección de Estadística y Censos, Industrias, Año 1956, Santiago, 1961.

TABLE VIII-2

PERCENTAGE DISTRIBUTION OF MANUFACTURING OUTPUT AMONG

PROVINCES, BASED ON MARKET VALUE, 1956

Province	Percent of National Total
Tarapacá	0.6
Antofagasta	1.0
Atacama	1/
Coquimbo	0.9
Aconcagua	0.8
Valparaíso	17.7
Santiago	53.0
O'Higgins	1.6
Colchagua	0.7
Curicó	0.4
Talca	1.6
Linares	0.3
Ñuble ← Maule 0.1	0.6
Concepción	13.4
Arauco	0.1
Bío-Bío	0.7
Malleco	0.7
Cautín	0.9
Valdivia	2.4
Osorno	1.4
Llanquihue	0.6
Chiloé	1/
Aysén	1/
Magallanes	0.5

_____

1/ less than .05%

Source: Industrias Año 1956, op. cit.

Annual rate of increase in:

Assumption	National Income	Population [1]
A	3.75%	2.43%
B	5.50%	2.43%

Per capita, the annual rates of growth in income were:

Assumption A: 3.75% - 2.43% = 1.32%

Assumption B: 5.50% - 2.43% = 3.07%

Per capita demand was then projected as the product of the coefficient of income elasticity [2] multiplied by the rate of growth of per capita income. This product was augmented by the rate of population increase to yield the rate of growth of total demand for a given industry group, i.e. total demand was projected as growing at a rate equal to:

$$.0132E + .0243 \quad \text{for assumption A}$$

$$.0307E + .0243 \quad \text{for assumption B}$$

where E is the income elasticity of demand and .0243 is the medium rate of population growth. The way in which growth in production was related to growth in demand was established separately for each industry class. Projections were made for food and beverages, pulp and paper, chemicals, petroleum refining, and steel. All other manufacturing activity was consolidated into a single category.

The method of determining regional distributions varied with the industry. In the case of food, we assumed that the 1956 percentage

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[1] The "middle" rate of population growth was used for both assumptions; hence we identify these projections as "Medium A" and "Medium B". We assume that personal income grows at the same rate as GNP.

[2] Income elasticity coefficients were computed as linear in logarithms.

Table VIII-3

PERCENTAGE DISTRIBUTION OF MANUFACTURING OUTPUT AMONG PROVINCES, 1985

	Food 1/	Pulp 2/	Paper 3/	Chem. 4/	Petro-chem. 5/	Petroleum Ref. 6/	Steel 7/	All others 8/
Tarapacá	1	-	-	2	-	-	-	-
Antofagasta	1	-	-	8	-	-	-	-
Atacama	-	-	-	-	-	-	-	-
Coquimbo	2	-	-	2	-	-	-	1
Aconcagua	2	-	-	-	-	-	-	1
Valparaíso	22	.5	2	16	3	50	-	17
Santiago	36	2	22	63	-	30	5	64
O'Higgins	5	-	-	1	-	-	-	-
Colchagua	1	-	-	-	-	-	-	1
Curicó	1	-	-	-	-	-	-	-
Talca	4	.5	2	2	-	-	-	1
Maule	-	15	-	-	-	-	-	-
Linares	1	-	-	-	-	-	-	-
Ñuble	1	-	-	-	-	-	-	-
Concepción	6	9	25	5	12	20	95	11
Arauco	-	15	-	-	-	-	-	-
Bío-Bío	2	57	45	-	-	-	-	-
Malleco	2	-	-	-	-	-	-	-
Cautín	2	-	-	-	-	-	-	1
Valdivia	4	1	4	-	-	-	-	2
Osorno	4	-	-	-	-	-	-	-
Llanquihue	2	-	-	-	-	-	-	-
Chiloé	-	-	-	-	-	-	-	-
Aysén	-	-	-	-	-	-	-	-
Magallanes	1	-	-	-	85	-	-	-
Grand Total	100	100	100	100	100	100	100	100

See next page for notes.

Notes to Table VIII-3

(1) Based on the 1956 distribution of market value, as reported by "Industrias, 1956", bulletin published by Dirección de Estadística y Censos.

(2) Based on the expected distribution of output in 1970, as reported by FAO-CEPAL's study "El Papel y la Celulosa en América Latina", Revisión 2, May 1965.

(3) Same as (2).

(4) Same as (1). Aconcagua, Ñuble, Bío-Bío, Cautín, Valdivia, Osorno, Llanquihue and Magallanes together add up to 1 percent.

(5) This distribution is implied in company plans extended to 1985.

(6) Based on company plans for 1976.

(7) Based on 1961.

(8) Same as (1). Tarapacá, Antofagasta, Atacama, O'Higgins, Curicó, Maule, Linares, Ñuble, Arauco, Bío-Bío, Malleco, Osorno, Llanquihue, Chiloé, Aysén and Magallanes together add up to 1 percent.

distribution would be maintained. We made the same assumption for chemicals and "all others". For pulp and paper we assumed that the planned relative distribution for 1970 would be perpetuated to 1985. Petro-chemicals and petroleum refining were based upon company plans as extended into the future. The distribution of steel production was based upon the 1961 percentage distribution. Table VIII-3 shows the results.

Food and Beverages

The food industry is composed of a relatively large number of small enterprises, except in a few activities such as sugar refining, milk products, and beer. Output of the industry as a whole was projected by combining foods and beverages into a single group in order to make it comparable to the U.S. classification. This was done by weighting foods 85 percent and beverages 15 percent, in reflection of the average respective market values of outputs during the period 1948-1955. Separate income elasticities of demand were applied to each. The coefficient for food was taken as .5, based upon an estimate drawn from a study of the Centro de Investigaciones Económicas, Universidad Católica,[1] and an elasticity for beverages of 2.41 taken from an index of output of beverages prepared by Dirección de Estadística y Censos.[2] Weighting the two as indicated above yielded a combined income elasticity of demand of .8. In the absence of a clear policy regarding the imports and exports of foods, and in the presence of possible contradictory forces such as increased production of import-substitutables and increased consumption

[1] This elasticity was suggested by Mario Corbo of the Centro.

[2] That is, imports of beverages have been negligible and so we have assumed that output has met demand and that the effects of price elasticity could be ignored.

of imports such as tea, coffee, and tropical fruits as incomes rise, we
assumed that the absolute trade balance in food manufactures would remain
unchanged and that production would follow the projection of demand.

Production was distributed by province in accordance with the 1956
distribution of market value.

Pulp and Paper:

A study by FAO-CEPAL [1] estimated production for 1970. From data in
this study estimates of income elasticity of demand were drawn and an
export balance obtained for 1970. The absolute size of the 1970 export
balance was assumed to persist through 1985 and production was assumed
to grow in accordance with the rate of growth yielded by the growth of
population, the change in per capita income, and the income elasticity
of demand. Projections of paper and cardboard were separated from pro-
jections of pulp. The input of pulp per unit of paper was based upon the
1970 relationship given in the FAO-CEPAL study. Pulp exports were assumed
to persist to 1985 at the level estimated for 1970. The relative distribu-
tion of output of pulp and paper among provinces was assumed to remain
constant over the period 1970-1985 in accordance with FAO-CEPAL estimates
for 1970.

Chemicals:

This category includes inorganic chemicals, miscellaneous organic
chemicals, petrochemicals, and pharmaceuticals. There has been no pro-
duction in Chile, up to now, of petrochemicals. ENAP's [2] plans for

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[1] "El Papel y la Celulosa en América Latina", E/CN, 12/570/Rev.2, May
1965, prepared for the Eleventh Sessions of CEPAL, Mexico, mimeo.

[2] Empresa Nacional de Petróleo; interview with Sr. Estanislao Fabres.

production of petrochemicals through 1978 were adopted and extended to 1985 at the rate of growth of 8 percent annually, as estimated by ENAP. Their plans included data on aggregate output and location of plants.

Inorganic chemicals, miscellaneous organic chemicals, and pharaceuticals, have been produced in Chile. Output grew at 3.4 percent per year during the period 1953-63. This was the low rate of growth projected to 1985. Because CORFO [1] expected a much higher rate of growth in the future, but without specific production plans, we also projected the industry's growth at 6 percent per year, the rate used by CEPAL, as the high rate of growth.

Output was distributed among provinces on the basis of the 1956 distribution of market value produced.[2]

Petroleum Refining:

Demand was projected on the basis of population and income growth, since ENAP's engineers indicated that refining operations would not exceed domestic consumption because of the shortage of domestic crude. Output was distributed among plants in accordance with ENAP plans for 1976.

Steel:

Virtually the entire steel industry is within one establishment, Compañía de Acero del Pacífico (CAP). We envisioned no change in the structure of the industry. CAP has production plans to 1970. Domestic consumption was projected on the basis of population and income growth,

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[1] During the interview with Sr. Patricio Castro he said that CORFO hoped to have the industry grow at 12 percent per year to 1976.

[2] Dirección de Estadísticas y Censos; "Industrias, Año 1956".

except that income elasticity was computed by lagging consumption two years. The difference between projected demand for 1970 and CAP's planned production for 1970 was assumed to be exported. Exports were kept constant to 1985, and total production was assumed to grow in accordance with projected domestic demand.

All other Manufacturing Industries:

The remaining industries are tobacco, textiles, apparel, lumber and wood products, printing, rubber products, leather and hides, stone, clay and glass, fabricated metal products, machinery, electrical machinery, transportation equipment, instruments, and miscellaneous. These were aggregated by value added and projected at two rates: (1) the historical rate of growth of the total manufacturing sector during the period 1953-63, namely, 6.1 percent; (2) an expected rate of growth according to the Oficina de Planificación Nacional, of 8 percent.[1]

The foregoing industrial projections are not to be confused with serious industry location studies. We neither investigated possible new marketing opportunities nor barriers created by unfavorable costs. Nor did we seek to establish the optimum location of an activity within the country. Instead, projections are designed to approximate, roughly but rapidly, reasonable expectations on the basis of readily available evidence. There is also the possibility that some projections are inconsistent with others--such as implicit labor requirements of projected industrial outputs and the implicit labor supply of projected populations.

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[1] Interview with Mr. Eduardo García, vice-director. The Oficina's estimate for rate of growth during the period 1965-70 was extended to 1985.

The implicit annual rate of growth projected to 1985 for manufacturing as a whole is about 4.9 [1] percent for assumption A, and about 6.8 [1] percent for assumption B, the latter being a rate slightly lower than the approximately 7 percent growth rate in all manufacturing output between 1958 and 1963 reported by CEPAL. [2] Should the actual rate of growth follow the low path while planning follows the high path, by 1985 planned use of water will lead actual use by about five years. Most, but not all, major water-using industries in Chile have been growing more rapidly than manufacturing as a whole, the main laggards being food, beverages, and chemicals. Current programmes for food and chemicals envisage an acceleration in their growth, but by how much relative to manufacturing as a whole cannot be ascertained.

Estimates of Water Use: Revision of 1957 Water Use Coefficients in Manufacturing

The Chilean census of manufactures (1957) collected information by industry and province covering employment, payrolls, installed horsepower, energy consumed, new investment, current expenses, total income, and value added. No data were tabulated or published on physical output. CEPAL based its projections of water use on its own survey of water use and physical output of major water-using industries. Our procedure, benefitting somewhat by the passage of time, was the same as CEPAL's. We secured from pulp and paper, petroleum refining, steel, and sugar refining industries data on 1957 water use and production. The coefficients of

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1/ Exclusive of the petro-chemical industry.

2/ Statistical Bulletin for Latin America, Vol. II, No. 1, page 181.

Table VIII - 4

MANUFACTURING OUTPUT PROJECTIONS, 1985

	Growth rate (%)		Output Index (1964=100)		Output (thousand metric tons)	
	Medium A	Medium B	Medium A	Medium B	Medium A	Medium B
Paper	4.4	6.5	247	377	402.5	614.4
Pulp	6.0	7.3	343	439	610.4	781.7
Food and beverages	3.5	5.0	206	279		
Chemicals	3.4	6.0	202	340		
Petro-chemicals 1/						
Ethilene					100.0	
Aromatics					25.0	
Ammonia					740.0	
Steel	4.5	6.2	252	355	1,513.6	2,131.2
Petroleum refining	4.7	7.7	262	475	7,619.9	14,176.3
All others	6.1	8.0	347	503		

1/ There is no present output of petro-chemicals. Our projection is based on data furnished by Empresa Nacional de Petroleo, (ENAP) interview with Estanislao Fabres, engineer.

water use so reported (see discussion of projections) fell within the
range of coefficients given in studies prepared by the National Association
of Manufactures and the United Nations.[1]

Information given by the sugar refining industry,[2] indicated that
CEPAL's estimate for "food"--a two digit class that included sugar re-
fining--was probably too low by a substantial amount. There were dif-
ferences between the figures reported to CEPAL and to us for steel, pulp
and paper, and petroleum, as well, but these were differences of 10 - 15
percent, small enough to be explained by the passage of time, inaccuracies
of measurements, or source of information within the industry. In the case
of food, however, the discrepancy was much greater. CEPAL estimated 1957
water intake as 2.5 million M^3, whereas the water use coefficient for the
refining of sugar beets indicated that for sugar refining alone, after
adding the refining of cane sugar, water use amounted to 8.4 million M^3.

Since the coefficients of water use for the four industries about
which we had direct information corresponded with experience in the United
States, it seemed reasonable to use a U.S. coefficient when no other was
available. This procedure was barred, however, by the absence of data
on production measured in physical units. Barred also was the possibility
of using a U.S. water coefficient per unit of labor by the fact that the
ratio of productivity of Chilean workers to U.S. workers was probably
different from the ratio of the respective water inputs per unit of product.

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[1] NAM, Water in Industry, December 1950, N.Y.
UN, Water for Industrial Use, Department of Economic and Social
Affairs, New York, 1958.

[2] Ltr. from Enzo Meschi, Chief Department of Research, Industria
Azucarera Nacional, S.A., April 21, 1965.

Also, we had no reason to expect that physical product per unit of value added would be the same in both countries (after establishing a parity between US$ 1954 value added and Chilean E° 1957 value added).

The problem was especially important for foods and beverages, since these are highly polluting as well as water using industries. The only component of the food and beverage industries in Chile for which we could get an estimate of water use was the refining of sugar beets. An official of Industria Azucarera Nacional, S.A.[1] estimated that the rate of water use was 1.5 liters per second per ton of sugar per day of operation. IANSA's refineries are in continuous operation for five months a year; water intake for the five-month year in 1957 was 3.2 million M^3. In that year sugar refined from cane amounted to 158,200 tons, and from beets 24,200 tons. (Today the output of beet sugar is much higher, and has grown relative to cane.) We had no water use data for cane sugar. Using the 1954 U.S. co-efficient for cane sugar yielded 34.4 M^3 per ton or 5,400,000 M^3 per year. Thus, estimated partly from IANSA data and partly from the U.S. coefficient for cane sugar, the result was 8.6 million M^3 per year. When we estimated Chilean water use by the value added method (see below) our answer was 7,500,000 M^3. The figure for IANSA's water use, 3,200,000 M^3, exceeded by 700,000 M^3 the estimate made by CEPAL for the food category as a whole.

From the four industries in Chile for which we had physical output and water input data we concluded that in the absence of direct information on water use we might be able to make a reasonably good estimate by using U.S. industry coefficients per unit of value added after establishing a monetary equivalence. A rate of parity, albeit subject to various infirmities, was suggested by the CEPAL study of Latin American price

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[1] Letter from Enzo Meschi, op. cit.

levels.[1] Purchasing power parity of $1.05 for one escudo, as of June 1962, was established on the basis of a low-income consumer market basket priced in Santiago, representing Chile, and Los Angeles and Houston representing the United States. At that date the official rate was $0.95 for one escudo. We therefore adjusted U.S. 1954 values added to 1962 prices, Chilean 1957 values added to 1962 prices, converted from escudos to dollars at the rate of $1.05 per escudo, applied U.S. water intake coefficients per $1 of U.S. value added to Chilean value added and emerged with the following, for the four industries for which we had water intake data:

Water Intake, Selected Industries, Chile, 1957
(millions of M^3)

	Computed from Value Added	Computed from Reported Coefficients
Pulp and paper	13.8	13.3
Steel	114.6	75.1
Petroleum refining	41.3	30.9
Sugar (including cane)	7.5	8.6
TOTAL	177.2	127.9

The agreement in pulp and paper as well as sugar was quite good. Since part of the reported sugar coefficient--that pertaining to cane sugar--was based on the U.S. coefficient, sugar could not be used to verify the value added method of computation. The results of steel and petroleum refining were quite poor. If we could explain this lack of correspondence, we could make a further adjustment that would permit us to use the U.S. coefficient of water use per unit of value added to estimate Chilean water use from Chilean value added.

Several reasons could explain the disparity between reported water

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[1] "A Measurement of Price Levels and the Purchasing Power of Currencies in Latin America, 1960-1962," Economic Commission for Latin America, E/CN.12/653, 1963, mimeo, page 149.

intake and that estimated from value added. First, as noted above, physical output per unit of value added might be different in the two countries. Second, we might have used an inaccurate parity exchange rate. Third, there might be differences in rates of recirculation that would affect intake per unit of output. Fourth, there might be differences in production methods, apart from recirculation, that resulted in different amounts of water used per unit of product.

We could readily ascertain that physical output per unit of value added, was, in fact, different in the two countries, assuming that the parity of $1.05 per escudo, after adjusting both prices to 1962 levels, was correct. (If it was not, we had no other source of information for a better parity.) Tons of product per dollar's worth of value added in the two countries compared as follows:

	Tons of Product per $1 of Value Added [1]		
	US (1954)	Chile (1957)	US/Chile
Pulp and paper	.010	.008	1.25
Steel	.018	.008	2.25
Petroleum refining	.195	.062	3.15
Sugar	.024	.031	0.77

If intake per physical unit of output was the same in both countries the U.S. coefficient would overstate Chilean water use in three industries. The overstatement would be greatest for steel and petroleum refining. A possible offset of such overstatement would be the difference in recirculation rates, assuming that recirculation was greater in the United States than in Chile. The only information available on recirculation was an estimate by ENAP's petroleum refinery that water intake during the four months of low flow on the Aconcagua River was reduced to one-tenth normal

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[1] Ignores quality and product mix within the specified industry class.

intake, the balance being made up by recirculation. If intake in a "normal" month is 1, total intake for the year would be 8.4 to supply needs, without recirculation, of 12. The ratio of water intake in the absence of recirculation to water intake with recirculation, therefore, would be 1.4. For the U.S. the same ratio was 3.3. We could correct the "value added" estimate by dividing by the ratio of U.S. to Chilean output per dollar of value added (or multiplying by the reciprocal) and multiplying by the ratio of U.S. to Chilean rates of recirculation, i.e.

$$41.3 \times \frac{.062}{.195} \times \frac{3.3}{1.4} = 30.8 \text{ million M}^3$$

or a figure almost identical with what was reported directly. The result may indicate that we have correctly accounted for all variables or may have only accumulated several offsetting errors. The method has obvious limitations, because if we solve for the Chilean rate of recirculation for steel, we get a value of .88, which is impossible.[1] However, it is only 12 percent away from one, which is correct. For pulp and paper the Chilean inferred rate of recirculation rate is 2, and for sugar refining the rate is 1.1, computed by solving for the Chilean rate of recirculation in the above equation. (Direct information on recirculation rates was not available.)

If we accept the findings for petroleum refining, we can conclude that there is a relationship between the results obtained by multiplying the 1954 U.S. coefficient of water use per U.S. dollar of value added

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[1] The "rate of recirculation" is computed in this instance as equal to the total amount of water taken in in the absence of any recirculation divided by the amount of intake. In the absence of recirculation the "rate" is equal to 1.

(adjusted to 1962 prices) by 1957 Chilean value added, (adjusted to 1962
dollars) and that the estimate will deviate from reality by (1) the
variation in output per $1 value added between U.S. and Chile, (2) the
respective rates of recirculation, (3) unexplained factor or factors. If
we assume that industry in general reflects the relationships revealed
by averaging our findings for pulp and paper, steel, petroleum refining,
and sugar (and we have no information that will support or contradict such
hypothesis), we can estimate Chilean water intake by applying a U.S. water
use coefficient to Chilean value added, reducing downward the results by
38 percent to correspond to the average overstatement revealed by the
four industries about which we have data. This then, is what we did. The
results are shown in Table VIII-6. In the aggregate the difference between
CEPAL's and our estimate is on the order of 10 percent, although in a number
of particular industries the disparity is much greater. The effect of the
differences in estimates is magnified several times if pollution is taken
into account. Rates of water intake per unit of value added for 1957 were
assumed to prevail in 1985.

Because recirculation can increase, intake is an unsatisfactory
measure of water requirements. Furthermore, for a basin as a whole intake
overstates total requirements. We therefore need to know how much water is
lost. Since we have no Chilean data on the rate of loss per unit of output,
we had to adapt to Chilean conditions coefficients based on United States
experience.

The relationship between intake and loss as given by U.S. Census data
was adjusted to reflect the difference between the U.S. rate of recircula-
tion and the estimated Chilean rate of recirculation. The loss rates per
unit of intake that were used for Chile are shown along with the U.S. loss

TABLE VIII - 5

MANUFACTURING: TOTAL INCOME AND VALUE ADDED, CHILE, 1957

(E° 1,000)

Industry	Income [a]	Value Added [a]
Food	167,272	54,939
Beverages	22,682	13,709
Tobacco	18,591	16,327
Textiles	75,490	40,198
Shoes & Clothing	50,010	23,642
Wood Products & Furniture	26,071	14,465
Paper & Paper Products	18,951	5,740
Printing & Publishing	17,156	11,171
Hides & Leather	9,973	3,814
Rubber Products	8,333	3,765
Chemicals	48,436	23,763
Petroleum Refining & Coal Products	23,343	9,643
Cement, Clay, Glass, etc.	28,316	15,858
Basic Metals	58,025	33,016
Machinery & Miscel.	55,217	33,348
TOTAL	627,866	303,398

a/ Rounded

Source: III Censo Nacional de Manufacturas

Table VIII-6

MANUFACTURING: WATER INTAKE 1957

(In millions of m^3 yearly)

Province	Food and beverages	Pulp a/	Paper a/	Chemicals b/	Petroleum refining c/	Steel	All Others d/	Total
Tarapacá	.2	-	-	.6	. -	-	-	.8
Antofagasta	.2	-	-	2.6	-	-	-	2.8
Atacama	-	-	-	-	-	-	-	-
Coquimbo	.3	-	-	.6	-	-	.2	1.1
Aconcagua	.3	-	-	-	-	-	.2	.5
Valparaíso	3.7	.1	-	5.2	15.4	-	4.1	28.5
Santiago	6.1	3.1	2.1	20.3	-	3.8	15.4	50.8
O'Higgins	.9	-	-	.3	-	-	-	1.2
Colchagua	.2	-	-	-	-	-	.2	.4
Curicó	.2	-	-	-	-	-	-	.2
Talca	.7	.2	-	.6	-	-	.2	1.7
Maule	-	-	-	-	-	-	-	-
Linares	.2	-	-	-	-	-	-	.2
Ñuble	.2	-	-	-	-	-	-	.2
Concepción	1.0	2.8	3.9	1.6	-	71.3	2.6	83.2
Arauco	-	-	-	-	-	-	-	-
Bío-Bío	.3	-	-	-	-	-	-	.3
Malleco	.3	-	-	-	-	-	-	.3
Cautín	.3	-	-	-	-	-	.2	.5
Valdivia	.7	.6	.5	-	-	-	.5	2.3
Osorno	.7	-	-	-	-	-	-	.7
Llanquihue	.3	-	-	-	-	-	-	.3
Chiloé	-	-	-	-	-	-	-	-
Aysén	-	-	-	-	-	-	-	-
Magallanes	.2	-	-	-	-	-	-	.2
Total	17.0	6.8	6.5	31.8	15.4	75.1	23.6	176.2

a/ For pulp and paper we used the 1958 provincial distribution of output, as reported by FAO-CEPAL's study, "El Papel y la Celulosa en América Latina", Revision No. 1 (New York, 1962).

b/ Intake in Aconcagua, Ñuble, Bío-Bío, Cautín, Valdivia, Osorno, Llanquihue and Magallanes is estimated to add up to .5 million m^3.

c/ Intake of ocean water at Concón was estimated in 15.5 million m^3.

d/ Intake in all the other provinces adds up to .4 million m^3.

rates, both expressed as a percent of intake in Table VIII-7.

Although we probably overestimate intake in 1985 by using the same intake coefficient as prevails today,[1] we do not necessarily overestimate loss--at least relative to U.S. experience. Our ignorance of what will happen to loss rates (and dilution requirements) per unit of product as the rate of recirculation rises is no more profound for Chile than it is for the United States.

Table VIII-8 shows both intake and loss rates per unit of output that we adopted for Chile. A change in the Chilean rate of recirculation that would lead to a change in intake per unit would not automatically imply a change in loss rate per unit of output.

We face a choice in the way in which losses are to be measured. If all plants recirculate water to the maximum degree practicable, total losses for a river basin (or province) are equal to the aggregate of losses sustained by all plants within the basin. If no plant adopts recirculation techniques, total losses for the basin are equal to losses sustained by upstream plants plus the fresh water intake of plants whose wastes are discharged into estuarine or coastal waters. Since there is relatively little recirculation of water by Chilean manufacturers today, and since the acquisition of recirculation machinery adds to total capital and foreign exchange requirements, recirculation techniques may not be adopted unless compelled by absolute necessity. Because of this uncertainty we have computed losses in two ways: (1) as the sum of losses of upstream plants plus intake of coastal (downstream) plants; (2) as the sum of losses of all plants.

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[1] For steel we used the coefficient estimated for 1970.

Table VIII - 7

LOSS AS PERCENT OF INTAKE

	U.S.	Correction Factor [1]	Chile
Food and Beverages	11	1.8	6
Pulp and Paper	11	1.2	9
Chemicals	12	1.8	7
Petro-Chemicals	4	1.8	2
Petrol. Refining	9	2.4	4
Steel	4	1.3	3
All Others	13	1.8	7

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[1]   Correction factor: Recirculation Rate in U.S./Recirculation
       rate in Chile. "Recirculation rate" is equal to estimated
       intake in absence of recirculation divided by actual intake.
       U.S. loss (as a percent of intake) is multiplied by correc-
       tion factor to yield Chilean loss as a percent of Chilean
       intake.

Table VIII-8

MANUFACTURING: RATES OF WATER USE PER UNIT OF OUTPUT, CHILE

Industry	Unit	Water intake per unit (m^3)	Losses per unit (m^3)
Food	Value Added [1]	.13	.01
Pulp	ton	272.6	24.5
Paper	ton	95.7	8.6
Chemicals	Value added [1]	.69	.05
Petro chemicals:			
Ethylene	ton	1,051.2	21.0
Aromatics	ton	1,576.8	31.5
Ammonia	ton	45.1	.9
Petroleum refining	M^3	26.6	1.1
Steel	ton	94.6	2.8
All Others	Value Added [1]	.08	0.01

[1] Value added computed in escudos of 1962.

Output was distributed between downstream and upstream locations for all manufacturing groups except foods and beverages by classifying each province on an all-or-none basis as inland or coastal. This could be done because most manufacturing activity can be assigned to a single city or small region in each province, and an all-or-none classification introduces little additional error relative to the uncertainties that are already a part of the projections. In the case of food processing, however, the industry is diffuse and numerous and tends to be distributed in the same pattern as population. For this reason food manufacturing was distributed in proportion to the estimated distribution of urban population between coastal and inland cities. Table II-1 shows the all-or-none and percentage distributions that were used.

The results of these estimates are summarized in Table VIII-9 for 1985. Loss I is computed on the assumption that seaside plants do not recirculate and that all intake is discharged into salt water. Loss II assumes that only evaporation, transpiration, and water incorporated into the product has to be taken into account in downstream plants as well as upstream. This assumes, in turn that either there is complete plant recirculation or that all waste discharge is captured for other uses. Only one intake rate is given. One can, however, assume that the theoretical limit to which intake falls as recirculation rises is given by the column headed Loss II. The theoretical limit is not likely to be reached since process water is usually purged after it has reached a certain level of contamination.

Table VIII-9 shows the very large estimated effect on requirements that result from failure to adopt maximum recirculation efforts at coastal points of intake. The industrial region around the cities of Valparaíso

and Concepción can reduce their intake of fresh water by a magnitude that approaches 95 percent, if we can judge by the relationship between intake under present conditions of recirculation and estimated evaporation losses. Detailed tables for the Medium B projection are in the appendix.

Substitution of saline water for fresh water for cooling, washing, and waste disposal would not materially reduce losses of fresh water computed as Loss II, but would, of course, have an absolute effect equal to the amount of fresh water displaced under Loss I. Loss II, therefore, is also indicative of minimum fresh water requirements where there is maximum use of salt water.

Table VIII-9

MANUFACTURING: INTAKE AND LOSSES I AND II, 1985, MEDIUM A AND B

(In thousands m^3/yr)

Province	Medium A			Medium B		
	Intake	Loss I a/	Loss II b/	Intake	Loss I a/	Loss II b/
Tarapacá	2,000	1,955	136	3,300	3,232	225
Antofagasta	7,000	6,842	486	11,400	11,163	792
Atacama	-	-	-	-	-	-
Coquimbo	3,700	3,277	250	5,700	5,136	387
Aconcagua	2,100	163	138	3,000	232	198
Valparaíso	141,800	139,036	6,203	211,500	210,534	9,610
Santiago	235,100	14,518	14,217	374,400	22,564	22,164
O'Higgins	3,000	188	188	4,400	278	278
Colchagua	1,800	140	121	2,400	185	162
Curicó	400	28	24	600	42	36
Talca	6,200	446	446	9,000	648	648
Maule	24,900	24,900	2,241	32,000	32,000	2,880
Linares	400	24	24	600	36	36
Ñuble	500	35	30	600	42	36
Concepción	331,500	331,348	11,625	444,200	444,003	16,312
Arauco	25,000	25,000	2,250	32,000	32,000	2,880
Bío-Bío	113,000	10,143	10,143	149,100	13,383	13,383
Malleco	900	54	54	1,100	66	66
Cautín	2,200	162	145	3,000	221	198
Valdivia	7,500	6,789	571	10,400	9,452	792
Osorno	1,800	108	108	2,400	144	144
Llanquihue	900	646	54	1,200	862	72
Chiloé	-	-	-	-	-	-
Aysén	-	-	-	-	-	-
Magallanes	33,800	33,800	692	34,000	34,000	704
Total provinces	945,500	599,602	50,146	1,336,300	820,223	72,003

a/ Loss I, manufacturing losses computed on the assumption that downstream plants do not recirculate and all downstream intake is lost.

b/ Loss II, manufacturing losses computed on the assumption that there is complete recirculation in downstream plants.

