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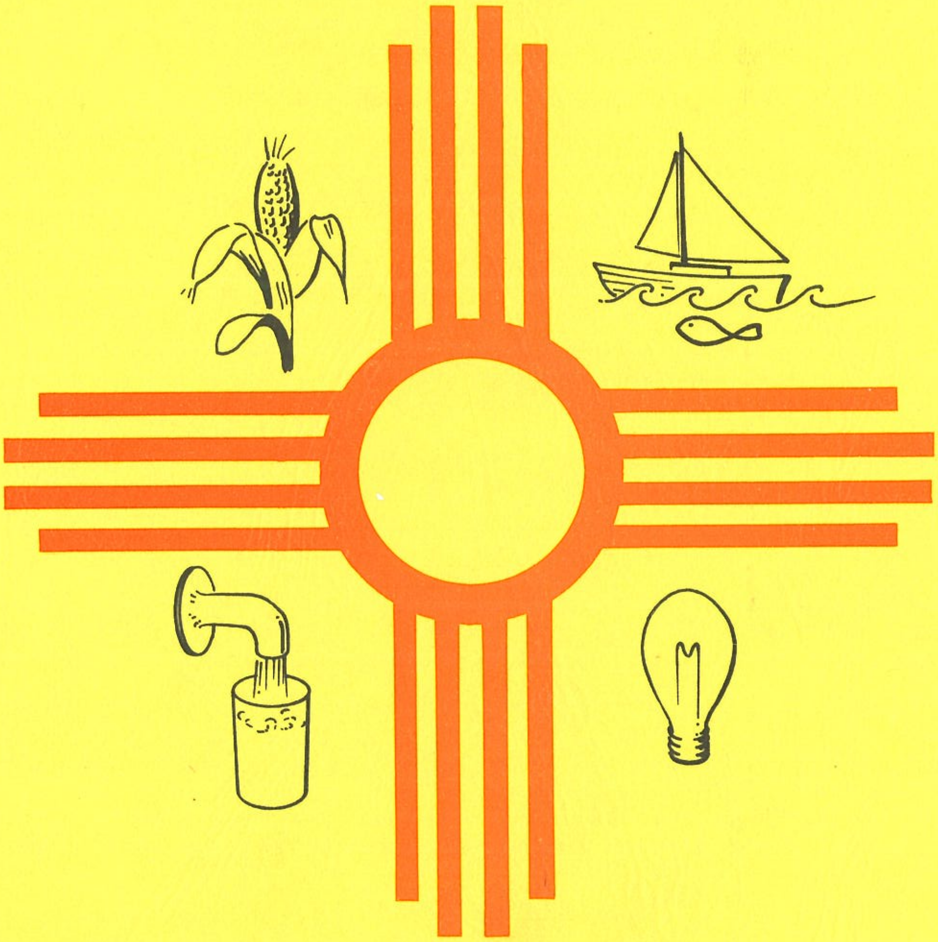
A SET OF PAPERS SUPPORTING THE THEME OF THE PROPOSED NINETEENTH ANNUAL NEW MEXICO WATER CONFERENCE

Theme: Water In Food And Fiber Production



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WATER IN FOOD AND FIBER PRODUCTION

A SET OF PAPERS SUPPORTING THE THEME OF THE PROPOSED

NINETEENTH ANNUAL NEW MEXICO WATER CONFERENCE

NEW MEXICO STATE UNIVERSITY

LAS CRUCES, NEW MEXICO

1974

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PREFACE

The nineteenth Annual New Mexico Water Conference was to be held on April 4-5, 1974 for the purpose of exchanging information pertaining to New Mexico water resources. This meeting was postponed due to the energy crisis. We felt that it would be irresponsible from a conservation standpoint to hold the meeting during this critical energy use period.

The possibility of holding the Water Conference in conjunction with the 1974 Land Use Symposium was investigated. The consensus was that if federal land use legislation is enacted (that possibly still exists as sponsors are exploring procedural maneuvers to gain reconsideration on the House floor as a rider to another bill), the question of implementing state land use legislation may require more than the full two days presently scheduled for the Symposium.

A meeting of the Advisory Committee is planned to be held during October 16 and 17, 1974 in Albuquerque at the Land Use Symposium for the purpose of planning the 1975 Water Conference.

The enclosed set of papers attempts to carry out the proposed conference theme "Water in Food and Fiber Production" and is being distributed to all persons who attended the 1973 Water Conference.

Credit is due Ms. Kathleen Hain, Assistant to the Director, who assembled the papers and arranged for their printing.

A portion of the funds required for publication of the papers was provided by the United States Department of the Interior, Office of Water Resources Research as authorized under the Water Resources Act of 1964.

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MYTHS: CORNERSTONES FOR COUNTERPOSITIONS

Harold M. Stults*

The history of development, management and use of water resources in the United States is a fantastic success story. The development of large quantities of water suppliers has played an important role in the economic development of the United States. Irrigation development has transformed areas of low productivity into some of the most productive lands in the United States. While millions of people throughout the world have gone hungry, the United States has had an abundance of high-quality, low-cost food. Exports of agricultural products have an important effect on our balance of payments. Water developments also provide power, recreation and flood protection. Many viable, productive communities exist because of water development.

But, in spite of all that has been accomplished, nagging questions and controversies keep arising. Counterposition views seem to be increasing in numbers and gaining greater strength. The wisdom of simultaneously carrying out public programs for resource development and for cropland retirement has been questioned many times. Acts of development alledged to be in the public interest are viewed by others as atrocious crimes against nature. Some groups prefer zoning people out of the flood plains rather than building expensive flood control structures. Projects have been stopped or delayed, and studies terminated.

In view of the rapidly changing environment facing water planners, perhaps this is the time to critically appraise how we plan the development, management and use of our natural resources.

* Reprinted by permission from Water Spectrum, Vol. 5, No. 4, pp. 9-15, 1973.

The Author is the Economic Research Service Representative with the U. S. Department of Agriculture to the Western U. S. Water Plan Study.

This article discusses water myths of false images that influence public attitudes about water, examines some of the constraints on water planning, discusses the impact of uncertainty in planning, and outlines an approach to planning that would lead to better planning decisions.

Myths and False Images

Water is unique in several ways. Because it flows, quantity and quality changes resulting from its use at one place and time may affect other uses at other places and times. These *externalities* are an important characteristic of water resources. Water also has a *cyclic* peculiarity. Its supply is generally replenished continuously through the hydrologic cycle. It generally is not consumed in use. Rational planning requires that these objective traits of water be considered in establishing policies and programs for water use.

But the *water-is-different* images often ascribe to water peculiarities that go far beyond its objective characteristics. They appear again and again in our water planning reports, issue papers, and everyday conversations. As planners for public agencies, it is in our own self-interest to recognize these false images and become more realistic about water and its role in society.

Scarcity

The most realistic concept of scarcity is the use made of the term by economists. Scarcity is the relationship between the supply and demand of a good or service as reflected by its price. If the demand is large relative to supply, the price is high and the good or service is considered very scarce (diamonds, Picasso paintings, or vintage wines). When the supply is large relative to demand, the produce is less scarce and the price is cheap.

The term "scarce" is probably used more often to describe water than any other commodity in the United States. Almost every water study begins with the premise of scarcity. Is this premise fact or myth?

As measured by its price *water is the cheapest of all commodities* marketed in the United States. It is the least scarce of all the things we buy. There is nothing in the market cheaper or less scarce than water. We have all heard the expression "dirt cheap." The price of dirt in the Denver area is about $1.50 per ton. Delivered, it runs around $2.00 per ton. Water is delivered to Denver homes on demand, 24 hours a day, 365 days a year for about 14 cents per ton (56 cents per 1,000 gallons). In Central Arizona, where the water scarcity is often labeled "critical," water is delivered to Salt River Project farmers for about $.0015 per ton ($.000006 per gallon).

There is little basis for special selection of water as a scarce commodity when it sells for 165 gallons for one penny--delivered! It does nothing for objective water planning to single out the least scarce of all commodities and tag it with the scarcity label.

Free Good

In direct conflict with the scarcity image is the "free good" image. It holds that water is a "free gift of nature" so should cost its user no more than the net cost of its production and delivery. This implies an unlimited supply, free at its source, a complete absence of scarcity. Many people apparently hold the scarcity and free good image at the same time.

Survival

Water is necessary to life and essential for sanitation. It is a survival absolute. Without it, we die. Man must have a couple of quarts of water per day to survive. It is not necessary for survival, however, that every person have 200 gallons per day or that another irrigation project be developed.

A major public official speaking in support of a large irrigation project states: "Water is life. We must have water to survive. The question is, how do we get it?" This kind of attitude is not unusual, even among planners, and presents a major obstacle to rational water planning.

Priceless Resource

Closely related to the scarcity myth and the survival image is the priceless resource image. Because water is necessary for survival and people would pay almost any price rather than go without, development of water is often viewed as providing this priceless resource to consumers. Yet, not a single planning decision we make today is relevant to survival or to providing "priceless" water. Most of our decisions are relevant to providing water at a cost of under 15 cents per ton, as discussed earlier.

Irrigation Fundamentalism

Based on the concept that agriculture is the cornerstone of any viable society and that, in an arid environment, irrigation is either required or or is highly beneficial for crop production, this image holds that in much of the West, irrigation is a requirement for a viable society. While it is true that, in the past, many communities developed around an irrigation economy, only a fraction of future Western economic growth is expected to be associated with irrigation development. This is not to say that the growth of certain local communities will not be tied closely to irrigation development; only that irrigation is not a necessary condition for viable growth in the West.

Environmental Quality

The newest, but fastest growing, of the absolute images of water is in the environmental quality-recreation areas. The idyllic idols of open and green spaces, parks, playgrounds, greenbelts, recreation, camping, and wild rivers are lining up along with other water uses in establishing water *requirements* for these purposes and demanding their share of water resources.

Implications

These myths and false images interact with each other and with the realistic images and reflect the public policies and institutions that guide the control, development, and allocation of water resources. As a result, each user of water views his desires for water as *water requirements*. But, except for a couple of quarts per day, they are *not* requirements. They are *preferences* and should be viewed as such. We do not have irrigation requirements, instream requirements, or municipal and industrial requirements. We do have preferences or demands for these uses of water.

The almost total insulation of water from the market mechanism tends to reinforce the image that man's desires for water are absolute water requirements, rather than demands that are relative values. The absence of price signals tends to reinforce the "free good" image and leads to the development and allocation of water as if it were free at its source. Administrative rules and regulations are used in lieu of prices. Rigid, unresponsive administrative practices lead to inflexibilities in water allocations. This leads to an overemphasis on security of water rights and rigidity and inflexibility in the allocation of water among users. Water-users emphasize security at the cost of flexibility, and thus policies and institutions emphasize tenure and rigidity rather than the flexibility required to achieve equity and efficiency in water allocation.

The inevitable outcome is that we have much economic inefficiency in water allocation over space and time--inefficiency in the allocation of water in the short run between uses and between users, and inefficiency in the commitment of development capital to long-run water uses and allocations. Historical patterns of water allocation and past relative preferences among water uses get locked into distribution patterns of water because of resistance to transfer and the lethargic character of the institutions by which such transfers are possible. Although initial water allocations may have been efficient at the time they were made, they have steadily diverged from efficiency goals as demand and technology have changed at ever increasing speed.

In the West, where most water development is tied to irrigation, the inflexibility of water transfer has hastened the development of remaining unused supplies, even to the extent of importing water at high costs to satisfy growing demands. At the same time, little effort is made to divert irrigation water supplies to other uses in spite of the general abundance of agricultural production. The result is an ever increasing cost of water development and transport, insulated against lower cost competition from local water transfers between uses, users, and locations.

In areas where surface supplies have been fully developed, development has often turned to groundwater as the cheapest available additional water supply. This results in the depletion of a stock resource that in most cases is irreplaceable. Depletion of a stock resource is not bad in itself. The tragedy is that we are depleting it now instead of saving it for efficient use later. At the same time we are using our surface (flow) resources inefficiently because of false images and the resulting inflexible institutions and policies.

As long as society perceives the false images of water described in this article, there is little that we as water planners can do to improve the situation. Society's "unseen hand" prescribes the policies and institutions--defines the rules--of the water game. Rational action calls for playing the game according to the rules established by society.

But, we *are* in a period of change. Water attitudes and values of society are changing. As new supplies of water become increasingly scarce, conflicts increase and society reassesses its attitudes. New rules are being examined, demands are being evaluated, and traditional planning approaches are being challenged. If we want to continue in water planning, we need to continue to develop rules for planning that reflect society's changing attitudes and values.

Uncertainty

As if the problems of working in an area filled with myths, false images, and widespread inefficiency were not enough, planners also must contend with uncertainty. It is highly unlikely that the conditions on which water requirements for the year 2000 would be based will be reasonably close to actual conditions. In fact, the statistical probability of this situation approaches zero. Said another way, when we make economic projections and establish water requirements to meet these projections, we are almost certainly planning for the development of the wrong quantity of water.

For example, in establishing irrigation water requirements, if there were three equally likely but singificantly different population growth rates, three levels of exports, three consumption patterns, three patterns of regional development, three levels of yield growth and three levels of water use per acre, there would be 729 equally possible future situations. The same kind of situation exists for the many other uses of water. Taken all together, the water requirements approach to planning will likely result in planning for a situation that will not occur. A different approach to planning is needed. The new approach must go beyond simply developing a new set of terms for the same old practices.

Better Decisions

The intent of this essay is not simply to criticize past mistakes but rather to establish the background for proposed changes in water planning that can lead to greater efficiency in planning for the development, management, and use of our natural resources. Two major changes are proposed: (1) stop planning to meet water requirements and start planning to meet the demands of alternative futures, and (2) stop developing a long-range plan and begin developing a planning process that continuously provides current, reliable intelligence to decision makers. Specific recommendations follow:

> Planners should utilize every opportunity to *broaden the scope* of planning to include total resource planning. The ties between land, water, and environmental resources are so strong that planning for a single resource often results in serious negative external impacts on other resources or institutions.
>
> It is not enough to simply identify these impacts. Rather, the objectives of land, water, and environmental planning must all be integrated into the planning process, and significant trade-offs must be identified for the relevant range of alternatives.

Much more effort must be expended in measuring the demand schedules for the products that use water as a major input against the corresponding derived demand schedule for water.

In other words, we must measure the *preferences of society* for varying quantities of water for major uses by estimating the price society would be willing to pay rather than go without. It is especially important that these preferences (prices) are identified over the relevant range of possible quantities of water available. This is required in order to analyze the marginal impact of varying quantities of resource use. Major errors in estimating the effect of alternative courses of action are made by estimating average rather than marginal values.

Planners must begin to utilize *economic projections* as a tool for evaluating alternative futures by (1) providing insights into the nature and level of future economic activity; (2) identifying potential problems or inadequacies in resource supplies; and (3) providing a baseline, or measure, against which alternative plans can be tested. The distinction between the above and the traditional approach is more than semantics.

The recommended approach is to stop viewing regional market shares and associated water requirements as an indication of needs that must be met--stop viewing economic projections as providing a goal or target--and begin to utilize projections as a tool in an analytical framework designed to measure impacts of alternative plans. There is no single fixed quantity of water supply to plan for. Rather, there is a range of resource development management and use alternatives, each with a different set of economic, environmental, and social consequences. Planners should be concerned with reliable measurement of these consequences.