Chapter IX

MUNCIPAL WATER USE

Municipal water requirements are treated as a homogeneous use although they are composed of several separate elements: household, commercial, light manufacturing, civic and sanitary. The usual method of estimating municipal requirement is to start with a historical per capita figure for each class of use, project the trend, compute total requirements by multiplying by expected urban population and sum up the results. There are a number of obstacles to the pursuit of such method in Chile, yet no other is likely to yield better results.

Data on current use of water per capita from municipal systems are inexact because the number of people in each community served by the water system is not known.[1] Projections for the future cannot be made on the basis of current quantities being used because of the restrictions imposed on users in "almost all of the large services." Also, "it has been statistically impossible to distinguish with precision the domestic use of water from other municipal uses."

CEPAL estimated that municipal water use was distributed as follows: domestic, 40 percent; industrial, 10 percent and public services 20 percent. The destination of the remaining 30 percent is not known, although it is suspected to be mostly leakage.[2]

Organization of Municipal Supply

Domestic water supply in Chile is the responsibility of the Dirección de Obras Sanitarias of the Ministerio de Obras Públicas for all communities except Santiago, Antofagasta and a few coastal and mining towns, which

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1/ Hansen, op. cit. p. 47

2/ CEPAL, p. 59-60

have their own systems. The rate schedule used by Obras Sanitarias is uniform for the entire country except for two groups of coastal communities, one of which pays a higher and the other a lower rate than the country-wide schedule. Several of the coastal cities that pay lower than average rates are in the far North: Pisagua, Iquique, Tocopilla, and Taltal. Water is metered and consumption beyond a stipulated quantity is subject to a progressive rate schedule that becomes constant after the second jump in unit price.

According to Chilean law the rates charged water users are supposed to be fixed to cover all costs including an "adequate" return to capital.[1] CEPAL concluded that in 1958 the "situation was very far from this objective," that rates did not cover a quarter of estimated costs, and that the deficiency in income was equivalent to the cost of supplying municipal water to 500,000 people annually.

The deficiency in income today is apparently much greater. On the basis of an "average" Chilean household water bill,[2] the charge per cubic meter in 1965 was about three and a half times the charge computed by CEPAL for 1958 (about 53 pesos per M^3 in 1965; about 15 pesos per M^3 in 1958), an increase that falls short of the change in the consumer cost index (dominated by prices subject to control) by about 30 percent.[3]

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[1] CEPAL, p. 64.

[2] Based on the basic rate schedule of 30 M^3 for 760 pesos, plus another 30 M^3 at 40 pesos per cubic meter, plus 80 pesos per M^3 for the remainder, computed bi-monthly, and assuming 35 M^3 per person per day.

[3] One thousand pesos equals one escudo. The 1965 price is about US $ 0.05 per 1,000 gallons.

Varying estimates can be found of the present deficiency in domestic water supply CEPAL, (p. 59), estimated that 3,200,000 people or 44.5 percent of total population, had a public water supply in 1956. According to Hansen, (p. 56), 3,500,000 people in urban centers of 900 or more were served by public systems, but of this number 900,000 (or about 25 percent) were supplied by public spigots. Twenty-one percent of urban residents lacked any type of service, and only six percent of rural population (centers of less than 900 people) were served.

A background report of Dirección de Planeamiento of the Ministerio de Obras Públicas[1] showed that 56 percent of dwellings in the country as a whole were supplied with plumbing in 1960. The highest percentage was in Santiago, with 81 percent; the lowest was in Chiloé with 9.7 percent. Current per capita water use supplied by municipal systems is relatively low. For the country as a whole Hansen quotes an estimate of 262 liters/per capita/per day. This can be compared with a per capita use of 480 liters per day in the United States in 1950.[2]

The rapid growth of urban population, the pressure of sanitary needs, and the programs of the Alliance for Progress, WHO, and other international agencies will contribute to a rapid increase in domestic water use. Under legislation now in force in Chile all urban centers of 1,000 and more are to have a public water system which "is equivalent

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[1] Antecedentes para el Planeamiento Provincial de Obras Publicas, Vol. I, Generales e Inversiones, Oct. 1963.

[2] Hansen, pp. 46, 47.

to supplying practically the total urban population of the country."[1]
The decennial plan of the Dirección de Obras Sanitarias calls for
extending new facilities to 26,100 inhabitants located in centers of
less than 1,000 inhabitants.

From the point of view of water use the extension of facilities
to relatively small communities poses no significant problem. There
still remain the questions of the minimum size that a community can
be and still be given a public supply system and what type of service
should be rendered. These are important questions relative to the
allocation of capital funds even if unimportant relative to water per se.
They are, however, outside the scope of this study.

Projected Municipal Intake and Loss

Municipal water intake was estimated as a function of urban population
and size of urban community.[2] A distinction was also made among broad
zones of the country. In common with estimates made by CEPAL and other
authorities, per capita use in the four northern provinces was assumed
to be less than in cities of the same size in the central zone, a
reflection of the inadequate capacity of municipal systems to meet the
demand for water. While this assumption mingles supply and demand forces,
the Centro de Investigaciones concluded that any other assumption would
be unrealistic for the period of the projection.

Estimated water use for domestic purposes by rural inhabitants is
also given. This category covers communities below 1,000 inhabitants as
well as isolated families.

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1/ Hansen, op. cit. p. 57; also memorandum of 18 Feb. 1965 of the
    Director of Obras Sanitarias to the Director de Planeamiento of the
    Ministry of Public Works. This memorandum states, in addition,
    that sewage systems are being provided for all cities of 5,000 or
    more.

2/ Estimates made by Centro de Investigaciones Económas, Universidad
    Católica de Chile

A distinction between upstream (inland) and downstream (coastal) users
(Table II-1) makes it possible to compute requirements for municipal
purposes as equal to upstream losses plus downstream intake. Losses are
assumed to be 20 percent of intake in all cities. Wherever downstream
waste discharge can be captured for industrial or agricultural use, the
downstream flow requirement can be computed with the use of downstream
municipal losses rather than intakes. All rural domestic intake was assumed
to be lost, whether upstream or downstream.

Table IX-1

MUNICIPAL INTAKE PER CAPITA PER DAY

(Liters)

Zone

	Group				
	I	II	III	IV	V
I.	150	200	250		
II	200	250	290	370	400
III	160	230	260	350	

Zone I	Tarapacá - Coquimbo
Zone II	Aconcagua - Linares
Zone III	Ñuble to the south

Group I	Cities up to 5,000 inhabitants
II	5,000 - 10,000 inhabitants
III	10,000 -100,000 "
IV	100,000 -500,000 "
V	Over 500,000 "

Rural domestic intake for all regions: 100 liters per capita per day.

Source: Centro de Investigaciones Económicas

Table IX - 2

L REQUIREMENTS, 1985 MEDIUM

(Thousands m³/yr)

n	Intake	Municipal losses	Downstream Rural domestic intake	Downstream Total intake	Total losses	Upstream losses plus down stream intake	Total Upstream and down stream losses
4	14,440	2,888	342	14,782	3,230	15,516	3,964
8	23,106	4,621	-	23,106	4,621	26,814	8,329
5	2,988	598	251	3,239	849	8,754	6,364
3	13,799	2,760	1,080	14,879	3,840	22,422	11,383
3	91,736	18,347	586	92,322	18,933	106,625	33,236
7	17,433	3,487	286	17,719	3,773	202,596	188,650
8	435	87	42	477	129	16,905	16,557
8	1,890	378	786	2,676	1,164	26,064	24,552
4	173	35	-	173	35	11,047	10,909
3	111,374	22,275	937	112,311	23,212	148,304	59,205
1	35,257	7,051	11,622	46,879	13,673	54,540	26,334
7	2,760	552	1,712	4,472	2,264	4,569	2,361
-	5,545	1,109	1,241	6,786	2,350	6,786	2,350
-	19,163	3,833	748	19,911	4,581	19,911	4,581
1	240,099	68,021	19,633	359,732	87,654	670,853	398,775
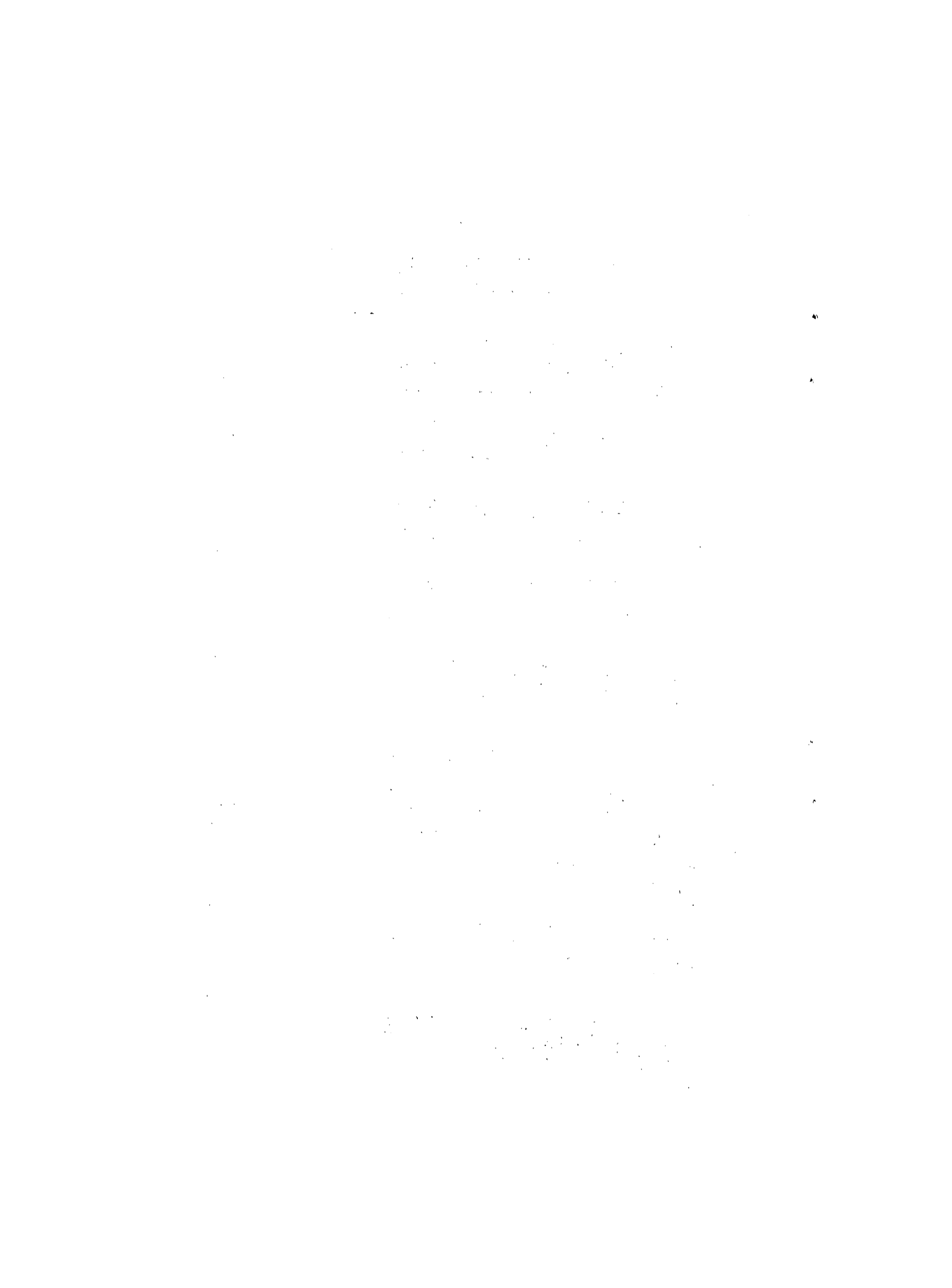
Chapter X

WASTE TREATMENT AND WASTE DILUTION

Data on pollution and water quality are particularly deficient. There is no information on volumes of waste produced, levels of treatment, effect of waste discharge on water quality, and effects, if any, of deterioration in water quality on subsequent uses.

The CEPAL report had this to say about pollution: "Currently the River Mapocho, because of large quantities of polluted water discharged from Santiago that go directly into the river, and the Rapel River, because of processing residues from the copper mine of El Teniente which are discharged into the Cachapoal, are contaminated or in danger of contamination, notwithstanding the works designed to avoid this objectionable state of affairs...The pulp mills under construction (San Rosendo) or that will be built on the Itata, Maule and Bío-Bío rivers will also be able to defile the waters."[1]

In addition to waste dilution there is a requirement in many communities for a flow of water to flush the sewers. Some of the newer sewage systems have enough slope to eliminate the need for "washing" the sewers, but most, apparently, require either intermittent or continuous flushing. Most cities possess water rights for flushing. According to Hansen the rights are usually for quantities in excess of needs: as sewage systems are improved or replaced the need for flushing will be reduced or eliminated. Flushing now represents a relatively small demand for water in each province, except for the city of Santiago. CEPAL stated that only eleven cities, all relatively small, had sewage treatment plants. (In 1965 Santiago was still without a treatment plant). No information was available on the quality of coastal and estuarine waters. Except for

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[1] Op. cit. p. 100.

the siltation of shell fishery beds in the south, as a result of the 1960 earthquake, there was no information on the possible threat to coastal fisheries by pollution.

If the requirement for water is measured by loss to the atmosphere or incorporation in the product, it is implicitly assumed that recirculation can proceed indefinitely. The question still unsettled is the quality of intake water as each user discharges waste into the stream. In lieu of the exact knowledge acquired by routing water down the stream we shall assume that if the dissolved oxygen content of water in the river does not fall below a designated minimum after mixing with the decomposable organic matter discharged by cities and industrial users, the river will serve the usual range of purposes without exceptionally high costs of treatment or aesthetic offense. A commonly used standard is a dissolved oxygen content of four milligrams per liter of water. [1]

In computing waste dilution requirements it was assumed that if the outfall of waste was "downstream" no dilution was required. By failing to provide dilution water for waste discharged along the coast or in estuarine waters we implicitly assumed that coastal marine habitat would not suffer nor would beaches used for recreation be adversely affected. We have no information on the validity of this assumption.

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[1] The choice of 4 mg/l of dissolved oxygen as a standard of water quality does not rest upon knowledge that DO is a critical factor in the quality of Chilean waters or that DO is a satisfactory proxy in Chile for other qualitative characteristics. It has been adopted for this report because we shall make estimates of organic pollution -- municipal and industrial -- and required waste dilutions based upon United States coefficients. Our discussion of water quality is limited to organic pollution in the absence of information regarding other pollutants. There is a salinity problem (but we do not know how much is natural and how much man-made, or how serious it is) as well as pollution by coliform bacteria, about which data also incomplete.

In order to estimate what might happen in 1985 we used coefficients
originally prepared for the Central Pacific region of the United States.[1]
Dilution requirements were computed over a range of treatment levels
extending from zero to 90 percent removal of biochemical oxygen demanding
(BOD) substances. According to Reid's formulas, dilution flows are linearly
related to the quantity of waste discharged, given a desired level of dis-
solved oxygen in the stream after mixing with the waste. The dilution needed
for waste that has had half its BOD removed (50 percent treatment) is
twice the dilution needed for 75 percent treatment and half the quantity
for no treatment. Among the possible sources of error in translating
Central Pacific conditions to Chile is the fact that dilution flows
for the former are computed for summer low flows, when temperatures are
high and velocities low, conditions under which the natural oxygenation
capacity of the river is at its lowest point within the year. The degree
to which the reoxygenation capacity, and therefore the waste assimilation
capacity, of Chilean rivers behaves in corresponding fashion is not
known. For example, if high temperatures are accompanied in Chile by
peaks rather than troughs of flow and turbulence, as is the case in certain
basins, dilution flows based upon U.S. experience will overstate Chilean
requirements. Another possible source of overstatement is the fact that
the gradient of most Chilean rivers is relatively steep, contributing
to a relatively high average velocity. Furthermore, Reid's estimates are

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[1] Estimates of waste produced and dilution requirements for various levels
of treatment were taken from "Water Requirements for Pollution Abatement,"
by George Reid, Water Resources Activities in the United States, Committee
Print #29, U.S. Senate Select Committee on National Water Resources,
Washington 1960, as adapted by N. Wollman, Water Supply and Demand, manu-
script in preparation for Resources for the Future, Inc. The Central
Pacific region was selected because it resembles Chile more than any
other region of the United States.

subject to an unknown range of error for rivers of the United States.
His method of estimation is based upon the assumption that the discharge
of waste along the river is proportional to the gradual increase in flow
from headwaters to mouth, an assumption contrary to the point loading
that is actually encountered. We cannot emphasize too strongly that
our estimates of dilution requirements can be accepted only as a starting
point for the necessary investigations that must be undertaken in Chile.

Reid concluded that treatment levels in excess of 90 percent would
contribute nitrogen and phosphorus to the rivers of the Central Pacific
region in such quantity that algal blooms would create a secondary demand
for oxygen and lead to an increase, rather than reduction, in dilution
water requirements. Even at 90 percent the effect of plant nutrients
is visible in his estimates, since requirements at 90 percent treatment
are somewhat in excess of half the amount shown for 80 percent. Whether
Chilean rivers would respond in the same way to high levels of waste
treatment is another question that must be settled specifically for Chile.[1]
Another source of possible error is the fact that we make no distinction
among rivers in various parts of Chile. In the North, some of the rivers
appear to behave as trickling filters, whereas in the south rivers carry
large volumes of water, are much deeper, and seem to move more slowly.

In estimating Chilean waste dilution flows the same relationships
were maintained between industrial intake water and pollution that was
estimated for 1980 for the Central Pacific region, after adjusting for
estimated differences in intake per unit of output. Thus, in the Central
Pacific region 1980 water intake for food and beverages was estimated

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[1] There is, also, the possibility of adopting treatment techniques,
about which little is known at the level of practical operation, that
would remove plant nutrients from waste liquor and eliminate the need
for their dilution.

at 277 millions of gallons per day (MGD) and P.E.'s as 13.8 per day.[1]
Converting 277 MGD to millions of cubic meters per year and multiplying
by 1.8 to correct for less recirculation in Chile gave 2 P.E.'s per day
per 100 million cubic meters of intake water per year. By applying
this coefficient to Chile we implicitly adopted the Central Pacific mix of
the food processing industry--more accurately, the same waste-producing
mix per unit of intake water. Since we had no way of making distinctions
among the various sub-groups of the food industry according to their
capacity to produce waste, we could follow no other course.[2] In the same
way we estimated the output of P.E.'s for pulp and paper and chemicals.

Petroleum refining wastes were handled differently because of the
problem introduced by extensive use of salt water for cooling. Accordingly,
we used Reid's implicit estimate for the United States of 4.4 P.E.'s per
day for an annual output in 1954 of 403.1 million cubic meters of crude
runs to stills, or .011 P.E.'s per day per million cubic meters of output.
This figure was then applied to the estimated Chilean production.

To summarize: We estimated pollution produced as a function of
intake, after adjusting U.S. intake to correspond with estimated Chilean
recirculation rates. We then estimated dilution flow as a function of
P.E.'s discharged into rivers after treatment, after subtracting waste
that was discharged directly into coastal waters. All pollution was
measured in "population equivalents."

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[1] "Population equivalents," a measure of industrial waste, in millions
     of units when in capital letters. One unit (p.e.) is the quantity of
     "oxygen required to completely reduce the organic oxygen demanding
     wastes of one population equivalent", Reid, p. 9.

[2] The same problem applies to the estimates of pollution in the various
     regions of the United States, since the "food industry" was conceived
     to be homogenous throughout the country for the purpose of estimating
     gross pollution.

By adopting a standard of instream water quality as 4 mg/1 of dissolved oxygen, we implicitly assumed that other pollutants would also be adequately diluted to render unnecessary special costs of treating intake water. There may be, of course, special cases in which this assumption might not hold.

Table X-1 shows the coefficients taken from the Central Pacific region of the United States, the special computation of waste load from petroleum refining, and the dilution requirements, expressed in millions of cubic meters per year per one million population equivalent discharged per day into the stream.

Using the coefficients of Table X-1 we estimated P.E.'s produced in each province, subtracted P.E.'s discharged downstream (i.e. into brackish or salt water) and computed dilution requirements as a function of the level of treatment. Waste dilution flows are shown in Table X-2 for the projection of manufacturing output based upon the higher, 5.5 percent, rate of growth. Manufacturing waste dilution requirements for the lower rate of growth would be about 28 percent lower. Since only manufacturing flows are affected by changing the assumed rate of growth in GNP,[1] the difference in total required flows, municipal as well as industrial, between the low and high rates of growth is only 6 1/2 percent. (See Appendix for summary of Medium A plus municipal flows and P.E.'s produced and discharged.)

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[1] This assumption is most likely to be wrong, since the ratio of urban to rural population is likely to be related to the rate of economic growth.

Table X - 1

ADAPTATION OF CENTRAL PACIFIC COEFFICIENTS TO CHILE

	Central Pacific U.S.A., 1980		Adjusted to Chilean conditions		P.E.'s produced per day per 100 million m³/yr. of intake	Million m³ of petroleum refined	P.E.'s produced per day per million m³ of petroleum refined
	P.E.'s produced per day	Water intake (MGD)	Factor to correct for less recirc. correction	Million M³ after correction			
Food	13.8	277	1.8	689	2.00		
Pulp and paper	.8	73	1.2	121	.66		
Chemicals	4.4	442	1.8	1,098	.40		
Petroleum refined	.4	394	2.4	1,305	.03		
Petroleum refined (U.S.)							
Municipal a/	4.4					403.1	.011

Dilution requirements per P.E. produced per day Central Pacific, 4/mg/1 of D.O.

Dilution

Level of treatment (percentage)	MGD b/	Million M³/yr
0	2,300	3,179.2
35	1,500	2,073.2
70	690	952.7
80	450	620.5
90 c/	275	379.6

Table X-2

WASTE DILUTION REQUIREMENTS, 1985, MEDIUM B, 4 mg/lt. DO

(Millions m³/yr.)

Province	Zero			35 percent			70 percent			80 percent			90 percent		
	Muni-cipal	Mfg.	Total	Muni-cipal	Mfg.	Total	Muni-cipal	Mfg.	Total	Muni-cipal	Mfg.	Total	Muni-cipal	Mfg.	Total
Tarapacá	86	3	89	56	2	58	26	1	27	17	1	18	10	a/	11
Antofagasta	595	16	610	388	10	398	178	5	183	116	3	119	71	2	73
Atacama	505		505	330		330	151		151	99		99	60		60
Coquimbo	553	38	591	361	25	386	166	11	177	108	7	115	66	5	71
Aconcagua-Valparaíso	1,389	321	1,710	906	209	1,115	416	96	513	271	63	334	165	38	204
Santiago	15,305	2,938	18,242	9,980	1,916	11,896	4,586	880	5,467	2,987	573	3,560	1,827	351	2,178
O'Higgins-Colchagua	1,262	248	1,510	823	162	985	378	74	453	246	48	294	151	30	180
Curicó-Linares	1,488	308	1,796	970	201	1,171	446	92	538	290	60	350	178	37	214
Ñuble	750	38	788	489	25	514	225	11	236	146	7	153	90	5	94
Concepción-Cautín	2,124	3,338	5,462	1,385	2,177	3,562	636	1,000	1,637	414	652	1,066	254	399	652
Valdivia-Llanquihue	938	238	1,176	612	155	767	281	71	353	183	47	230	112	28	140
Chiloé	22		22	15		15	7		7	4		4	3		3
Aysén	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Magallanes	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
TOTAL	25,017	7,487	32,504	16,314	4,882	21,196	7,497	2,244	9,740	4,883	1,461	6,344	2,987	894	3,881

a/ Less than 500,000 m³ per year.

Disparities in totals are due to rounding.

X - 8

Table X-2 reveals that estimated flows are divided roughly in the ratio of 3 1/2 for municipal to one for industrial requirements.[1] Dilution flows for the projected population and industrial output would be about 33 billion M^3/year in the absence of treatment, about 21 billion M^3/year if primary treatment is provided, about 10 billion M^3/year if secondary treatment is provided, and about 4 billion M^3/year if treatment is carried to 90 percent removal of biochemical oxygen demanding substances. Should the stipulated oxygen level be higher or lower, required flows would be higher or lower, but not necessarily in direct proportion.

One province, Santiago, accounts for more than half of the total dilution flow, and most of the requirement is generated by municipal (rather than industrial) waste. Regions south of Santiago are also faced with the threat of quality deterioration but compared with Santiago the threat is almost inconsequential.

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[1] By contrast, projected requirements for the United States for 1980, medium growth rate, indicate a required flow of 1 1/2 for manufacturing to 1 for municipal waste dilution.

Chapter XI

TOTAL WATER REQUIREMENTS

We can now put together the projections of water requirements in industry, agriculture, mining, steam electric power, and general municipal use, and compare the results of alternative assumptions regarding rate of income growth and the form in which "water requirement" is expressed. We can, after examining the water supply, compare projected requirements with available runoff and see what shortages, if any, should be anticipated, which activities contribute most to the shortage, and whether the need to meet downstream requirements will provide adequate dilution flows. We can also see how much regulation of surface flow is implied in the projections, and whether a regional redistribution of activity can significantly lower projected costs of water. We can compare projected agricultural output in the absence of water constraints with water resources available, and determine by how much productivity per hectare [1] will have to be increased in order to meet, or at least come as close as possible, projected outputs. These matters will be discussed in this and succeeding chapters.

The reader must never lose sight of the fact that the empirical base on which all conclusions rest is a compound of meagre bits of information, frequently contradictory, tentative measurements, and boldly adopted assumptions usually involving the transposition of a technical coefficient from one context to another. We have no way of knowing what range of

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[1] Because we have assumed a considerable improvement over present practices in the use of water for agriculture, the main consumptive use, we do not expect that further economies in the use of water are likely to be achieved within the time horizon of this study.

error should be anticipated, not only because we deal with hypothetical conditions twenty years hence but because the error of measurement in the present cannot be established.

By water "requirements" we mean the amount of water of appropriate quality that must be available to a user whose output is included in the projections for 1985 and whose product requires a water input plus the water required for municipal systems. The amount of water required for a particular bill of goods and services depends upon the technology of water use that prevails. (Possible variations in technology that one might theoretically consider are considerable, and include variation in the degree of recirculation, substitution of dry processes for wet processes and other changes in technique of production, and variation in the intensity of waste recovery. Except for what has already been stipulated we do not consider these possibilities). To some degree changes in technology can take place without destroying the basis of our estimates. For example, an increase in the rate of recirculation practiced by up-stream non-agricultural users should have little effect on our estimates of evapotranspiration loss, since the amount of water consumed during each cycle is presumably about the same as is consumed on a once-through basis. Intake would change considerably, but loss very little if at all.

When we talk of a region's "water requirements" we mean the amount of water that must be flowing in the stream in order to meet intake require-ments of all users and at the same time satisfy instream uses. This is not an abstract idea if we know every point of use within a river basin and what relationships exist at any point among intake requirements, rate of flow, original quality, recoveries from previous users, quality changes

water treatment, and waste treatment.[1]   In the absence of such detailed
knowledge we have adopted the convention of a two-point region: an up-
stream point and a downstream point, between which all activity is divided.
All water discharged from an upstream user is presumed to be recoverable
for further use; water discharged from a downstream user is presumed to
be irrecoverable unless it is intercepted before it mingles with waters
of the estuary or sea.

In the formulation of alternative ways of measuring water requirements
the term "intake" refers to a diversion of water from the stream channel
to a separate hydraulic system such as a city water works, irrigation
project, power plant, or foundry. The term "loss" refers to the dis-
appearance of water to the atmosphere by evaporation, transpiration,
incorporation in the product, or wetting of the soil or penetration of
the sub-soil in such fashion as to be irrecoverable. "Discharge" refers
to waters turned back into a river or other receiving body of water after
use; the drainage of irrigation water is a comparable phenomenon, but is
usually described as "return flow" or "recovery of waters". The "loss"
of water for all uses except irrigation is usually measured by the
difference between intake and discharge. In the case of irrigation loss
it is equal to the difference between the amount of intake and the amount
recovered by drainage to surface channels or recoverable from recharged
aquifers. Fresh water that is discharged into brackish or salt water is
"lost" from the fresh water supply of a region, but in our discussion we
shall try to maintain the distinction between losses suffered within the
process of use and losses suffered by virtue of the place in which used

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1/ We assume that surface and ground water are interrelated and that
    we can speak of all water supply in terms of surface flow.

water was discharged. Both types of losses are subject to modification by variation in the technique of use or disposal.

Intake

Although the aggregation of intake requirements yields a figure that has little meaning, since it fails to account for the possibility that water can be used more than once, it is a common indicator of water use and will reveal, for a designated level of water supply, the implicit rate of basin-wide recirculation. Because of the relatively small differences revealed between projections A and B, (see last two columns in Table XI-1) we shall limit ourselves for the most part to the results of the higher rate of income growth.

The figures on offstream use show the dominance of irrigation.[1] Of a projected total intake of 50.5 billion M^3/year agriculture accounts for 45.9 billion M^3, or roughly 90 percent. Mining, which is Chile's main export industry, accounts for less than 1 percent. Roughly 3 percent each goes into manufacturing, municipal, and steam-electric power.[2]

The geographic distribution of projected requirements, which, of course, is only distantly related to the geographic distribution of water

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[1] The total of 45,907 million M^3/year for agriculture and livestock is divided into 45,759 million M^3/year for irrigation and 149 (rounded) million for livestock watering.

[2] By contrast, projected water use in the United States for 1980 shows agricultural withdrawals accounting for about thirty percent, steam-electric power accounting for almost one-half, roughly 15 percent for manufacturing, about 5 percent for municipal use, and about 1 percent for mining. Part of the difference between the two patterns of use is the result of the dominance of hydroelectric power in Chile.

Table XI-1

INTAKE (WITHDRAWALS): OFF-STREAM USES, 1985, MEDIUM B

(Millions m^3/yr.)