Total resource planning is an extremely complex business. The only way to adequately consider all of the relevant relationships is to make a major commitment to the development and use of *systems analysis* as an important tool in planning. The system should be structured so that independent component models can be added to or taken from the system without disturbing the operation of the system. The system should be designed to simulate alternative futures, to measure economic and social consequences of each alternative, and to display these consequences in the multi-objective accounts.

Uncertainties should be explicitly recognized and efforts taken to reduce them. This can be done by statistical analysis, testing of model--both physical and economic--and, in some cases by developing and evaluation of prototypes.

While much can be done to reduce uncertainties, they cannot be totally eliminated. In order to avoid costly errors that may be caused by uncertainties, the planning process must be designed to provide maximum flexibility. This requires that alternative futures and alternative solutions be continually evaluated.

The planning process should employ a sequential decision-making approach. This approach identifies the critical point in time when decisions must be made, and directs the planning process to provide the information needed to make those decisions.

Planners must recognize that the end result of planning is not another project but rather an improved society. There are many ways we can develop, manage, and use our resources to achieve this goal, including changes in policies or institutions, increased efficiency, and better conservation and preservation of resources. We need to broaden our method of analysis to include these future alternatives on a par with engineering solutions.

Proper planning demands equal attention to both.

The viewpoints expressed are those of the author and do not necessarily reflect those of the Economic Research Service or the Department of Agriculture.

VALUES AND CHOICES IN THE DEVELOPMENT OF AN ARID LAND BASIN - THE ROLE OF AGRICULTURE

Gerald W. Thomas*

There is no doubt that competition for resources in the Colorado River Basin is increasing. This competition results from pressures within the area as residents seek to satisfy their own objectives for livelihood and well-being but, more importantly perhaps, competition results from pressures without as the U. S. and World population grows and the demands increase for Basin resources and services. It is this outside pressure that complicates the situation and makes choices difficult--or even reduces the alternatives.

Since my topic is agriculture and grazing, I cannot examine the problems within this arid land basin without some discussion of the world-wide food and fiber problem--pressures largely external to the basin. I will keep this brief in order to get back more specifically to the alternatives for development of the region.

I know that it is dangerous to make sweeping generalizations because "no generalization is absolutely true including this one" or, in other words, "a generalization that is unquestionable is certainly questionable." Nevertheless, generalizations can serve to stimulate discussion so here is my first broad generalization:

Yesterday and Today - An Environmental Crisis

Today and Tomorrow - An Energy Crisis

Tomorrow and Day-after-Tomorrow - A Food and Fiber Crisis

We move from crisis to crisis. Perhaps a "crisis" is necessary for Americans to recognize a serious problem--to initiate action programs. I'm convinced that the Arabs did us a favor by closing the oil spigot. They alerted us to an energy problem that would have been really serious with another lapse of 5-10 years of lethargy. We now have an unprecedented

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opportunity to examine our life styles--to plan for the future with a deeper economic, social and environmental understanding.

The reason I am concerned about food and fiber is partly because of the energy crisis (we use vast amounts of energy to produce, process, package and transport food and fiber), but more appropriately because of my concern about all resources involved in agricultural production, particularly land and water. It is likely that world-wide demands for food and fiber in the near future will place resources for agricultural purposes in a much higher priority than is now the case. Even a doubling of food production in the next three decades would only maintain the world's population at present dietary levels (1).

As Lester Brown stated recently, there are two major reasons for the increased demand for food. "During the 1970's, rapid global population growth continues to generate demands for more food; but, in addition, rising affluence is emerging as a major new claimant on world food resources." (2) Dr. W. Robert Parks, President of the National Association of State Universities and Land-Grant Colleges added a third factor to the "new circumstances" facing agriculture (3). He stated that our "bank account" of food technology has been drawn down to a very low level and there is a special need for new breakthroughs in agricultural research. When the U. S. decided to open up trade with the Communist Nations, another 2 billion people became potential customers for U. S. agricultural products. The Colorado River Basin, where a wide variety of crops are produced, will be involved in this increased demand for food and fiber. Thus, priorities for resource allocation in the Basin may change.

Competition for Farm Land - The "Cultivated" Land Base.

It is estimated that, with the present technology of the developed countries, nearly one acre of cultivated land is needed on the average to provide an "adequate" standard of living for each person. This takes into consideration some variation in land productivity as well as some variation in level of affluence. With the present population in the U.S., we have about 1.2 acres of cultivated land per capita and a potential of about two acres per capita if we expand acreage to the maximum. We do not as yet know the effects of the recent farm programs to enlarge the acreage under cultivation nor we know the new per acre yields. The experience of many countries has shown that most efforts to expand cultivated acreage have resulted in reduced per acre yields. We are already using the very best lands for cultivation.

The U. S. is now exporting the production of about one acre out of every four--leaving about 0.9 of an acre per capita for home use. The Far East has less than 0.8 acre of cultivated land per capita with Communist Asia at about 0.4 acre per capita. Latin America with 1.3 acres per person, and Africa with about 2.3 acres per person still have a good cultivated land resource base.

For the world, the cultivated acreage now stands at about 3.5 billion acres, or 11 per cent of the earth's land surface. The area actually harvested for crops in a given year is considerably less (due to fallow practices and crop failures)--usually about 2.4 billion acres. This means that we now have only about 0.6 acres of usable cultivated land per person in the world compared with an estimated need of one acre per person. By the year 2000, the cultivated land base will likely be reduced to about 0.3 acre per capita. World-wide yields will have to be doubled to maintain our present position of food availability.

These world-wide and national statistics on farm land are presented for the purpose of indicating that pressure from outside the Colorado River Basin will influence priorities of land use within the basin. The basin itself now has a surplus land base for farming--about 8 acres of cultivated land per capita in the Upper Colorado (4) and about seven acres per capita in the Lower Colorado (5).

Water and Agriculture

Water is probably the most important--and most limiting factor--in the growth and development of the Colorado River Basin. A high percentage of the cropland in the Basin is irrigated and the potential for irrigation is still greater. However, in view of the National Water Commission Report, it is unlikely that irrigated cropland acreage will be expanded. One conclusion from the Report is as follows (6):

> "Land will not be scarce by 2000.... Output from U. S. farm and range lands, including lands now set aside in government programs, will be adequate to meet projected food demands even at the high level that would be expected if population increases to 325 million persons and some food exports grow to about twice their 1967-69 levels."

Furthermore, the report concluded that "Expansion of irrigation is not needed to meet future food needs. Quite to the contrary. The most efficient pattern of production at most projected demand levels would be achieved with a reduction in the acreage of irrigated land used for annual crops."

Needless to say, I do not agree with these statements. A good review of the National Water Commission Report was prepared by the Western Agricultural Economics Research Council (7). This Council challenged some assumptions of the "Heady Report" on which the Commission conclusions were based. In addition, the world outlook has changed with the energy crisis and the opening of markets for our food and fiber in the Communist Nations. U. S. Agricultural exports in 1973 were about $12.9 billion. The USDA Economic Research Service estimates that total agricultural exports could reach $20 billion by 1975 (8). Food has indeed become a potent factor in foreign policy (9).

Reports by the Colorado River Basin Inter-Agency Study groups (released in 1971) on land use, project the need for cropland to increase from 1,816,000 in 1965 to 1,852,000 by the year 2020 in the Lower Colorado River Basin (15) and for the Upper Colorado Region increases from 1,621,500 in 1965 to 2,625,000 in 2020 (4). Most of the increases were projected for irrigated lands.

At the Colorado River Basin Environmental Management Conferences held in Salt Lake City in October 1973 (10), several concerns were expressed about irrigated farming in the Basin: (1) There is a serious problem of ground water mining (some aquifers now being tapped for irrigation water are not being recharged to offset withdrawals, and the "closed basin" approach has not been adopted), (2) Increased salinity and other pollution problems--partly associated with irrigation--present both a regional and international challenge, (3) The status of Indian water rights continues to be unsettled, and (4) Transfers of water rights to summer home development, to industries, and other uses is continuing to reduce irrigation in the agricultural sector.

Thus, while the debate over world-wide requirements for cultivated land and for irrigation continues, and while certain groups are projecting increased food and fiber needs, we are actually experiencing continued losses of farm land in the Colorado River Basin to other uses--usually to some form of urban or industrial development. These transfer decisions are being made piecemeal, under economic pressure, and without adequate consideration of land-range needs or systematic planning for optimum land use. No part of the Basin has so far been able to successfully zone or build in the necessary legal and economic incentives for the protection of good farm land.

Impact of the Energy Crisis on Agriculture.

The Colorado River Basin is an energy rich area--that is, rich in basic energy sources. The story is somewhat different for the finished consumer product. Here again the ties to the outside areas--and to the world situation--become important. Energy shortages and increased energy costs will have a substantial impact on all development in the Colorado Basin. We can anticipate increased pressure for exploitation and mining of petroleum and mineral resources. We can anticipate increased research and development activity for alternate sources of energy--geothermal, nuclear, hydropower, wind, and solar energy. We can expect economic and political pressure to compromise standards on environmental pollution. Furthermore, we can anticipate changes in expenditure patterns and consumer demands--that is, food, clothing, forestry and housing, may increase in priority while tourism, recreation and energy luxury activities may diminish. Perhaps, the long overdue reconsideration of life styles of the affluent American may change. All of these factors could impact on development and decision-making in the Colorado River Basin.

The gigantic food and fiber industry, taken in its entirety, uses more petroleum products than any other industry in this country. Large amounts of energy are consumed in the "supply sector" to provide the farmer and rancher with fertilizers, pesticides, machinery, and other inputs. Large amounts of energy are used in the "production sector" for planting, cultivation, irrigation, care and harvesting of crops and livestock. Large amounts of energy are also consumed by the "storage, processing, packaging and distribution sector" in order to place food on the table and clothes on the backs of 210 million Americans. Estimates of the petroleum products used by agriculture, in this broad sense, vary from 10 to 18 percent of total consumption of petroleum in the United States.

Through the years, farmers in the U.S. have steadily mechanized and have substituted over five million tractors and many other forms of power equipment for about 22 million horses and mules. As a measure of progress, we have released about 72 million acres of land that would have been required to feed the horses and mules and may now be used for direct food production for humans. In addition, we have increased efficiency and output per acre (11). Years ago, a man with a good team of horses would plow about 2 acres a day. Today, mechanized power makes it possible for him to plow over 100 times that much. However, as a result of this increase in mechanization on croplands in the U. S., energy flow patterns have been significantly changed. Horsepower, mulepower, oxenpower, and manpower operate on the solar energy collected by vegetation--a continuing resource for all practical purposes. Tractors and machinery utilize fossil fuel--a finite and depletable resource.

The trend toward mechanization on farms is not confined to this country. In 1950, FAO estimated that there were about 6.1 million tractors in the world. By 1970, this number had exceeded 15.5 million (12). In addition, world fertilizer use, which is heavily tied to petroleum, increased from 15.2 million metric tons in 1950 to almost 68 million metric tons in 1970. As the technology associated with the "Green Revolution" spreads, more energy will be required. Thus, the world pressure on petroleum for the agricultural sector is increasing at an accelerated rate. Farmers in the Colorado River Basin will also feel these pressures on petrochemicals and fuel supplies.

One of the difficulties in arriving at accurate statistics on agriculture and energy relates to the definition of "agriculture." However, for the "production," or "on-farm" sector, we do have some fairly good studies which show that in the relatively primitive rice cultures of the Phillippines about 16 calories of digestible energy (food) resulted from each calorie of "cultural" energy input. In this case the "cultural" energy was hand labor. As mechanization developed, the ratio of "cultural" energy input to digestible energy output has increased and thus, the net caloric gain has decreased. According to Heichel (13) some modern cropping systems yield approximately 5 calories of digestible energy at the farm level per calorie of cultural energy (including fossil fuels). Pimentel et al (14) have calculated that only 2.8 K calories of corn are produced for each K calorie of fuel. However, one farm worker can now produce enough food for himself and 49 others compared with only 8 others in 1950 and the trend toward more mechanization is continuing.

Heichel (13) reports that "on-farm" corn production in the early 20th century derived about 17 per cent of its cultural energy from labor and 70 per cent from depreciation of machines and buildings. In comparison, corn production in 1970 derived about 0.7 per cent of its cultural energy from labor, 50 per cent from fuel, 15 per cent from fertilizer, 4 per cent from pesticides, and 24 per cent from depreciation of machines and buildings.

Using U. S. Agricultural Technology, Pimentel (14) states that to feed the world population of 4 billion (projected for 1975) would require the energy equivalent of 488 billion gallons of fuel just for the "production" sector of agriculture.

As the concept of agriculture is enlarged to include the "supply" sector and to encompass "processing, storage and distribution," the net energy becomes negative and the outside energy subsidies increase. Hansen (15) recently stated that it has been estimated that about 12 per cent of total energy consumed in the U. S. goes to the food industry.

A task force at the University of Arizona, headed by Dr. Kenneth Barnes (16), reported that "In the overall energy picture which includes hydropower, nuclear energy, natural gas, coal and oil, the U. S. food system uses 12 to 15 per cent of the total." They report a breakdown of total energy use to put food on the U. S. dinner table as follows:

Farming	-	18%
Food Processing	-	33%
Transportation	-	3%
Wholesale & Retail Trade	-	16%
Household Preparation	-	30%

It is my belief that the Task Force figures on transportation are low, but data are not available to substantiate this assumption.

Limited studies have also been made of energy flow patterns for cotton and other fibers. Table 1 presents a comparison of energy (large fossil fuel) required for cotton and cellulosic and non-cellulosic fiber production (17). To produce and process a pound of cotton as a finished broadwoven fabric requires about 14,620 calories. Energy consumption for the synthetic fibers is more than double this amount. Wool places the lowest demand on fossil fuel. The raw materials for the non-cellulosic fibers are petrochemicals from petroleum and natural gas.

Table 1. Energy Consumption for Selected Fibers* - Raw Materials to Finished Broadwoven Fabric (Kilowatt hours per pound of fiber)

	Cotton	Cellulosic	Non-cellulosic
Consumed as Raw Materials	0.20	1.61	6.28
Consumed in Fiber Production	3.55	22.09	11.36
Consumed in Weaving & Spinning	6.30	7.03	7.03
Consumed in Finishing Mills	6.98	8.52	8.52
Cumulative Total	17.03	39.25	33.19

*Adapted from Gatewood, National Cotton Council of America

From an ecological viewpoint, the natural fibers (cotton, wool and mohair) have an advantage in that they place less pressure on the energy resource base than synthetic and highly-processed fibers. In spite of these ecological considerations, synthetic fibers have been capturing an increasing share of the fiber market. Each person in the United States is now consuming over 20 pounds of synthetic fiber per year. Just prior to the energy crunch, Resources For The Future predicted that synthetic fibers would capture over 54 per cent of the fiber market by the year 2000. In my opinion, these projections will not materialize due to the pressure on petroleum products. Japan and Western Europe are already placing more emphasis on natural fibers. It is safe to anticipate increased demands for natural fibers produced in the Basin--wool and cotton.

Uncultivated Lands - Competition for land use.

Uncultivated lands constitute the largest acreage of land in the Colorado River Basin. Management and land-use decisions on these lands is complicated by three major factors: (1) land ownership patterns, (2) extreme variability in climate, soils, vegetation, and topographic conditions, and (3) multiple-use possibilities.

Approximately 65 per cent of the total land area in the Basin is Public Land. Decisions on the use of public land are becoming more and more "everybody's business." Social welfare weighs heavily against economic value. Environmental concerns are more apt to be considered. The tradition for decision-making on private or corporation land is somewhat different. Right or wrong, the land owner still makes most of the decisions on land use and this prerogative is strongly established by American tradition.

Given this difference in management prerogatives and/or objectives on private vs. public lands, the situation is further complicated by the fact that many ranch operators graze livestock on both public and private lands. Thus, the land-use decisions on federal or state lands has a significant effect on private lands. A change in the use of one has an immediate impact on the others. This dependence on public lands for forage supplies varies among the states--reaching a high in Nevada where 49 per cent of the livestock forage comes from public lands.

As many of you know, there is a national movement sponsored by the Natural Resources Defense Council to force the Public Land Agencies--primarily the Forest Service and the Bureau of Land Management--to close all Federal lands to grazing. I have been working with a Task Force of the Council for Agricultural Science and Technology to prepare a position paper on the effects of such a ban on our national economy and the environment. This Task Force, composed of 15 scientists from the Western U. S., is taking a very strong stand to oppose the elimination of all grazing by domestic livestock from federal lands (18). A quotation from the Task Force Report is as follows:

> "Eating of plant materials by animals is a natural process in terrestrial and aquatic systems. Thus, with the coming of European man to the West, the introduction of domestic livestock did not constitute an entirely new component in the environment. More realistically, the domestic livestock replaced, or were added to, the wild animals that were already there. Rangeland vegetation, especially grassland and shrubland, in the Western States evolved to withstand grazing to a moderate degree. Without grazing, different vegetational characteristics develop. The range forage that livestock utilize is a renewable natural resource because the forage regrows each year and has done so for many centuries.....
>
> .....The environmental effects of grazing depend upon the kind of range, the intensity of grazing, and the kind of management employed to control livestock on the range."

In a paper presented to the 1973 annual meeting of the Society for Range Management, I made the following concluding statement: "A careful examination of long-range research can only lead to the conclusion that: (1) on vast areas of public lands, livestock grazing, under proper management, is compatible with other uses, (2) on a limited number of sites, grazing by domestic livestock is detrimental to the resources and competitive with other uses, and (3) on other sites, grazing by livestock can be the most beneficial use to society for economic, social and ecological reasons." (19)

The concept of multiple use of the western range resources has been accepted and practiced for many years. That is, these lands have value to the individual and to society for more than one purpose. Although the primary income may be from livestock or forest products, the lands also are important from the standpoint of mineral production, wildlife, recreation, and water yield. Recently, another dimension has been added--that of "total environmental enhancement"--particularly air and water quality as well as aesthetic or wilderness values.

The pressure from individual interest groups is often so great that commitments are made excluding other uses. This trend is of special concern--particularly when political and legal restraints are imposed during a period of emotionalism or under one of the "crisis situations" which appear to develop frequently in the United States. Let's examine briefly some of these pressures on uncultivated lands.

Timber production has been increasing in relative importance because of the high demands for lumber, pulp, and paper products. This situation has become more critical with the energy crisis--and even the most extreme environmental groups are recognizing the need for more forest products. From a recent report by the National Commission on Materials Policy the following statements are pertinent to our discussion of land-use alternatives (20):

> "Three-fourths of the Nation's softwood is in the west.... Projections to the year 2000 for softwood sawtimber demand, at current prices and the present level of management, would require almost doubling the 1970 domestic production...Even with intensified management, prospects for balancing future supply and demand at 1970 process appear remote. However, stepped up investment in a variety of forestry activities could produce significant increases in timber production by the turn of the century."

From a recorded high of 507 million acres in 1962 in the U. S. the area of "commercial forest" land is projected by the Materials Policy Commission to drop to 475 million acres in the year 2020. They state that "quite possibly, additional areas on National Forest lands will be removed from the timber supply base for recreation and environmental protection." Nevertheless, forest production will remain a strong competitor as a major-use or as a concurrent use of uncultivated land in the Basin.

Recreation use on all of the range and forest lands in the Colorado River Basin has continued to rise at a more rapid pace than population numbers would indicate. Increased mobility and affluence of the people contribute to this pressure on the resource.

In 1957 the Forest Service estimated that the total recreation visits by 1975 would reach 135 million, but this estimate was reached in 1965. Dr. Marion Clawson, of Resources For The Future, estimates that the recreation visits on National Forests could reach 400 million by 1980 and more than 1 billion by the year 2000. The amount of use on BLM lands is increasing at an even more rapid rate. It is clear that the National Park Service, like most other public agencies and private observers, has also greatly underestimated the continued growth in recreation demand in the West.

A Forest-Range Task Force, in December 1972 (21), projected outdoor recreation requirements on U. S. uncultivated lands to increase, in terms of 1965 uses, as follows: Camping-560 per cent, picnicking-400 per cent, horseback riding-370 per cent, and hiking-300 per cent. Their projections for requirements for fishing and hunting were much lower. The National Commission on Population Growth and the American Future states as follows (22):

> "During the postwar years, participation in outdoor recreation in the United States has grown by an average annual rate of 10 to 15 per cent. During more recent years, a slowdown in this rate has been observed for some specific recreational activities; however, the overall annual rate of growth may still be close to 10 per cent."

The increased importance of wildlife production and management on the Western range can also be readily illustrated. While livestock numbers on Federal lands have been reduced substantially since 1935, the number of big game animals has increased. At the present time, estimates indicate that there are more than five million big game animals on the Nation's forest-range lands (21). On BLM lands big game animals increased from an estimated 600,000 in 1945 to about 1.8 million in 1970 (23). Pressure by the public for hunting and other outdoor recreational opportunities has also opened up new possibilities for economic returns to many private ranching enterprises in the Colorado River Basin. Bird watching and nature photography, while not reported in wildlife-use statistics, also constitute an important part of the use of uncultivated lands.

The two Comprehensive Framework Studies of the Colorado River Basin, from which I have drawn much basic material, estimate that the acreage of land set aside for Wilderness Areas in 1965 was about 2.2 million acres. This acreage has already been increased substantially and hearings are continuing in many parts of the basin to add to our Wilderness and Primitive Area base. Naturally, the ranching industry is concerned about this trend since livestock will be excluded from an increasing acreage of Federal land.

Most of us recognize the need for wilderness and primitive areas, but the management of Wilderness Areas is of special concern to ecologists. Dr. D. W. Hedrick (24) stated recently that, "Many of the wilderness and National Park areas are occupied by fragile ecosystems where human and animal impacts are more crucial and significant than on the bulk of public ranges grazed by livestock." He expressed special concern over the effects of horses--both riding and beasts of burden. Dr. Hedrick also stated that, "It is only a matter of time before our policy on use of wilderness and remote recreational areas is attacked by minority and low-income groups. Our present policies on the use of wilderness areas is among the most discriminatory followed by public officials."

Watershed values of the western range are difficult to evaluate. The concern here is both water yield and water quality. On forest lands, a review of 39 watershed experiments throughout the world concluded that when timber stands are harvested, or sufficiently reduced in density, water yield is increased (21). The magnitide of change varies over a wide range of climates, forest cover types, and geomorphic situations. The role of vegetation management cannot be underestimated. On many brush-infested range areas there may be as much as 100 tons of water associated with the production of each pound of beef. But, even water expenditures for "undesirable" vegetation may not be wasted in terms of oxygen production or environmental enhancement.

Mineral production in the Colorado River Basin, particularly on the Federal lands, is subject to much controversy. The total acreage under petroleum leases or mineral claims may have stabilized somewhat, but the volume of production and the value of production of many minerals is still rising (21). Increasing concern about the total environment has reduced some of the speculative and haphazard exploration and/or exploitation, but many problems remain to be faced by this and future generations. Land-use policies, as they relate to mineral production, often have a heavy economic impact on small communities in the West. The energy crisis may force us to comprise our standards on environmental protection--at least for the short term.

For purposes of economic analysis, Gray (25) has classified multiple use of range resources into three categories: competitive, supplementary, and complementary. The traditional viewpoint of the rancher is that all other uses tend to compete with livestock production. This is certainly true for many ranching enterprises. But, for others, it may be both economically advisable and ecologically sound to consider supplementary or complementary activities such as grazing two or more classes of livestock, producing game, and managing the resource for recreational purposes.

Furthermore, while the rancher, as an individual with a direct economic interest in the range resource, may desire single-use management, the public must always consider multiple-use as the most desirable approach. As we come more and more to realize the impact of man's land-use practices on the total environment, we become even more heavily involved in the ecology of multiple-use management.

Some Ecological Considerations

Uncultivated lands present a complicated ecosystem for study involving the interrelationships among plants, animals and environment. Basic and applied studies are needed in many fields. But because of the need for correlating and analyzing the many variables, ecology has become the dominant science to bring the purpose of man in harmony with the forces of nature on range areas. Plant physiology, soil science, climatology, hydrology, genetics, forestry, entomology, taxonomy, wildlife biology, recreation management, and animal science are all complementary to ecology. And, while the economist is needed for determining managerial alternatives and other economic considerations, the ecologist must provide the essential service for analysis of interrelationships.

<u>In any ecological analysis, vegetation is the key, since Plants are the first step in energy capture, and are the major factor in eco-system stability</u>. The traditional approach to vegetation surveys on rangelands is often described as "dynamic ecology," the central concepts of which are succession and the climax as developed by Cowles, Clements, and Cooper in the early part of this century. Figure 1 is a schematic diagram of this concept (26).

Climate is shown as the overall controlling factor in vegetation and soil development. On any particular area, vegetation changes with time in

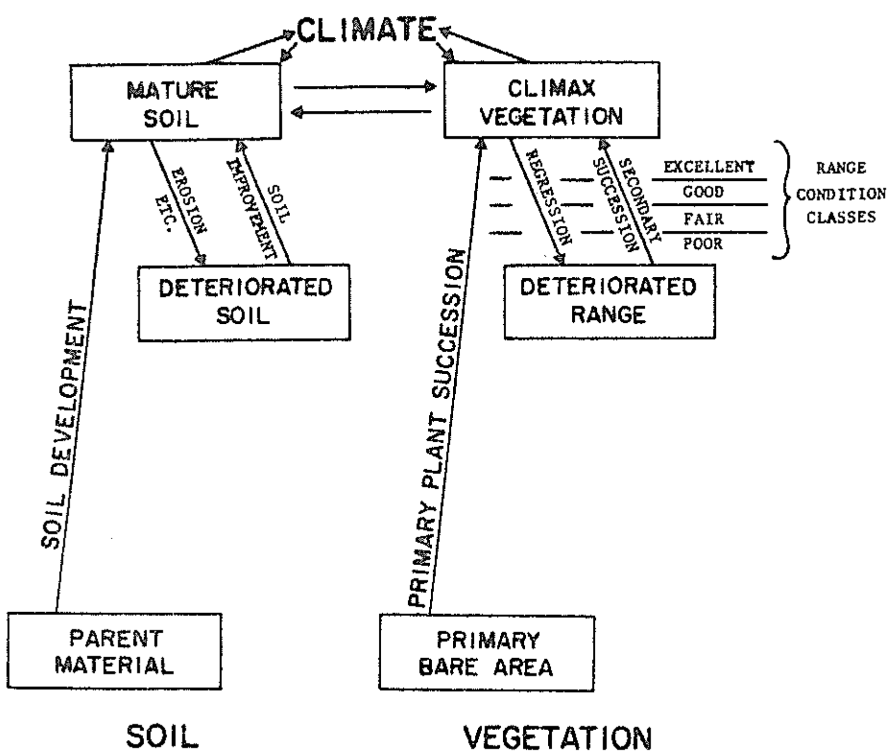

Figure 1. A concept of vegetation succession and regression patterns and the Range Condition Classification System.

a rather systematic pattern (primary plant succession) until a plant community (climax) ultimately appears in equilibrium with the environment. It might be more appropriate to call the terminal plant community an "Environmental Max" rather than a "Climatic Climax" since the total environment predetermines the outcome. This concept excludes the influence of civilized man, but includes other natural biotic factors. This climax condition is very dynamic and encompasses "normal" variation in climate. It means, also, that since geologic processes are still active on most areas, "Change is inevitable."

Man enters the picture and brings about vegetation change (regression or retrogression) through manipulation of livestock, harvesting of forests, cultivation, recreation, or other disturbance techniques. Man can also bring about improvement by controlled management to hasten "secondary succession." Corresponding changes such as deterioration in physical properties, or erosion, can take place in the soil depending upon the severity of the treatment imposed.

Attempts to quantify the succession-regression patterns were not very successful until the "Range Condition" method was developed following World War II. Ecologists first worked with the secondary succession sequence but found this rather frustrating because of the variation in developmental plant communities due to the extent of soil deterioration, availability and nature of seed source, short-run climatic adversity, size of the area, and other factors.

A major contribution was made by Dyksterhuis and others when a system of "Range Condition" classes was proposed, based primarily upon the regression sequence using livestock grazing as the disturbance factor (27). Most Federal agencies are now using a modification of this technique in evaluating the effects of grazing. Similar techniques could be used for other "disturbance factors." Unfortunately, little research data is available concerning such man-caused regression effects as the impact of recreational vehicles, uncontrolled hiking, camping, pack horses, etc. Some of the "substitutes" for livestock are probably more detrimental to the ecosystem and more difficult to evaluate and control than cattle or sheep.

Under this Ecological approach, vegetation classification "in time" is shown as "Range Condition," and classification "in space" is determined primarily by soil, topographic, and climatic conditions forming "Range Sites."

Once the boundaries of Sites are established, the succession-regression patterns are broken into Range Condition Classes: Excellent, Good, Fair, and Poor. These classes, therefore, represent departures from the so-called climax plant community, departures based upon grazing pressure or other disturbances over time. All plants on a particular range Site are identified as to their response to pressure and their probable place in the climax plant community. Thus, the vegetation survey establishes both present condition and potential productivity. It also reflects "stability" and "diversity" of biological populations.

Reliable soil or site surveys are vital to this system of classification. The spatial pattern of vegetation communities is complex, "a field of phenomena notably lacking in fixed points of reference, lines of division, invariable rules, and easy definitions" (28) and it is necessary to determine the role of soils in this distribution pattern. For the Colorado River Basin, with its extreme variability in rainfall, soils and topographic conditions, the proper identification of "Sites" and the proper analysis of vegetation change is critical--not only for evaluating the effects of grazing but to determine the effects of other man-caused or man-accelerated disturbance factors.

It is my hope that, to an increasing extent, we will base our values and choices in determining proper land and water use on ecological considerations. Under these conditions, agriculture and grazing will still remain competitive as a part of the economy and development potential in the Colorado River Basin.

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AFTER THE GREEN REVOLUTION

Wallace Cloud*

The Cincinnati Bengals football team also suffered during the mid-summer meat shortage. They had to cut their weekly training camp grocery list down to 180 pounds of prime rib, 120 pounds of New York cut steaks, 145 T-bone steaks, 137 sirloin steaks, 75 chickens, and about 60 pounds of cold cuts. The Bengals' chef could get only half of the customary 1,000 pounds of meat a week for the 75 team members.

The meat shortage had to be seen as a relative matter, however. At the same time that the Cincinnati Bengals were doing without, other Bengals--natives of Bangladesh--were living in famine conditions. They were not alone. Food shortages or actual famine prevail in many of the world's nations, caused in part by last year's drought; these situations include the sub-Sahara famine in Africa and shortages in Afghanistan, Pakistan, India, Indonesia and Central America. The drought belt also reached into Russia, where crop shortages were worsened by late flooding; floods also caused serious food problems in the Philippines.