Province	Agriculture	Mining	Manuf.	Steam Elec.	Municipal	Total a/ Medium B	Total intake medium A
Tarapacá	371	1	3	1	17	394	392
Antofagasta	91	78	11	989	40	1,210	957
Atacama	588	166		12	23	790	693
Coquimbo	2,438	21	6	12	33	2,510	2,495
Aconcagua-Valparaíso	2,771	87	215	130	147	3,349	3,197
Santiago	6,112	19	374	78	886	7,470	7,324
O'Higgins-Colchagua	6,940	36	7	-	49	7,032	7,016
Curicó-Linares	11,772	-	42	2	70	11,887	11,876
Ñuble	3,546	-	1	-	25	3,571	3,571
Concepción-Cautín	11,214	-	629	13	203	12,059	11,902
Valdivia-Llanquihue	29	-	14	1	81	125	121
Chiloé	5	-		-	3	8	8
Aysén	8	b/	34	-	6	14	14
Magallanes	23	-	-	2	19	78	78
Total a/	45,907	409	1,336	1,239	1,603	50,495	49,644

a/ Discrepancies due to rounding.

b/ Less than 500,000 m^3/yr.

resources, is determined by two major forces:

(1) The availability of irrigable land;

(2) The pattern of population and non-agricultural activity.

We cannot render any judgment regarding the likelihood that water shortages will make impossible the production of projected outputs so long as we look at gross requirements, but we can see what is implied in the way of average rates of basin-wide recirculation. If we assume "full" regulation--i.e. flows are regulated to yield a steady flow equal to estimated average flow $\underline{1/}$-- and also assume that water is required in the same even manner, the implicit rate of basin-wide recirculation is as follows:

Tarapaca	-	4.6
Antofagasta	-	11.5
Atacama	-	3.4
Coquimbo	-	2.6
Aconcagua-Valparaíso	-	2.4
Santiago	-	2.2
O'Higgins-Colchagua	-	1.0

Elsewhere the rate is below one. Most of the implicit recirculation in these figures is attributable to agriculture. Only in Antofagasta does non-agricultural intake imply considerable reuse. In Atacama non-agricultural intake is approximately equal to average flow.

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$\underline{1/}$ Because of the likelihood that flow in a future period will not exactly repeat the experience of the period of record, "full" regulation is a hyperbolic phrase.

The significance of implicit basin-wide recirculation is in the relationship that might exist between repeated intake and discharge and change in water quality. If the cycle is attributable to agriculture, water is likely to become mineralized; if the cycle is attributable to domestic use, water will accumulate organic material and some salts as well; if the cycle is attributable to mining or manufacturing, water may accumulate a wide variety of organic and inorganic substances, depending on specific activities; if the cycle is attributable to steam-electric power, water can accumulate heat. Manufacturing uses can also add heat. Except for the estimates made regarding biochemical oxygen demand of industrial and municipal pollution we have ignored the obviously important question of whether projected uses will have serious qualitative effects.

Losses

If we assume that all water can be used until it is lost to the atmosphere or incorporated in the product (which implies that all discharged water can be recaptured for further use) the measure of loss is as given in Table XI-2. If we assume that certain downstream users or class of users discharge used water into estuaries or coastal waters, so that such water is no longer recoverable as "fresh" water, "losses" must be raised to account for such discharge. Under these latter circumstanc.s, the fresh water supply that is lost is equal to evaporation and transpiration losses, water incorporated into the product, and, for designated users or classes of users, gross intake or withdrawal of fresh water. Table XI-3 shows alternative estimates of losses when:

(1) all downstream municipal and agricultural intake is considered to be lost,

(2) all downstream intakes are considered to be lost.

Also, because of uncertainty regarding the estimates of mining water use, we have made an alternative computation on the assumption that all mining intake is lost.

The projected "requirement" for water can be framed either in terms of all losses, certain losses plus certain intakes, or certain losses and intakes plus waste dilution flows, depending upon options that a country may have regarding instream uses of water, recirculation, treatment at point of intake vs. treatment at point of discharge, and substitution of dilution flow by treatment or vice-versa. In particular instances some options may not be available because of limited supplies of water and constraints upon the expenditure of funds on water resources.

Table XI-2 shows what losses would be sustained on the assumption that no discharges took place into salt water. That is, losses of down-stream users, including agriculture, are computed as though they were upstream users (or as though all users recirculated their water until it disappeared.) Such an estimate of losses is, of course, an under-estimation in comparison with practices that are now current, but does reveal what might be considered a minimum water requirement for projected activity on the basis of production technology in use or readily available. These losses are estimated in all cases from coefficients derived from U.S. experience and therefore may be in error because of errors of trans-lation. It is likely that the errors are on the side of underestimation.[1]

The figures reveal that about 98-1/2 percent of losses so computed

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[1] Mainly because of the relatively inefficient canal system in Chile that would contribute to higher delivery losses of irrigation water.

Table XI - 2

LOSSES: OFF-STREAM USES, 1985, MEDIUM B

(Million M^3/year)

Province	Agriculture	Mining	Mfg.	Steam-elect.	Municipal	Total a/	Average supply
Tarapacá	242	b/	b/	b/	3	245	86
Antofagasta	59	12	1	4	8	84	105
Atacama	383	25	-	b/	5	413	229
Coquimbo	1,590	3	b/	b/	7	1,600	953
Aconcagua-Valparaíso	1,806	13	10	1	29	1,859	1,423
Santiago	3,983	3	22	b/	177	4,185	3,371
O'Higgins-Colchagua	4,522	5	b/	-	10	4,537	6,973
Curicó-Linares	7,672	-	4	b/	14	7,690	23,302
Ñuble	2,322	-	b/	-	5	2,327	6,749
Concepción-Cautín	7,344	-	33	b/	41	7,417	61,487
Valdivia-Llanquihue	29		1	b/	16	46	71,164

Sub-total average supply -- 176,203

Chiloé	5	-		-	1	6)	
Aysén	8	b/		-	1	9)	269,317 c/
Magallanes	23	-	1	b/	4	28)	
Total	29,989	61	72	5	320	30,446	

Note: In this table losses are limited to evaporation-transporation, disappearance
into the product, and irrecoverable ground water..

a/ Disparities due to rounding.

b/ Less than 500,000 M^3/year.

c/ Sum of flows in seven major rivers of three southern provinces (CEPAL, p. 31.)

Table XI-3

SUMMARY: ALTERNATIVE WAYS FOR COMPUTING FLOW REQUIREMENTS, 1985, MED. B

(Million M^3/year)

Province	Case I [a] Municipal and agriculture downstream intake plus all other losses	Case II [a] (Case I with mining intake instead of loss)	Case III Upstream losses All intakes down	Case IV Waste dilution at 90% treatment + losses
Tarpacá	311	312	328	256
Antofagasta	103	169	344	157
Atacama	439	580	493	473
Coquimbo	1,766	1,784	1,794	1,671
Aconcagua-Valparaíso	1,979	2,053	2,456	2,063
Santiago	4,240	4,287	4,254	6,363
O'Higgins-Colchagua	4,557	4,587	4,557	4,717
Curicó-Linares	7,946	7,946	7,977	7,904
Ñuble	2,333	2,333	2,333	2,421
Concepción-Cautín	7,591	7,591	8,150	8,069
Valdivia-Llanquihue	56	56	95	186
Chiloé	7	7	9	9
Aysén	11	11	15	9
Magallanes	28	28	79	28
Total	31,366	31,714	32,883	34,327

a/ Agricultural intake is the excess over municipal discharge.

Table XI-4

LOSSES PLUS WASTE DILUTION, 1985, MEDIUM B, MG/1

(Million M³/year)

Province	Losses only	Level of treatment				Average supply
		0%	35%	70%	90%	
Tarapacá	245	334	303	272	256	86
Antofagasta	84	694	482	267	157	105
Atacama	413	918	743	564	473	229
Coquimbo	1,600	2,191	1,986	1,777	1,671	953
Aconcagua-Valparaíso	1,859	3,569	2,974	2,372	2,063	1,423
Santiago	4,185	22,427	16,081	9,652	6,363	3,371
O'Higgins-Colchagua	4,537	6,047	5,522	4,990	4,717	6,973
Curicó-Linares	7,690	9,486	8,861	8,228	7,904	23,302
Ñuble	2,327	3,115	2,841	2,563	2,421	6,749
Concepción-Cautín	7,417	12,879	10,979	9,054	8,069	61,487
Valdivia-Llanquihue	46	1,222	813	399	186	71,164
Chiloé	6	28	21	13	9)	
Aysén	9	9	9	9	9)	269,317
Magallanes	28	28	28	28	28)	
Total	30,446	62,950	51,642	40,186	34,327	

are from irrigation; mining, manufacturing and steam electric power to-
gether account for about 1/2 percent and municipal losses for about 1
percent. In comparison, projected losses for 1980 in the United States
indicate that agriculture will account for 55 percent of the total,
municipal losses for 1 1/2 percent and manufacturing for about 2 percent.[1]

These figures indicate that in the process of economic development,
very small changes in the extent of irrigated agriculture can have very
large effects on the relative quantities of water available for non-
agricultural use, whether such use is measured by intake or by loss.
Since our estimates of 1985 agricultural use are based upon a combination
of Chilean coefficients and coefficients expected to prevail in the United
States, specifically in California, in 1980, rather than upon rates of
use that now prevail in Chile, which are much higher according to various
authorities, the probability of being able to transfer water from 1985
agricultural uses to 1985 non-agricultural uses without a reduction in
irrigated area is relatively low. At lease it is lower than it would
have been if the coefficients of water use had been based on current
Chilean experience.[2] We can at this time introduce the question of
supply in its simplest dimension, namely average annual flow, and
relate it to projected losses. These relationships,

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[1] Total losses in the United States are affected by inclusion of items
for which no provision has been made in Chile, but which accounted for
37 percent of U.S. losses: soil and moisture conservation programs and
expansion of fish and wildlife habitat. Further study might reveal
comparable requirements in Chile.

[2] However, even on the assumption that the likelihood of achieving
economies greater than already assumed is nil, some saving in water
without corresponding reduction in irrigated area would be possible by
concentrating production in water short regions on crops with the
lowest water requirements.

as elementary as they are, indicate the basic imcompatibilities between
the distribution of water resources in Chile and projected demands upon
them. (See last column in Table XI-2.)

The deficit of water cumulates progressively as we go from Tarapacá
to the province of Santiago. Coquimbo and Santiago, because of large
irrigation requirements, reveal the largest deficit. Antofagasta alone,
of all seven northern provinces shows a slight surplus. This surplus
disappears, and the deficit of the other six regions increase, if losses
are computed according to one of the other options that are considered.
Regardless of the alternative ways that are considered in the computation
of water requirements the basic pattern as revealed by Table XI-2 persists.

Water Requirement as a Combination of Intake and Loss

A water requirement specified by the sum of intakes within a basin
overstates what is needed if uses are arranged in tandem and water is not
contaminated too severely for reuse. A water requirement specified by
the sum of losses within a basin is the theoretical minimum amount of
water that will suffice. However, such a measure is likely to be an under-
statement of what is practically attainable. For example, cities resist
reusing their own sewage water. If, therefore, a city is located at the
discharge point of a basin and draws its water supply from the river,
directly or through the ground, the minimum flow requirement is equal to
upstream losses plus municipal intake. If an irrigation project is located
adjacent to the city and shares the river with the city at its downstream
point, the minimum flow requirement is equal to upstream losses plus
municipal and agricultural intake. If the irrigation project can intercept
the discharged waters of the municipality before they reach the sea, the

minimum requirement is equal to upstream losses plus municipal intake,
plus the excess of downstream agricultural intake over municipal dis-
charge (assuming that downstream agricultural intake exceeds downstream
municipal discharge), which is equal to downstream agricultural intake
plus all other losses. If downstream industries, mines and power plants
do not recirculate their water and there is no interception of municipal
discharge, total flow requirements within a basin are equal to upstream
losses plus the sum of downstream intakes. (It is implicit in the
definition of "downstream" that the discharge (i.e. return flow) of a
downstream irrigation project cannot be recovered for further use.) If
water is in shorter supply than irrigable land we shall assume that irriga-
tion will be limited to upstream land unless the agricultural productivity
per unit of gross input of water downstream is greater than the agricul-
tural productivity per unit of net input of water upstream, other inputs
being equal.

In general, the minimum flow requirement, (without considering dilu-
tion flows), is equal to all losses plus the intake of the last user re-
gardless of whether the last user is in an upstream or downstream position.
The maximum flow requirement, without considering quality maintenance
flows, is equal to upstream losses plus all downstream intake.

In order to simplify further exposition we shall compare three alterna-
tives, all in the absence of a water constraint. We shall compare these
cases with an alternative that takes waste dilution into account. We shall
then examine the question of water supply and the regulation of flow by
means of storage, (see Chapter XII), after which we can study the effects
of costs of water on projected outputs, (see Chapter XIII).

The three cases that are examined in detail are the following:

Case I

Downstream municipal discharge is assumed to be captured for use for downstream irrigation. All other downstream users recirculate completely. In effect, requirements are equal to the sum of all losses plus downstream agricultural intake.

Case II

Case I is modified by assuming that mining requirements are measured by intake instead of loss. There are no data for Chile on the amount of water that is reusable when discharged from a mining, beneficiation, and refining complex. We know that about 94 percent of intake at El Teniente is discharged, but we do not know how much to lagoons where the liquid is evaporated or how much to treatment facilities for ultimate return to the river. Case II is clearly incompatible with plans for an increase in copper production unless relatively large quantities of water are imported into Antofagasta and Atacama. We shall not have more to say about Case II.

Case III

In this case water requirements are measured as the sum of upstream losses and downstream intakes. If Case I is at one extreme of the water-economizing spectrum, Case III is at the other, (without consideration of dilution flows.)

Detailed computations of Cases I, II and III are shown in the appendix tables. Summary results are shown in Table XI-3.

The difference between adopting reasonably complete water economizing techniques (Case I) and no economizing techniques (Case III)[1], is of no significance for the country as a whole (31.4 billion M^3/year vs. 32.9

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[1] Presumably treatment levels are high enough to allow reuse of water for offstream purposes even if no dilution is provided.

billion M^3/year), but of importance in Antofagasta, Atacama, and Aconcagua-Valparaíso.

Presumably the main effect of assuming that downstream municipal discharge is recovered for use is in the additional area capable of being irrigated. Whether additional land would in fact be irrigated would depend upon the availability of irrigable land at suitable elevation and distance from the point of municipal discharge. If we assume that all downstream municipal discharge is recaptured, the areas capable of being irrigated by the discharge is as follows:

Tarapacá	-	340 hectares
Antofagasta	-	540 "
Atacama	-	110 "
Coquimbo	-	510 "
Aconcagua-Valparaíso	-	3,410 "
Santiago	-	650 "
Total		5,560 "

These figures do not indicate how much water is available from a single municipal system, nor whether the benefits would justify the costs. Such determinations would have to be made separately for each locality. Another possibility is the use of treated municipal discharge for industrial purposes. Except in the Aconcagua-Valparaíso region, estimated municipal discharge exceeds estimated manufacturing intake in all of the regions from O'Higgins-Colchagua to the north. This option would be attractive if there were no downstream lands for irrigation or if upstream lands of better quality than those available downstream had been withdrawn from use in order to meet downstream manufacturing intake. In any case, by

computing municipal losses on the assumption that all municipal discharge were recoverable, as is done in Table XI-2, we automatically increase the total use that can be made of the water supply within each region.

At present there not only is no recapture of downstream municipal discharge, except experimentally in the Antofagasta area, but there is also very little recirculation of manufacturing water. As a consequence, virtually all downstream manufacturing intake is lost.

One should note that since the most likely effects of water shortage will be a reduction of land under irrigation, the failure of downstream manufacturing users to recirculate will compel further contraction of irrigated agriculture. In Antofagasta this means another 300 hectares. In the Aconcagua-Valparaíso region it means 9,350 hectares. In the case of Aconcagua-Valparaíso, if 50 percent of manufacturing intake is saved by recirculation and 50 percent of municipal discharge can be reused for irrigation, 6,600 hectares could be irrigated.

The effect of taking a more realistic account of downstream municipal and agricultural requirements than is given by considering only evapotranspiration losses, pushes southward into the Curicó-Linares region the line at which average annual supply accumulated in going southward from Tarapacá balances annual losses, as one adds requirements and flows. If we cumulate losses shown in Table XI-2, without accounting for irrecoverable downstream use, the surplus of the O'Higgins-Colchagua region offsets, with a little to spare, the deficit accumulated to the north. If the deficit is computed on the basis of Case I, the surplus of O'Higgins-Colchagua falls short of meeting the deficit in the provinces to the north. Chile from its northern boundary to the southern boundary of Colchagua province

would be a net deficit region on the basis of projections for 1985. The deficit computed on the basis of Case III is approximately 1,000 million M^3/year greater.

Case IV: Losses Plus Waste Dilution

An alternative measure of water requirements is the sum of losses and waste dilution. By fixing the water requirement as waste dilution plus total losses rather than upstream losses we are assured of an outflow to the sea equal to the quantity of waste dilution.

Losses plus waste dilution serve as a satisfactory measure of required flows if waste dilutions are always large relative to intake at any single point. Although this condition most likely holds for the United States, it may not for a country such as Chile, where upstream reaches are relatively short and, except for Santiago and several minor inland points, most polluting activities take place on the coast.

Required flows depend upon the level to which treatment is carried. If a quality standard were imposed in water short regions, it is most likely that treatment would be raised to the point that minimized the requirement for dilution water; in the present instance to 90 percent. The use of total loss plus waste dilution flow introduces a slight overstatement of water requirements, since downstream loss could be met out of waste dilution flow. The overstatement is negligible.

If treatment were 90 percent in all regions, losses plus waste dilution flows for all provinces from Santiago to the north would be 10,983 million cubic meters per year compared with an average annual flow of 6,170 million cubic meters. Every province down to and including Santiago contributes to the total deficit, but more than half comes from Santiago.

At zero treatment no additional regions are in short supply, but the net deficit is, of course, much greater. Without treatment the balance between cumulated demand and cumulated supply, moving southward from Tarapacá, is not achieved until virtually the entire average flow of the Curicó-Linares region is used.

So long as the use of water downstream from major points of pollution is mainly irrigation, there is little reason to believe that dilution of wastes will become important unless the waters become heavily mineralized or polluted with persistent chemicals. Without additional information there is no way of assessing the impact of this form of pollution. If it is established that waste dilution flows are unnecessary, the required flow is equal to one of the alternative measurements of upstream losses plus downstream intake.

Chapter XII

THE COST OF WATER [1]

River basins and provinces were grouped into regions for which
coterminous boundaries could be drawn. (See Table XII-1). A few small
rivers included in Table XII-1 made such small contributions to total
regional runoff and suffered from such deficiencies in data, that they were
ignored. Several small coastal streams were also excluded. In all, the
exclusions account for a few percent of total surface runoff.

No account was taken of ground water except that which is discharged
into streams and is measured by stream gages. The quantity of water that
escapes measurement may be significant, but data on the volume of under-
ground reservoirs, the rate of recharge, and the linkage with measured
surface flow are not available. A few sample studies portend a greater
relative importance of ground water in the northern desert provinces.

Basic data are incomplete in several ways. (1) Virgin flows cannot
be accurately ascertained because diversions are not measured. (2) It
is difficult to separate the effect of irrigation return flows from
independent contributions from underground aquifers. (3) The period of
record is too short to provide a reasonably accurate flow duration curve
for most rivers. [2] (4) Gaging stations are far too few in number and are
rarely placed at those points that allow reconstruction of virgin discharge
into the sea. Because of these limitations many flows were estimated

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[1] Data on flows of Chilean rivers and storage requirements required
to achieve varying levels of regulation were prepared by the Centro
de Planeamiento of the Faculty of Physical Sciences and Mathematics
of the University of Chile. "Estudio de la Disponibilidad de Recursos
Hidráulicos en Chile", Profesor Fernán Ibañez, Chief of the Project,
Ricardo Harboe and Juan Antonio Poblete, research associates. Publica-
tion N° 65-5/B, July 1965, supported by a grant from Resources for the
Future, Inc. See this study for details of estimates and limitations
in quality of data.

[2] As noted elsewhere, the period of record for computed virgin flows
ranges between three and thirty-four years, and averages twelve years.

Table XII-1

WATER RESOURCE REGIONS

		River Basins
1.	Tarapacá	Lluta, Lauca, Azapa
2.	Antofagasta	Loa
3.	Atacama	Copiapó, Huasco
4.	Coquimbo	Elqui, Limarí, Choapa
5.	Aconcagua Valparaíso	Petorca, Ligua, Aconcagua
6.	Santiago	Maipo
7.	O'Higgins Colchagua	Rapel
8.	Curicó Talca Maule Linares	Mataquito, Maule
9.	Ñuble	Itata
10.	Concepción Arauco Bío-Bío Malleco Cautín	Bío-Bío, Paicaví, Imperial, Toltén
11.	Valdivia Osorno Llanquihue	Valdivia, Bueno, Maullín, Chamiza, Petrohué, Puelo
12.	Chiloé	Yelcho
13.	Aysén	Palena, Cisnes, Aysén, Baker, Bravo, Pascua
14.	Magallanes	Serrano

indirectly, based on correlations with meteorological data and the behaviour of rivers for which more complete information was available. The authors caution the reader to accept the flow data and flow storage relationships as approximations, and not as suitable for detailed planning.

Ibañez, Harboe, and Poblete concluded that on the basis of the hydrologic balance of the main longitudinal central valley between the provinces of Aconcagua and Llanquihue, underground supplies where rivers come from the cordillerra into the central valley are not important. Underground supplies increase further downstream through infiltration from the river bed, return flow from irrigation, and rainfall in the central valley. For this reason, measurements of flow in the foothills of the Andes would account for most (98% - 99%) of the supply, including ground water recharge, in the summer months, when the contribution from rain over the lowlands is negligible, as is the case in the glacial and pluvio-glacial basins more to the north. In winter the station near the mouth of the river measures supply since it records all contributions and is not appreciably altered by consumptive uses, which at this time of the year are at a minimum. Further to the south the measure of supply, or of virgin flow, is given by gaging stations near the mouth of the river, after correcting the data for the "use" season by correlation with data of the "no-use" season. [1]

Flows in cubic meters per second were averaged for each month of record and the flows equalled or exceeded 95, 90, 70 and 50 percent of the time for each separate month were identified as well as the long run average flow for the entire period of record.

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[1] Ibañez, Harboe, and Poblete, pp. 19-27

Storage requirements needed to raise the present low flow (the flow
equalled or exceeded 95 percent of the time for the month that had the
lowest flow) to successively higher minimum flows up the average flow
were computed for three levels of certainty: 100, 95 and 85 percent.[1]
Table XII-2 shows storage requirements to assure designated flows with
a security of 85 percent. We concentrate on storage requirements needed
to yield 85 percent security -- i.e. the flow will equal or exceed the
specified flow in 17 years out of twenty -- because this is the level
of security which has been used by Dirección de Riego in planning its
projects.[2] Later we shall discuss the implications of a higher degree of
security.

Storage Requirements to meet Seasonal Variation in Demand:

Seasonal requirements for irrigation reach a peak in the summer and fall
to as little as zero during the winter months. After we had ascertained
projected requirements for all uses a comparison was made by Ricardo
Harboe between the amount of storage needed to meet the seasonal pattern
of use and the amount of storage needed to provide a constant flow, on
the assumption that regulation was extended to the theoretical limits of
average annual flow in the seven northern provinces and to projected require-
ments in the rest. Storage requirements for seasonal needs were greater than
storage requirements for a constant flow in all regions except Aconcagua-
Valparaíso and Santiago. In some regions storage volume to meet seasonal

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[1] Regulation to achieve average flow at 100 percent certainty is
theoretically impossible unless future flows duplicate the historical
record.

[2] More exactly, in three years out of twenty the flow in one or more months
can be less than the amount indicated.

Table XII - 2

FLOW-STORAGE RELATIONSHIP: 85% SECURITY

(Flow equalled or exceeded indicated percent of time in million M³/year: Storage in million M³)

Province	Flow now equalled or exceeded 95% of the time	70%*		50%**		Long Run Average	
		Flow	Storage	Flow	Storage	Flow	Storage
Tarapacá	41	45.7	.37	47.2	.37	85.5	44.7
Antofagasta	81	92.1	1.80	94.6	1.80	104.7	8.8
Atacama	81	120.1	12.8	154.2	86.5	229.2	374.3
Coquimbo	199	335.8	42.9	434.6	118.2	952.6	2,526.0
Aconcagua-Valparaíso	373	492.2	18.5	537.3	33.5	1,423.2	2,552.0
Santiago	1,220	1,567.3	67.5	1,781.8	196.0	3,371.2	3,385.0
O'Higgins-Colchagua	1,602	2,106.6	41.0	2,601.7	96.0	6,972.6	6,175.0
Curicó-Linares	3,264	4,837.6	167.6	5,714.4	314.0	23,301.9	32,801.0
Ñuble	1,009	1,482.2	35.0	1,545.3	48.0	6,748.7	11,250.0
Concepción-Cautín	10,925	16,096.9	799.4	18,040.3	1,177.3	61,487.0	45,361.0
Valdivia-Llanquihue	22,088a/	30,722.7	2,069.0	37,225.2	4,021.0	71,164.2	41,228.0
Chiloé-Magallanes	83,482b/					269,317 (estimated)	

* Lowest of monthly flows now equalled or exceeded 70% of the time (see Tables of flows).

** Lowest of monthly flows now equalled or exceeded 50% of the time (see Tables of flows).

a/ 95% security from indicated storage.

b/ Estimated at same ratio of flow equalled or exceeded 95% of the time to average flow found in Valdivia-Llanquihue. Average flow taken from CEPAL, p. 31.

irrigation needs was more than twice the volume needed to assure a
specified minimum flow. The ratio of storage required for seasonal needs
to storage required for a constant flow is referred to as the "storage
coefficient".

In computing the costs of storage we first assumed that irrigation
requirements could be expressed as an annual amount, (i.e. ignoring
seasonal variation). After storage was computed on this basis, volume
and costs were adjusted by using the storage coefficient for each
region. In this way we could use a cost-of-flow schedule designed to
show the costs of increments of minimum flow and adjust the results to
conform to the seasonal requirements of each region.

In several of the preliminary models, we made no distinction between
storage for constant flows (non-agricultural uses) and storage for
seasonally variable flows, since the former usually constituted a
relatively small fraction of the total. We therefore computed storage
requirements on the assumption that all followed the same seasonal
pattern. In the more detailed cases, where we were concerned with
variation in marginal costs, we made a separation between the two. A
detail omitted from all models was the determination of additional
evaporation losses from additional seasonal storage requirement.
Research is needed on the question of reservoir evaporation generally,
but beyond this one also needs to know how evaporation losses would be
affected by the seasonal patterns of storage and release.

We shall use the multiplier derived from a comparison between
constant average flow and seasonally regulated flows even when we
deal with lower flows. This procedure may understate required storage
at less-than-average flow. Computations for the Rio Elqui show that

the multiplier to meet seasonal variation tends to be higher for less than average flows than it is for the average flow (see Table XII-3). This may partly explain the relatively high coefficients for the four regions south of Santiago. If, in northern regions, regulation were introduced for a lower level of water use than represented by average annual flow, presumably the multiplier coefficient would rise, based upon results derived from the Río Elqui. However, a reduction in water use would probably be accompanied by a reduction in the relative importance of agriculture, and therefore a reduction in seasonal variability of requirement, which would tend to reduce the multiplier in all regions except Aconcagua-Valparaíso and Santiago, where the multiplier would rise. We shall not, however, take these refinements systematically into account for any of the hypothetical variations in regional production with which we shall be concerned.

We shall assume that the effect of the coefficient is to change total costs by the same factor as the indicated change in the storage coefficient. This assumes that the size-distribution of storage sites to meet requirements for seasonal flows is the same as the distribution to meet requirements for a given minimum flow. In regions in which less than average flow is required -- i.e. O'Higgins-Colchagua and south -- we shall follow the same procedure, rather than 'move up" the schedule.[1]

Reservoir Evaporation Losses:

The Centro de Planeamiento study did not include in its flow-storage relationships an adjustment to account for the net increase in evaporation from the basin resulting from added water surface exposed to the atmosphere as the volume of surface storage would be increased. Relatively little

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[1] In making detailed plans one further adjustment would have to be taken into account which we have ignored, namely, the additional evaporation.

TABLE XII-3

MULTIPLIERS TO ADJUST STORAGE FROM MINIMUM FLOW TO
SEASONALLY VARIABLE REQUIRED FLOW [1]

Tarapacá	1.24
Antofagasta	2.28
Atacama	1.13
Coquimbo	1.13
Aconcagua-Valparaíso	0.95
Santiago	0.92
O'Higgins-Colchagua	1.85
Curicó-Linares	2.82
Ñuble	2.88
Concepción-Cautín	[2]
Valdivia- Llanquihue	no irrigation

[1] Based upon storage requirements to meet seasonal pattern of flow at "full regulation" for first six regions, and for projected water requirements for remaining four regions.

[2] For projected requirements at 85% security no storage would be needed if flow were constant. Storage to meet seasonal variability of required flow was computed as 473 million M^3.

RIO ELQUI: MULTIPLIERS FOR FLOWS LESS THAN AVERAGE

	Storage (mil. M^3)		
Flow Mil. M^3/yr.	Constant	Seasonal	Multiplier for Seasonal
262	403	408	1.01
205	76	142	1.87
165	30	48	1.6
350 (average)	1,285	1,420	1.1

Table XII-4

ASSUMED RELATIONSHIPS BETWEEN HEIGHTS AND VOLUMES OF RESERVOIRS

Volume (Million M^3)	Height (Meters)
0 - 100	15
100 - 200	20
200 - 400	25
400 - and over	35

Table XII-5

ESTIMATED AVERAGE RATE OF EVAPORATION

(Meters per Square Meter of Reservoir Surface)

Tarapacá	1.4
Antofagasta	2.5
Atacama	1.2
Coquimbo	1.5
Aconcagua-Valparaíso	1.0
Santiago	1.0
O'Higgins-Colchagua	.9
Curicó-Linares	.7
Ñuble	.6
Concepción-Cautín	.5
Valdivia-Llanquihue	.4

is known about the relationships that would be found between operation
of the reservoirs and exposed area. Estimated annual net rates of
evaporation from water surfaces in the areas where reservoirs are likely
to be range from 400 millimeters in the vicinity of Valdivia to 1,400
millimeters and higher in the Norte Grande.[1] In order to give some
expression to the potential loss by evaporation and the effect on marginal
costs of flow we assumed that average reservoir heights were directly
related to volumes up to a point, (See Table XII-4) and that rates of
evaporation were as given in Table XII-5. With these assumed values we
reduced each increment in minimum flow by the amount of estimated added
evaporation from storage.

The Costs of Regulating Surface Flow:

On the basis of data on reservoirs already built, under construction,
and under study, Messrs. Ibañez, Harboe, and Poblete constructed cost
curves for rock-fill and earth dams, showing costs of water impounded as
a function of the size of the reservoir.[2] On the basis of these curves
the cost schedule as shown in Table XII-6 was adopted. The values selected
for the smaller size classes tend to be closer to the curve for earth-fill,
which is the lower of the two, than for rock-fill; and coincide exactly
with the earth fill curve for the largest size class. Based on current
experience, the selected values understate by 50 percent the costs of
large rock-fill dams. It is difficult to predict which form of dam will
dominate future construction. One point in favor of an earth dam is the
fact that a clay core tends to resist tremor damage a little better than
a more rigid structure. Most dams already built or in one stage or

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[1] Unofficial estimates supplied by Centro de Planeamiento.

[2] See Graph 2, page 39, Op. cit.

Table XII-6

UNIT COST SCHEDULE ACCORDING TO SIZE CLASS

Size Class of Reservoir (Million M^3)	Cost per 1000 M^3 in E^o 1964
(A) 0 - 49	200
(B) 50 - 99	150
(C) 100 -199	100
(D) 200 -399	80
(E) 400 and over	50

another of being under way are earth fill. A single size-class unit-cost curve is used for the entire country.

There still remains the question of how one should distribute future reservoir capacity among the various size classes. Presumably all reservoirs cannot be of the largest size class, since the availability of sites, the places where water will be used, the flow of the river, the degree of regulation already attained, and the additional degree of regulation desired will vary from basin to basin and, in fact, tributary to tributary. It is reasonable, therefore, to assume that reservoirs of all size classes will be built as total storage capacity is increased. One can, of course, assume several ways in which total storage in a basin grows: (1) by first using the largest reservoir sites; (2) by first using the smallest sites; (3) by random or studied additions that do not follow an order by size class.

The history of Dirección de Riego indicates that it is following the third course, but with an ascertainable trend such that, on the average, future reservoirs will be larger than past reservoirs.

Of 45 reservoirs built, under construction, and under study, as of 1958, the mean sizes varied as follows:[1]

reservoirs already built	31,000,000 M^3
reservoirs under construction	450,000,000 M^3
reservoirs under study	310,000,000 M^3

Of the twenty-one reservoirs under study in 1958 five had a capacity of less than 49,000,000 M^3, and twelve had a capacity of less than 200,000,000 M^3. The largest under study had a capacity of 2,750,000,000 M^3; the largest already built had a capacity of 150,000,000 M^3, and the largest under construction had a capacity of 1,570,000,000 M^3.

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[1] CEPAL, pp. 65, 72.

Table XII-7

ASSUMED DISTRIBUTION OF RESERVOIR CAPACITY BY SIZE CLASS

Where Full Regulation Requires: (Million M^3)	Distribution
0 - 49	All of Size Class A [1]
50 - 399	First 50% of capacity, C
	Next 25%, B
	Last 25%, A
400 - 2,999	50% - E
	20% - D
	10% - C
	10% - B
	10% - A
3,000 - up	75% - E
	15% - D
	5% - C
	3% - B
	2% - A

[1] See Table XII-6 for size classes and costs per unit of capacity.

Our synthetic cost curves were constructed wholly on an intuitive

basis, on the assumptions that, wherever appropriate, large rather than

small reservoirs would be used, that to reach the capacity needed for

complete regulation some reservoirs of all size classes would be used,

and that storage capacity would be increased by first building large

reservoirs followed by smaller. [1] The order in which reservoirs of

different size classes are assumed to be constructed has a significant

effect on the steepness of a curve that describes the marginal cost of

minimum flow. This curve will rise on the basis of "diminishing marginal

physical productivity of storage" -- a reflection of the fact that it takes

more and more storage capacity to raise minimum flow by equal successive

increments. If, in addition, we assume that "later" (i.e. smaller)

reservoirs cost more per cubic meter of capacity than "earlier" (i.e. larger),

the marginal cost of flow is subject to a double upward thrust. Our cost

curves are constructed on the assumption that this double thrust will

prevail and that every basin will use at least a few small reservoirs if it

regulates at full capacity. In order to make these assumptions specific,

total reservoir capacity at assumed full regulation in each basin was

divided among reservoir classes of different sizes in accordance with

the values specified in Table XII-7. [2] By applying this distribution

to the unit costs indicated by Table XII-6 we constructed for each basin

a set of schedules showing increments of storage, successively higher

levels of minimum flow, costs of increments of storage, costs of incre-

ments of flow, and cumulative costs.

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[1] A number of large reservoirs in Chile consist of natural lakes
with regulated outlets. These were excluded, insofar as they
could be identified, from the mean figures given above.

[2] The distribution roughly reflects what is happening in the country as
a whole after taking into account reservoirs built, under construction
and under study.

Capital costs were converted to annual costs on the assumption that the
rate of interest applicable to a loan of fixed real value (or one for which
the capital sum was subject to revaluation with changes in the price level)
was 8 percent and that the life of a reservoir was 50 years. The results
for each water resource region are shown in the appendix tables. The
effect of the storage coefficient for seasonal requirements on the costs
of storage for the six northern regions in the aggregate is negligible.
Increases in the first four regions are slightly overbalanced by decreases
in Aconcagua-Valparaíso and Santiago.

Chapter XIII

THE EFFECT OF WATER SHORTAGE

Three conclusions emerge when we compare projected requirements
with the natural availability of flows:

(1) If nothing is done to modify the natural seasonal and annual
variability of flows, there will be periods of shortage in all
regions from the province of Cautín to the northern boundary
of the country.

(2) There is no way by which the distribution of activity can be
modified in order to overcome the scarcity of water in the
North and the scarcity of arable (irrigable and non-irrigable)
land in the South except diversions of water from surplus to
deficit areas. Each region, from Tarapacá to and including
the province of Santiago, (the Maipo-Mapocho basin) has an
average flow that is less than projected requirements. The
first region with a projected surplus is O'Higgins-Colchagua
(the Rapel and several minor streams), but the surplus is
less than the deficit cumulated to that point, even if require-
ments are measured conservatively (i.e. as being equal to
downstream municipal intake and agricultural intake in excess
of municipal discharge plus all other losses, (Case I)) or as
the sum of losses plus waste dilution flows at 90 percent treat-
ment, (Case IV). In order to bring the available supply into
balance with projected requirements, streams would not only
have to be regulated to the maximum degree possible[1] but

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[1] See below for description of regulation needed. Flows would have to
be controlled to meet the seasonal variability of requirements, which
means, for most streams, a larger volume of storage capacity than
would be needed to yield constant flows at the historical average.

a series of northward transbasin movements would also have to
be undertaken. This movement would be comparable to diverting
half the average annual flow of the Rapel northward plus
replacing the deficit that would then appear in O'Higgins-
Colchagua. The cumulated deficit including that of the
O'Higgins-Colchagua region is 252 million M^3 per year
for Case I, 1,083 million M^3 per year for Case III, and
2,557 million M^3 per year for losses plus waste dilution
after 90 percent treatment. If requirements are measured
only as losses, and there is no provision for waste dilution,
the projected surplus of O'Higgins-Colchagua almost matches
the deficit accumulated to the north.

(3) In the absence of transbasin movements, there is no way of
meeting projected outputs except by increasing the agricultural
productivity of land beyond the increase implicity assumed up
to this point in the analysis.

First Estimate of the Costs of Storage

The closest we can come to meeting Case I [1] without disturbing the
pattern of non-agricultural activity projected for 1985 is by providing
maximum regulation in all regions from Santiago to the northern border.[2]
In the remaining regions regulation is assumed to proceed up to projected

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[1] The reader will recall that Cases I, II, III, and IV are alternative ways
of stipulating the water requirements of a single economic projection -
the medium rate of population growth and the high rate of growth of GNP
(Medium B). Water requirements of the four cases are specified as follows
(See Chapter XI, Table XI-3):

      Case I - Municipal and agricultural downstream intake plus all
          other losses.
      Case II - Case I with mining intake instead of mining loss.
      Case III- Upstream losses; all intake downstream.
      Case IV - Evaporation-transpiration losses from all uses plus
              waste dilution to yield 4 mg/l of dissolved oxygen
              after 90% removal of BOD by waste treatment.

[2] See page XIII-3 for footnote.

requirements. The deficiency of water will mean that some irrigable land in the north will not be irrigated.

Table XIII-1, which is a basic table since in the discussion that follows we shall be concerned with possible changes in the regional distribution of activity that will induce changes in this table, shows the costs of maximum regulation of all streams in the northern part of the country (Maipo and northward) and the costs of meeting projected requirements in the remainder. Additional storage needed to meet seasonal requirements are also given.

Under these conditions total additional investment cumulated for the next twenty years is about one billion escudos (about $ 250,000,000 at October 1965 official rate) or about 50 million escudos per year.[1] Equivalent annual cost of the cumulated capital investment at full development would be about 84 million escudos (interest and amortization).

The distribution of total costs among the various regions depends upon the use or non-use of the seasonal variation coefficient. Without the coefficient northern regions account for 87 percent of total costs; with the coefficient, the north accounts for 72 percent. Marginal costs of water, important for regional planning purposes, are very much higher in the north than in the south.

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[2] By "maximum regulation" is meant the amount of storage that would raise minimum flow to average flow on the assumption that future runoff would duplicate the experience of the period of record. This is also what we mean when we speak of "100%" or "complete" regulation.

[1] This compares with 24 million escudos budgeted in 1964 by Dirección de Riego for reservoir construction.

TABLE XIII-1

CASE I: COSTS OF FLOW REGULATION (85% SECURITY)

Province	Required flow (million m³/yr)	Storage (million m³)	Coefficient for seasonal requirements	Storage for seasonal requirements (mil.m³)	Cost before applying storage coefficient (E° 1,000 - 1964)			Cost after applying storage coefficient (E° 1,000 - 1964)		
					Annual Equivalent	Cumulative capital	Marginal	Annual Equivalent	Cumulative capital	Marginal
Tarapacá	311 a/	45	1.24	55	730	8,940	96	905	11,086	119
Antofagasta	103 a/	9	2.28	20	144	1,760	22	328	4,013	50
Atacama	439 a/	374	1.13	422	4,126	50,500	817	4,662	57,065	923
Coquimbo	1,766 a/	2,526	1.13	2,858	17,647	216,000	551	19,941	244,080	623
Aconcagua-Valparaíso	1,979 a/	2,552	.95	2,413	17,892	219,000	481	16,997	208,050	457
Santiago	4,240 a/	3,385	.92	3,114	19,461	238,200	117	17,904	219,144	108
Subtotal		8,891		8,882	60,000	734,400		60,737	743,438	
O'Higgins-Colchagua	4,557	1,075	1.85	1,990	4,391	53,750	1	8,123	99,438	2
Curicó-Linares	7,946	934	2.82	2,634	3,815	46,700	c/	10,758	131,694	1
Ñuble	2,333	210	2.88	605	858	10,500	c/	2,471	30,240	1
Concepción-Cautín	7,591	0		473 b/	---	---	---	1,932	23,650	c/
Valdivia-Llanquihue	56	---		---						
Subtotal		2,219		5,702	9,064	110,950		23,284	265,022	
Chiloé	7	---		0						
Aysén	11	---		0						
Magallanes	28	---		0						
TOTAL	31,366	11,110		14,584	69,064	845,350		84,021	1,028,460	

a/ Required flow exceeds average flow. Storage is for average flow.
b/ Centro de Planeamiento, separate estimate.
c/ Interpolated cost is less than E° 1,000.

Since there is a projected shortage of land nation wide (relative to expansion of cultivated area needed to meet projected outputs at current rates of production per hectare) and a projected shortage of water in the seven northern provinces, the question remains of how land and water resources should be used. One possibility is to retain as much agriculture as possible in the North, moving all other mobile activity to regions of water surplus. If all water in northern provinces were used for agriculture, the following amounts, roughly speaking, of irrigated area could be supplied with water:

		Hectares
Tarapacá	-	3,620
Antofagasta	-	2,626[1]
Atacama	-	14,350
Coquimbo	-	57,000
Aconcagua-Valparaíso	..	93,300
Santiago	-	232,000
Total (Rounded)		403,000

In general we know that output per unit of water (loss or intake), measured by value added, is greater for non-agricultural than for agricultural products, especially if no allowance is made for dilution of discharge. Therefore, if water is allocated among competing uses in such a way as to maximize the region's gross product, non-agricultural uses will force out agricultural uses. The same result usually occurs if the objective is to maximize a region's employment. Under these circumstances, if we assume that all non-agricultural requirements of

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[1] All irrigable land. Some water would remain for other uses.

Case I are met in water short regions, and streams are fully regulated, the
water supply that remains for agriculture will allow irrigation of about
372,500 hectares. (In other words, using Case I as the basis for computing
requirements, to meet all non-agricultural requirements means taking about
30,500 hectares out of cultivation. Cases II or III would require larger
reductions in irrigated area.)

Marginal Cost of Water Constraints

If water in the seven northern regions is fully developed, marginal
costs of regulated flow reach very high levels. It is doubtful whether
agriculture or manufacturing could afford to pay more than a fraction of
such costs. What, then, would be the effect on the distribution of
economic activity of charging a price for water equal to its marginal
product? Although the data necessary for the answer to this question
do not exist, we can speculate about the results by using proxy information.

Since there is no reason to expect productivity per unit of water
to differ materially among regions for non-agricultural uses, we shall
examine only the available evidence for agriculture. There are no data
available on marginal productivity. Relative prices of agricultural land
would be a useful index of net value productivity (adjusting for transport-
ation costs) but these are not available. We can, however, make use of
a scale of values of Class IIIr land issued for tax assessment purposes
on the assumption that it reflects relative productivities among com-
munities. (Assessed values are given by comuna.)

The unweighted average of assessed valuation for each comuna was
converted to a scale of values for provinces and water resource regions.
The scale was based upon Class IIIr land because this class is the largest
of the irrigated classes and because it maintained a constant relationship

with other classes of irrigated land in each comuna. The highest values
are for Aconcagua and Santiago provinces. Since an additional assessment
factor was to be applied to these valuations to account for the quality
of transportation facilities only part of locational, as distinct from
physical productivity characteristics, are included in the indexes. How
much the assessments reflect speculative changes in value induced by
prospective transfer from agricultural to urban use cannot be ascertained.

The assessed valuation indexes do not correspond very closely to
marginal costs of water that are implied when regulation is extended to
the limits indicated in Table XIII-1. Presumably the valuation indexes
reveal the relative prices for water that owners of the land could pay.
If, for example, development could proceed economically up to a marginal
outlay of 20,000 escudos per million cubic meters per year in the
Province of Santiago, we might say that investment could proceed to a
marginal outlay of 15,000 escudos per million cubic meters per year in
Tarapacá and Antofagasta and to 7,600 escudos in Concepción-Cautín.
The amount of water required per hectare would affect this relationship,
moderating it if inputs of water were directly correlated with land values
and reinforcing it if inversely correlated. The results of these
adjustments are shown in Table XIII-2. The indexes must be considered
as illustrative only. We have no information regarding the factors that
went into the original assessments, nor do we know what distortion was
introduced by averaging values by comuna without weighting by the amount
of land per comuna. The final column displays an interesting symmetry
of values north and south of Santiago. The low value for the Curicó-Linares
region, which is a deviation from this symmetry, reflects the depressed
quality of the region's economy.

What value can we assign to the marginal cost of water in Santiago, on the basis of which "reasonable" marginal outlays elsewhere can be determined? In the absence of benefit-cost studies for specific projects one can only hazard a guess. Let us assume that a marginal annual outlay of 8,900 escudos per million cubic meters per year is economically feasible.[1] The marginal value in each region, based upon the indexes of Table XIII-2 are shown in Table XIII-3. Also shown is the level of development as measured by minimum flow which such marginal cost would support. These flows have been translated into the hectareage that would be supplied with irrigation water with 85 percent security, on the assumption that non-agricultural needs as measured by Case I would first be met. Costs of storage have been multiplied by the coefficient that represents additional storage to meet seasonal variations in requirements.[2]

By introducing a marginal cost limitation the following changes are introduced relative to "complete" regulation:

(1) Flows would be regulated to levels ranging, roughly, between 60 percent and 90 percent of "complete" regulation in water short regions.

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[1] This would be about $ 3.42 per acre foot, converted at the rate of 3.2 escudos per dollar, which was the official average rate for 1964. Farmers would also have to pay for delivery (canals, siphons, etc.) and on-the-farm costs.

[2] The marginal productivity of water, where water clearly meets a supplemental rather than full time need can be much higher than is revealed by comparative land values. This consideration is especially relevant for the southern provinces.

Table XIII-2

AVERAGE VALUES FOR CLASS IIIr, LAND FOR TAX ASSESSMENT AND

ADJUSTMENT FOR WATER USE

Province	Unweighted Average of communas E°/ha a/	Index of Land values		Index of water use (Santiago = 100)	Index of land value adjusted for index of water use
		Index (Santiago = 100)	Weighted by irri-gated area		
Tarapacá	1,055	75	75	160	47
Antofagasta	1,065	75	75	160	47
Atacama	960	68	68	100	68
Coquimbo	1,065	75	75	100	75
Aconcagua	1,285	91	-		
Valparaíso	1,090	77	-		
Aconcagua-Valparaíso	-	-	84	100	84
Santiago	1,415	100	100	100	100
O'Higgins	1,120	79	-		
Colchagua	977	69	-		
O'Higgins-Colchagua	-	-	74	100	74
Curicó	839	59	-		
Talca	701	50	-		
Maule	384	27	-		
Linares	587	41	-		
Curicó-Linares	-	-	46	98	47
Ñuble	631	45	45	64	70
Concepción	615	43	-		
Arauco	227	16	-		
Bío-Bío	524	37	-		
Malleco	475	34	-		
Cautín	418	30	-		
Concepción-Cautín	-	-	33	65	51

a/ Cuadro 3, Supplement, El Mercurio, 15 August 1965, New values for property, Servicio de Impuestos Internos.

Province	Present minimum flow	Index of land value adjusted for water use	Marginal cost of water E°/Millions m³/yr.	Storage coefficient	Effect of marginal cost limit: Agriculture in residuary position							
					Minimum flow marginal cost E°/millions m³/yr.	Storage millions m³/yr.	Minimum flow millions m³/yr.	Capital costs (1964 E°1,000)		Annual costs (1964 E°1,000)		Flow for agricul-ture after meeting non-agricult. requirements case 1
								Minimum flow	x coeff't client	Minimum flow	x coeff't client	
Tarapacá	41	47	4,180	1.24	3,370	2	56	400	496	33	41	40
Antofagasta	81	47	4,180ª/	2.28	2,684a/	1	88	236	538	19	43	44
Atacama	81	68	6,050	1.13	5,350a/	63	113	6,310	7,130	516	583	79
Coquimbo	199	75	6,680	1.13	5,910a/	665	601	33,250	37,573	2,717	3,070	575
Aconcagua-Valparaíso	373	84	7,480	.95	7,870	919	1,093	45,950	43,653	3,754	3,566	963
Santiago	1,222	100	8,900	.92	9,670	1,848	2,920	92,400	85,008	7,549	6,945	2,692
Sub-total			—		—	3,498	4,871	178,546	174,398	14,588	14,248	4,393
O'Higgins-Colchagua		74	6,590	no reduction in use	All flow adjusted for seasonal variation							
Curicó-Linares		47	4,180									
Ñuble		70	6,230									
Concepción-Cautín		51	4,540									

a/ See note.

b/ Exceeds maximum; storage and costs are for maximum. Available water supply meets 1/3 of non-agricultural needs; remaining reduced to 2,630, as shown in last column. Storage is for constant minimum flow.

*/ See page XIII-10a for footnote.

XIII-3

MARGINAL COST OF WATER

Hectares served	Hectares served	Case I non-agric flow req. millions m³/yr.	Required minimum flow (mil. m³/yr.)	Storage (million m³)	Capital cost (E° 1,000)	Annual cost (E° 1,000)	Marginal annual cost per million m³/yr. (E° 1964)	Hectareage adjusted for Antofagasta	Costs adjusted for storage coefficient (E° 1,000)	
									Capital	Annual
1,786	2,500	16	72	14	2,833	232	25,059	2,500	3,513	288
1,965	3,929	44	132b/	9	1,760	144	21,787	2,626	4,013	328
5,643	8,071	34	147	130	13,000	1,062	11,000	8,071	14,690	1,200
41,071	42,929	26	627	706	35,300	2,884	6,270	42,929	39,889	3,259
68,786	78,071	130	1,223	1,560	86,400	7,059	43,549	78,071	82,080	6,706
192,286	208,571	228	3,148	2,868	161,500	13,195	42,900	208,571	148,580	12,139
311,537	344,071	478	5,349	5,287	300,793	24,576		342,768	292,765	23,920

Note that this flow is assumed to be available as an even flow -- not adjusted for seasonal variation.

2/3 (equal to 29 million m³/yr) must be transferred to another province or hectareage must be

*/ <u>Note for Table XIII-3</u>.

The relation between constrained marginal cost and available flow was estimated on the assumption that the marginal cost curve was equal to zero at the existing minimum flow and rose linearly to the first point in the schedule. This is a simple and possibly incorrect assumption and was not used for Antofagasta, as will be explained in a moment. It seemed perfectly reasonable for Coquimbo because the constrained marginal cost was almost equal to the computed marginal cost for the first interval of storage. For Atacama, the first interval gives a marginal cost of 16,119 escudos per million m^3 of minimum flow, yet if we build the 6.4 million cubic meters of storage estimated to raise minimum flow by 32 million cubic/meters per year, average annual cost per million cubic/meters of added flow would be 3,270 escudos. If anything, for Atacama, the assumption that one can interpolate linearly is conservative - i.e. flow is biased downward for a given marginal expenditure.

For Antofagasta, if we estimate additional storage to raise flow from 81 million m^3/year to 88 as requiring 1.15 million m^3 of storage, and build this at the highest unit cost used, namely 200 escudos per 1000 m^3 of capacity, (since the largest reservoir to handle this required storage falls into the smallest size class), average annual cost per million cubic/meters of added annual flow would be 2,684 escudos. This figure was adopted as the marginal cost of flow. (At the computed constraint of 1,840 escudos only the minimum flow would be supplied). We assumed that flow would be raised to the amount indicated by a marginal cost of 2,684 escudos by interpolating on a marginal cost curve that is assumed to rise linearly from zero at present minimum flow to the point given by the first interval in the table of costs.

The behaviour of marginal cost when the size-order of reservoirs is reversed is discussed later.

Table XIII-4

HECTAREAGE, IRRIGATED AND PROJECTED

Province	Irrigated 1959 a/	Irrigable area (basic projection)	Case I full regulation (Agriculture residuary)	Case III full regulation (Agriculture residuary)	Marginal Cost Constraint Agric. resid.	Non-agricultural beyond marginal constraint	If all water went to irrigation
Tarapacá	7,000	10,773	2,900	2,680	1,786	2,500	3,620
Antofagasta	4,200	2,626	2,626	0	1,965	2,626	2,626
Atacama	26,081	27,288	11,930	8,390	5,643	8,071	14,360
Coquimbo	107,081	113,023	55,140	53,930	41,071	42,929	57,000
Aconcagua-Valparaíso	92,062	128,641	84,000	55,140	68,786	78,071	93,290
Santiago	228,412	283,852	215,860	215,860	192,286	208,571	232,140
Subtotal	464,836	566,203	372,456	335,900	311,537	342,768	403,036
O'Higgins-Colchagua	249,810	322,394	322,394	322,394	322,394	322,394	322,394
Curicó-Linares	395,778	558,457	558,457	558,457	558,457	558,457	558,457
Ñuble	100,000	260,415	260,415	260,415	260,415	260,415	260,415
Concepción-Cautín	178,660	799,960	799,960	799,960	799,960	799,960	799,960
Valdivia-Llanquihue	-	-	-	-	-	-	-
Total	1,389,084	2,507,429	2,313,682	2,277,126	2,252,763	2,283,994	2,344,262

a/ CORFO - Unpublished data

(2) Reduction in irrigated hectareage is 62,000 or approximately three percent of irrigated area in the country as a whole. The loss in irrigated area would be, of course, relatively more critical with respect to the local economy. Also, the reduction in output would be relatively greater than the reduction in irrigated area.

(3) The savings in capital costs, after adjusting by the seasonal storage coefficient is E^O 443 million or 24 percent of "full development" costs. For the six regions of the north considered by themselves the saving is about 60 percent. Savings in annual costs would be about E^O 37 million.

(4) The costs of going _from_ the level of development represented by accepting the marginal cost limitations of Table XIII-3 _to_ full development under Case I, would represent a capital cost per hectare of new irrigated area amounting to about E^O 23,000, and an annual cost of about E^O 1,875. These are only the costs of regulation and do not include annual on-the-farm costs (about E^O 500 per hectare according to Villarroel & Horn, p. 52) or costs of major canals (about E^O 40-50 escudos per hectare according to Villarroel & Horn, after adjusting 1962 escudos to 1964 values).

(5) The chosen marginal cost limit for flow regulation, which ranges between E^O 8,900 (1964 escudos) for Santiago and E^O 4,200 for Tarapacá and Antofagasta compares quite favorably with average costs incurred by the Dirección de Riego for past reservoirs. On the basis of data in Villarroel & Horn's study, annual capital cost computed at 8 percent interest and 50 year amortization, ranged between 67 escudos (1962) and 158 escudos per hectare for past reservoir projects constructed by Dirección

de Riego. These values should be doubled to convert to 1964
escudos, the price level on which our costs are based. For
Atacama, for which a marginal cost of 6,050 escudos per million
cubic meters of flow was fixed, this means (at net loss rates,
since return flow is usable) an annual capital cost of about
84 escudos per hectare, a figure that is low when compared with
past investments converted to 1964 prices. The marginal cost
limits of Table XIII-3 appear to be within the limits of
credibility, on the assumption that historical average costs
do not materially differ from historical marginal costs.

It is possible to construct models of water use based on other
assumptions. What, for example, are the implications of regulating water
resources in each region only up to the level at which regulated flow
never falls below the flow available 50 percent of the time, or alter-
natively, never falls below one-half the average annual flow. In either
case the total amount of regulation would be lower than is given by the
marginal cost limit used in Table XIII-3.

An interesting speculation is the effect on total costs of water
if projected growth of municipal and manufacturing activity in water
short regions were transferred to water surplus regions. The level of
water resource development by agriculture would also have to be settled
in order to ascertain the savings in the costs of water used by the
displaced non-agricultural activity in the water short regions. In fact,
the greatest development of activity in a water-short region, given
national production goals, can be justified by "assigning" as much as
possible of the high cost water to non-agricultural users for which
water costs are a relatively small part of total costs and water
economizing techniques can be adopted at costs that are not prohibitively

high. We can, therefore, assume that if the level of agricultural development is given by the marginal costs of water in Table XIII-3, non-agricultural water use is met by the more expensive increments of supply beyond the indicated marginal cost. Costs of non-agricultural users as well as savings in expenditures on water if non-agricultural activity is moved to regions of lower water costs can be determined on this basis.

According to Case I, which implies maximum recirculation in use of non-agricultural water, non-agricultural flow requirements in the six northern regions amount to 478 million cubic meters per year. Supplying this flow in the regions in which the uses are projected, (except that in Antofagasta maximum regulation falls short of meeting projected requirements), would require an additional E^O 122 million in original capital outlay and about E^O 10 million in equivalent annual cost over the costs required to meet flows subjected to a marginal cost constraint out of which non-agricultural needs had to be supplied. The computations are given in Table XIII-3.[1]

1/ In examining Table XIII-3 the reader must bear in mind the fact that neither the flow-storage curve nor the shape of the marginal cost of flow curve is well established at the lower end of the scale, especially for flows with a security of 85 percent, since for these flows the Centro de Planeamiento supplied fewer points from which to construct a flow-storage curve. In applying the idea of a marginal cost constraint, we assumed that the marginal cost curve was zero at zero increments to existing minimum flow, and that the curve rose linearly from this point to the first interval computed in Appendix Tables 18 to 28. If, in fact, the movement of the marginal cost curve is discrete, and the first increment in regulation (which is not necessarily the first step in Appendix Tables 18 to 28), indicates that marginal costs have a minimum value that exceeds the constrained values of Table XIII-3, then the flows shown in Table XIII-3 are over-stated. For each basin in which the constrained marginal cost is less than the minimum marginal cost that would be experienced by the first unit of storage, the existing minimum flow would have to be substituted for the indicated flow.

Table XIII-3 also reveals that for the northern regions taken as a whole, the effect of adjusting required storage to meet seasonal requirements is negligible. Requirements are increased in Tarapacá, Antofagasta, Atacama and Coquimbo, but are reduced in Aconcagua-Valparaíso and Santiago. The net effect is an aggregate reduction, relative to storage designed to yield a constant flow, of about 2 1/2 percent. An effect of greater consequence that should be incorporated in more detailed studies is the increased evaporation that must be taken into account--especially in Antofagasta, where the evaporation rates are high and the seasonal coefficient large--of the added regulation needed to meet seasonal requirements.

The effect of yielding to agriculture all flow that is provided by storage after introducing the marginal cost limits of Table XIII-3 implies that marginal costs of water for non-agricultural purposes would range between 6,000 escudos and 44,000 escudos [1] per million cubic meters per year, depending upon the water resource region. Antofagasta is the only province that would exhaust its water supply before supplying all projected requirements, implying, therefore, a reduction in irrigated hectareage below the projected amount. It is this reduced level of irrigation that is implied in Table XIII-1, Case I, (no marginal cost constraint), a level that falls between the two alternative situations described in Table XIII-3 (marginal cost constraint). Total hectareage in Antofagasta would fall to 2,626, thereby reducing the northern regional total by 1,300. A rounded

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[1] These are prices equivalent to a range of $ 2.31 to $ 17.50 per acre-foot at 1964 official rates of exchange, or between seven-tenths of a cent per 1000 gallons and 5.5 ¢ per 1000 gallons, prices that would be within the economic range of municipal users in general, even with additional costs of purification and delivery that would have to be incurred. Furthermore, the high marginal costs are in the Aconcagua-Valparaíso and Santiago regions, the two regions that are most urbanized and most able, by virtue of the concentration of urban activity, to bear relatively high costs of water.

figure of 343,000 hectares being supplied with water for irrigation in the northern provinces appears reasonable in terms of a land constraint and estimates (very crude) of marginal costs of water.