The drought decreased world grain production about four per cent. "This small change was enough to cause violent responses in prices and shifting of foreign-exchange expenditure, and human suffering," says Dr. Lowell Hardin, Agricultural Program Officer of the Ford Foundation. In the mid-1960s, the Ford Foundation joined with the Rockefeller Foundation to sponsor development of special crops that, according to their advocates, would produce a "Green Revolution" and end hunger in the poor nations of the world. These crops included "miracle rice," "wonder wheat" and special varieties of corn--all developed to produce high yields under tropical growing conditions with the help of modern technology.

For a few years after introduction of the new crops, there were glowing reports of success. In early 1972, India announced that some food grain reserves had been accumulated, and that it planned to become independent of

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U.S. grain imports by 1973; the Philippines planned to become a major exporter of rice. More recently, however, the Green Revolution has come under attack. Its critics say that the successes are mythical and that application of the new agricultural technology has contributed to social unrest in Third World nations.

An Agricultural Miracle?

The Green Revolution got under way when new varieties of wheat were developed in Mexico under Rockefeller Foundation sponsorship, and "miracle rice" was developed at the International Rice Research Institute in the Philippines, a joint project of the Rockefeller and Ford Foundations. More recently, the foundations and the U. N. have sponsored work on new strains of corn suitable for tropical conditions. These "supercrops" are dependent on large quantities of fertilizers, pesticides and other chemicals and, in the case of rice and some wheat varieties, on irrigation.

Crop yields are considerably higher than those of older local varieties, but at the expense of some reduction in individual plants' protein content. That's because of the "inverse nitrogen law." Protein is based on nitrogen compounds; the effect of nitrogen fertilizer is to increase the protein per acre--in terms of number of plants--but to decrease the ratio of starch-to-protein in the individual plant. Thus, the new crops tend to have more calories in carbohydrates and fats but not in proteins, which remain at about the pre-Green Revolution level.

Campaigns to encourage use of the new seeds were conducted by the local governments with the help of U.N. agencies and the U. S. Agency for International Development, and crop-subsidy and farm-credit programs were set up. The results were widely hailed in the late sixties, but then problems began to develop. These include consumer resistance to some "tasteless" rice strains; a shortage of irrigated land and difficulty in providing irrigation when rainfall is absent; increased costs in terms of fertilizers, pesticides and drying machinery to prevent mildew and sprouting (some new rice varieties grow quickly, which means they have to be harvested during the rainy season).

The reports of success have been called deceptive by some critics. William C. Paddock, an agricultural consultant and author, for one, says, "The revolution is green only because it is being viewed through green-colored glasses like the Emerald City in *The Wizard of Oz*"--otherwise invisible. He ridiculed AID claims of 27 per cent increases in the output of rice and wheat in India in the 1967-69 period. "1965 and 1966 were poor weather years for the farmer of South Asia," he says, but then the weather improved. "A drought followed by rain will cause a spurt in production with or without new technology." In those same years, Paddock maintains, India had 20 to 30 per cent increases in barley, chickpeas, tea, jute, cotton and tobacco without miracle varieties. "When crops are poor, governments blame it on the weather. When crops are good, governments take credit," he says.

Paddock also claims that the Philippine government's reports of self-sufficiency in rice were based on high subsidies. The government "increased the price support paid for rice by 50 per cent. The support price of corn was also raised but to a lesser degree than rice. Rice production went up. Corn became cheaper to eat than rice, thus more people ate corn. Result: a 'surplus' of rice in the Philippines."

Social Consequences

Other observers have said that the Green Revolution defeated agrarian reform measures in the Philippines. Large landholdings were being broken up, but farming became more profitable as a result of the new methods, and the big landowners were able to retrieve their holdings. Dr. Marvin Harris of Columbia University, an anthropologist who worked in the Philippines, goes even farther. "The precise objective of the managers of the Green Revolution," he says, "is to wipe out the class of small farmers and to replace them with efficient agribusinessmen who will be heavily dependent upon industrial products and world markets."

American corporations are heavily involved in credit and supply arrangements, Dr. Harris says. "In the Philippines, for example, Esso Standard Fertilizer and Agricultural Company has played a critical role in all phases of the introduction and marketing of the high-yield varieties." Esso set up a network of 400 supply stores, and the Philippine government made credit available for purchase of the chemicals, but on terms unfavorable to the small farmer. "The inexorable, planned effect of the Green Revolution is for the millions of 'inefficient' farmers with small landholdings to sell out."

A somewhat more cautious statement of the same problem has been made by Lester Brown, senior fellow of the Overseas Development Council: "Another question persistently raised concerning the Green Revolution is, who benefits from the adoption of these new technologies? The new seeds can be used with equal success by both large and small farm owners if the farmers have equal access to the requisite inputs and supporting services. In many countries and locales, however, the owners of large farms have easier access to credit and to technical advisory services than the owners of small ones. Where these circumstances prevail, there is a disturbing tendency for the rich farmers to get richer and the poor ones poorer."

Summing up the situation, a recent World Bank working paper said, "Far from reducing social tensions in rural areas, the spread of the new technology is likely to sharpen them, and lead to great demand for the implementation of measures, such as land reform, for the redistribution of wealth and incomes."

Breeding Out Resistance

The Green Revolution also raises ecological questions in the form of threatening plant disease epidemics. As Dr. H. Garrison Wilkes, a University of Massachusetts plant geneticist, says: "Never before in human history have there been comparable monocultures--dense, uniform stands--of billions of plants covering thousands of acres, all genetically similar."

The problem is created by two aspects of the Green Revolution: genetic uniformity of the crop as a result of the breeding process, and world-wide planting of these miracle grains. The Green Revolution is ideal for the domino effect because there always exists the constant threat of mutations for pathogenicity in disease agents, making entire crops vulnerable.

That is what happened in the U. S. corn blight epidemic of 1970, in which one fifth of our hybrid corn crop was lost because of favorable growth conditions for the pathogen (a fungus), and widespread genetic uniformity in the American corn crop. Similarly, wheat stem rust wiped out 65 per cent of our Durum wheat crop in 1953, and 75 per cent of Durum wheat and 25 per cent of bread wheat in 1954. The 1970 corn blight is considered a factor in our present high meat prices. If a similar event took place in one of the tropical areas where large populations have become dependent on new crops, the result could be as catastrophic as the Irish potato famine of the 1830s.

As Dr. Wilkes indicates, we have been going through a Green Revolution of our own in the U. S.--a drastic change in farming methods since World War II. In fact, the Green Revolution abroad has been based on technology pioneered largely in this country, although certain innovations are traceable to Japan. Historically, the starting point of the process was the "yield takeoff"--a dramatic increase in the yield of crops per acre--initiated in the rice fields of Japan shortly after the turn of the century.

Intensive Cultivation

Japan, short of farmland and under population pressure, was the first country to practice "intensive cultivation," using large quantities of chemical fertilizer and many farm workers. Over a period of about 70 years, this has resulted in a jump in rice production from a little more than 2,000 pounds per acre to about 4,500 pounds per acre; an earlier doubling of the yield, from about 1,000 pounds per acre, had taken more than 1,000 years. A few small countries in northern Europe also achieved yield takeoffs in the early years of the 20th century through intensive cultivation, but the next important takeoff took place in the United States. Corn yields have more than doubled since the late 1930 s, and the U. S. farmer now produces three tons per acre.

This increase was caused mainly by the introduction of hybrid corn, another crop capable of increasing output when large amounts of fertilizer are applied to the land. More than 95 per cent of the corn acreage in the U. S. is now planted with hybrid corn, cultivated almost entirely for animal feed and industrially prepared foods. Like the "miracle rice," hybrid corn is somewhat lower in protein than the old feed corn, so protein supplements have been added. Fish meal was used until the recent depletion of Peruvian anchovies--caused either by overfishing or by temporary changes in ocean currents; soybean meal and milk products have since been substituted.

A whole cattle-feeding industry has grown up around hybrid corn. Calves, raised by "cow-calf" ranchers to a weight of 400 pounds, are sold to feed-lot operators. In the feed-lot pens, they do nothing but eat, and are shipped to the slaughterhouse when they weigh about 1,000 pounds. Similar feeding methods are now used in raising hogs and chickens. To meet the various nutritive requirements of different animals, hybrid corn feeds have become quite complex--they contain vitamins, antibiotics, tranquilizers, hormones and growth agents.

The Mechanized Meadows

Another reason for vastly increased crop production is the growing use of farm machinery. The number of tractor horsepower on American farms, for example, increased from five million in 1920 to 93 million by 1950, and is well over 200 million today, according to the Department of Agriculture.

Most basic farm machinery was developed during the 19th century, when horsepower still meant horses. Much of the increase in food production then resulted from bringing more land under cultivation; the new machinery was partly a response to labor shortages on the frontier. The development of animal-powered machinery continued until about 1930, when "big-team hitches" were still used to pull plows and combines on the prairies. Horse-drawn machinery reduced the manpower required to produce a given quantity of crops twelve times; since then, tractor power has reduced labor requirements only an additional 50 per cent.

Replaced by high-horsepower tractors with stereo-equipped air-conditioned cabs, draft horses and oxen disappeared from American farms after World War II, releasing many acres of land on which their feed had been grown. However, tractors on U. S. farms consume about eight billion gallons of gasoline a year, according to Dr. Michael J. Perelman, an agricultural economist at California State University, who calls modern agriculture "farming with petroleum."

Calculating the total energy consumption of farming in this country, including that used to manufacture fertilizer, Dr. Perelman arrives at a figure equal to more than 30 billion gallons of gasoline per year. In caloric value, he says, that's more than five times as much energy as Americans get from the food they eat.

Big Business

The great demands of modern farming has turned it into "agribusiness," a system that requires more and more "inputs"--chemicals, machinery, special seed, livestock feed, technical information--and capital or the credit to borrow it. The diversified, self-sufficient farm has passed into history, and farmers find themselves in specialized, highly competitive industries controlled by powerful, well-organized marketing interests.

Under these pressures, farmers' costs and debts have achieved a "take-off" of their own: According to the Agribusiness Accountability Project, a farmer-consumer group based in Washington, D. C., overall U. S. farm expenses have risen 122 per cent and farmers have 355 per cent higher debts since 1952. During the same period, the prices received by the farmer have gone up only six per cent (while the retail price of food was increasing 43 per cent). Consequently, the number of small farms has been dropping and the land has been consolidated into large farms.

Farmers have been going out of business at a rate of 2,000 a week since the 1930s. During World War II we had over six million farms; today there are less than 2.7 million. This process is expected to continue. Secretary of Agriculture Earl Butz says there will be only 1.8 million farms by 1980.

"Lack of management ability" is often given as the reason why the "marginal, inefficient" farmer loses out in today's agribusiness atmosphere. "We're primarily concerned with working with commercial farmers," says Dr. David Call, director of extension services at Cornell's College of Agriculture. County extension agents from agricultural colleges are among the farmers' most important sources of technical help and advice. "One of the most valuable services we provide, sometimes, is to help a man exit from farming," Dr. Call told me. "The guy that finally goes out usually goes out gracefully."

Concentration of economic power in farming is proceeding even more rapidly than the decline in the overall number of farms indicates. The largest 223,000 farms in the United States, only 7.6 per cent of the total number of farms, already produce slightly over 50 per cent of agricultural products, according to "Who Will Control U. S. Agriculture?" a study prepared by the agricultural schools of several midwestern universities, and coordinated by Dr. Harold Guither of the University of Illinois. "If this trend continues," says the study, "it is conceivable that within two or three decades 70 to 80 percent of total farm production could be concentrated on about 100,000 farms."

Large corporations are also buying and operating farms. Dow Chemical, for example, grows lettuce, Boeing Aircraft potatoes, and Getty Oil thousands of acres of vegetables in California. "Vertical" integration, the most significant form of corporate involvement, controls the farmer completely through contracts to buy crops at a guaranteed price. "Food processors routinely develop new seed strains for use by their hired farmers; they research and develop new machinery for crop production and harvesting, and they stipulate the timing, amount, and kinds of chemicals applied to crops that end up in their cans," according to the Agribusiness Accountability Project.

Del Monte, the world's largest canner of fruits and vegetables, has 10,000 farmers in the United States directly under contract. They have the prerogative of determining whether any given delivery is "of good quality and condition for canning." In 1972, the price of asparagus was

23 cents a pound; asparagus deemed unsatisfactory by Del Monte was bought at .0005 cent a pound. These rejects were used to make asparagus soup and asparagus cuts and tips, according to the Agribusiness Accountability Project.

Ninety-five per cent of the vegetables produced for processing are grown under contract integration. Sugar cane and sugar beets and fluid milk are even more heavily integrated. So is chicken farming or, as it's known in agriculture, the broiler industry. Ninety-seven per cent of all chickens are produced under contract integration. Ralston Purina and Pillsbury, among the large companies that dominate the broiler industry, produce chickenfeed and thus profit on the feed as well as on the end product.

Despite the Green Revolution at home and abroad, world reserves of food grains are just about exhausted, and we are living on current production. Whatever speculative economic pressures may be involved, this is a precarious situation indeed, which can be thrown off balance by crop failures or manipulation of supply and demand. Although world food supplies--with a growth rate of 2.8 per cent a year--have kept slightly ahead of world population's 2.6 per cent growth rate, the ghost of Malthus has been raised again.

"The worst is yet to come," a prominent agricultural expert told me. "Population in parts of the world where the problem is most acute is not being brought under control. That can lead to only one result--serious famine. It's already happening in Bangladesh and Africa. If Malthus was right, it's in operation now. Mother Nature's not going to be pushed around."

To compound the world food situation, some nations are responding to food shortages in new ways. "Historically," the Ford Foundation's Dr. Hardin says, "people have adjusted themselves to the food supply instead of adjusting the food supply to people. If the weather turned against you, you ate the stuff the livestock would have eaten."

However, "for the first time in the knowledge of man, the U.S.S.R. responded differently [to 1972's bad crops]. They did not liquidate their livestock, but rather somehow got together enough resources to go on the world market and buy enough cereals--some 30 million tons--to maintain livestock heads and also feed their people." The sale of one quarter of last year's U. S. grain crop to the Soviet Union has been blamed for triggering world food shortages and production cost increases.