The significance of this reduction in irrigated area is quite a bit greater when converted into agricultural output. If all land that was irrigable were supplied with water, estimated production (at current rates of output per hectare) would be about 48,900,000 metric quintals of wheat equivalent; production from arable dry land would be 13,800,000 metric quintals, for a total of 62.7 million metric quintals of wheat equivalent. If agriculture is extended in all water short regions to the full extent of the available water supply after meeting non-agricultural projected requirements according to the conditions of Case I, output would be reduced by 4.8 million metric quintals of wheat equivalent, or a reduction of 8.3 percent. If irrigated hectareage were further limited by a marginal cost constraint, giving agriculture all water up to the amounts supplied within the constraint, total output would drop another 800,000 metric quintals to an output of 57.1 million metric quintals of wheat equivalent.[1] If we supposed that the marginal cost constraint applied to all water and that agriculture received what was left after meeting Case I non-agricultural requirements, total production in the northern regions would be 700,000 metric quintals less. In both cases, if we were to assign all costs of regulation to agriculture, an extreme step, the average cost of storage would be twelve and a half escudos per metric quintal of wheat equivalent. At full regulation under the same assumed allocation of cost, average

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[1] See Tables XIII-5 and Appendix Table 29 for example of adjustments. Outputs from non-irrigated land is increased as irrigable hectareage is converted to dry land.

cost would be 15.3 escudos per metric quintal. The marginal cost of water, expressed in relation to agricultural output mounts rapidly if we go from a cost constrained supply to full regulation. In going from the condition in which agriculture is a residual claimant to being a full claimant of the cost constrained supply, the water cost per marginal metric quintal of wheat equivalent is 13.8 escudos; in going to full regulation, water cost per metric quintal of wheat equivalent rises to 46.6 escudos.[1]

It is very difficult to know with the data we have, how much production originates on irrigated land of the northern part of the country (Santiago northward) since area that is shown as "irrigated" is not necessarily producing as effectively as an area that enjoys 85 percent security, the security implied in projected storage figures. Thus, the presumed levels of present output in metric quintals of wheat equivalent constitute a measurement that ought to be abandoned in favor of something better at the earliest opportunity. The use of such arbitrary values for determining present (1959) output is likely to be more misleading than when used to compare one hypothetical model with another, in which the relative changes are significant enough to sustain interest in the model even if the absolute values are incorrect. According to all Case I models, whether full regulation or cost constrained, total irrigated hectareage in the six northern regions would fall below 1959 levels. Production would probably rise merely as a matter of higher security of water, but without more information we cannot say by how much. For this reason we cannot

[1] In 1964 the average wholesale price of wheat was about 21 escudos per metric quintal. The fraction represented by costs of water is unknown but must have been quite small. A comparable outlay for water presumably would hold, with minor variation, for other products when expressed as "wheat equivalent."

Table XIII-5

COMPARISON OF OUTPUTS AND COSTS OF WATER, ALTERNATIVE PROJECTIONS FOR AGRICULTURE, 1985

Projection	Output qqm/wheat equivalent	Annual costs of stream regulations (thousands of 1964 escudos
Basic, all irrigable land	62,683,078	Beyond limits of water supply without transbasin movements
Case I, full regulation	57,892,352	84,021
Case I, water supplied to agriculture up to specified marginal cost	57,102,823	47,204
Case I, water supplied to all users up to specified marginal cost, agriculture's needs met after all non-agricultural requirements	56,404,210	37,532

indicate what would be the marginal changes in production (relative to present levels of production) as a result of specified levels of expenditure on stream regulation. The need for such information is paramount. At the moment we shall assume that one or another of our cost constrained models will meet the test of economic feasibility.

In spite of the qualifications with which we must hedge any measure of current output from dry and irrigated land, we shall proceed with its use. The reader will recall that projected increased demand over the present for agricultural products on the basis of Medium B rates of growth were as follows:

Increase in demand with no change in import balance   - 118%

Increase in production to eliminate substitutable imports   - 14%

Total projected increase over present   - 132%

Present output was estimated as being equal to 53,500,000 metric quintals wheat equivalent. In order to meet projected requirements output in 1985 must be equal to 124,120,000 metric quintals. If Chile develops all flows to their theoretical limit, output would be 57.9 million metric quintals at current rates of productivity per hectare. Output per hectare would have to increase by 2.14 times for projected requirements to be met. If Chile applies the marginal cost constraint that we have used in our illustration and agriculture is put into a residual position, (i.e. non-agricultural water requirements are fully met first), total output would be 56.4 million metric quintals. Productivity per hectare would then have to rise by 2.2 times. The difference between these alternative water resource policies would have a negligible effect on the required increase in productivity. Other water resource policies might be stipulated but implied effects on the required increase in

productivity would not yield results that materially differ from those
already indicated. In short, without a doubling, and then some, of
output per hectare, Chile cannot meet its production goals even after all
steps have been taken to expand the area of irrigated land.

Another inference to be drawn from the estimates is also significant.
The difference in annual costs of water between full utilization and a
marginal cost constraint is about 46 million escudos. This amount, sup-
plemented by the additional delivery and on-the-farm costs of bringing
the larger amount of land under irrigation, is an alternative to the
cost of raising output per hectare from 2.14 times its present level
to 2.2 times its present level--i.e., an alternative to the marginal
cost of raising output per hectare by another four percent after it
had already been doubled.

One final note. The water supply available for agriculture, on the
assumption of full regulation, after meeting non-agricultural requirements
of Case III (all downstream intake lost), is about the same as is available
to agriculture if it receives all water after applying the marginal cost
constraint. Output and implied increases in productivity fall between
the cases we have just discussed.

The economic consequences of these adjustments can be stated in
simple terms:

   (1) It is impossible to irrigate all irrigable land without
        transbasin movement of water, (given the coefficients that we
        have used).

   (2) Full regulation under conditions of Case I, allocating to
        agriculture the water that is available after meeting non-
        agricultural requirements, would allow production of 57.9 million
        metric quintals of wheat equivalent, at a total annual cost

of stream regulation of 84 million escudos (1964 prices) and
a cumulated capital investment of 1.0 billion escudos.

(3) Imposing a marginal cost limit to the conditions of Case I,
allocating to agriculture all water available within the
specified limit (except in Antofagasta, where non-agricultural
needs exceed the balance, agriculture's use is reduced), implies
a total output of 57.1 million metric quintals of wheat equivalent,
at a total annual cost of stream regulation of 47 million
escudos, and a cumulated investment of 0.6 billion escudos,
(See Table XIII-6).

The saving of 36.8 million escudos (1964) per year is accompanied by
a reduction in agricultural output of 789,529 metric quintals of wheat
equivalent. This is tantamount to saying that the extension of irrigable
hectareage to the full limit of runoff (with 85 percent security)
involves a marginal water cost of 46.6 escudos per metric quintal of wheat
equivalent. Given the structure of agricultural and non-agricultural prices,
in the world as well as Chile, the extension of irrigable area to the limit
of full regulation is not warranted.

By adopting the marginal costs of water that are implied when non-
agricultural requirements are met after agriculture receives all water
up to the marginal cost constraint, we can ascertain the savings that
would result from moving non-agricultural activity from water short to
water-surplus regions. Since we do not know exactly what is or is not
footloose, we shall assume that one-half of the non-agricultural require-
ments in the four northern provinces and three-quarters of the requirements
in Aconcagua-Valparaíso and Santiago could be transferred to another

Table XIII - 6

COSTS OF STORAGE FOR ALTERNATIVE MODELS WITH STORAGE COEFFICIENT
(to 1,000)

	Annual			Capital		
	Case I Full Regul.	Marginal Cost Constraint Agric. All	Agric. Resid.	Case I Full Regul.	Marginal Cost Constraint Agric. All	Agric. Resid.
Sub-total of 7 northern provinces	60,737	23,920	14,248	743,438	292,765	174,398
Sub-total of O'Higgins-Llanquihue	23,284	23,284	23,284	285,022	285,022	285,022
Grand Total	84,021	47,204	37,532	1,028,460	577,787	459,420

region.[1] Total movable water requirements computed in this way would
be 329 million M^3/year. This quantity could be supplied at zero cost
of regulation at 85 percent security (or more) in the Valdivia-Llanquihue
region, and at relatively low marginal costs (roughly, between one and
four thousand escudos per million cubic meters per year), in the other
regions. Marginal costs of storage of the displaced water in the northern
regions ranges, for this model, between 6,270 and 43,549 escudos per
million cubic meters per year. For the six regions in the aggregate the
savings would be an estimated 12.5 million escudos (1964) annually,[2] of
which 11.5 million originated in the Aconcagua-Valparaíso and Santiago
regions. At the 1964 official rate of exchange this amounts to about
$ 3 million per year, an amount that seems relatively small in comparison
with the violent shifts in population and activity that is implied. If,
however, to the costs of regulation are added costs of high level treatment,
the savings in costs of water by transferring urban activity to water
surplus regions grow considerably.

The assumption that three-fourths of non-agricultural activity in the
Valparaíso-Santiago area can be moved implies a decline in population over
present levels. Let us, then, reduce this percentage to 50 percent,
implying thereby the maintenance of existing population and urban activity

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[1] Given the existing Chilean preference for domicile in the Santiago
area this is probably an extreme assumption. We ignore the problem
of generating excess capacity of overhead services in the losing
region and shortage of overhead services in the gaining region.

[2] Apart from local distribution and treatment costs. If long-line
transmission costs are required in the north, as in some cases they
are, this should be added, because such requirement would not be
necessary in the south.

(since projected urban population for Santiago in 1985 is approximately double the present population). The most extreme measure of potential saving is provided by moving all footloose activity into the Valdivia-Llanquihue region. Here agricultural demands are negligible,[1] if not zero, and projected non-agricultural requirements range between 56 and 186 million cubic meters per year, depending upon the model. The flow equalled or exceeded 95 percent of the time,[2] is 22,088 million cubic meters per year. The amount of storage necessary to raise the level of security for that flow to 100 percent would be 475 million cubic meters.[3]

If waste dilution requirements are proportional to non-agricultural water use, we can conclude that at zero treatment flow requirements for waste dilution of the six northern regions would be about 11,000 million cubic meters per year. This quantity, plus the intake requirements of 239 million cubic meters per year (one-half the projected Case I non-agricultural requirements) is well within the capability of the Valdivia-Llanquihue region at zero costs of regulation for 95 percent security. Consequently, in addition to saving 8.7 million escudos (less than the 13 million escudos discussed above because only one-half of non-agricultural

[1] The photogrammetric survey shows 16.4 hectares irrigated in Osorno, 0.7 hectares in Llanquihue, and 541.4 hectares of mixed classification in Osorno. We assumed that there was no demand for irrigation in the three provinces--Valdivia, Osorno and Llanquihue.

[2] As defined by the Centro de Planeamiento, see above.

[3] Ibañez, Harboe, and Poblete, op. cit. This can be compared with the 3.5 billion cubic meters needed to raise the minimum flow in the six northern regions to 4,871 million cubic meters per year with 85 percent security.

water use in the Aconcagua-Valparaíso and Santiago regions are transferred), 22.7 million escudos (including collection costs) in treatment costs at 90 percent treatment would be saved.[1] Total savings would be about 31.4 million escudos, or approximately $ 8 million, annually. Cumulated capital savings would be on the order of $ 100 million, since we have assumed annual costs to be 8.17 percent of capital costs.

Net capital (and annual) savings would be somewhat less, because of the additional housing costs that would be incurred against a slightly lower average winter temperature and considerably greater rainfall. There might be a net change in transportation costs, but whether positive or negative cannot be ascertained without further investigation. There might also be a net change in per capita costs of other urban services; but again the direction and magnitude of difference cannot be determined without additional study. The possibility of saving a capital sum of about 377 million escudos in costs of water (regulation of supply plus treatment) over the next twenty years is, however, attractive enough to warrant further detailed study. Chile might decide that the benefits of living in the Valparaíso-Santiago area are worth the costs, (either in the form of capital costs to provide an adequate quantity of water of suitable quality or in the form of deterioration in the quality of water and regularity of supply), but the benefits of investing this large sum in alternative activities has an attraction of its own.

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[1] Savings at 35 percent treatment would be 12.8 million escudos, but since Santiago accounts for 84 percent of the treatment costs, and because its inland position will probably compel high level treatment, it is more reasonable to assume 90 percent.

Chapter XIV

THE QUESTION OF WATER QUALITY

In the previous chapter it was noted that if water quality became a matter of such concern that a standard was adopted, whether formally or informally, and whether by zoning or other type of regulation, substantial savings would be made by inducing the migration of non-agricultural activity from the water-short to the water-surplus regions, especially to such cities as Valdivia and Puerto Montt, located on Tidal waters. However, it is in this southern region, plus Cautín province immediately to the north of Valdivia, that instream quality maintenance is likely to be of greatest consequence. Here is the famed lake region of Chile, one of the outstanding fresh water sport fisheries of the world. While the rivers of the region can assimilate a certain amount of waste, their natural beauty would undoubtedly be defiled by a substantial increase of waste-producing activity along their banks, even on the assumption that treatment would reach a high level. For this reason, and because the reversal of the "natural" extrapolation of events from the past to the future that is implied in such population redistribution raises forbidding obstacles, we shall return to our basic projections as modified by Case I in order to examine the conditions under which water quality can be maintained. Our analysis will be limited to the maintenance of quality at a level of 4 milligrams per liter of dissolved oxygen.[1] The output of pollution and dilution requirements after treatment were inferred from coefficients based upon studies prepared for the United States.

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[1] The choice of 4 mg/l of dissolved oxygen is arbitrary. Should further investigation reveal that a lower (or higher) oxygen content is appropriate for planning purposes, it would not be difficult to change all relevant flow and cost figures.

Costs of treatment were inferred from data taken from the United States, but reduced by fifty percent in agreement with some slight evidence regarding construction costs in Chile vis-a-vis the United States.[1]

Treatment costs were estimated for 35 percent, 70 percent, and 90 percent levels of BOD removal. Collection costs were assigned only to municipal treatment and were assumed to be one-half the U.S. per capita figure. Annual costs were assumed to be based on an 8 percent interest rate rather than the 2 1/2 percent used for the United States.

The costs of maintaining water quality are the sum of treatment costs and costs of waste dilution flows - i.e. the costs of maintaining a flow greater than is necessary to meet offstream intake or losses. In order to estimate these costs as conservatively as possible (i.e. by adopting a model for which the marginal costs of flow would be as low as possible) we have based all cost estimates on the marginal cost constraining variant of Case I for which agriculture was a residual claimant after non-agricultural water needs were met.

In order to make the most of a given flow we shall assume that all water not consumed upstream is available for both waste dilution and downstream intake. Therefore, only the excess of waste dilution over downstream intake is charged against quality maintenance. (In computing upstream losses and irrigated hectareage all agriculture was assumed to be upstream, since a limited amount of water will go farthest if irrigated areas are far enough upstream to allow recovery of return flow).[2]

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[1] According to Walter A. Castagnino, Engineering Adviser, Natural Resources Division, Economic Commission for Latin America, capital costs of plants providing primary and secondary treatment, are about $ 37.50 per capita in the Unites States and about $ 20.00 per capita in Chile.

[2] In the northern regions irrigation return flow will probably contain dissolved minerals. We may, therefore, be overstating the possible usability of water downstream, both for agricultural and non-agricultural purposes. Subsequent investigation may reveal that a more accurate picture is yielded by assuming that all irrigation is downstream - i.e. all intake is lost.

Tables XIV-1 through XIV-3 and Appendix Tables 30, 31 and 32, show estimated costs of collection, treatment, and flow augmentation for various treatment levels. (Industrial waste treatment costs are based upon the number of P.E.'s produced for Medium B projections).

What should one do in Antofagasta and Santiago, where the supply of water is too low to maintain a dissolved oxygen content of 4 mg/l even if subjected to complete regulation and treatment is extended to 90% BOD removed? Should regulation be carried to the limit anyway? Should treatment be carried to 90 percent? At full regulation and 90 percent treatment about 60 percent of Antofagasta's flow dilution requirement can be met, but only about 16 percent of Santiago's. For the purpose of Table XIV-2 we have assumed that a maximum effort was made, and have ignored the possibility of 35 percent and 70 percent levels of treatment, since at these lower levels of treatment flows would be hopelessly inadequate. In regions of limited supply, only the costs of 90 percent treatment and full regulation were estimated. A reasonable alternative for the seven northern provinces would be 90 percent treatment without flow regulation, since the cost of augmenting flow is very high relative to the probable additional benefit of maintaining instream water quality.

Costs of treatment were assumed to be incurred only for wastes discharged at inland points. Wastes produced along the coast, domestic and industrial, were assumed to be discharged into the sea without treatment. It was not possible to establish what effect this would have on the usability of beaches for recreation and the productivity of coastal fisheries. The assumption coincides with present practice. In coastal areas that are summer resorts it is likely that at least primary treatment will become necessary. Hence treatment costs for the Aconcagua-Valparaíso provinces are probably under-estimated.

Table XIV-1

TREATMENT COSTS PER MUNICIPAL AND INDUSTRIAL POPULATION EQUIVALENT

	South Pacific		Chile							
	Annual costs without collection (dollars 1960)	Capital costs without collection (1) x 22.22 (dollars 1960)	Municipal annual costs without collection (2) x .0817 (dollars 1960)	Collection costs (dollars 1960)	Total municipal annual costs (dollars 1960)	Total municipal annual costs E° 1964 (5) x 1.6	Industrial, annual costs (2) x .0937 (dollars 1960)	Industrial annual costs E° 1964 (7) x 1.6	Collection costs (4) x 1.6 E° 1964	Municipal annual costs without collection (6) - (9) E° 1964
	(1)	(2)	(3) a/	(4)	(5)	(6) b/	(7) c/	(8)	(9)	(10)
35	.67	14.89	1.22	1.30	2.52	4.03	1.40	2.24	2.08	1.95
70	1.22	27.11	2.21	1.30	3.51	5.62	2.54	4.06	2.08	3.54
90	1.64	36.44	2.98	1.30	4.28	6.85	3.41	5.46	2.08	4.77

a/ 8 percent interest and 50 years amortization.

b/ US$ 1 = E° 3.2 = official 1964 average rate. We supposed Chilean costs to be 1/2 of U.S. costs.

c/ 8 percent interest and 25 years amortization.

Table XIV - 2

ESTIMATED COSTS OF QUALITY MAINTENANCE (4 mg/l of D.O.). CASE I. AGRICULTURE RESIDUAL,

MARGINAL COST CONSTRAINT 1985, MEDIUM B d/

(1964 E° 1,000)

Province	Annual Treatment cost (excluding collection costs)			Additional annual cost of flow			Annual cost of quality maintenance treatment plus flow		
	35%	70%	90%	35%	70%	90%	35%	70%	90%
Tarapacá	55	100	134	a/	109	0	a/	209	134
Antofagasta	376	682	919	a/	a/	138	a/	a/	1,057
Atacama	310	563	758	a/	a/	774	a/	a/	1,532
Coquimbo	366	665	896	a/	3,909	376	a/	4,574	1,272
Aconcagua-Valparaíso	1,078	1,957	2,636	a/	a/	1,446	a/	a/	4,082
Santiago	11,457	20,793	28,008	a/	a/	(11,900)a/	a/	a/	39,908
O'Higgins-Colchagua	949	1,722	2,320	2,987	1,314	456	3,936	3,036	2,776
Curicó-Linares	1,130	2,051	2,762	1,875	--	--	3,005	2,051	2,762
Ñuble	487	884	1,191	2,405	1,104	440	2,892	1,988	1,631
Concepción-Cautín	3,655	6,628	8,919	0	0	0	3,655c/	6,628	8,919
Valdivia-Llanquihue	Minimum flow dilutes at zero treatment			0	0	0			
Total of above provinces	19,863	36,045	48,543	7,267	6,436	3,330 (15,530)b/	13,488	18,486	64,073

a/ Flows are beyond average annual flow. Figures in parenthesis are additional cost to achieve full regulation.

b/ Includes added costs of full regulation in two regions, although water quality would fall short of 4 mg/l of dissolved oxygen.

c/ At zero treatment, the added cost of waste dilution flow would be 3,330,000 escudos - roughly the cost of 35 percent treatment.

d/ See Appendix table 32 for detail.

Table XIV-3

LEAST COST COMBINATION OF QUALITY MAINTENANCE

Annual Costs in E° 1.000 (1964)

Province	Level of treat-ment (percent-age)	Total Annual Cost Excluding collection	Annual treat-ment cost Excluding collection	Annual Storage Cost	Extra flows required (million m³/yr)	Agricul-tural gross use (m³/yr/ha)	Added area irrigable (hectares)	Total annual costs including collec-tion
Tarapacá	90	134	134	0	0	34,400	0	190
Antofagasta	90 a/	1,057	919	138	15 a/	34,400	436 b/	1,446
Atacama	90	1,532	758	774	48	21,500	2,233	1,863
Coquimbo	90	1,272	896	376	55	21,500	2,558	1,634
Aconcagua-Valparaíso	90	4,082	2,636	1,446	89	21,500	4,140	4,991
Santiago	90 a/	39,908	28,008	11,900	330 a/	21,500	15,349	49,921
O'Higgins-Colchagua	90	2,776	2,320	456	145	-	-	3,602
Curicó-Linares	70	2,051	2,051	0	0	-	-	3,024
Ñuble	90	1,631	1,191	440	94	-	-	2,122
Concepción-Cautín	35	3,655	3,655	0	0	-	-	5,044
Valdivia-Llanquihue	0	0	0	0	0	-	-	614
Chiloé	-	-	-			-	-	15
Aysén	-	-	-			-	-	-
Magallanes	-	-	-			-	-	-
Total	-	58,093	42,568	15,530	776	-	24,716	74,456

a/ Assumes that flows are raised to full regulation and treatment carried to 90%; flows so marked are quantities available, not quantities required.

b/ Is there land?

Annual treatment and collection costs for the country as a whole were estimated to be 37 million escudos for 35 percent treatment, 54 million escudos for 70 percent treatment, and 67 million escudos for 90 percent treatment. Of these totals, about 60 percent were attributed to the Aconcagua-Valparaíso and Santiago regions. Santiago itself accounted for more than half the national total.

The growth of collection costs is inevitable even with little or no treatment or dilution. Water borne diseases in Chile are more likely to be caused by pollution of ground waters (that then infiltrate into water pipelines) by inadequate sewage systems than by inadequate treatment of municipal water. Many sewage systems are relatively primitive - e.g. in Santiago they must be flushed - and are likely to be replaced as soon as possible. Hence, we have assumed that collection costs are a direct function of total urban population rather than of the increase between now and 1985 in urban population.[1]

No additional factor was introduced for the costs of collecting industrial wastes. Altogether, collection costs were estimated at about 16 million escudos annually (1964 prices). They do not vary with the level of treatment.

In Table XIV-2 the costs of treatment (without collection) and costs of additional flow are added together to measure the costs of quality maintenance.

Each region has its own response to the maintenance of a quality standard. Tarapacá, for example, in spite of being a water-short region, needs no additional dilution if treatment of upstream wastes is carried to 90 percent BOD removal. Neither Antofagasta nor Santiago can meet a standard of 4 mg/l of dissolved oxygen even with full regulation. This

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[1] Most likely this assumption results in some overstatement of required sewage outlays.

suggests that not only will treatment have to be carried to high levels but that other techniques, such as artificial aeration might be necessary. Atacama and Aconcagua-Valparaíso can maintain water quality only if treatment is carried to 90 percent; Coquimbo and Tarapacá can maintain water quality with treatment as low as 70 percent.

All regions from O'Higgins-Colchagua southward can meet the dissolved oxygen standard by various combinations of treatment and flow. Where there is such a choice presumably the selection will depend upon the combination that costs the least, unless the possibility of earning income warrants a more expensive alternative, (e.g. hydroelectric power revenues). In Curicó-Linares the least cost combination is at 70 percent treatment, and in Concepción-Cautín at 35 percent. (Zero treatment with augmented flow would cost about the same). In the Valdivia-Llanquihue region the projected discharge of untreated wastes would not reduce instream content of dissolved oxygen below 4 mg/l even at zero treatment and present minimum flows.

If we assume that whenever full regulation falls far short of meeting required flows no expenditure is incurred for waste dilution but that otherwise such expenditure is made, annual costs of dilution range between 1.3 million escudos for 35 percent treatment (but all northern regions fail to meet the quality standard) to 3.5 million escudos at 90 percent treatment, at which all regions except two meet the standard.

The least cost combination of flow and treatment is shown in Table XIV-3. Altogether, quality maintenance would cost 58.1 million escudos per year, (exclusive of collection costs) of which 42.6 million are treatment costs and 15.5 million are storage costs. The "minimum cost" quality maintenance program [1] is estimated to cost about one-half of the amount that would be required to regulate flows for all other purposes. If only treatment were

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[1] This is "minimum" only within the limits of the underlying assumptions of waste produced and the technology of waste treatment. If these assumed conditions are changed another combination might be "minimum".

provided, the total costs of quality maintenance would fall by 27 percent.
Including collection and dilution, total costs of quality maintenance are
estimated at about 75 million escudos (1964) annually.

Except for Ñuble and O'Higgins-Colchagua, which together account for
only 6 percent of total waste dilution costs, all required waste dilution
flows of the minimum cost model are to be found in the northern part of
the country where they could serve agriculture if recaptured before discharge
to the sea. Land area so served would be determined by gross rather than
net water requirement per hectarea, since the land would be "downstream"
rather than "upstream". Dilution flows required in O'Higgins-Colchagua and
Ñuble would have no additional use, unless such flows were part of a
regulated release for hydroelectric power, since there is no irrigable land
that would not already be irrigated. (All Ñuble requirements are computed
at loss rates since Ñuble is "upstream". O'Higgins-Colchagua downstreams
intake requirements have already been taken into account in fixing the
"extra" waste dilution flows at 144 million cubic meters per year. Of
course, new developments not anticipated in our model might make use of
the water).

Total irrigable area that could be served by waste dilution flows
amounts to 24,700 hectareas, provided additional downstream regulatory
storage were available. Conceivably such reregulation might be met by
small on-the-farm ponds, since the amounts of water and irrigable area are
not large. The additional area supported by dilution flows would not
offset the relatively high cost of dilution water. (The cost of waste dilution/
excluding O'Higgins-Colchagua and Ñuble - is about 27,300 escudos per
million M^3 per year, or, if assigned wholly to agriculture, 590 escudos
per hectarea per year).

The question of water quality involves the two kinds of action that have been discussed: treatment of wastes before discharge and dilution of the discharged, treated effluent. Because of Chile's limited experience with matters pertaining to water quality there are few supports for any extrapolation of policy into the future, and because of past unconcern there is little information. The figures we have used and the conclusions we have reached are wholly inferential and based upon translations of foreign experience and data to Chilean waters. The need for a Chilean "import-substitute" for information is obvious to anyone who begins study of Chilean water resource problems.

We have said nothing about the cumulated capital investment that maintaining high quality water would require. Capital costs are assumed to be approximately twelve times annual costs, based upon 8 percent interest and 50 year amortization. A collection system alone (whose costs have not been included in several of the previous tables), would require a total investment by 1985 of approximately 200 million escudos (1964). Treatment plants, for the least cost combination of treatment and flow, would require another 500 million escudos. The added cost of flow would require another 186 million escudos. Altogether, the cumulated capital cost by 1985 amounts to about 900 million escudos (1964) (about $300 million at 1964 official exchange rates).

A minimum program (as distinct from the minimum cost program discussed above) that would provide primary treatment to all domestic and industrial wastes discharged upstream, except where present minimum flows would adequately dilute untreated wastes, would cost 16 million escudos annually for collection and about 20 million escudos annually for treatment, or about one-half the cost of a program designed to meet a DO standards of 4 mg/l. Its capital costs would be about 432 million escudos.

Chapter XV

VARIATIONS ON THE MAJOR THEME

Higher Degrees of Security

All estimates of storage costs are based on the assumption that a
certainty of 85 percent was assured for the indicated flows. This means
that three years out of twenty, on the average, flows will fall below the
specified quantity.

Our data enable us to give approximate answers to two additional
questions: (1) What would be required to raise the level of security to
100 percent? (2) What flows have a certainty of 100 percent when the
indicated flows have a security of 85 percent?[1]

If existing flows equalled or exceed 95 percent of the time are raised
to 100 percent certainty, non-agricultural requirements, assuming high
levels of recirculation for industrial uses, can be met with no difficulty,
(at the expense, of course, of agriculture). This can be accomplished with
less storage than is specified for Case I, marginal cost constraint,
agriculture as residuary.

If, on the other hand, there is a desire to raise the level of security
of all users from 85 percent to 95 percent or 100 percent, the amount of
storage is significantly increased. Table XV-1 shows the percentage changes
in storage that would be needed beyond that required for 85 percent
security. Storage volumes would have to be raised by amounts ranging
between 2 percent and 55 percent in order to reach 95 percent certainty;
and by amounts ranging between 3 percent and 68 percent to reach 100
percent certainty. In several regions the additional storage requirement
appears to be insignificant, relative to all other uncertainties with

1/ See earlier comments on "100% certainty".

which our estimates deal. These regions are Tarapacá, Antofagasta,
Aconcagua-Valparaíso (for 95 percent certainty), Santiago, and Ñuble.
Elsewhere, where storage volumes would have to be increased by amounts
ranging between 30 percent and 60 percent, the economic effect, when
translated to marginal cost would be quite constricting.

The amount of storage required for Case I, marginal cost constraint,
agriculture residual, will provide flows with 100 percent security that
are roughly 90 percent of the amount provided with 85 percent security.[1]

Non-agricultural requirements fall well within these quantities unless
all downstream industries, foundries and power plants, as well as municipal
systems, use water on a once-through basis. If, however, steam power plants
and mining activities recirculate, so that their intake is equal to their
losses, downstream flow, when highly regulated, is ample enough to
allow manufacturing plants and municipalities to use water without re-
circulation. A further safety margin for non-agricultural uses is provided
by the additional storage to meet seasonal irrigation requirements.[2]
Whether the storage does in fact provide a safety margin for non-agricultural
uses will depend, of course, on the amount of advance notice that is in
possession of those responsible for controlling releases from storage and
on their authority to withhold the water for agriculture.[3]

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[1] Estimated from curves derived from flow-storage relationships supplied
by Ricardo Harboe.

[2] Except in Aconcagua-Valparaíso and Santiago.

[3] The fact that the runoff record is relatively short in many regions
means that our estimates of flow-storage relationships may be in error.
Furthermore, a given volume of storage will provide 100 percent
security of a given flow only if the administration of releases follows
a rule consistent with such objective over many years, and not only
during a period of water shortage.