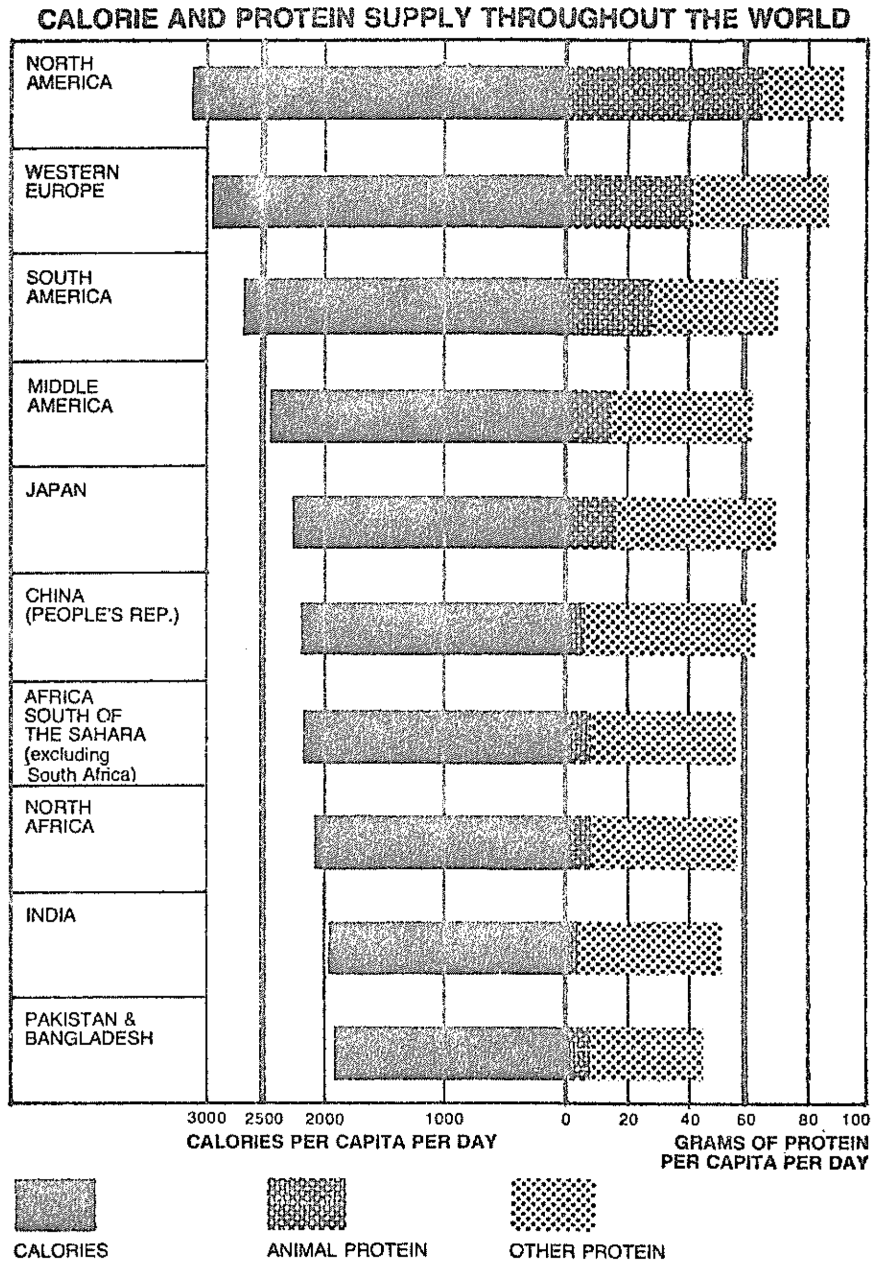
The Soviet Union made a "highly consumer-oriented response," to their grain shortage, Dr. Hardin says; that nation is attempting to upgrade the diet of its population by providing greater amounts of animal protein, nutritionally more desirable than plant protein. Generally speaking, a high protein diet distinguishes the affluent from the undernourished. This process has been going on not only in the U.S.S.R., but in all the northern industrial countries of Europe and also in Japan. In those nations, the diet is now approximately equivalent to that of the U. S. in 1940, according to Lester Brown, and consumption of meat is still going up. This kind of excess consumption of animal protein over absolute needs is what is straining world resources, say many experts, rather than a real shortage of food.

Feeding Animals

Dr. Georg Borgstrom, Professor of Nutrition and Food Sciences at Michigan State University, has calculated the food needs of the various livestock populations of the world in human population equivalents--the numbers of people who could be fed on equal amounts of food. The livestock population of the United States, says Borgstrom, consumes enough food materials to feed 1.3 billion people. Add to this our human population of about 200 million, and the U. S. has a total food population equivalent of 1.5 billion people. That's what our crops have to support. Globally, the population equivalent of all livestock being supported amounts to a load of 15 billion people, in addition to the human population of 3.9 billion.

There may be grounds for optimism in the fact that we are supporting so many livestock. Perhaps, if more of the primary foods went to people instead of animals, the world's farmland could feed many more billions of human beings. "The U. S. could no doubt feed some 800,000,000 to a billion people if a drastic switch took place in our daily food consumption to something resembling the present-day Chinese standard," says Dr. Borgstrom. But the tendency is to expand livestock herds, and for the rich countries to improve their diets at the expense of the poor nations.

Ecologists have pointed out that carnivorous animals need a longer food chain than herbivorous animals, i.e. they consume animals that consume plants. So the total primary food intake of the dominant carnivorous animals can be very large. It takes 50,000 pounds of primary plankton, consumed by marine organisms, to yield one pound of codfish, according to Dr. Borgstrom.



Diet of affluent nations vastly exceeds that of poor ones, in proteins and total calories--and may also exceed amounts needed for good health. Lines at 60 grams protein and 2,500 calories indicate basic dietary requirements for adult males.

In the race for protein, the tremendous expansion of commercial fishing, especially by Russia and Japan, may be utilizing the protein capacity of the sea to its limits already. "World fisheries are in serious trouble, largely because of overfishing," says Lester Brown. "Many marine biologists now feel that the global catch of table-grade fish is at or near the maximum sustainable level. A large number of the 30 or so leading species of commercial grade fish may currently be overfished, i.e. stocks will not sustain the current level of catch."

Moreover, the tendency of modern food production methods is to lengthen the food chain. Until the failure of the Peruvian anchovy fishery, the U. S. imported enough fish meal from Peru and Chile to meet the entire animal protein requirements of Peru--and this went into feed for chickens and other animals in the U. S. Animal protein was used to produce animal protein.

A Need for Action

The food situation, especially on the world scale, is generally regarded as critical by the experts. In the immediate future, the Farm Bill, recently passed by Congress--eliminating acreage set-asides so that almost all U. S. cropland will be production--should be of some help. However, this will add a comparatively small amount of arable land; in 1973, only about 19 million of the 350 million U. S. crop acres were withheld from use. Meanwhile, there is likely to be "rationing by price," as the Ford Foundation's Dr. Hardin says.

For the long run, much more comprehensive action seems mandatory. Says Lester Brown, "In this decade, the overriding objective of a global food strategy in an increasingly interdependent world should be the elimination of hunger and malnutrition among the large segment of humanity whose food supply simply is inadequate. To be successful, such a strategy must be designed to alter existing trends in food production and population growth while seeking a more equitable distribution of food supplies both among and within societies."

EXPLOITING GRASS-ROOTS FOOD TECHNOLOGY IN DEVELOPING COUNTRIES

Samuel M. Weisberg*

Major food technology advances generally start in developed countries and find gradual application in the developing world. However, application of such advances nearly always requires a large capital investment which can be justified only in the presence of a mass consumer market. This generally limits the application of these advances to urban areas and to products for those consumers of better income living in a money economy. An example of such technology is that which has resulted in textured vegetable protein foods. This development from the United States has proved of great interest to numerous developing countries and is beginning to achieve some application in these countries.

In the villages, however, where people live in a subsistence economy, such advanced food technology can only have a marginal effect because money is lacking to purchase the more sophisticated foods. And, a concentrated mass market does not exist. Thus, there is no warrant for the capital investment and effort needed to market such foods. Yet, the existence of malnutrition and undernutrition is widespread in the rural areas.

To meet these urgent needs, a grass-roots science of applied nutrition and food technology is needed. This grass-roots science should:

1. Identify and fully characterize useful native food ingredients, especially those rich in protein;
2. Provide simple technology for the removal of toxic, inedible, and ill-tasting components from such native crops;
3. Prepare good foods by formulating readily made blends of culturally accepted foods (corn, rice, and cassava for example) with useful native supplementary food ingredients;
4. Create recipes that will fit the improved foods or food blends into the current eating patterns of the people;
5. Provide simplified nutrition education to motivate village people to prepare and use the improved foods.

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What is Grass-Roots Food Technology?

Fish Concentrate

The contrast between sophisticated food technology and the grass-roots variety can be exemplified by comparing the production of fish protein concentrate with the production of a salted fish block.

In the former, the fish is subjected to a highly sophisticated solvent extraction process requiring a considerable investment in plant equipment. And although the resultant product has a long shelf life, it is essentially a new food ingredient requiring extensive consumer education and motivation for acceptance.

In the case of the fish block (del Valle, 1972), the fish flesh is minced and simultaneously salted and compressed into a block. The block is then sun dried. Presumably, enough of the original texture and flavor of the fish is thus retained so that a major consumer motivation effort will not be needed (consumer tests have so far been satisfactory). The useful shelf life of such a salted block is no doubt shorter than that of fish protein concentrate. Yet it is long enough to permit supplying fish for a considerable distance inland from the sea. The developers of this process believe that a small operating plant could be managed by virtually one family with a very modest capital investment.

Soybean-Banana Blend

Another interesting example of grass-roots food technology has been that applied to making a soybean-banana blend (Steinberg, 1972). "Drop dry soybeans into boiling water and simmer for 30 minutes, drain, and discard water. Rinse the soybeans in tap water to cool. Mash the beans (as in a hand meat grinder). Mash the bananas in the presence of a little citrus fruit juice (such as lemon or lime). Mix the banana and soy pulps together. Let stand for a few minutes and then eat."

This blend could no doubt be made supplementing the bananas with one of many other native legumes or oilseeds besides soybeans (if these are not available). The banana supplies good flavor, minerals, trace elements, vitamins, and readily digestible carbohydrates. The legume or oilseed supplies primarily protein and oil. The combination would seem to be a happy one for such purposes as weaning and children's foods, and, in general, as a very acceptable well-balanced low-cost food.

Besides the very elementary procedure described Steinberg (1971) has also described a pilot plant process for making a weaning food which is closely related to the soybean-banana blend just described: Whole soybeans are simultaneously hydrated and blanched for 30 minutes in boiling water. Ten parts water are added to one part blanched beans. The beans are then finely ground in a comminuting mill. Fresh ripe bananas are added at a ratio of one part banana solids to one part soybean solids and blended in the same mill in the presence of 100 ppm of sodium bisulfide to prevent darkening. The slurry is dehydrated to the present moisture using a double-drum drier with 0.01 in drum spacing and 40 psig steam pressure in the drums. The resulting product has a pleasant flavor and is readily reconstituted with water. It has a very acceptable shelf life. Other native fruits could be used in place of the banana and other native legumes or oilseeds in place of the soybeans.

The process just described would require a substantial investment for the comminuting mill and the drum drier. However, one can visualize a process using thermal extrusion equipment, such as is used in producing textured vegetable protein, but of possibly a less-sophisticated character. I have dwelt on this example because it does indicate several levels of food technology sophistication and does make use of indigenous ingredients.

Bread-Making

Another example of applied food technology which can range from the grass roots to a more sophisticated type is the production of baked goods of enhanced nutritional value. It has been long known that wheat flour (the mainstay of break-making) contains an incomplete protein. With the development of new bread improvers such as sodium stearoyl lactylate or the sucrose fatty esters, it is possible to make acceptable bread of improved nutrition by adding substantial increments of legume or oilseed flours to the wheat flour, or by adding nutritionally valuable by-products such as rice polish. Even when the bread is baked in relatively primitive ovens using rudimentary dough-making equipment, acceptable bread can be made closely resembling in appearance the unfortified bread that the available equipment produces. Relatively minute percentages of the bread improvers are required and these can be imported from the USA or Europe.

Another procedure consists of adding intact bits of a high-protein food such as fish, poultry, meat, legumes, oilseeds, or textured vegetable protein to a dough before baking (Bacigalupo, 1972). This causes a minimum change in the desired structure of the baked goods. At the same time, there is enhancement of the protein content.

Preservation Methods

Simple methods of preservation to extend the shelf life of foods are in ever-present need in developing countries. One such method, osmotic dehydration (Hope and Vitale, 1972) is applied to mangoes, plantains, and bananas. In this process a 67% sugar solution is prepared in unheated water. Ripe bananas or plantains are cross-cut into 2-4 cm thick segments and placed in four times their weight of this sugar solution and held for 18 hours with occassional gentle mixing. Next, the slices are transferred to a 60% sugar solution containing one percent SO_2 supplied from potassium metabisulfite and held for one hour. The slices are then removed and drained thoroughly. They are then given a brief dip (one minute) in clear cold water to reduce stickiness.

The partially dehydrated slices (if extended storage is needed) can now be sun- or even shade-dried. A cabinet drier (if available) will accelerate the drying which can be safely completed in about 18 hours at 48°C, 50% relative humidity and with a linear air flow of 300 meters/minute. One can visualize an array of tropical fruit confections made by variations of this osmotic dehydration process.

Marmalade

Interesting marmalades can also be made by boiling down a citrus juice made from oranges, lemons, or limes to which sugar has been added and then adding thin slices of ripe banana at the later stages of cooking. The acidity of the juice completely preserves the light color of the banana slices and the slices contribute an appealing flavor and appearance.

Fermentation Technology Offers Promise

Fermentation technology lends itself with great flexibility to producing foods of extended shelf life having excellent flavor and nutritive value. Such technology can be applied in the home, at the village level, or in full-scale commercial production. Fermented food using mold cultures play an important role in Asia and the processes developed there and practiced for millennia could no doubt be applied in other developing countries.

An example of one of these foods is tempeh, a major Indonesian food. Whole soybeans are washed and soaked overnight in tap water. The seed coats are removed and the beans are boiled in water for 30 minutes with the mold *Rhizopus oligosporis*. Small patties of the beans are tightly packed in banana leaves and incubated for 20-24 hours at 31-32°C. At that time the patties are completely bound together with mold filaments. They can now be sliced and fried in oil. The texture and flavor is remarkably good even for the palate of the western world. The mold culture is transferred from batch to batch of the fermented beans and the environmental conditions of humidity and temperature are well suited to its growth.

While mold cultures have been extensively applied in Asia for preparing valuable foods from soybeans fermentations based on milk-souring types of bacteria have not received equal attention. Yet it is clearly indicated that buttermilk and yoghurt types of bacteria products can be made by fermenting soy milks with such cultures as *Lactobacillus acidipholus, Streptococcus lactis*, and *Leuconostoc citrovorum*. Cheese-like products can also be made from soy milk with the help of *Streptococcus thermophilus* (Angeles and Marth, 1971).

The art of fermenting vegetables has been practiced for more than 4,000 years. Cabbages, cucumbers, tomatoes, brussel sprouts, cauliflower, peppers, olives, carrots, and other horticultural products have long been successfully preserved by fermentation.

However, improved technology can surely be applied to such fermentation procedures as by the use of pure mixed cultures, and/or the use of a hot water blanch to pasteurize the vegetables prior to inoculation with suitable cultures of microorganisms. Such improvements can greatly speed the fermentation, prevent spoilage, and produce products of better flavor. There is also the excellent possibility of extending suitably controlled fermentation technology to a great variety of perishable products, such as animal protein foods (fish, meat, and eggs).

Pickling procedures involving the use of such acid as acetic and/or lactic also still offer unexplored possibilities for preserving many perishable foods or food ingredients. The use of such organic acids can by-pass the need for fermentation procedures and the extended time involved. However, one cannot expect the same desirable unique organoleptic properties to be developed as in the case of suitable fermentations.

What Grass-Roots Technology Will Involve

It is hoped that, while not neglecting the great potential of major food technology innovations--spun fiber or thermoplastic vegetable protein extrusion, for example--that grass-roots technology for developing countries will not be neglected. Such technology will involve:

1. Nutritional characterization of hitherto unexplored native valuable food crops;
2. Relatively simple processing steps for rendering these crops ready to use safely as food ingredients;
3. Formulating available food ingredients to make acceptable balanced foods of adequate shelf life;
4. The application of procedures for preservation requiring a minimum of sophisticated processing such as pickling, fermentation, osmotic dehydration, or depressed water activity.

The challenge here to the food technologist, chemist, and engineer is no less than in the case of applying highly sophisticated food technology. A high level of creative imagination and an intimate knowledge of cultural habits and environmental conditions is needed. There is also a need for constantly devising simplified quality control methods and processing systems that are compatible with the limited resources available.