Table XV-1

STORAGE REQUIREMENTS FOR HIGHER LEVELS OF SECURITY

Province	Storage to raise .95% flow to 100% security a/ (million m³)	Percentage increase over store for 85% security to assure security of: b/		Minimum flow at marginal cost constraint, agriculture residual	
		95%	100%	85% security (million m³/yr)	100% security (million m³/yr)
Tarapacá	0.3	2	3	56	53
Antofagasta	0.52	3	18	88	83 c/
Atacama	2.34	29	52	113	100
Coquimbo	9.1	33	53	601	480
Aconcagua-Valparaíso	13.0	16	28	1,093	980
Santiago	65.0	5	8	2,920	2,830
O'Higgins-Colchagua	26.0	55	68	4,557	4,040
Curicó-Linares	130.0	32	51	7,946	6,300
Ñuble	39.0	11	15	2,333	1,830
Concepción-Cautín	118.0	42	61	10,940	10,000 c/
Valdivia-Llanquihue	476.0	-	-	22,088	22,000 c/

a/ Centro de Planeamiento - i.e. storage to assure at 100% certainty flow now equalled on exceeded 95% of the time.
b/ Centro de Planeamiento. Based on storage for average flow.
c/ Rough estimate; curves converging.

Sequence and Timing of Additions to Storage.[1]

Nothing has been said about problems of selecting the time when particular increments to storage capacity will be supplied, except the obvious fact that we have been discussing assumed conditions in 1985; nor, except by passing reference, have we discussed the possibility of alternative sequences by which reservoirs of different capacity could be added. Costs of storage were based upon ex ante schedules constructed by following the rule that large reservoirs would be built first, followed by reservoirs of successively smaller size. We assumed that reservoirs would vary in size as the total volume of storage would grow toward full regulation, but this assumption is itself subject to correction by better information.

Since the storage and treatment capacity with which our models deal are capacities in addition to what now exist, and since certain deficiencies - such as in food production and the water quality of certain regions - already exist, there is included in our models requirements for water to meet a backlog of need beyond the amounts that are dependent only upon future growth of population and demand. In order to overcome backlog "need", therefore, a relatively high rate of investment in the near future would have to be undertaken, after which, the growth of investment in water resources facilities could be based upon projected growth rates of water use. Because the planning, design, and construction of river basin projects usually require a lead time expressed in years rather than months, and because the deficiencies in data needed for rational planning

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require, in many instances, decades before they are remedied, the planning and data collection processes must reach a peak as soon as possible. Where adequate hydrologic records require more time than is available between now and the date that designs will be fixed and construction begun, substitute forms of information must be sought that will bridge the gap without incurring large risk of error. Not only are river basin projects expensive and long in gestation; they usually result in irreversible changes of a river's regimen and should not be undertaken until the risk of error is reduced to tolerable size.

Problems of timing are related to the general problem of capital shortage and the possibility of using alternative techniques, at least in the short run, to meet a given objective. For example, increases in agricultural productivity can be quickly achieved by adopting appropriate on-the-farm practices within the limits of available water supplies. Changes such as increased use of fertilizer, which are in perfect complementarity with investment in water resources, can be undertaken immediately without danger that later findings will prove them wasteful.

Beyond these obvious observations, which are made only to avert the accusation that they have been ignored, we shall not go. Further studies in greater detail are needed in order to yield more specific conclusions. We can, however, add a little to what has already been presented regarding the sequence in which reservoirs of different size are added.

Suppose the order in which reservoirs are added is reversed, beginning with the smallest instead of the largest. Presumably there is no effect on total costs if regulation is extended to the theoretical limit. But if regulation falls short of the hydrologic limit because an economic limit is encountered, and if the economic limit is determined by the marginal

costs of storage, there can be a significant difference in costs between the two sequences. By beginning with large reservoirs [1] and proceeding to the smaller we take advantage of the fact that the costs of the first increments of flow are low for two reasons: (1) they come "early" in the movement along the flow-storage curve (which displays diminishing marginal physical productivity of flow) and (2) they utilize the lowest costs per unit of storage that we postulate for each region. By reversing the sequence, so that the first increments to storage come from high-cost reservoirs, declining marginal physical productivity and declining unit costs of storage have opposing effects. The decline in marginal physical productivity is, however, the stronger force, so that the general movement of the marginal cost curve is still upward, [2] but at a markedly lower rate

[1] The term "large reservoirs" is a proxy for "low cost" reservoirs; by "low cost" we mean reservoirs whose cost per unit of impounded water is low. These circumlocutions reflect the fact that we do not have for each water resource region a schedule of reservoir sites whose costs of storage can be related to the total amount of regulation achieved at any given time. In the absence of such schedule we have arbitrarily assumed that there is an inverse relation between capacity of a reservoir and cost per unit of capacity. Furthermore, the analysis has rested upon the aggregation of flows of all rivers in a water resource region into a single flow-storage relationship, which conceals intra-regional variation in this relationship. Finer detail would show that a reservoir of given capacity on River X would add more to the control of flow, because of the natural pattern of variability of flow, than a reservoir of equal capacity on River Y within the same region. Further variation on this theme is encountered when the complementarity or competitiveness of uses is taken into account and systemic inter-action of demand is added to systemic interaction of supply, both converted from physical into monetary units. The full accounting of such interaction and the selection of a development program in light of an optimizing guide is the objective of operations analysis of river basin programs.

[2] These conclusions rest upon the data we have and the generalized cost of storage schedule that we have drawn from the data. Should further investigation reveal a different relationship between unit costs of capacity and size of reservoir (or between unit costs of storage and any other characteristic of storage sites that result in an upward sloping supply curve of storage capacity), the effect of changing the sequence of reservoirs might be different. Marginal costs of flow could be constant or declining.

of ascent.[1]

The general pattern that is revealed by comparing marginal costs of
"largest first" with "smallest first" sequences, is illustrated by the
accompanying graphs. Smallest first marginal costs are below Largest first
marginal costs for the earliest stages of development, rise above in the
middle stages, and fall below in the final stages. Cumulated capital costs
of Smallest first exceed cumulated capital costs of Largest first, once a
given amount of reservoir capacity has been installed and remains above
until full capacity has been reached.

In none of these comparisons has the question of time as a separate
dimension been considered. Time appears in several manifestations: big
reservoirs take longer to fill than little reservoirs on the same river;
the complementary activities of farm preparation take time; much of the
projected demand will not appear until some time in the future, yet work
must begin now in order to get ready. Real costs of construction may rise,
fall, or remain constant. Land values are likely to change.

1/ Another consideration is the fact that a "largest first" sequence may
imply relatively large capital outlays in the immediate future and
smaller capital outlays in the more remote future. If interest rates
are constant over the entire period of investment the present value of
capital costs would, therefore, be higher under a "largest first" sequence
than under a "smaller first" sequence. If interest rates in the more
remote future are expected to decline below near-term levels, the
difference between the two sequences in present value of capital costs
would be even greater.

It should also be noted that a "largest first" sequence does not
necessarily imply that capital costs will be higher in earlier years than
in later years of the investment period. It all depends on the volume
of new storage that must be added in each year. On the assumption
that a constant volume of storage is added each year, annual costs of
the "smallest first" sequence will be higher than costs of the "largest
first" sequence, since costs per cubic meter of capacity are higher
for small than for large reservoirs.

In general the stream of costs and benefits over time will be different for large and small projects. Under certain circumstances the choice of "smallest first" (or a combination of small and large) is more efficient than a sequence in which each succeeding reservoir requires higher unit costs of capacity. Small reservoirs may be more economical than large at certain stages of development, even if costs per unit of capacity are higher, because they avoid or reduce the costs of excess capacity or because of capital rationing.

If the experience of the United States is typical,[1] we can conclude that most countries follow a sequence of "smallest first"; which means that the economic limits of water resource development are extended farther than if the reverse policy had been adopted from the beginning. The cost of the extension of the economic limit is a greater cumulated capital outlay for intermediate levels of development. These relationships are indicated by points A, B, and C on Graphs XV-1 and XV-2. Marginal and cumulated capital costs of regulation to OA are less by following the smallest first sequence. Regulation to OB costs less by following the largest first sequence. At point C, the smallest first sequence displays lower marginal but higher cumulated capital costs than the largest first sequence.

Graphs XV-3 and XV-4 are based upon the unit cost and flow-storage functions that were used in Chapter XII. Atacama and Santiago were selected for illustrative purposes without special justification. Shown are the curves for cumulative capital costs and marginal annual costs per million cubic meters of flow. The values are taken from Appendix Table 20, 23, 33, and 34 and are plotted as step functions. These curves, based as they

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[1] Reservoirs in the United States, U.S. Geological Survey, Water-Supply Paper 1360-A, Government Printing Office, 1956, pp. 9-10.

Graph XV - 1

MARGINAL COSTS OF FLOW OF ALTERNATIVE SEQUENCES OF RESERVOIRS
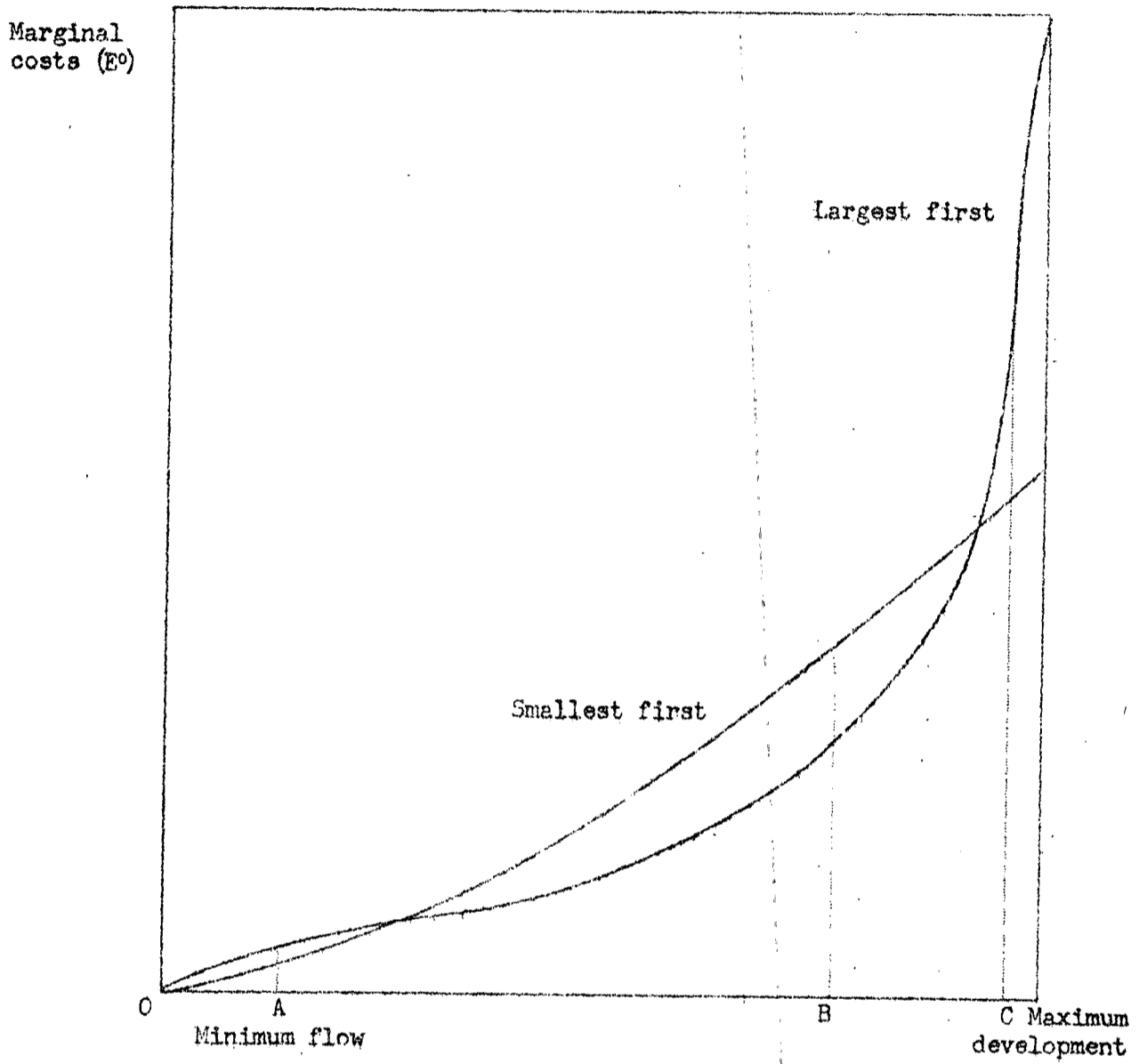
Graph XV - 3

ATACAMA : CUMULATIVE CAPITAL AND ANNUAL MARGINAL COSTS

Marginal cost (E° 1000)   Capital costs (E° 1 000000)

Marginal costs - Largest first

Cumulative capital costs - Largest first

Marginal costs - Smallest first

Cumulative capital costs - Smallest first

Cum. Cap.
Smallest
First

Marginal
Smallest
First

Cum. Cap. Largest First

Marginal Largest First

Minimum flow (Million M³/c,)
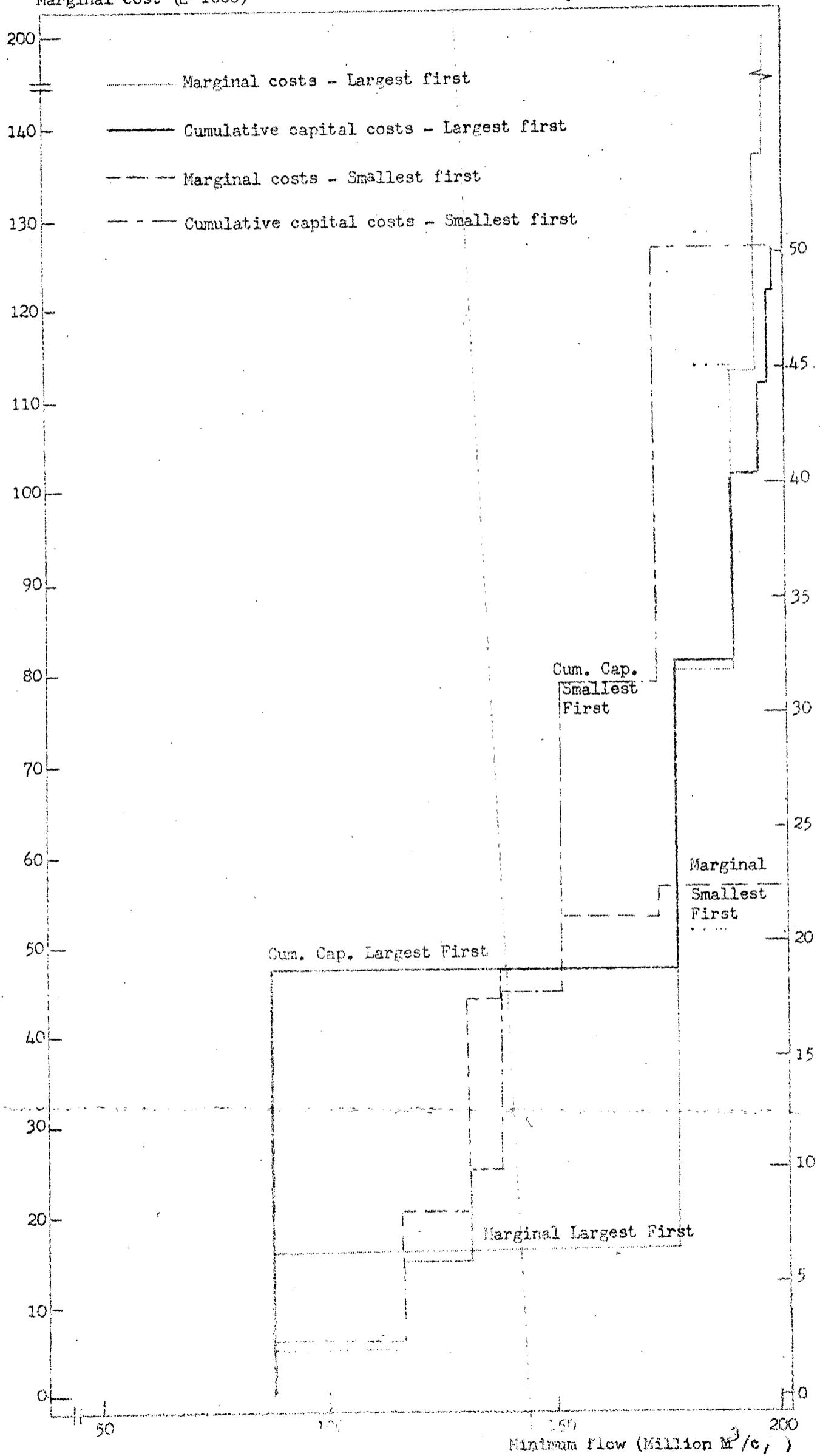
are on hypothetical rather than actual values indicate the importance of
having the underlying information. For Santiago, an increase in minimum
flow to, say, 2,850 million cubic meters per year can be acquired for a
cumulated capital outlay of 90 million escudos by following the largest
first sequence and for 190 million escudos by following the opposite
sequence. The advantages are reversed, however, for the first 500 million
cubic meters of additional minimum flow.

In Atacama, the advantage of a smallest first sequence persists over
a relatively longer interval of regulation than in Santiago. Marginal costs
of the smaller first sequence rise rapidly, however, and could inhibit
development more than a largest first sequence. Only a very restrictive
and prolonged capital constraint coupled with relatively high marginal
benefits would justify a smallest first sequence.

Because the marginal and cumulative costs of regulation ex ante are
dependent upon the policy that has been followed ex post, storage supply
curves are not as determinate as may have been implied in Chapter XII.
However, within a given planning horizon and on the basis of a given
historical record, most indeterminacy resting upon choice of sequence can
be removed.[1]

If the information on which the marginal cost constraints were
determined faithfully reflects actual differences in the marginal
productivity of irrigated land in different provinces (other inputs
being given), the optimum sequence of investment would be reasonably

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[1] Indeterminacy associated with the probability of guessing what the
future will bring still remains. Note also that in computing the
amount of storage (and change in regulated flow) permitted by an
upper limit on marginal cost, the method of interpolating linearly
between zero regulation and the first interval makes more sense if
a "smaller first" rather than "larger first" policy had been
followed, whereas interpolations made within "later" intervals
contain less error if a "larger first" policy had been followed.

well correlated with the gaps that now prevail between present levels of
regulation and projected levels of regulation in each water resource region.
One can hardly attach such credibility to the figures we have fabricated.
Presumably the tax assessment schedule reflects agricultural productivity,
but the evidence appears to be contradictory. One would imagine that yields
of a well-watered hectare of land in northern (i.e. Tarapacá and Antofagasta)
coastal regions would be highest in the country, because of mildness of the
climate and duration of the growing season,[1] yet on the average, irrigated
lands around Santiago have the highest assessed values. Should the relative
physical productivity of irrigated land be different from the relative value
for tax purposes, the difference may reflect several factors, among which
is cost of transportation to the central part of the country. Under these
circumstances, any significant lowering of transportation costs would alter
the relative merits of a given geographic sequence of water resource invest-
ments.[2]

Several other factors must also be taken into account. One is the
crop mix, which today may reflect security of water supply on the one
hand and, on the other, the fact that the overwhelming mass of Chileans
exist on subsistance incomes, the purchasing power of which is protected
by selective price controls. Price controls, in turn, have generated
other controls, the total effect of which cannot always be explained by
economic logic.[3] As an example, one might cite the governmental plans for

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[1] The oases of Pica and Mantilla, inland in the province of Tarapacá, have
agricultural land that is assessed at the highest of all values in Chile.
Coastal areas of the Norte Grande, at lower elevations, have much lower
valuations.

[2] Differences in land values reflecting prospective shifts from agricultural
to urban uses could, of course, persist after transportation costs were
reduced.

[3] An alleged instance of the haphazard effects of government policies is the
current (October 1965) shortage of sulphur, used as an antifungicide in
the vineyards. Chile apparently has no shortage of sulphuric raw materials
but, it is alleged, has controlled price so effectively that production
fails to meet demand)

agricultural production in the next five year period.[1] These plans call

for an increase in wheat cultivation from 878,000 hectares in 1965 to

967,000 hectares in 1970, but no increase in the area devoted to vineyards.

Since the gross product per hectare is six times higher in vineyards than

wheat (see Table IV-3), since land is a major constraint, and since vineyards

do not require unusually large amounts of water, the proposed changes in

cropping areas probably cannot be justified by economic criteria.[2]

A serious error in the schedule of marginal cost constraints could

have been introduced by the present security of water supply. Only

knowledge of production functions for various cropping patterns can eliminate

the possibility of error. If the natural variability of flow in a given

region is such that relatively large amounts of storage are needed to

regulate irrigation flows, agriculture in that region will have adopted

an extensive, minimum risk, pattern of cultivation rather than an intensive,

high risk, pattern. Present land values would reflect this circumstance

and yield a corresponding schedule of marginal cost constraints. By

uncritically adopting such constraints as the basis of policy, one fails

to explore the possibility that a large scale change in the character of

the agricultural economy might warrant much greater development of water

resources. On the other hand, short of desalination and transbasin

movements, potentials are limited no matter how optimistically they are

viewed.

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[1] Unpublished data supplied by Klaus Gerber, National Planning Office.

[2] It is likely that value added per hectare is correlated with gross
product per hectare. In the five year period 1951-55, Chile exported
an annual average of 6,600,000 liters of wine; in 1960, exports
were 1,900,000 liters. There does not appear to have been a vigorous
attempt to substitute exports of wine for imports of wheat. It may be
that the area into which new wheat production will go is not suitable for
vineyards. But why expand wheat production, when of all crops it has the
lowest gross yield per hectare (except for pasture)?

Whether we have grossly overstated or understated irrigation possibilities in any one region, or in all regions together, has relatively little importance for the country as a whole. The limited supply of land is the major constraining factor in total agricultural output. If we have mis-stated the costs of water, "required" future output per hectarea may be only 2.0 times present output instead of 2.2; or it may be 2.4 or 2.5 times the present. But these variations are relatively small compared with the big jump in productivity that is obviously needed if agricultural objectives are set against land resources.

Other Projected Rates of Growth

Virtually all of the analysis up to this point has been based upon the medium rate of population growth and the high rate of growth of GNP. We previously concluded that the differences between this projection and that based upon the medium rate of population growth and low rate of growth of GNP did not warrant detailed study. This conclusion rested upon the fact that because of its limited amount, irrigable land would be put to maximum use at either projection, and the other variations in water requirements were relatively small.

The effect of broadening the range of possibilities, by associating low rates of population growth with low income projections and high rates of population growth with high income projections would not materially change the results, mainly because the range between high and low rates of population growth and high and low rates of change in income growth were narrowly separated in the first place. In light of the poor state of basic data, an elaboration of the implications of "really" extreme possibilities does not seem worth the effort. Should the matter be pursued further at a later date, it is likely that the most important effects of adjusting to a wider range of possibilities would be most important for industrial uses of water and accommodation to the threat of

pollution. This is indicated even with the narrow range of possibilities
we have considered. (See Table II-5). The difference between the lowest
rate of growth and the highest in the cases of pulp and paper and petroleum
refining almost reach a ratio of two to one. For agriculture, on the
other hand, it is on the order of a ratio of four to five.

One might also consider the effect on water resource plans of extending
the time horizon from 1985 to, say, the year 2000. To make plans covering
a span of thirty-five years is nothing strange to ENDESA, although other
governmental agencies have not customarily looked so far ahead. For a
date so far in the future commitment of physical facilities today would,
of course, presumably be kept to a minimum. What ought not be minimized,
however, are the data collection effort and the steady elaboration of
essential investigations.

Chapter XVI

CONCLUSIONS AND OBSERVATIONS

The main conclusion to be drawn from the previous fifteen chapters
will hardly startle anyone: "efficient" or "rational" choices regarding
water use cannot be made without adequate facts and figures and Chile is
short on both.

We can, if we wish, draw substantive inferences regarding the place
of water in the Chilean economy, the prospective investments required to
assure a specified water supply, the distribution of economic activity
consonant with a designated expenditure in water resources, and the
implicit impact of water shortage on the productivity of related inputs.
We shall succumb briefly to the lure of figures we have confected and
point out that implied capital costs of flow regulation and waste treat-
ment (at 1964 prices) range between 1,900 million and 1,400 million
escudos (roughly $ 600 million to $ 400 million dollars) depending upon
whether the model is unrestrained Case I or Case I restrained by marginal
costs with agricultural in residual position. We can point out that even
with such expenditures, the shortage of water in the seven northern
provinces of Chile will restrict agriculture, or industry, or both, to
levels below those projected before taking water supplies into account.
We can also point out that the difference in required investment between
complete control over water resources and a lesser degree of control
as set by a marginal cost limit is on the order of 500 million escudos
($150 million), and that the cumulated capital costs of maintaining water
quality is on the order of 900 million escudos ($ 280 million).

The possible range of choices in the face of a growing shortage of
both land and water is so great that a few additional comments are in
order.

One accommodation is to keep all irrigable land under cultivation in the hope that each year will be wet enough for a successful crop. The needed increase in productivity will be more difficult to achieve if land is brought (or kept) under cultivation with water that is available only during relatively wet years, or if water is shared as widely as possible rather than allocated with greater security to a smaller total area. Unless water supplies are reasonably certain, the necessary complementary inputs for a doubling of output will not be provided. The mere possession of irrigable land will not be adequate justification for a claim to water, since there will be more irrigable land than water where water will be (is) in short supply.

If Chile is to come as close as possible to meeting its production goals, water will have to be rationed in the seven northern provinces in accordance with a marginal-product-of-water criterion. This implies either sensitive administrative controls or separate markets for water and land in which participants are impelled to maximize net product. Neither of these conditions can now be found. To the degree that institutional changes are not adopted, to that degree will the increase in productivity probably fall short of what is needed. While we are likely to emphasize efficiency of water use in an agricultural context, the special problems of mining, manufacturing, and steam electric power in the northern provinces cannot be ignored. As already noted, our projections, emphasizing losses rather than intake as they do, imply a high degree of engineering efficiency in non-agricultural uses, and a level of efficiency in agriculture comparable to what is projected for California in 1980. The question at hand is whether or not the legal-economic framework will induce the degree of efficiency that is implied in the projected requirements.

The likelihood that the marginal costs of water will vary substantially between water-short and water-surplus regions of the country, granting a wide margin of error in the specific values that have been computed, is a clear signal for someone to undertake detailed studies of regional economic plans that embrace costs of transportation and preferences for domicile as well as costs of water. Substantial savings of capital can be enjoyed by encouraging a greater growth of municipal and industrial water use in the southern part of the Central Valley than is projected, with a corresponding reduction in the northern part of the Central Valley and provinces further to the north. This conclusion is especially valid if high level waste treatment and waste dilution flows to maintain oxygen content are determined to be necessary. The desirability of encouraging a different pattern of urban concentration from what has been projected will be most intimately related to the question of water quality, a topic that has been only casually explored up to now.

If it turns out that land capable of being irrigated in the Norte Grande exists in larger quantity than the implausibly small amounts now shown for Antofagasta and Tarapacá, augmentation of the region's water supply by importation or desalination becomes a provocative speculation, especially if such lands can be found at relatively low elevation where the growing season extends throughout the year. If Chilean desert soils are like some desert soils elsewhere, their rich endowment of minerals will make them among the most productive of the country and may warrant expenditures on water supply that now seem absurd. The possibility of a series of transbasin diversions from south to north ought not be discarded without serious study in light of the rapid advances that have been made in large-scale, earth-moving technology.

Our findings not only suggest what are likely to be the trouble spots in the more distant future but provide a clue for near term policy as well. The deficiency in reliable information and the haphazard financial arrangements that have been followed for municipal and irrigation water supplies indicate that aggregate welfare has been enhanced only by accident, if at all, by public expenditures in water resources. There is little doubt that income has been transferred from the public at large to the beneficiaries of public water resource projects, except, perhaps, in the case of hydroelectric power.[1] While income transfers are neither desirable nor undesirable as such, in the case of municipal and irrigation water supplies they have not been contemplated by the laws under which the services have been supplied.[2] In view of probable increases in the marginal costs of water, the matter of income transfers will become more pressing. Who is going to pay? Will it be the taxpayer, the water user, a foreign entity, or some combination? The present system, whereby payments are only remotely related to benefits within the framework of a law that assumes otherwise is apt to yield unsatisfactory results when measured against an economic efficiency criterion.

It is also likely that public welfare will be best met by a moratorium on the construction of new irrigation projects. This suggestion

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[1] No study was made of ENDESA's operations. We are under the impression that power consumers pay their way, and that income transfers are not significant.

[2] We have no data on the incidence of Chile's tax system. It is likely that the system is regressive. If so, the effect of the income transfers has been to make the poor poorer and rich richer, a result that might even be encountered if the tax system were progressive. (See El Sistema Tributario Chileno, Oficina de Estudios Tributarios, Santiago, 1960, Ch. 5, "Progresividad del Sistema Tributario."

does not contemplate that the Dirección de Riego go out of business, but only that the agency will need time to assay itself and its policies and to bring before the government a programme under which the government will be reimbursed for projects on the basis of marginal social costs, or at least a programme that will assure construction of projects for which marginal social benefits will equal marginal social costs. During the moratorium progress can also be made in settling such questions as the amount of arable land (irrigable and dry) in Chile, establishing present and optimum rates of water use, filling in the hydrologic record, completing soil surveys in prospective new irrigated areas, accumulating an inventory of reservoir sites, developing system plans that will make maximum use of reservoirs, and accumulating the other miscellaneous bits of information that have been unavailable up to now. Without a moratorium until the state of information is improved, costly errors of judgement will be almost inevitable.

A moratorium on new starts will also allow the government to complete projects now under construction, after reassessing the advisability of continuation in each case. Plans for rapid expansion of irrigated area are wholly unrealistic in view of the record of the past thirty years, in which a total of 116,000 hectares were brought under irrigation. At the same time it is equally unrealistic to separate the required increase in agricultural productivity from the need to improve the regularity of water supply. This means that priority should go to projects that serve the best land and whose supplies of water are so erratic that farmers have been reluctant to make the necessary complementary investments. A moratorium would allow time for the necessary determination of priorities as well as time to revise the procedures of contracting, cost estimation, and repayment--procedures that at present fail to meet standards of best practice.