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PROFOUND CHANGES COMING IN POLLUTION ENFORCEMENT

Dale S. Bryson*

Far-reaching changes in our entire system of pollution control are being brought about by the Federal Water Pollution Control Act of 1972. It will upgrade a crude and shaky structure of targets, gaps and loopholes into a tight regulatory system. Precise, detailed abatement requirements will be established. They will be enforced through streamlined legal procedures and heavy penalties for violations. In my judgment, these changes are going to revolutionize the social structure of water pollution control. Within a few years the new law will end the reign of evasion and emotion. It will in their place establish the rule of law.

The sweeping statements I have just made are based on specific provisions of the new law and their application to our programs. I would like now to explain what these are and how I believe they will operate. The chief factors are as follows:

Precise Limits for Waste

First, the law mandates establishment of effluent limitations. These will be specific numerical requirements setting forth precise upper limits on the waste loads which a plant will be permitted to discharge into our waterways. In the past a chief weakness of the regulatory programs has been the absence of specific yardsticks to measure satisfactory performance. This has permitted polluters to claim that they were meeting requirements despite inferior systems of control or sloppy operation and maintenance of their abatement facilities.

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Second, the law established higher standards for pollution control. The law specifies that each industry must by July 1, 1977, meet effluent limitations reflecting application of best practicable control technology currently available. In cases where the receiving water requires more stringent control, then higher levels of treatment or control must be achieved. This will establish at the minimum a uniform national standard applicable to all plants wherever located. By ending the total reliance on receiving water conditions, the new standards immesurably simplify problems of evidence. This will facilitate effective regulation of many gross polluters who have strenuously resisted their clean-up obligations. During the next five years all plants must undertake programs to achieve the new control requirements.

Tough Penalties

The new law established tough penalties to enforce compliance. Violations of permit conditions or other requirements will be subject to civil penalties of up to $10,000 a day, in addition to other civil remedies and administrative actions. Willful or negligent violations will be subject to criminal penalties of up to $25,000 per day. For the first time the pollution control requirements will be backed up by meaningful sanctions. This is a fundamental and indispensable (though previously missing) element of any regulatory system. From a legal viewpoint it is critical to the basic legal advice that, "The law is the law. It must be obeyed."

The new requirements will be enforced and foot dragging will be harshly punished. The key to an effective regulatory system is that there be firm, specific requirements imposed on all parties with even-handed fairness. The exact requirements must be clearly understood and publicized. They must also be uniformly and strictly enforced.

Permits Will Be Required

Third, the new law creates a national permit program. Every industry will be required to obtain a permit under Section 402 of the law. Issuance of these permits will provide the mechanism through which the new, more stringent abatement requirements will be set. Moreover, once issued, these permits will contain in a single document the complete schedule of requirements for each individual plant. Copies of the permits will be available to the companies, State officials, Federal officials and private citizens.

The new national permit program will not begin from scratch. Many States already have permit programs. In addition our Agency has been working persistently for two years to lay the foundation for an effective national program. We already have on hand roughly 23,000 applications submitted under the Refuse Act Permit Program established by President Nixon in December 1970. These applications have been processed with great care. We have concentrated our efforts on roughly 2,700 major discharges, whom we believe in the aggregate account for the vast majority of all industrial wastes discharged into our waterways. As the legislation has been developing in Congress, we have made vigorous efforts to prepare for it. Although the determinations of best practicable control technology must be made individually as to each plant. We have already developed a vast amount of guidance to our professional personnel for use in making such determinations.

Permits under the new program will specify effluent limitations that must be met after anticipated abatement programs have been completed during the first few years. These will set firm targets for each company's engineers. The permits will also set effluent limitations applicable during the interm. The effluent limitations will apply to numerous parameters of each plant's discharges. Too often in the past requirements have focused only on the oxygen demanding wastes and have not zeroed in on other substances in the waste. The new requirements will specify limits not only for BOD but also for total suspended solids, alkalinity or acidity, temperature, oil and grease, and individual heavy metals and toxic substances. Permits will require continuous monitoring by the major dischargers, with frequent reports subject to the penalties of perjury. All of the permits and all of the reported data will be made readily available for public inspection.

Framework for Cooperation

Perhaps our most promising concern in establishing the national permit program under the new law will be to establish, promptly and smoothly, good working relationships between EPA and State agencies. The new law authorizes the Environmental Protection Agency to begin issuance of permits under Section 402 immediately. It also contains detailed provisions for approval of State programs to authorize the States to assume operating responsibility for the new national permit program. In a great many cases State Agencies will have to receive new legislative authority from their State Legislatures before we will be permitted under the law to give final approval to the State programs.

Our objectives will be to work closely with the States to enable them to meet the strict requirements of the law as rapidly as possible. In the meantime we will move forward to issue permits out of EPA, though in these cases also we will seek active participation by the States. We will need to establish effective arrangement so that the issuance of permits will go ahead at full speed whichever level of government has the formal authority. Since permits are necessary to trigger the next step forward in pollution abatement, our foremost concern will be to make certain that the program moves ahead as fast as possible.

CLEANING OF FOOD -
Alternatives to present water use patterns

John M. Krochta and Richard J. Bellows*

Cleaning is probably the most widely used of all food processing operations, ranging in significance from the major processing step to a simple housekeeping activity. Raw products must be cleaned of contaminants accumulated during growth, harvest, and transport; processing equipment and facilities must be kept clean to prevent recontamination of the food. This paper emphasizes cleaning of the food itself, the so-called "soft surface cleaning" in contrast to the cleaning of equipment and facilities ("hard surface cleaning").

Cleaning is a separation and transport process. Its function is to 1) separate soil from the substrate (material being cleaned) and 2) transport the soil away in the cleaning medium to prevent recontamination of the clean surface. In this regard "soil" is defined generally as "matter out of place" (Jennings, 1965). Field soil, trash, insects, pesticides, and plant exudates are of concern in cleaning raw foods.

Mechanical harvesting has increased the cleaning problem because of increased soil contamination and product breakage. As an example, soil loads on machine-picked tomatoes have been found close to 2%, with 10% of the soil present in the difficult-to-remove smear form (Mercer, 1967). It is not unusual for a canner to receive loads of tomatoes having 30% broken fruits. This compares with approximately 10% damaged with handpicking. Broken fruit contributes to the plant exudate soil and can aggravate insect contamination problems. Broken fruit and heavy soiling have increased effluent strengths and volumes as the food processor has attempted to clean raw product entering the plant solely through the use of greater amounts of water.

* Reprinted by permission from Food Technology, Vol. 28, No. 2, pp. 34-37, 47, 1974.

The Authors are, respectively, research chemical engineer and NRC-ARS postdoctoral research associate with the USDA Western Regional Research Laboratory, ARS, Berkeley, California.

We have explored factors affecting the nature of soiling and cleaning in attempting to reduce water consumption and pollution from this process. For soiling, this includes the effect of moisture content and fruit exudate on soil deposition and adherence. For cleaning, this includes the effect of water, detergent solution, foam, nonpolar liquid, and a water nonpolar liquid suspension as cleaning media. The degree of soil removal in terms of water used is of interest.

Development of Theory

Soiling is a spontaneous process (Jennings, 1965) which can be represented as

$$\text{Free Soil} \rightarrow \text{Deposited Soil}; \ \Delta G = -\ N \text{ calories.} \quad (1)$$

This process is shown schematically in Figure 1. There is a negative change in free energy, ΔG. Therefore, a certain amount of energy is always required to produce a clean surface. For soils (2) which wet a surface (1), the change in free energy for soiling in air or other media (3) is

$$\Delta G_{\text{SOILING}} = A(\gamma_{12} - \gamma_{13} - \gamma_{23}) \quad (2)$$

where γ is surface tension and A is area of soiling. For situations of this type with a measurable contact angle, Θ, the Young and Dupre equation (Adamson, 1967) may be used:

$$\gamma_{13} = \gamma_{12} + \gamma_{23} \ (\text{COS } \Theta) \quad (3)$$

Combining equations (2) and (3), one obtains

$$\Delta G_{\text{SOILING}} = A[-\gamma_{23}(1 + \text{COS } \Theta)] \quad (4)$$

This shows that for any Θ less than 180°, soiling will occur spontaneously. For all real cases, soiling will therefore occur; and any factor which reduces Θ will enhance the soiling process. These factors must be identified, and if possible be controlled during growth, harvest, and transport so that spontaneous soiling is minimized prior to final cleaning for preservation. We have evaluated the effect of soil moisture content and fruit exudate, two primary factors affecting soil deposition and adherence and hence the cleanability of raw product prior to processing.

The basic system of interest here consists of a waxy surface in air (e.g., a tomato) which is soiled with wet clay particles having free surface moisture. The soil is assumed to have the wetting properties of water and the waxy surface is assumed to have the properties of paraffin in order to estimate the free energy change during soiling. This model assumes that the adhesion of the wet clay soil to the waxy surface is primarily due to the continuous wax-water interface formed by the free water, rather than point-

$$\Delta G_{SOILING} = -N \text{ CALORIES}$$

$$\Delta G_{SOILING} = A\,[\gamma_{12} - (\gamma_{13} + \gamma_{23})]$$

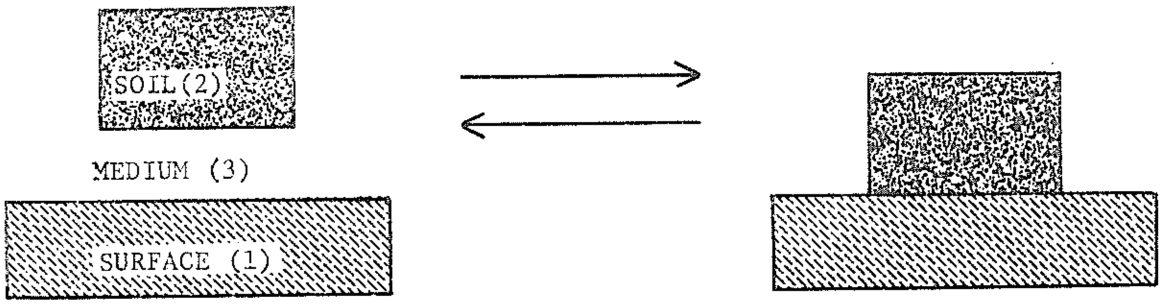

Figure 1. Thermodynamics of soiling

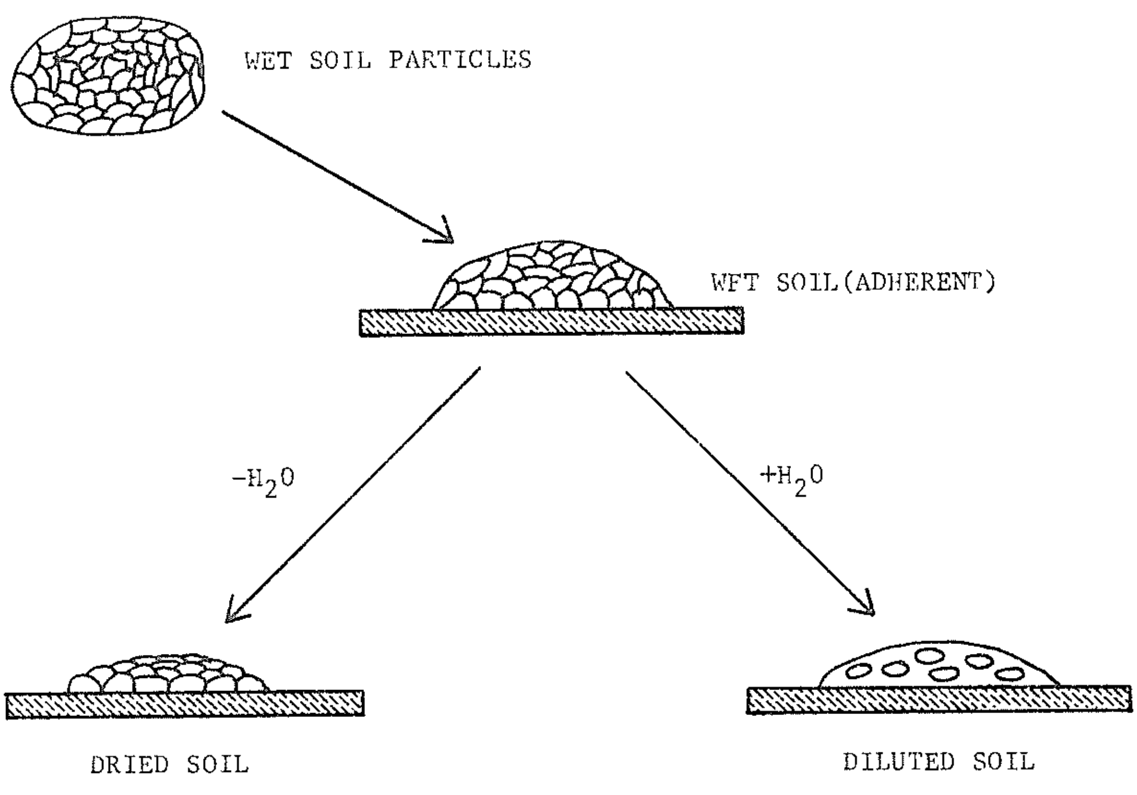

Figure 2. Wet soil on a waxy surface

wise wax-clay adhesion, such as with a totally dry soil. Inserting the necessary surface tensions from Table 1 into equation (2) yields:

$$\Delta G^{\text{AIR}}_{\text{SOILING}} = A(51 - 26 - 73) = -48\ A\ \text{ergs/cm}^2 \qquad (5)$$

Cleaning is the reverse of soiling. As a result the change in free energy for removing a soil (2) from a surface (1) in a cleaning medium (3) is

$$\Delta G_{\text{CLEANING}} = A(\gamma_{13} + \gamma_{23} - \gamma_{12}) \qquad (6)$$

or

$$\Delta G_{\text{CLEANING}} = A[\gamma_{23}(1 + \cos\Theta)] \qquad (7)$$

Thus, removing wet soil from a waxy surface in air would require an energy input of

$$\Delta G^{\text{AIR}}_{\text{CLEANING}} = A(26 + 73 - 51) = 48\ A\ \text{ergs/cm}^2 \qquad (8)$$

However, placing the soiled surface into a different medium results in a different free energy of cleaning. The surface tension values of Table 1 give the following free energy change for cleaning in a water medium:

$$\Delta G^{\text{WATER}}_{\text{CLEANING}} = A(51 + 0 - 51) = 0 \qquad (9)$$

The free energy change calculated for cleaning in a paraffin oil medium is also zero:

$$\Delta G^{\text{PARAFFIN OIL}}_{\text{CLEANING}} = A\ (0 + 51 - 51) = 0 \qquad (10)$$

Table 1. Interfacial Tensions, γ, for several interfaces (Fowkes, 1964)

Interface	γ, ergs/cm^2
Water-air	73
Paraffin wax-air	26
Paraffin oil-air	29
Paraffin wax-water	51
Paraffin oil-water	51
Paraffin wax-paraffin oil	0
Water-water	0

Determined using Fowkes approximation for interfacial tension with γ = 22 ergs/cm^2 for water.