The urgency with which output per hectare must be increased can hardly be overemphasized, since no other way of feeding Chile's population offers more promise. Present plans of the Chilean government [1] call for the following increases in output per hectare during the period 1965-70:

wheat	22%
rice	20%
corn	28-40%
grains	24%
beans	11%
oil seeds	11-24%
sunflower seeds	25%
raps	0-15%
sugar beets	0%
potatoes	10%
vegetables	3-4%
garlic	8-24%
onions	10-20%
fruits	0%
grapes	10%
livestock and poultry	4%
milk	21%
wool	3%
total livestock and products	8%
agriculture, except livestock	17-18%

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[1] Information supplied by Klaus Gerber, National Planning Office.

The expected rate of increase in productivity per hectare, averaged for the agricultural and livestock sectors on the basis of the relative values of production in 1959-60, is 14% for the quinquennium 1965-1970. If this rate of improvement is achieved and if it is maintained for each of the next three quinquennia, total agricultural and livestock output per hectare will grow about 70% during the twenty year period 1965-1985, leaving a shortage by 1985 of about 25% relative to projected requirements. Unless productivity goals are raised we can expect the demand for food and fibers to exert pressure on Chile's balance of payments indefinitely into the future, with corresponding adverse effects on the rest of the economy.[1]

We had hoped that this study would advance our understanding of the role of water resources in economic development as well as supply an evaluation of the existing state of information in light of what is needed if economical (i.e. cost-minimizing--output maximizing) decisions regarding water resources are to be made. Several conclusions can be drawn: (1) Most of the unsuccessful public projects that have been built in the past owe their failure to the lack of reliable data on flows, soils, land capabilities, and water requirements. (2) The government has not undertaken a systematic programme of data collection on ground water, water quality, and water use by agriculture, industry, and municipalities. (3) During the past fifteen years or so a number of studies dealing with Chilean water resources have unanimously identified the same deficiencies.

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[1] See appendix, Productivity of Agriculture in Chile in Comparison with Selected Countries.

One ought to be aware of the possible irrelevance of economic analysis to policies that actually are adopted. It is clear that Chile's poor state of economic health cannot be blamed on lack of water or lack of land since both are used now at relatively low levels of efficiency. Moreover, without knowing why so little attention has been paid to reports already written, analyses already made, and prescriptions already offered, a limit is quickly reached to what can be added to our knowledge of the way in which natural resources relate the economic development. It follows, therefore, that an understanding of the role of water resources in economic development rests upon knowledge of motivation, habits of thought, the distribution of economic and political power, and the factors inducing or inhibiting their change.[1]

An "economic analysis" of Chilean water resources is relevant only within a context in which the analyst and Chilean policy makers are in agreement on the importance of the goal of economic efficiency and the constraints within which attainment of the goal will be sought. There is no reason to believe in the existence of such consensus and, in fact one can cite examples to prove its absence. Irrelevance may explain the oblivion to which previous studies were consigned.

Within the broad context of economic development inefficient use of water is not likely to be of greater consequence than waste of land, labor, and equipment. Attention to water is merited for other reasons. First, most of the development in the future will be dependent upon government financing, subject to government budgetary forces rather than to the more decentralized controls of private markets. (This

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[1] The author's interest in pursuing these lines of thought led to Everett H. Hagen, On the Theory of Social Change, Dorsey. Hagen's book is required reading for anyone interested in economic development.

contrast is weakened by the many controls over private markets exercised by the government). Second, the efficient use of water can have an important catalytic effect on the prickly matter of agrarian reform and land ownership. The public utility characteristics of water supply provide a device whose legitimate exercise of power over private property in the public interest is reasonably well accepted. Third, the limitations on activity imposed by the geographic distribution of land and water resources reduce the indeterminacy which the regional planner faces in accounting for various inter-regional possibilities within the context of a given set of national outputs. By pursuing further the question of cost constraints and settling the question of water quality, indeterminacy might be further reduced. While technological innovations may widen the range of alternative regional distributions of activity at some time in the future, the risk of being wrong is no greater than is assumed in any other sector of planning. Fourth and last, the scope of data that must be acquired and the web of decisions that are interwoven in the process of efficiently developing and using water resources draw upon many diverse disciplines of the social and physical sciences and establish their relevance to each other with a clarity not matched by many other undertakings.

Unfinished Business

The termination of this study should be the beginning of another. There is much unfinished business. Paramount are the inadequacies of data that have already been identified. To summarize these inadequacies would be tedious. They encompass all aspects of hydrologic, engineering, and economic measurements that are relevant to the effective planning of water resource use.

In addition to the need for systematic acquisition of basic data, the most valuable contribution that could be made to an understanding of demand would be a model of the agricultural sector that revealed the crop mix, quantity of output, regional distribution of output, and marginal revenue product of water under specified conditions. From the point of view of supply the most valuable contribution would be a schedule of reservoir sites for each basin systematically related to increments of control over flow and with information on costs of storage and delivery to points of use. Costs of desalinating sea water, transbasin movement, and exploitation of ground water as well as costs of reducing waste as an alternative to increased regulation ought also be developed. It is likely that brackish waters are available in some places and that their desalination may be economically feasible in the not too distant future.

The question of water quality has scarcely been touched by Chilean authorities but will become a matter of urgency in the foreseeable future. In the area around Santiago, pollution will be urban in origin. Farther north, downstream flows may become too mineralized for further use if irrigation is extended to the limit of water supplies. Under these circumstances the requirement for water may have to include waste dilution flows, in which case the relevant model would involve a demand consisting of upstream losses plus the greater of waste dilution flows or downstream intake. Even urban uses can contribute to the build-up of salinity, and the possibility of damage by detergents will also be a matter of concern as Santiago grows and the level of income increases. Related to the unknowns of water quality problems is the fate of coastal and fresh water fisheries and the necessary precautions that must be taken to preserve the ocean beaches and lakes for recreational uses. Also related

to water quality is the question of costs of treatment. Are Chilean costs
one-half the level of costs in the United States, as we assumed, or are they
equal to or more than U.S. costs?

The reader will appreciate that nothing was said of water rights
and administrative organization, although no programme of water resource
planning could ignore them. Little was said of the problems of benefit/
cost analysis and the recovery of governmental expenditures, especially
in a context of persistent and relatively severe (but not hyper-
inflation). Related to these questions is the matter of multiple vs.
single purpose projects and the techniques of analysis, construction,
and administration that must be adopted in order to be certain that net
benefits are maximized and costs equitably distributed.

Appendix - Table 1

MANUFACTURING: WATER INTAKE 1985, MEDIUM B

(In millions of m³ yearly)

Province	Food	Pulp	Paper	Chemicals	Petrochemicals	Petroleum Refining	Steel	All others	Total
Tarapacá	.6	-	-	2.7	-	-	-	-	3.3
Antofagasta	.6	-	-	10.8	-	-	-	-	11.4
Atacama	-	-	-	-	-	-	-	-	-
Coquimbo	1.2	-	-	2.7	-	-	-	1.8	5.7
Aconcagua	1.2	-	-	-	-	-	-	1.8	3.0
Valparaíso	13.0	1.1	1.2	21.6	39.4	104.7	-	30.5	211.5
Santiago	21.3	4.3	12.9	85.2	-	125.7	10.1	114.9	374.4
O'Higgins	3.0	-	-	1.4	-	-	-	-	4.4
Colchagua	.6	-	-	-	-	-	-	1.8	2.4
Curicó	.6	-	-	-	-	-	-	-	.6
Talca	2.4	1.0	1.1	2.7	-	-	-	1.8	9.0
Maule	-	32.0	-	-	-	-	-	-	32.0
Linares	.6	-	-	-	-	-	-	-	.6
Ñuble	.6	-	-	-	-	-	-	-	.6
Concepción	3.5	19.2	14.7	6.8	105.1	83.8	191.4	19.7	444.2
Arauco	-	32.0	-	-	-	-	-	-	32.0
Bío-Bío	1.2	121.4	26.5	-	-	-	-	-	149.1
Malleco	1.1	-	-	-	-	-	-	-	1.1
Cautín	1.2	-	-	-	-	-	-	1.8	3.0
Valdivia	2.4	2.1	2.3	-	-	-	-	3.6	10.4
Osorno	2.4	-	-	-	-	-	-	-	2.4
Llanquihue	1.2	-	-	-	-	-	-	-	1.2
Chiloé	-	-	-	-	-	-	-	-	-
Aysén	-	-	-	-	-	-	-	-	-
Magallanes	.6	-	-	-	33.4	-	-	-	34.0
Total country	59.3	213.1	58.7	133.9) 135.3)	177.9	314.2	201.5	177.7) 179.5)	1,336.3 1,339.5

Appendix - Table 2

FOOD AND BEVERAGES, 1985, MEDIUM B

(In thousands of m³ yearly)

Province	Percentages		Total Intake	Total Loss	Intake of down-stream Plants	Loss of up-stream Plants	Total
	Down-stream	Up-stream					
Tarapacá	88	12	600	36	528	4	532
Antofagasta	58	42	600	36	348	15	363
Atacama	-	-	-	-	-	-	-
Coquimbo	50	50	1,200	72	600	36	636
Aconcagua	3	97	1,200	72	36	70	106
Valparaíso	70	30	13,000	780	9,100	234	9,334
Santiago	2	98	21,300	1,278	426	1,252	1,678
O'Higgins	-	100	3,000	180	-	180	180
Colchagua	4	96	600	36	24	35	59
Curicó	1	99	600	36	6	36	42
Talca	-	100	2,400	144	-	144	144
Maule	-	-	-	-	-	-	-
Linares	-	100	600	36	-	36	36
Ñuble	1	99	600	36	6	36	42
Concepción	94	6	3,500	210	3,290	13	3,303
Arauco	-	-	-	-	-	-	-
Bío-Bío	-	100	1,200	72	-	72	72
Malleco	-	100	1,100	66	-	66	66
Cautín	2	98	1,200	72	24	71	95
Valdivia	58	42	2,400	144	1,392	60	1,452
Osorno	-	100	2,400	144	-	144	144
Llanquihue	70	30	1,200	72	840	22	862
Aysén	-	-	-	-	-	-	-
Magallanes	100	-	600	36	600	-	600
Total country			59,300	3,558	17,220	2,526	19,746

Appendix-Table 3

PULP AND PAPER, 1985, MEDIUM B

(In thousands of m^3 yearly)

| Province | Percentages | | Total intake | Total Loss | Intake of Down-stream Plants | Loss of up-stream Plants | Total |
	Down-stream	Up-stream					
Tarapacá							
Antofagasta							
Atacama							
Coquimbo							
Aconcagua							
Valparaíso	100		2,300	207	2,300		2,300
Santiago		100	17,200	1,548		1,548	1,548
O'Higgins							
Colchagua							
Curicó							
Talca		100	2,100	189		189	189
Maule	100		32,000	2,880	32,000		32,000
Linares							
Ñuble							
Concepción	100		33,900	3,051	33,900		33,900
Arauco	100		32,000	2,880	32,000		32,000
Bío-Bío		100	147,900	13,311		13,311	13,311
Malleco							
Cautín							
Valdivia	100		4,400	396	4,400		4,400
Osorno							
Llanquihue							
Chiloé							
Aysén							
Magallanes							
Total country			271,800	24,462	104,600	15,048	119,648

Appendix - Table 4

CHEMICALS, 1985, MEDIUM B

(In thousands of m^3 yearly)

Province	Percentages		Total Intake	Total Loss	Intake of Down-stream Plants	Loss of up-stream Plants	Total
	Down-stream	Up-stream					
Tarapacá	100		2,700	189	2,700		2,700
Antofagasta	100		10,800	756	10,800		10,800
Atacama							
Coquimbo	100		2,700	189	2,700		2,700
Aconcagua							
Valparaíso	100		21,600	1,512	21,600		21,600
Santiago		100	85,200	5,964		5,964	5,964
O'Higgins		100	1,400	98		98	98
Colchagua							
Curicó							
Talca		100	2,700	189		189	189
Maule							
Linares							
Ñuble							
Concepción	100		6,800	476	6,800		6,800
Arauco							
Bío-Bío							
Malleco							
Cautín							
Valdivia							
Osorno							
Llanquihue							
Chiloé							
Aysén							
Magallanes							
Total country			133,900	9,373	44,600	6,251	50,851

Appendix - Table 5

PETROLEUM REFINING, 1985, MEDIUM B

(In thousands of m^3 yearly)

Province	Percentages		Total intake	Total loss	Intake of down-stream Plants	Loss of up-stream Plants	Total
	Down-stream	Up-stream					
Tarapacá							
Antofagasta							
Atacama							
Coquimbo							
Aconcagua							
Valparaíso	100		104,700	4,188	107,400		107,400
Santiago		100	125,700	5,028		5,028	5,028
O'Higgins							
Colchagua							
Curicó							
Talca							
Maule							
Linares							
Ñuble							
Concepción	100		83,800	3,352	83,800		83,800
Arauco							
Bío-Bío							
Malleco							
Cautín							
Valdivia							
Osorno							
Llanquihue							
Chiloé							
Aysén							
Magallanes							
Total country			314,200	12,568	191,200	5,028	196,228

Appendix - Table 6

PETROCHEMICALS, 1985, MEDIUM B

(In thousands m^3 yearly)

Province	Down-stream	Up-stream	Total intake	Total loss	Intake of down-stream Plants	Loss of up-stream Plants	Total
Tarapacá							
Antofagasta							
Atacama							
Coquimbo							
Aconcagua							
Valparaíso	100		39,400	788	39,400		39,400
Santiago							
O'Higgins							
Colchagua							
Curicó							
Talca							
Maule							
Linares							
Ñuble							
Concepción	100		105,100	2,102	105,100		105,100
Arauco							
Bío-Bío							
Malleco							
Cautín							
Valdivia							
Osorno							
Llanquihue							
Chiloé							
Aysén							
Magallanes	100		33,400	668	33,400		33,400
Total country			177,900	3,558	177,900		177,900

Appendix - Table 7

STEEL, 1985, MEDIUM B

(In thousands of m^3 yearly)

Province	Percentages		Total intake	Total loss	Intake of down-stream Plants	Loss of up-stream Plants	Total
	Down-stream	Up-stream					
Tarapacá							
Antofagasta							
Atacama							
Coquimbo							
Aconcagua							
Valparaíso							
Santiago		100	10,100	303		303	303
O'Higgins							
Colchagua							
Curicó							
Talca							
Maule							
Linares							
Ñuble							
Concepción	100		191,400	5,742	191,400		191,400
Arauco							
Bío-Bío							
Malleco							
Cautín							
Valdivia							
Osorno							
Llanquihue							
Chiloé							
Aysén							
Magallanes							
Total country			201,500	6,045	191,400	303	191,703

Appendix - Table 8

ALL OTHER INDUSTRIES, 1985, MEDIUM B

(In thousands of m^3 yearly)

Province	Percentages		Total intake	Total loss	Intake of down-stream Plants	Loss of up-stream Plants	Total
	Down-stream	Up-stream					
Tarapacá							
Antofagasta							
Atacama							
Coquimbo	100		1,800	126	1,800		1,800
Aconcagua		100	1,800	126		126	126
Valparaíso	100		30,500	2,135	30,500		30,500
Santiago		100	114,900	8,043		8,043	8,043
Colchagua		100	1,800	126		126	126
Curicó							
Talca		100	1,800	126		126	126
Maule							
Linares							
Ñuble							
Concepción	100		19,700	1,379	19,700		19,700
Arauco							
Bío-Bío							
Malleco							
Cautín		100	1,800	126		126	126
Valdivia	100		3,600	252	3,600		3,600
Osorno							
Llanquihue							
Chiloé							
Aysén							
Magallanes							
Total country			177,700	12,439	55,600	8,547	64,147

Appendix - Table 9

MANUFACTURING - LOSS I - 1985, MEDIUM B

(In thousands of m³ yearly)

Province	Food and beverages	Pulp and paper	Inorganic chemicals	Petroleum refining	Petro-chemicals	Steel	All others	Total
Tarapacá	532	-	2,700	-	-	-	-	3,232
Antofagasta	363	-	10,800	-	-	-	-	11,163
Atacama	-	-	-	-	-	-	-	-
Coquimbo	636	-	2,700	-	-	-	1,800	5,136
Aconcagua-Valparaíso	9,440	2,300	21,600	107,400	39,400	-	30,626	210,766
Santiago	1,678	1,548	5,964	5,028	-	303	8,043	22,564
O'Higgins-Colchagua	239	-	98	-	-	-	126	463
Curicó-Linares	222	32,189	139	-	-	-	126	32,726
Ñuble	42	-	-	-	-	-	-	42
Concepción-Cautín	3,536	79,211	6,800	83,800	105,100	191,400	19,826	489,673
Valdivia-Llanquihue	2,458	4,400	-	-	-	-	3,600	10,458
Chiloé	-	-	-	-	-	-	-	-
Aysén	-	-	-	-	-	-	-	-
Magallanes	600	-	-	-	33,400	-	-	34,000
Total	19,746	119,648	50,851	196,228	177,900	191,703	64,147	820,223

Appendix - Table 10

MANUFACTURING - LOSS II - 1985, MEDIUM B

(In thousands of m^3 yearly)

Province	Food and beverage	Pulp and	Inorganic chemicals	Petroleum refining	Petrochemals	Steel	All others	Total
Tarapacá	36	-	189	-	-	-	-	225
Antofagasta	36	-	756	-	-	-	-	792
Atacama	-	-	-	-	-	-	-	-
Coquimbo	72	-	189	-	-	-	126	387
Aconcagua-Valparaíso	852	207	1,512	4,188	788	-	2,261	9,808
Santiago	1,278	1,548	5,964	5,028	-	303	8,043	22,164
O'Higgins-Colchagua	216	-	98	-	-	-	126	440
Curicó-Linares	216	3,069	189	-	-	-	126	3,600
Ñuble	36	-	-	-	-	-	-	36
Concepción-Cautín	420	19,242	476	3,352	2,102	5,742	1,505	32,839
Valdivia-Llanquihue	360	396	-		-	-	252	1,008
Chiloé	-	-	-		-	-	-	
Aysén	-	-	-		-	-	-	
Magallanes	36	-	-		668	-	-	704
Total	3,558	24,462	9,373	12,568	3,558	6,045	12,439	72,003

Appendix - Table 11

INDUSTRIAL P.E.'s PRODUCED a/

Province	Food	Pulp and paper	Chemicals	Petroleum Refining	Total
Tarapacá	.012	-	.011	-	.023
Antofagasta	.012	-	.043	-	.055
Atacama	-	-	-	-	-
Coquimbo	.024	-	.011	-	.035
Aconcagua	.024	-	-	-	.024
Valparaíso	.260	.015	.244	.088	.607
Santiago	.426	.114	.341	.052	.933
O'Higgins	.060	-	.006	-	.066
Colchagua	.012	-	-	-	.012
Curicó	.012	-	-	-	.012
Talca	.048	.014	.011	-	.073
Maule	-	.211	-	-	.211
Linares	.012	-	-	-	.012
Ñuble	.012	-	-	-	.012
Concepción	.070	.224	.448	.035	.777
Arauco	-	.211	-	-	.211
Bío-Bío	.024	.976	-	-	1.000
Malleco	.022	-	-	-	.022
Cautín	.024	-	-	-	.024
Valdivia	.048	.029	-	-	.077
Osorno	.048	-	-	-	.048
Llanquihue	.024	-	-	-	.024
Chiloé	-	-	-	-	-
Aysén	-	-	-	-	-
Magallanes	.012	-	.134	-	.146
Total country	1.186	1.794	1.249	.175	4.404

a/ P.E. = Population equivalent in Millions.

Appendix - Table 12

P.E.'s DISCHARGED UPSTREAM AND DOWNSTREAM, 1985

Province	Food	upstream All others	Total	downstream	upstream	downstream
		Industrial			Municipal Discharge	
Tarapaca	.001		.001	.022	.027	.200
Antofagasta	.005		.005	.050	.187	.258
Atacama					.159	.026
Coquimbo	.012		.012	.023	.174	.174
Aconcagua	.023		.023	.001	.121	.052
Valparaíso	.078		.078	.529	.316	.736
Santiago	.417	.507	.924	.009	4.814	.098
O'Higgins	.060	.006	.066		.293	
Colchagua	.012		.012		.104	.003
Curicó	.012		.012		.097	.001
Talca	.048	.025	.073		.195	
Maule				.211	.046	.020
Linares	.012		.012		.130	
Ñuble	.012		.012		.236	.002
Concepción	.004		.004	.773	.059	.917
Arauco				.211	.040	.025
Bío-Bío	.024	.976	1.000		.141	
Malleco	.022		.022		.152	
Cautín	.024		.024		.276	.006
Valdivia	.020		.020	.057	.105	.145
Osorno	.048		.048		.141	
Llanquihue	.007		.007	.017	.049	.114
Chiloé					.007	.037
Aysén						.043
Magallanes				.146		.119
Total country	.841	1.514	2.355	2.049	7.869	2.977

Appendix - Table 13

INDUSTRIAL WASTE DILUTION, 1985, MEDIUM A, 4 mg/l of D.O.

(In millions of M^3 yearly)

Province	Treatment level			
	0	35	70	90
Tarapacá	3.2	2.1	1.0	.4
Antofagasta	9.5	6.2	2.9	1.1
Atacama	-	-	-	-
Coquimbo	28.6	18.7	8.6	3.4
Aconcagua-Valparaíso	241.6	157.6	72.4	28.8
Santiago	1,996.5	1,302.0	598.3	233.4
O'Higgins-Colchagua	181.2	118.2	54.3	21.6
Curicó-Linares	216.1	141.0	64.8	25.8
Ñuble	31.8	20.7	9.5	3.8
Concepción-Cautín	2,533.8	1,652.3	759.3	302.5
Valdivia-Llanquihue	178.0	116.1	53.4	21.3
Total of above provinces	5,420.5	3,534.8	1,624.4	647.2
Chiloé Aysén Magallanes				
Total	5,420.5	3,534.8	1,624.4	647.2

Appendix - Table 14

CASES I, II, III, UPSTREAM LOSSES, 1985, MEDIUM B

(In thousands of m³ yearly)

Province	Municipal	Manufac-turing	Total (1+2)	Agricul-ture	Total (3+4)	Mining	Steam electri-city	Rural domestic	Non-agri-cultural losses (3+6+7+8)	Total losses (5+6+7+8)
	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)	(10)
Tarapacá	393	4	397	121,048	121,445	-	-	341	738	121,786
Antofagasta	3,347	15	3,362	59,234	62,596	9,167	3,243	361	16,133	75,367
Atacama	3,671	-	3,671	337,021	340,692	16,466	34	1,844	22,015	359,036
Coquimbo	2,940	36	2,976	1,288,186	1,291,162	1,944	32	4,603	9,555	1,297,741
Aconcagua-Valparaíso	10,009	430	10,439	1,589,445	1,599,884	-	-	4,294	14,733	1,604,178
Santiago	170,840	22,138	192,978	3,903,608	4,096,586	2,894	329	14,037	210,238	4,113,846
O'Higgins-Colchagua	8,016	439	8,455	4,499,596	4,508,051	5,341	-	8,412	22,208	4,521,804
Curicó-Linares	11,078	720	11,798	7,211,381	7,223,179	-	8	12,310	24,116	7,235,497
Ñuble	3,421	36	3,457	2,321,759	2,325,216	-	-	7,453	10,910	2,332,669
Concepción-Cautín	13,508	13,659	27,167	7,050,630	7,077,797	-	-	22,485	49,652	7,100,282
Valdivia-Llanquihue	7,661	226	7,887	-	7,887	-	-	-	7,887	7,887
Chiloé	97	-	97	-	97	-	-	-	97	97
Aysén	-	-	-	-	-	-	-	-	-	-
Magallanes	-	-	-	-	-	-	-	-	-	-
Total	234,981	37,703	272,684	28,381,908	28,654,592	35,812	3,646	76,140	388,282	28,770,190

Appendix - Table 15

CASE I. DOWNSTREAM REQUIREMENTS, 1985, MEDIUM B

(In thousands of m³ yearly)

Province	Mining	Steam power a/	Rural domestic b/	Manufacturing	Total (1+2+3+4)	Municipal intake	Municipal discharge	Agriculture intake	Agricultural intake minus municipal discharge	Total intake downstream regulation (5+6+9)
	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)	(10)
Tarapacá	206	3	342	221	772	14,440	11,552	185,686	174,134	189,346
Antofagasta	2,585	915	-	777	4,277	23,106	18,485	-	-	27,383
Atacama	8,483	17	251	-	8,751	2,988	2,390	70,517	68,127	79,866
Coquimbo	1,191	20	1,080	351	2,642	13,799	11,039	463,225	452,186	468,627
Aconcagua-Valparaíso	13,074	544	586	9,378	23,582	91,736	73,389	332,520	259,131	374,449
Santiago	-	-	286	26	312	17,433	13,946	122,240	108,294	126,039
O'Higgins-Colchagua	-	-	42	1	43	435	348	34,701	34,353	34,831
Curicó-Linares	-	-	786	2,880	3,666	1,890	1,512	706,338	704,826	710,382
Ñuble	-	-	-	-	-	173	138	-	-	173
Concepción-Cautín	-	53	937	19,180	20,170	111,374	89,099	448,560	359,461	491,005
Valdivia-Llanquihue	-	3	11,622	782	12,407	35,257	28,206	28,739	533	48,197
Chiloé	-	-	1,712	-	1,712	2,760	2,208	4,652	2,444	6,916
Aysén	53	-	1,241	-	1,294	5,545	4,436	8,338	3,902	10,741
Magallanes	-	8	748	704	1,460	19,163	15,330	22,827	7,497	28,120
Total	25,592	1,563	19,633	34,300	81,088	340,099	272,078	2,428,343	2,174,888	2,596,075

a/ Distribution between down and upstream is the same as for mining. From Aconcagua-Valparaíso to Ñuble all losses are classified "upstream". South to Ñuble they are considered downstream. South of Cautín all losses were considered as downstream.

b/ Distribution between down and upstream based on distribution of irrigated land.

Appendix - Table 16

CASE III, DOWNSTREAM INTAKES, 1985, MEDIUM B

(In thousand m^3 yearly)

Province	Agriculture	Manufacturing	Rural domestic	Municipal	Mining	Steam electricity	Total
Tarapacá	185,686	3,228	342	14,440	1,390	637	205,723
Antofagasta	-	11,148	-	23,106	17,236	217,560	269,050
Atacama	70,517	-	251	2,988	56,551	4,115	134,422
Coquimbo	463,225	5,100	1,080	13,799	7,941	4,693	495,838
Aconcagua-Valparaíso	332,520	210,336	586	91,736	87,160	129,622	851,960
Santiago	122,240	426	286	17,433	-	-	140,335
O'Higgins-Colchagua	34,701	24	42	435	-	-	35,202
Curicó-Linares	706,338	32,006	786	1,890	-	-	741,020
Ñuble	-	6	-	173	-	-	179
Concepción-Cautín	448,560	476,014	937	111,374	-	12,752	1,049,637
Valdivia-Llanquihue	28,739	10,232	11,622	35,257	-	769	86,619
Chiloé	4,652	-	1,712	2,760	-	1	9,125
Aysén	3,338	-	1,241	5,545	350	1	15,475
Magallanes	22,827	34,000	748	19,163	-	1,882	78,620
Total	2,428,343	782,520	19,633	340,099	170,628	372,032	4,113,255

Appendix - Table 17

UPSTREAM-DOWNSTREAM SUMMARY REQUIREMENTS, 1985, MEDIUM B

(In thousands of m³ yearly)

Province	Upstream losses	Downstream: losses, municipal intake, excess of agricultural intake over municipal discharge	Total: Case I (1)+(2)	Mining losses	Mining intake	Total Case II (3)-(4)+(5)	Total: Downstream Intakes	Total: Case III (1)+(7)
	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)
Tarapacá	121,786	189,346	311,132	206	1,390	312,316	205,723	327,509
Antofagasta	75,367	27,383	102,750	11,752	78,345	169,343	269,050	344,417
Atacama	359,036	79,866	438,902	29,949	166,326	580,279	134,422	493,458
Coquimbo	1,297,741	468,627	1,766,368	3,135	20,898	1,784,131	495,838	1,793,579
Aconcagua-Valparaíso	1,604,178	374,449	1,978,627	13,074	87,160	2,052,713	851,960	2,456,138
Santiago	4,113,846	126,039	4,239,885	2,894	19,294	4,256,285	140,385	4,254,231
O'Higgins-Colchagua	4,521,804	34,831	4,556,635	5,341	35,607	4,586,901	35,202	4,557,006
Curicó-Linares	7,235,497	710,382	7,945,879	-	-	7,945,879	741,020	7,976,517
Ñuble	2,332,669	173	2,332,842	-	-	2,332,842	179	2,332,848
Concepción-Cautín	7,100,282	491,005	7,591,287	-	-	7,591,287	1,049,637	8,149,919
Valdivia-Llanquihue	7,887	48,197	56,084	-	-	56,084	86,619	94,506
Chiloé	97	6,916	7,013	-	-	7,013	9,125	9,222
Aysén	-	10,741	10,741	53	350	11,038	15,475	15,475
Magallanes	-	28,120	28,120	-	-	28,120	78,620	78,620
Total	28,770,190	2,596,075	31,366,265	61,404	409,370	31,714,231	4,113,255	32,883,445

Appendix - Table 18

TARAPACÁ: COSTS OF FLOW

Storage (million M³)	Net minimum flow (million M3/year)	Cumulative capital costs of storage (E° 1,000)*	Cumulative annual costs of storage (E° 1)	Annual marginal cost per million M3/yr. of minimum flow (E° 1)	Marginal costs in $/Acre ft. of minimum flow
-	41.0				
.5	46.0	100	8,170	1,634	0.63
1.0	50.9	200	16,340	1,634	0.63
2.0	55.8	400	32,680	3,333	1.28
5.0	63.5	1,000	81,700	6,366	2.43
8.0	67.2	1,600	130,720	13,249	5.10
10.0	69.5	2,000	163,400	14,209	5.47
15.0	72.5	3,000	245,100	27,233	10.05
20.0	75.0	4,000	326,800	32,680	12.96
25.0	77.0	5,000	408,500	40,850	15.75
30.0	78.5	6,000	490,200	54,466	20.93
35.0	79.5	7,000	571,900	81,700	31.49
40.0	80.4	8,000	653,600	90,778	35.00
44.7	81.2	8,940	730,400	96,000	37.00

* Escudo values are in 1964 prices in Tables 18-28.