It can be seen that waxy surfaces wetted with clay soils are more easily cleaned in water than air. However, our analysis also shows the potential equal effectiveness of a paraffin-oil cleaning medium. A paraffin oil cleaning medium would have the benefit of keeping the soil in a concentrated form, since it would settle in a liquid paraffin, like (nonpolar) cleaning medium rather than disperse. The decanted paraffin oil may be easier to clean for reuse. Interestingly, equation (7) shows that $\Delta G = 0$ for cleaning in water ($\gamma_{23} = 0$) and in liquid paraffin ($\Theta = 180°$). Liquids intermediate in polarity with $\gamma_{23} > 0$ and $\Theta < 180°$ give a $\Delta G_{CLEANING} > 0$ for the wetted clay soil on a waxy surface.

The assumption that soil has the wetting properties of water, which was used in this model, is hardly ever realized completely in practice. Thus, although ΔG for cleaning is reduced by immersion of a soiled waxy object in water, some energy input is usually required, i.e., $\Delta G^{WATER}_{CLEANING} > 0$. The energy requirement would increase as the moisture content of the soil decreased. With the exception of a completely watery soil, some energy would also be required in an oil-cleaning medium; i.e., $\Delta G^{OIL}_{CLEANING} > 0$. Nonetheless, the model shows the potential of an oil-cleaning medium. The analysis also suggests an oil-water suspension cleaning medium, with the water available both to help cleaning and to hydrate the soil.

Such an analysis also shows the advantage of adding detergents to aqueous cleaning media, since they reduce γ_{13} and γ_{23}. The result is also a reduction of $\Delta G_{CLEANING}$. We have attempted to compare the cleaning effectiveness of water, a detergent solution, a foam, a non-polar liquid, and a suspension of water and a non-polar liquid.

Tomatoes Used for Experiment

We selected tomatoes for the study because of their economic importance and the large amount of water consumed and effluent generated in their cleaning. Soiling and cleaning experiments were performed in most cases on Mexican-grown, store-bought tomatoes. Evaluation of paraffin oil and water-paraffin oil suspension cleaning media was performed using store-bought cherry tomatoes.

Experimental soil was obtained by slurrying silty-loam soil in water, discarding soil which settled within the first 20 minutes, and collecting the remaining suspended soil by further settling and/or centrifugation. The fine clay obtained by prolonged settling and centrifuging was expected to adhere most strongly to tomatoes and to simulate the fine soil a tomato would pick up during mechanical harvesting.

Water or tomato juice was added to the heavy soil slurry (39-42% water) to achieve any desired total moisture content soil. Tomato juice was prepared by cutting, mashing, and then screening ripe tomatoes through 10- and 35-mesh screens.

Advancing contact angles were determined by pipetting a 0.02-ml drop of wet soil onto a tomato surface and measuring directly. Receeding contact angles were determined after quickly flattening the wet soildrop into the tomato surface with a metal spatula and then allowing the drop to reform. All measurements were made with a Model No. A-100 Goniometer (Rame-Hart Inc., Mountain Lakes, N.J.).

Moist soil was applied for cleaning experiments with the fingertip of a rubber glove by smearing the soil as consistently as possible over a 1-in-sq area for the regular-size tomatoes and a 3/4-in-sq area for the cherry tomatoes.

Cleaning experiments with regular-sized tomatoes were performed in a seven-liter agitated bath, while experiments with cherry tomatoes were performed in a one-liter beaker with agitator. Experiments were performed in triplicate and results average.

Soil residues were determined by allowing the soil to dry, scraping the residual soil from the tomato surface, and then weighing the soil.

Foam used was generated with a Model 310 Foam Generator with a No. 1.5 feed pump (Waukesha Foundry Co., Inc., Waukesha, Wis.) operating at 3,200 rpm. An 0.3% solution of Duponol C (sodium lauryl sulfate) (E.I. Du Pont de Nemours and Co., Wilmington, Del.) in water was used to produce a foam of 0.1 g/ml density. A four-liter container was filled with the foam and soiled tomatoes dropped into the container where they remained for one hour before being removed for determination of soil residue. Foam treatment was compared with washing soiled tomatoes in stagnant water and 0.3% aqueous solution of Duponol C for one hour.

<u>Effect of Soil Moisture and Tomato Juice</u>

Figure 2 shows the different situations encountered in the soiling of the waxy tomato surfaces. When soil has no free surface moisture, adhesion is by point-wise clay wax contact. Thus the soil adheres weakly and any soil which does adhere is easily removed. When the soil exists essentially as a solution in water, the soil tends to assume the properties of water with a large surface contact angle which is indicative of easy cleaning. Between

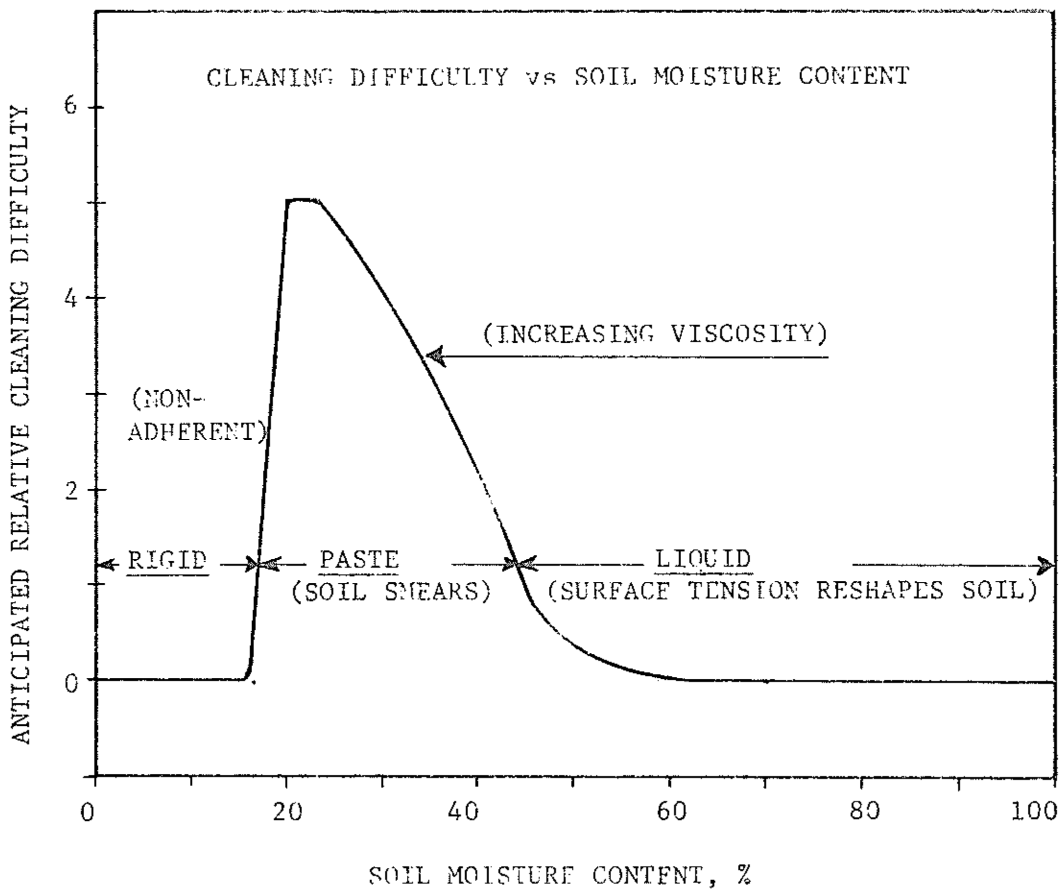

Figure 3. Physical and Soiling Properties of soils with indicated water content.

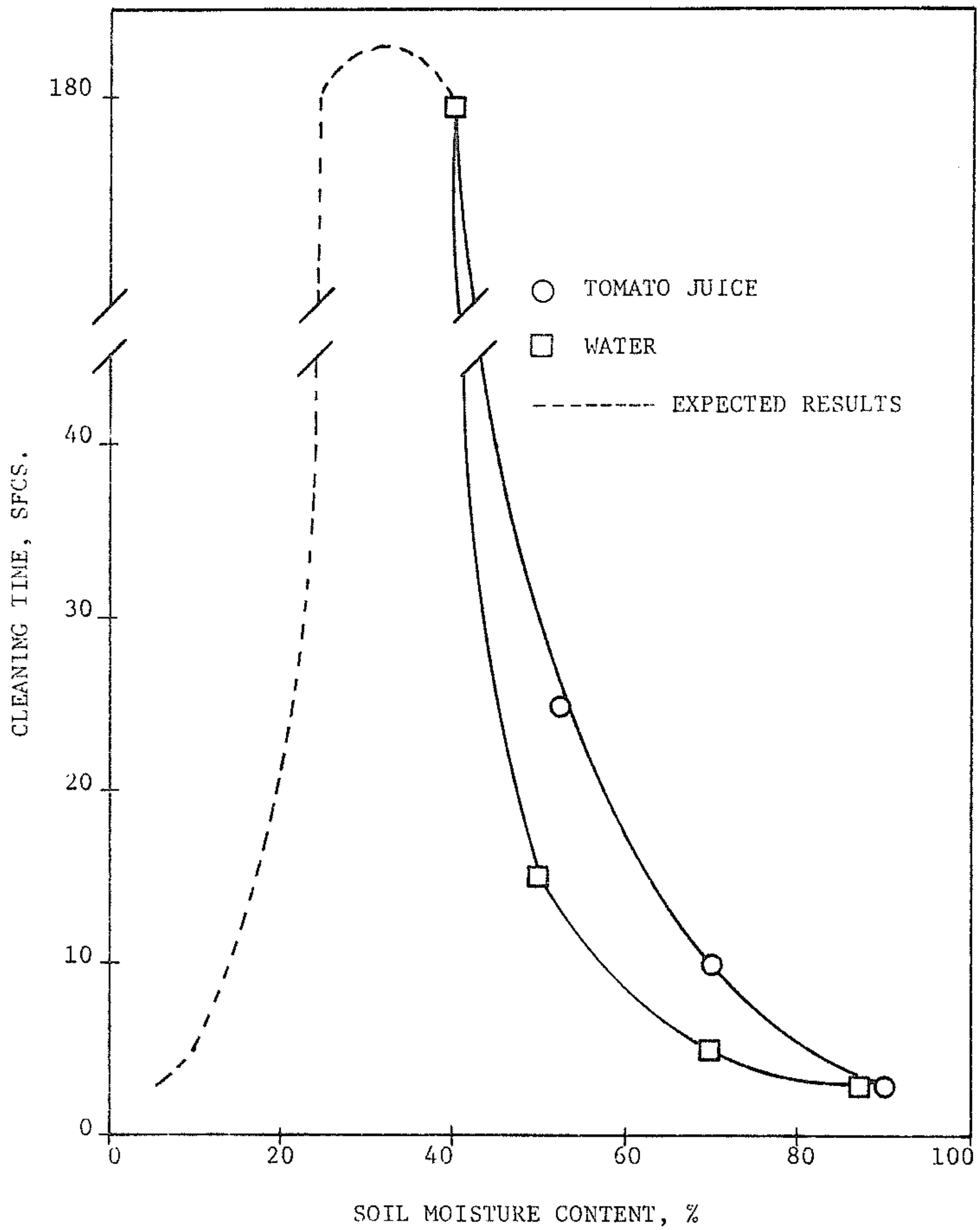

Figure 4. Cleaning times for tomatoes smeared with soils of various water and tomato juice content. Tomatoes cleaned immediately after soiling.

these extremes exists a paste-like soil which smears on the waxy tomato surface quite easily and has a very low contact angle.

Table 2. Contact Angles for water, soil-water, solutions and tomato juice on tomato surfaces

	Contact angles	
	Advancing	Receding
Water	90°	60°
80% moisture soil	89°	55°
70% moisture soil	88°	45°
Tomato juice	75°	16°

Table 2 shows the effect of decreasing moisture content on the contact angle of a soil on a tomato surface. At lower moisture contents, the soil eventually becomes a paste of high viscosity with a very small receding contact angle. Table 2 also shows the small receding contact angle of tomato juice, thus suggesting its role in promoting soil smearing on tomoto surfaces.

Figure 3 shows the observed soil characteristics and anticipated relative difficulty of soil removal for soils over the entire range of moisture contents. A dry, particulate, rigid soil exists in the range 0-20% moisture. Then, rather abruptly, a viscous, pasty soil forms with increasing moisture content which adheres strongly and is difficult to remove. As moisture content increases further, the soil loses its pasty character and eventually becomes a watery solution which is much easier to remove. Figure 4 shows some actual cleaning data obtained in an agitated bath. The cleaning time dependence on soil moisture content is clearly indicated. The effect of tomato juice in the soil is apparent, as it definitely promoted soil smearing and increased cleaning times. (Data for tomato juice is for tomato juice added to a 40% moisture soil to bring soil up to indicated moisture content.) The low expected relative cleaning difficulty of soil below 20% moisture indicated in Figure 4 reflects the nonadhering properties of this dry soil.

Figure 5 shows the total cleaning curve for a 52% moisture content soil. Soil residues are shown as a function of time. Cleaning was performed immediately after soiling, and each data point represents separately soiled tomatoes. The data approximates a semilog plot, suggesting first-order kinetics for soil removal when cleaning occurs soon after soiling.

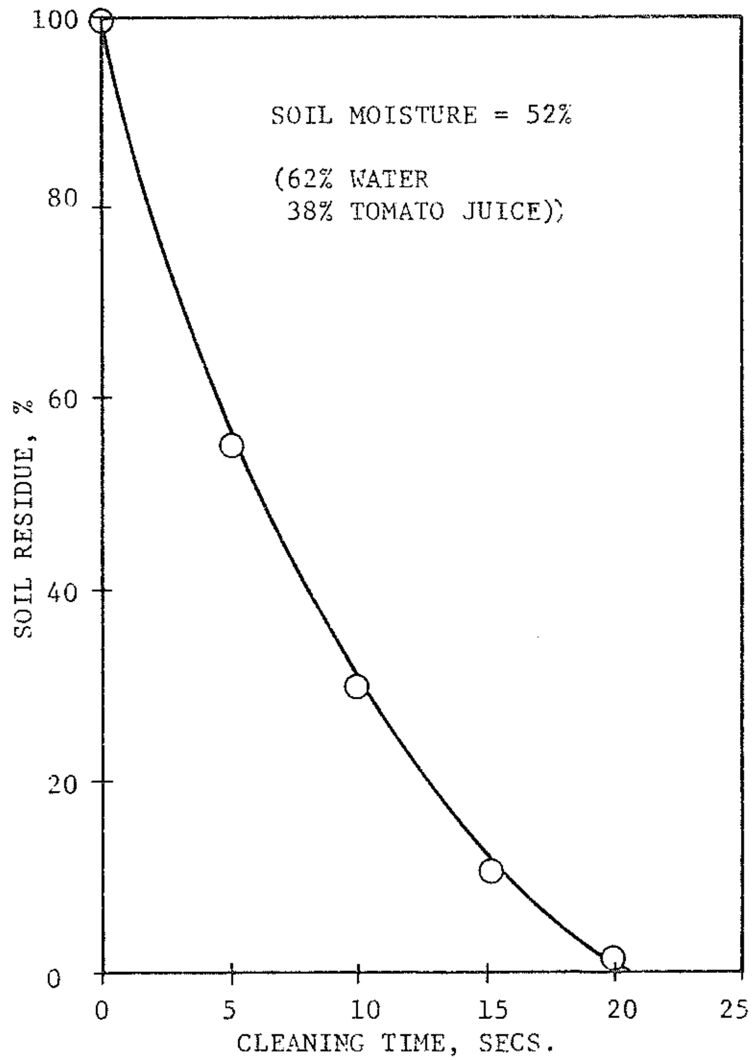

Figure 5. Soil residue on tomatoes after cleaning for specified times. Tomatoes cleaned immediately after soiling.