Appendix - Table 19

ANTOFAGASTA: COSTS OF FLOW

Storage (million M³)	Net minimum flow (million M3/year)	Cumulative capital costs of storage (E° 1,000)	Cumulative annual costs of storage (E° 1)	Annual marginal costs per million M³/year of minimum flow (E° 1)
-	81.0			
2	91.8	400	32,680	3,026
3	95.0	600	49,020	5,106
4	97.3	800	65,360	7,104
5	98.9	1,000	81,700	10,213
6	100.9	1,200	98,040	16,340
7	101.7	1,400	114,380	20,425
8	102.5	1,600	130,720	20,425
8.8	103.1	1,760	143,792	21,787

Appendix - Table 20

ATACAMA: COSTS OF FLOW

Storage (million M³)	Net minimum flow (million M3/year)	Cumulative capital costs of storage (E° 1)	Cumulative annual costs of storage (E° 1)	Annual marginal costs per million M³/year of minimum flow (E° 1)
-0	81.3	0	0	0
190	177.6	19,000	1,552,300	16,119
280	191.4	32,500	2,655,250	79,924
320	197.2	40,500	3,308,850	112,690
340	199.6	44,500	3,635,650	136,167
360	201.0	48,500	3,962,450	233,429
370	201.2	50,500	4,125,850	817,000

Appendix - Table 21

COQUIMBO: COSTS OF FLOW

Storage (million M³)	Net minimum flow (million M3/year)	Cumulative capital costs of storage (E° 1,000)	Cumulative annual costs of storage (E° 1)	Annual marginal costs per million M³/year of minimum flow (E° 1)
-	199.0			
770	665.0	38,500	3,145,450	6,838
1,270	741.6	63,500	5,187,950	26,664
1,570	767.6	87,500	7,148,750	70,028
1,770	783.6	103,500	8,455,950	81,700
1,920	791.3	118,500	9,681,450	169,766
2,020	795.8	128,500	10,498,450	181,556
2,110	797.8	142,000	11,601,400	551,475
2,190	797.8			
2,270	797.8			
2,310	797.8			
2,350	797.8			
2,390	797.8			
2,430	797.8			
2,470	797.8			
2,490	797.8			
2,500	797.8			
2,510	797.8			
2,520	797.8			

Appendix - Table 22

ACONCAGUA-VALPARAÍSO: COSTS OF FLOW

Storage (million M³)	Net minimum flow (million M3/year)	Cumulative capital costs of storage (E° 1,000)	Cumulative annual costs of storage (E° 1)	Annual marginal costs per million M³/year of minimum flow (E° 1)
-	373.0			
780	1,057.7	39,000	3,186,300	4,654
1,280	1,183.4	64,000	5,228,800	16,249
1,580	1,226.4	88,000	7,189,600	45,600
1,780	1,248.4	104,000	8,496,800	59,418
1,940	1,265.4	120,000	9,804,000	76,894
2,040	1,275.4	130,000	10,621,000	81,700
2,130	1,282.4	143,500	11,723,950	157,564
2,220	1,288.4	157,000	12,826,900	183,825
2,300	1,293.1	169,000	13,807,300	208,596
2,340	1,295.4	177,000	14,460,900	284,174
2,380	1,297.7	185,000	15,114,500	284,174
2,420	1,300.0	193,000	15,768,100	284,174
2,460	1,302.3	201,000	16,421,700	284,174
2,500	1,304.6	209,000	17,075,300	284,174
2,550	1,306.3	219,000	17,892,300	480,588

Appendix - Table 23

SANTIAGO: COSTS OF FLOW

Storage (million M³)	Net minimum flow (million M3/year)	Cumulative capital costs of storage (E° 1,000)	Cumulative annual costs of storage (E° 1)	Annual marginal costs per million M³/year of minimum flow (E° 1)
-	1,222.0			
1,000	2,541.4	50,000	4,085,000	3,091
1,800	2,908.5	90,000	7,353,000	8,902
2,370	3,037.2	118,500	9,681,450	18,092
2,710	3,118.6	145,700	11,903,690	27,300
2,880	3,150.1	162,700	13,292,590	44,092
3,050	3,181.6	179,700	14,681,490	44,092
3,140	3,205.6	193,200	15,784,440	45,956
3,220	3,220.3	205,200	16,764,840	66,694
3,260	3,227.6	213,200	17,418,440	89,534
3,300	3,234.9	221,200	18,072,040	89,534
3,340	3,242.2	229,200	18,725,640	89,534
3,380	3,249.5	237,200	19,379,240	89,534
3,385	3,250.2	238,200	19,460,940	1 6,714

Appendix - Table 24

O'HIGGINS-COLCHAGUA: COSTS OF FLOW

Storage (million M³)	Net minimum flow (million M3/year)	Cumulative capital costs of storage (E° 1,000)	Cumulative annual costs of storage (E° 1)	Annual marginal costs per million M³/year of minimum flow (E° 1)
	1,604.0			
3,320	5,914.6	166,000	13,562,200	3,144
4,320	6,288.9	216,000	17,647,200	10,914
4,940	6,466.6	265,600	21,699,520	22,804
5,260	6,552.2	297,600	24,313,920	30,542
5,560	6,628.7	327,600	26,764,920	32,039
5,870	6,700.1	374,100	30,563,970	53,208
6,070	6,748.1	414,100	33,831,970	68,083
6,175	6,771.8	435,100	35,547,670	72,392

Appendix - Table 25

CURICÓ LINARES: COSTS OF FLOW

Storage (million M^3)	Net minimum flow (million M^3/year)	Cumulative capital costs of storage (E^O 1,000)	Cumulative annual costs of storage (E^O 1,000)	Annual marginal costs per million M^3/year of minimum flow (E^O 1)
-	3,264			
15,000	18,300	750,000	61,275,000	4,075
24,600	21,008	1,230,000	100,491,000	14,482
26,600	21,552	1,390,000	113,563,000	24,029
28,600	21,996	1,550,000	126,635,000	38,000
29,600	22,168	1,630,000	133,171,000	38,000
30,400	22,290	1,710,000	139,707,000	53,574
31,200	22,412	1,790,000	146,243,000	53,574
31,700	22,478.7	1,865,000	152,370,500	91,867
32,200	22,515.4	1,940,000	158,498,000	166,962
32,400	22,526.1	1,980,000	161,766,000	305,421
32,600	22,536.8	2,020,000	165,034,000	305,421
32,800	22,537.5	2,060,000	168,302,000	4,668,571

Appendix - Table 26

TABLE: COSTS OF FLOW

Storage (million M^3)	Net mini-mum flow (million M^3/year)	Cumulative capital costs of storage (E° 1,000)	Cummulative annual costs of storage (E° 1)	Annual marginal costs per million M^3/year of minimum flow (E° 1)
-	1,009.0			
5,000	5,374.3	250,000	20,425,000	4,679
8,400	6,101.0	420,000	34,314,000	19,112
9,100	6,224.2	476,000	38,889,200	37,136
9,600	6,312.2	516,000	42,157,200	37,136
10,100	6,400.2	556,000	45,425,200	37,136
10,400	6,441.2	586,000	47,876,200	59,780
10,700	6,467.2	616,000	50,327,200	94,269
10,900	6,489.2	646,000	52,778,200	111,409
11,000	6,500.2	661,000	54,003,700	111,409
11,100	6,511.2	681,000	55,637,700	148,545
11,200	6,520.2	701,000	57,271,700	181,556
11,250	6,524.2	711,000	58,088,700	204,250

Appendix - Table 27

CONCEPCIÓN-CAUTÍN: COSTS OF FLOW

Storage (million M^3)	Net minimum flow (million M^3/year)	Cumulative capital costs (E^O 1,000)	Cumulative annual costs of storage (E^O 1)	Annual marginal costs per million M^3/year of minimum flow (E^O 1)
-	10,940.0			
10,000	36,857.1	500,000	40,850,000	1,575
20,000	46,414.2	1,000,000	81,700,000	4,274
30,000	53,071.3	1,500,000	122,550,000	6,136
34,000	55,314.2	1,700,000	138,890,000	7,285
36,800	56,958.2	1,924,000	157,190,800	11,132
38,800	57,818.2	2,084,000	170,261,800	15,200
40,800	58,678.2	2,244,000	183,334,800	15,200
42,100	59,345.7	2,374,000	193,955,800	15,912
43,100	59,820.7	2,474,000	202,125,800	17,200
43,600	60,104.0	2,549,000	208,253,300	21,629
44,100	60,287.3	2,624,000	214,380,800	33,429
44,500	60,423.9	2,684,000	219,282,800	35,886
44,800	60,543.9	2,744,000	224,184,800	40,850
45,100	60,653.9	2,804,000	229,086,800	44,563
45,361	60,732.2	2,856,200	233,351,540	54,467

Appendix - Table 28

VALDIVIA-LLANQUIHUE: COST OF FLOW

Storage (million M3)	Net minimum flow (million M3/year)	Cumulative capital cost of storage (E° 1,000)	Cumulative annual costs of storage (E° 1)	Annual marginal costs per million M3/year of minimum flow (E° 1)
-	22,088.0			
10,900	49,075.4	545,000	44,526,500	1,650
20,900	58,761.1	1,045,000	85,376,500	4,218
30,900	65,546.8	1,545,000	126,226,500	6,020
34,100	67,395.6	1,801,000	147,141,700	11,313
37,100	68,847.6	2,041,000	166,749,700	13,504
38,200	69,425.6	2,151,000	175,736,700	15,548
39,200	69,805.6	2,251,000	183,906,700	17,021
39,800	70,089.6	2,341,000	191,259,700	25,891
40,400	70,323.6	2,431,000	198,612,700	31,423
40,900	70,510.3	2,531,000	206,782,700	43,760
41,228	70,615.5	2,596,600	212,142,220	50,946

Appendix - Table 29

AGRICULTURAL PRODUCTION: CASE I, MARGINAL CONSTRAINT, AGRICULTURE RESIDUARY

Province	Hectares irrigated a/	Output per hectare qqm/W.E.	Output qqm/W.E.	Added dry (Hectares)	Output per hectare qqm/W.E.	Added dry output	Total output b/
Tarapacá	1,786	50	89,300			–	89,300
Antofagasta	1,965	50	98,250			–	98,250
Atacama	5,640	50	282,000	21,648	.5	10,824	292,824
Coquimbo	41,100	30	1,233,000	71,923	2.0	143,846	1,396,846
Aconcagua-Valparaíso	68,750	22.5	1,546,875	59,891	4.6	275,499	1,822,374
Santiago	192,000	22.5	4,320,000	91,852	4.6	422,519	4,742,519
Subtotal	311,241		7,569,425			357,688	8,422,113 c/
O'Higgins-Colchagua	NO CHANGE						
Curicó-Linares							
Ñuble							
Concepción-Cautín							
Valdivia-Llanquihue							
Chiloé							
Aysén							
Magallanes							

a/ Some rounding of larger amounts.
b/ Original projected output from irrigated land: 14,706,133
    Reduction: 6,284,020
c/ Total output for each province are these amounts plus the amounts originally projected from dry land.

Appendix Table 30

TREATMENT COSTS OF P.E.'S DISCHARGED INTO RIVERS WITHOUT COLLECTION COSTS, 1985 MED. B

(E° 1964)

Appendix 30

Province	Municipal			Total		
	35	70	90	35	70	90
Tarapacá	52,650	95,580	128,790	54,890	99,640	134,250
Antofagasta	364,650	661,980	891,990	375,850	682,280	919,290
Atacama	310,050	562,860	758,430	310,050	562,860	758,430
Coquimbo	339,300	615,960	829,980	366,180	664,680	895,500
Aconcagua-Valparaíso	852,150	1,546,980	2,084,490	1,078,390	1,957,040	2,635,950
Santiago	9,387,300	17,041,560	22,962,780	11,457,060	20,793,000	28,007,820
O'Higgins-Colchagua	774,150	1,405,380	1,893,690	948,870	1,722,060	2,319,570
Curicó-Linares	912,600	1,656,720	2,232,360	1,129,880	2,050,540	2,751,980
Ñuble	460,200	835,440	1,125,720	487,080	884,160	1,191,240
Concepción-Cautín	1,302,600	2,364,720	3,186,360	3,654,600	6,627,720	8,919,360
Valdivia-Llanquihue	575,250	1,044,300	1,407,150	743,250	1,348,800	1,816,650
Chiloé	13,650	24,780	33,390	13,650	24,780	33,390
Total	15,344,550	27,856,260	37,535,130	20,619,750	37,417,560	50,393,430

Appendix – Table 31

TREATMENT COSTS OF P.E.'S DISCHARGED INTO RIVERS, 1985 MEDIUM B., INCLUDING COLLECTION AS PART OF MUNICIPAL

(E° 1964)

Province	Manufacturing			Municipal a/			Total			Collection
	35	70	90	35	70	90	35	70	90	
Tarapacá	2,240	4,060	5,460	108,810	151,740	184,950	111,050	155,800	190,410	56,160
Antofagasta	11,200	20,300	27,300	753,610	1,050,940	1,280,950	764,810	1,071,240	1,308,250	388,960
Atacama				640,770	893,580	1,089,150	640,770	893,580	1,089,150	330,720
Coquimbo	26,880	48,720	65,520	701,220	977,880	1,191,900	728,100	1,026,600	1,257,420	361,920
Aconcagua-Valparaíso	226,240	410,060	551,460	1,761,110	2,455,940	2,993,450	1,987,350	2,866,000	3,544,910	908,960
Santiago	2,069,760	3,751,440	5,045,040	19,400,420	27,054,680	32,975,900	21,470,180	30,806,120	38,020,940	10,013,120
O'Higgins-Colchagua	174,720	316,680	425,880	1,599,910	2,231,140	2,719,450	1,774,630	2,547,820	3,145,330	825,760
Curicó-Linares	217,280	393,820	529,620	1,836,040	2,630,160	3,205,800	2,103,320	3,023,980	3,735,420	973,440
Ñuble	26,880	48,720	65,520	951,080	1,326,320	1,616,600	977,960	1,375,040	1,682,120	490,880
Concepción-Cautín	2,352,000	4,263,000	5,733,000	2,692,040	3,754,160	4,575,800	5,044,040	8,017,160	10,308,800	1,389,440
Valdivia-Llanquihue	168,000	304,500	409,500	1,188,850	1,657,900	2,020,750	1,356,850	1,963,400	2,430,250	613,600
Chiloé				28,210	39,340	47,950	28,210	39,340	47,950	14,560
Total	5,275,200	9,561,300	12,858,300	31,712,070	44,223,780	53,902,650	36,987,270	53,785,030	66,760,950	16,367,520

a/ Includes collection costs.

Appendix - Table 32

ADDITIONAL COSTS OF STORAGE FOR QUALITY MAINTENANCE, 1985, MEDIUM B, 4 mg/l

Province	Minimum flow at constrained marginal cost (Agricultural residuary)	Total upstream losses	Available for waste dilution and downstream use	Extra flow requirement for waste dilution			Annual cost of additional flow for waste dilution (E° 1,000) a/		
			Millions m3/year	35%	70%	90%	35%	70%	90%
Tarapacá	56	41	15	43	12	–	b/	109	0
Antofagasta	88	60	28	370	155	45	b/	b/	138 c/
Atacama	113	101	12	318	139	48	b/	b/	774
Coquimbo	601	585	16	370	161	55	b/	3,909	376
Aconcagua-Valparaíso	1,093	978	115	1,000	398	89	b/	b/	1,446
Santiago	2,920	2,902	18	11,878	5,449	2,160	b/	b/	11,900 c/
O'Higgins-Colchagua	4,557	4,522	35	950	418	145	2,987	1,314	456
Curicó-Linares	7,946	7,235	711	460	–	–	1,875	0	0
Ñuble	2,333	2,333	–	514	236	94	2,405	1,104	440
Concepción-Cautín	10,940	7,100	3,840	–	–	..	0	0	0
Valdivia-Llanquihue	22,088	8	22,080	–	–	–	Minimum flow dilutes at zero treatment		
Chiloé	7	–	–	–	–	–	=	=	=
Aysén	11	–	–	–	–	–	=	=	=
Magallanes	28	–	–	–	–	–	::	::	::

a/ Computed by multiplying required flow by marginal cost.
b/ Required flow is beyond capacity of region.
c/ Beyond capacity; cost of going to full regulation.

Appendix - Table 33

ATACAMA: SMALLEST RESERVOIRS FIRST
(E° 1964)

Storage	Net minimum flow Mil. M3 per year	Cumula-tive capital costs E° 1,000	Cumula-tive annual costs (E° 1)	Annual Marginal costs per million M3/year of net minimum flow (E° 1)
	88.0			
10	116.2	2,000	163,400	5,794
30	131.6	6,000	490,200	21,221
50	139.0	10,000	817,000	44,162
90	152.8	18,000	1,470,600	47,362
180	173.6	31,500	2,573,550	53,026
370	201.2	50,500	4,125,850	56,243

Appendix - Table 34

SANTIAGO: SMALLEST RESERVOIRS FIRST

Storage	Net minimum flow (Mil. M3 per year)	Cumulative capital costs E° 1,000	Cumulative annual costs (E° 1)	Annual marginal costs per million M3/year of net minimum flow (E° 1)
	1,340.3			
5	1,419.7	1,000	81,700	1,029
45	1,537.0	9,000	735,300	5,572
85	1,604.3	17,000	1,388,900	9,712
125	1,671.6	25,000	2,042,500	9,712
165	1,733.9	33,000	2,696,100	10,491
245	1,853.6	45,000	3,676,500	8,190
335	1,977.6	58,500	4,779,450	8,895
505	2,169.1	75,500	6,168,350	7,253
675	2,330.6	92,500	7,557,250	8,600
1,015	2,587.0	119,700	9,779,490	8,667
1,585	2,780.7	148,200	12,107,940	12,021
2,385	3,007.8	188,200	15,375,940	14,390
3,385	3,250.2	238,200	19,460,940	16,852

PRODUCTIVITY OF AGRICULTURE IN CHILE IN COMPARISON
WITH SELECTED COUNTRIES[1]

We have concluded that without an increase in productivity per hectare
amounting to about 2.2 times present output Chile cannot meet its output
goals in 1985. Is such an increase in productivity credible? A satis-
factory answer to this question ultimately rests upon experimental activity
carried out on the land. In the absence of information so derived we
rely on inference from comparisons with yields and history of yields in
several other countries. These comparisons suffer several weaknesses.
They do not distinguish between irrigated and dry land and they do not
account for qualitative differences in the product. Furthermore, because
of deficiencies in information, such as absence of information on land
dedicated to fruit, the comparisons themselves display serious gaps.

Overall "productivity of land" comparisons between two countries are
a reflection of differences in physical output per unit of land and crop
mix. Where the comparisons involve crop mix, the Chilean distribution
of hectareage among crops (excluding, because of lack of information,
natural pasture, artificial pasture, vegetables and fruits) was used.
Productivity in value terms reflects prices. Comparisons were made using
Chilean prices and European prices as weights. The differences between
the results of the two sets of prices turned out to be negligible.

An estimate of arable land[2] per capita for Chile and selected other
countries is given in Appendix Table 35. Chile's arable land endowment

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[1] Based on a study made by Manuel Agosín.

[2] See FAO *Production Yearbook*, 1963, Rome, p. 406 for definition of
arable land. The amount shown in the *Yearbook* for Chile is 5,514,000
hectares. We have used for Chile the figure given by the Instituto
de Investigaciones de Recursos Naturales, based upon the air photo-
grammetric survey. The FAO figure yields .70 hectares per capita
for Chile.

per capita is roughly comparable to Denmark's (a little less, based on
the air photogrammetric survey; a little more if based on the figure
reported to FAO). It is substantially below the amounts indicated for
Argentina, Brazil, or the United States. Chile's future agricultural
policies will presumably be directed toward an intensive technique of land
use, comparable to European countries, rather than to an extensive tech-
nique such as is found in countries where per capita land resources are
notably higher.

We compared output per hectare among Chile, Denmark, France, and Italy
in order to gain some appreciation of conceivable levels of outputs that
Chile could attain, on the assumption that differences in land quality
and climate did not introduce significant errors to the relevance of the
comparisons. Denmark represents a relatively cool and humid region,
comparable to the southern part of Chile's Central Valley, and France and
Italy represent regions of Mediterranean climate comparable to the
northern part of the Central Valley.

The results for eighteen crops for which productivity measures could
be computed are given in Appendix Tables 36 and 37. In order to eliminate
some of the vagaries associated with annual variations in weather,
estimates were made of average output and best and worst yields experienced
by each of the four countries. Chile's average output per hectare is
below that of Denmark for every crop except onions, it is below that of
France for every crop except onions, linseed, and tobacco, and below that
of Italy for every crop except barley, potatoes, onions, dry beans,
linseed, and tobacco. The picture is not materially altered when we
make the comparisons on the basis of best yields or worst yields.

Appendix Table - 35

ARABLE LAND PER CAPITA IN SELECTED COUNTRIES (1962)

Country	Arable Land (1,000 has.)	Population (thousands)	Arable Land (Has. per Cap.)
Chile	4,893 [1]/	8,001	.61
Belgium	1,695	9,221	.18
Denmark	3,141	4,654	.67
Germany	14,179	56,947	.25
France	34,522	46,998	.73
Italy	20,652	50,170	.41
Greece	8,902	8,451	1.05
Spain	35,091	30,817	1.14
European average	243,000	432,500	.56
Argentina	143,151	21,418	6.68
Brazil	126,728	75,271	1.68
Japan	7,020	94,930	.07
U.S.A.	441,366	186,591	2.37

[1]/ Instituto de Investigaciones de Recursos Naturales, Proyecto Aerofotogramétrico, Chile/OEA/Bid.

Source: FAO, 1963, Production Yearbook, Rome, 1964.

Appendix Table - 36

AVERAGE YIELDS OF SELECTED CROPS, 1948/49-1952/53 to 1962/63

(100 Kgs. per hectare)

	Chile	Denmark	France	Italy
Wheat	13.3	39.4	23.5	17.9
Rye	8.7	26.4	12.7	14.5
Barley	16.4	35.6	23.8	12.1
Oats	11.0	32.9	18.0	12.6
Corn	18.9	-	25.4	27.6
Rice	27.2	-	39.3	51.2
Sugar Beets	308.0	337.0	315.0	310.0
Potatoes	91.0	189.0	152.0	89.0
Onions	269.0	203.0	157.0	133.0
Dry Beans	9.3	-	9.5	4.0
Dry Peas	6.5	-	18.4	6.9
Chick Peas	4.9	-	-	5.5
Lentils	5.8	-	7.7	6.0
Grapes	49.0	-	57.0	51.0
Linseed	7.4	10.0	6.0	6.8
Rapeseed	10.9	17.0	14.2	12.0
Sunflower Seed	13.3	-	14.5	14.0
Tobacco	22.4	-	19.1	13.8

Source: FAO, Production Yearbooks.

Appendix Table - 37

BEST AND WORST YIELDS (1948/49-1952/53 to 1962/63)

(100 Kgs. per hectare)

	Best Yields				Worst Yields			
Crops	Chile	Denmark	France	Italy	Chile	Denmark	France	Italy
Wheat	15.6	42.7	30.7	20.9	11.9	34.4	18.3	15.2
Rye	10.3	29.4	14.6	16.6	6.3	23.7	11.4	12.7
Barley	18.6	39.8	28.1	13.6	11.7	31.1	16.1	10.3
Oats	12.9	37.1	20.2	14.5	8.7	27.8	14.4	10.5
Corn	21.4	-	34.0	32.9	13.8	-	13.8	18.4
Rice	31.1	-	48.3	56.8	20.0	-	26.7	47.4
Sugar Beets	329.0	410.0	445.0	387.0	192.0	270.0	198.0	273.0
Potatoes	107.0	223.0	175.0	104.0	84.0	153.0	125.0	70.0
Onions	323.0	261.0	179.0	172.0	248.0	101.0	136.0	84.0
Dry Beans	10.6	-	10.3	5.1	6.8	-	7.5	2.9
Dry Peas	7.9	-	24.3	8.2	4.7	-	15.2	5.4
Chick Peas	5.8	-	-	5.9	3.8	-	-	4.8
Lentils	7.3	-	10.4	6.8	4.4	-	5.5	4.7
Grapes	53.0	-	81.0	62.0	46.0	-	35.0	39.0
Linseed	8.2	10.7	9.4	8.4	6.1	10.0	3.3	5.6
Rapeseed	12.4	24.5	17.8	15.1	9.6	8.5	11.6	9.5
Sunflower Seed	15.9	-	17.2	19.4	10.2	-	10.6	12.8
Tobacco	24.6	-	21.5	15.6	19.7	-	15.7	5.4

Source: FAO, Production Yearbooks.

One possible explanation of the differences in yields could be the differences in market prices among the respective countries, on the ground that unduly low prices in Chile, (alleged by some to be the case) might have discouraged the expenditure of funds on fertilizer and other inputs. We have no data on the relative cost among countries of various output-increasing outlays, but have made a comparison of 1962 product prices as reported for the four countries. In 1962 the estimated purchasing power parity was one escudo for $1.00. The figures in Appendix Table 38 indicate that for every product except onions, tobacco and wheat, Chilean prices were higher than the prices in Denmark, France and Italy.

A set of prices, when weighted by hectareage in Chile devoted to the various crops and multiplied by the yields of the respective countries, indicates average value productivities per hectare for a uniform set of prices and crop mixes. These comparisons are shown in Appendix Table 39. The crops that are common to Chile and Denmark are not the same as for the comparisons between Chile and France and Chile and Italy, since data on prices and land use were not uniformly available in all countries for all crops. The net results of including crop mix and prices in the measure of land productivity indicates that output per hectare in Denmark is about 2 1/2 times that of Chile, in France 1 1/2 times, and in Italy 1.1 times. Use of European rather than Chilean prices made virtually no difference in the comparisons. Productivity based upon a relatively large sample using Chilean prices as weights, revealed little difference from the results obtained from the smaller groups of products for which price data in each country existed.

Appendix Table - 38

SELECTED AGRICULTURAL PRICES

1962 Prices per 100 kgs.

Crops	Chile[1]/ (E°1962)	Denmark (US$1962)	France (US$1962)	Italy (US$1962)
Wheat	9.01	7.1[4]/	10.2	10.9
Rye	8.10	8.0	7.2	3/
Barley	8.46	6.6	7.8	6.3
Oats	8.04	6.7	7.1	3/
Corn	9.98	-	5.8[4]/	7.0
Rice	9.74	-	3/	9.8
Sugar Beets	1.69	1.5	1.5	1.5
Potatoes	8.75	6.1	5.2	6.3
Onions	4.86	3/	9.8	6.4
Dry Beans	22.61	-	17.9[4]/	17.4
Dry Peas	12.91	3/	3/	3/
Chick Peas	17.78	-	-	3/
Lentils	27.63	-	3/	3/
Grapes	16.55[2]/	-	3/	3/
Linseed	18.73	3/	3/	3/
Rapeseed	14.40	12.3[4]/	12.3	12.3[4]/
Sunflower seed	14.01	-	3/	3/
Tobacco	26.09	-	3/	61.0

Source: FAO, _Production Yearbooks, Rome_.

1/ From "Sinopsis de la Agricultura Chilena, 1961-1963", Ministerio de Agricultura, Santiago, August 1964.

2/ "All Fruits" price; price of grapes not available.

3/ Not available.

4/ European port price.

Appendix Table - 39

PRODUCTIVITY PER HECTARE IN CHILE, DENMARK, FRANCE AND ITALY

(Based on average yields)

	Reduced Samples				Large Samples	
	In Chilean Prices		In Foreign Prices		In Chilean Prices	
	E°1962	Index (Chile=100)	US$1962	Index (Chile=100)	E°1962	(Chile=100)
Chile	171.5	100	131.5	100	176.0	100
Denmark	433.1	253	333.3	253	433.8	246
Chile	179.2	100	163.9	100	220.9	100
France	281.5	157	255.6	156	322.4	146
Chile	191.7	100	187.3	100	220.0	100
Italy	215.9	113	217.2	116	243.0	110

Additional information leading to the inference that Chilean agricultural productivity is capable of substantial improvement is given in Appendix Table 40. Average annual growth rates in productivity per hectare were estimated for the period 1952/53 to 1962/63 for Denmark, France, Italy, United States, Japan, and Chile.[1] Whereas the five other countries found productivity per hectare rising annually by amounts ranging between 1.4 percent and 4.0 percent per annum, Chile's increase in productivity amounted to 0.2 percent. At the same rates continued into the future, between 1965 and 1985 productivity per hectare would rise by 70 percent in France and 78 percent in Italy, compared with 4 percent in Chile.

A comparison was made of the productivity of farms in various size classes in the Province of O'Higgins with the most productive in each size class and the most productive regardless of size class.[2] This study, conducted by Hector Morales, revealed that the highest output per hectare in each size class, after adjusting for differences in soil productivity, ranged from 1.6 times to 2.2 times the average output per hectare, and that if all yields were equal to the highest yields now (1959) being obtained, total output would be 92 percent higher than actually achieved. If yields rose to the average productivity of all farms whose outputs per hectare exceeded the average of the total sample, productivity would rise by 35 percent.

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[1] Computed as the ratio of index of output divided by the index of area of cultivated land. No adjustments were made for the possibility that a given amount of land was used for two or more crops or for inclusion of livestock products such as milk.

[2] Hector Morales, *Productividad presente y potencial en 96 predios de la Provincia de O'Higgins y en Relación con el tamaño de las propiedades*, Escuela de Agronomía, Universidad de Chile, Santiago, 1964.

Appendix Table - 40

RATES OF INCREASE IN PRODUCTIVITY PER HECTARE IN SELECTED COUNTRIES,

1952/53 - 1962/63

	Average Annual increase rate of 1952/53-1962/63 (in %)	Estimated 1962/63 Productivity Index (1952/53=100)
Denmark	1.4	114
France	2.7	130
Italy	3.0	133
U.S.	3.4	140
Japan	4.0	148
Chile	0.2	102

Studies of comparative yields of farms both inside and outside of Chile indicate, therefore, a reasonable presumption in favor of readily attainable increases in output per hectare. A doubling of average output per hectare would leave Chile somewhat below the present level attained by Denmark and somewhat above the level oi France and Italy. If changes in crop mix are taken into account, whereby more land is devoted to crops with a high market value per unit of crop, and account is taken of possible improvements in fruits, poultry and livestock, none of which were included in the international measures of productivity, there is no reason to consider a potential doubling of output within a very short period of time beyond the physical or economic capability of the country.[1] In light of the present Chilean government's awareness of the importance of agriculture, the success or failure of its programme will be an important augury of what can be expected by way of economic development within the country.

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[1] FAO studies indicate a high correlation between use of fertilizer and yield per hectare. See "Los Niveles de Producción Agrícola y el Empleo de Fertilizantes," Rome, 1962.

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