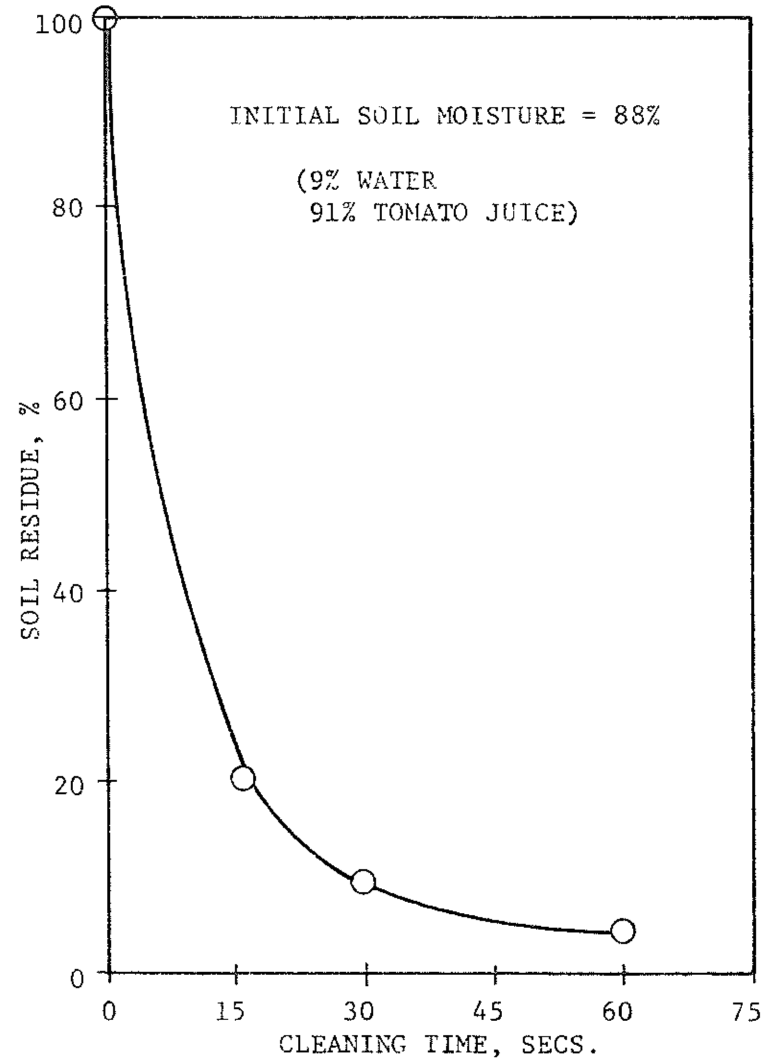

Figure 6. Soil residue on tomatoes after cleaning for specified times. Tomatoes cleaned after soil was allowed to dry overnight.

Dried soils with a small amount or with no tomato juice content flaked off leaving small streaks of residue smear. However, when the tomato juice content of the soil was high, a tenacious soil residue remained after drying.

The longer cleaning times required for this soil are shown in Figure 6. Plotting this data on semilog papers gives a curve similar to that obtained for the sum of two independent, first-order processes. This appears to be a common experience of workers studying cleaning of fabrics and hard surfaces (Bourne and Jennings, 1963), and suggests the existence of two species of soil one of which is more closely associated with the soiled surface.

Effect of Detergents and Foams

Figure 7 compares the effect of one hour exposure to water, 0.3% solution of Duponol C, and foam generated from the Duponol C solution on tomatoes smeared with 39% moisture soil. Soil of this moisture content is quite difficult to remove. A two-minute agitated wash does not remove much soil and the effect of soaking in water for one hour before cleaning is neglible. Soaking in the Duponol C solution for one hour removed all the soil without additional cleaning, thus showing the effectiveness of detergents of this type in speeding up the cleaning process. A one-hour exposure to a foam environment removed most of the soil and allowed one-minute wash in an agitated water bath to remove the remaining soil. The foam head above the soiled tomatoes was seven inches, and the tomatoes were supported on a screen which kept them above the small volume of liquid generated by the collapsing foam. The collapsing foam apparently continuously bathes the soiled tomatoes, removing or hydrating most of the soil and thus allowing eash removal of any remaining soil material.

Cleaning With Paraffin Oil

Figure 8 compares the effect of a one-minute exposure in agitated baths of water, paraffin oil, and a paraffin oil-water suspension on the removal of soils of different moisture contents from the surfaces of tomatoes. With a 46% moisture soil (quite watery), all three cleaning media were equally effective, thus confirming the model presented earlier. Water appears to remove soil by slow erosion of the soil surface with complete dispersion of the soil into the water cleaning medium. Paraffin oil tends to roll the water soil away from most of the tomato surface and accumulate it in bead-like mounds due to preferential wetting. The agitated bath removes the mounds of water soil from the surface as discrete drops which fall to the

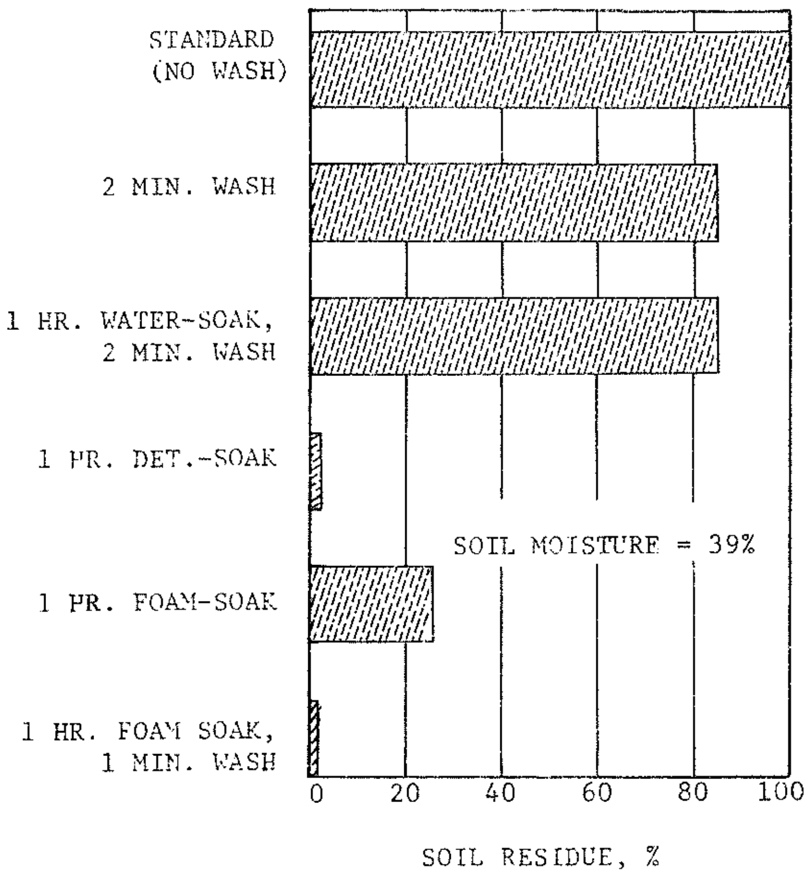

Figure 7. Soil residue on tomatoes after indicated pretreatment and/or wash immediately after soiling.

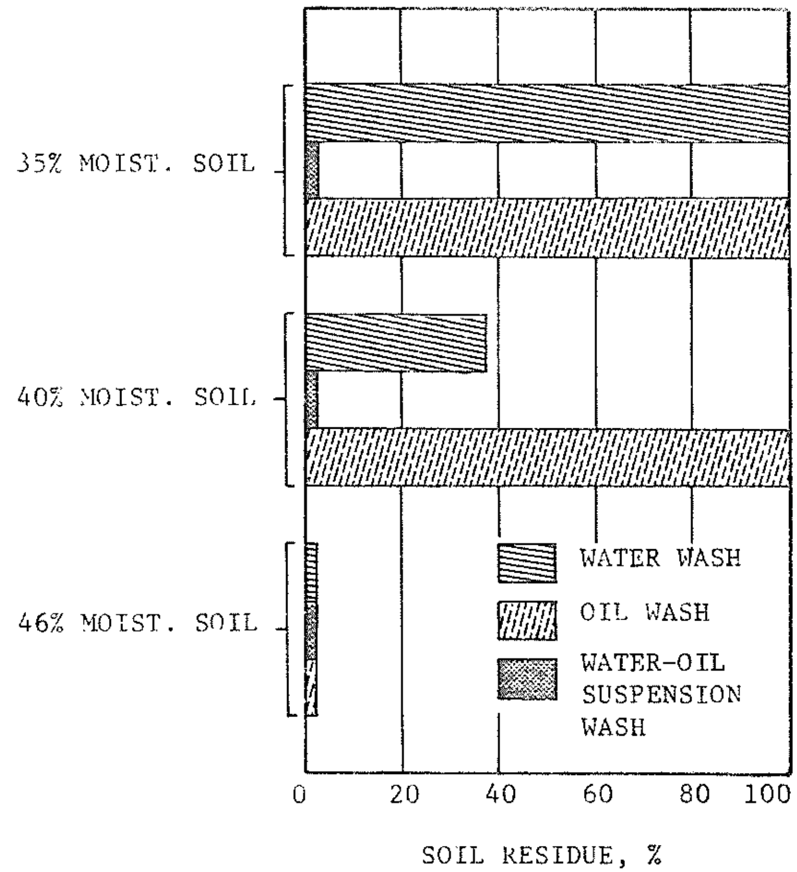

Figure 8. Effectiveness of water, oil, and water-oil suspension in removing soil from tomatoes during one-min agitated bath wash immediately after soiling.

bottom of the bath intact. It was impossible to observe the soil removal mechanism in the oil-water suspension. However, the soil was found to disperse in the water phase. The suspension broke very quickly, leaving the two discrete phases.

With a 40% moisture soil, water was only partially able to remove the soil in one minute. Paraffin oil was completely ineffective due to the soil's increased stickiness and viscosity. The oil was unable to roll up the soil and displace it from the surface. The paraffin oil-water suspension was very effective in achieving complete removal of this soil. This was even more dramatic in comparison with water or oil alone with the 35% moisture soil. The combination of the two soil-removal mechanisms, erosion and displacement, are apparently more effective than either alone. One factor may be the water content of the suspension which probably acts to increase the soil moisture content, thus increasing the oil's ability to preferentially displace the soil. The soil disperses in the water phase, leaving the oil phase completely clear.

Conclusions

Tomato breakage during harvesting, handling, and transport not only reduces over-all harvest quality, but contributes to soil moisture, soil smearing, and soil adherence. Minimum tomato damage is imperative to the delivery of a clean load. The effect of soil moisture on soiling is dramatic. Soil moistures in the range 20-40% yield a soil easy to smear onto a tomato surface and difficult to remove. Soils with moisture contents on either side of this range do not adhere well and are relatively easy to remove. Thus, harvesting with surface soil moisture below 20% would inhibit tomato soiling. The clean tomatoes obtained from a "dry" hand-picking operation illustrate the advantage of dry harvesting. On the other end of the moisture range, provision for a small amount of water on a harvester in the form of spray mists directed on the tomatoes and/or harvester conveyor belts could push soil moisture more than 40%, thus avoiding difficult-to-remove soil. However, this is not practical due to potential microbial growth on the moistened tomato surface. In any case, the objective is to avoid the approximately 20-40% moisture soil range.

Soils containing tomato juice which are allowed to dry are particularly hard to clean.

Use of a detergent promotes soil removal, thus reducing the energy input required from water and the exposure time for cleaning. Leaching from broken fruit should also be reduced. The potential of a foam cleaning medium in combination with mechanical wiping has been described elsewhere (Krochta et al., 1973). The compactness and low water consumption of the process suggests its use either in the processing plant or on the harvester.

Cleaning results with paraffin oil and paraffin oil-water suspensions indicate that liquids other than pure water may be effective cleaning agents for foods. Hydrocarbons may make useful cleaning media for very wet soils or for soils hydrated by a water pretreatment. Oil-water suspensions appear to be effective over a wide range of soil moisture conditions. A suspension containing a small volume of water (large oil-to-water ratio) would be desirable, since a small volume of concentrated aqueous waste for clean-up and recycle could result. Much work remains; nonetheless, the principle and concept have been demonstrated.

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Based on a paper presented at the "Water Substitutes in Food Processing Symposium" held at the 33rd Annual Meeting of the Institute of Food Technologists, Miami Beach, Florida, June 10-13, 1973.

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AIR AS A SUBSTITUTE FOR WATER IN FOOD PROCESSING

D. R. Heldman*

Availability is a major reason for using air in place of water for heat transfer and materials handling operations in the food plant.

Physical properties of air and water are shown in Table 1 for comparison. The viscosity, thermal conductivity, specific heat, and density of air do not change significantly over the range of temperatures where air could substitute for water in the food plant. The viscosity of air is approximately 1/50 that of water. Although this is an advantage, the differences in thermal properties and 80-fold density difference between air and water require that special equipment be used if air is to be substituted for water.

Table 1. Physical Properties of air and water at ambient temperature (70°F)

Property	Air	Water
Specific heat BTU/lb °F	0.24	1.00
Thermal Conductivity BTU/hr-ft^2-F/ft.	.015	0.36
Density lb /ft^3	.075	62.3
Viscosity lb /ft hr (centipoises)	.0435 (.018)	2.38 (.981)

The chemical composition and microbiological content of air must also be considered. Oxygen can react with food components to cause discoloration, flavor changes, and loss of nutritive value. The moisture content of the air will influence rate of evaporative weight loss from food materials whenever air is in contact with the product. Since the moisture holding capacity of air is a function of temperature and pressure, the potential for evaporative loss must be determined under specific operating conditions. Fortunately, relatively small quantities of water will saturate air under normal food processing conditions. At 70°F, air containing about 1.5% moisture (weight basis) is saturated.

* Reprinted by permission from Food Technology, Vol. 28, No. 2, pp. 40-46, 1974.

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Air may contain up to 1.5 million particles 0.3μ or larger per cu. ft. While total particle content is of concern, the microbial content of the air is a major consideration, due to the potential for product contamination.

Foreign chemicals that could contribute to off-flavors or otherwise contaminate the food must be eliminated from any process air used in direct contact with food materials.

Except when foreign chemicals are present, it may be easier to clean process air for use, disposal, or recycling than it is to clean water for the same purposes.

Current applications of air in various food processing operations are described below.

Cleaning and Separation

Mechanical harvesting of seasonal crops has caused great changes in the cleaning requirements for raw materials. The mobility of mechanical harvesters precludes the use of large amounts of water for in-field cleaning and trash removal. Yet mechanical harvesting can result in large amounts of trash, broken product, and dirt being delivered to the processing plant.

Air cleaning has proven effective for trash removal and the separation of loose soil and other low bulk density materials. Air separation is basically a form of pneumatic transport. Pneumatic transport for cleaning will be effective only if the physical properties of the unwanted material differ significantly from those of the food material being cleaned.

Zenz and Othmer (1960) describe the conditions affecting the free-fall velocity of particles in upward moving air. The drag force is proportional to the dimensions, shape, and velocity of the particle and the density and viscosity of the fluid. In general, air separation equipment is useful in removing waste material differing from food material in shape, size, and surface roughness, since density variation is not great among the edible and inedible portions of plants. Air velocity is selected to exceed the settling velocity of unwanted stems, leaves, and trash, while allowing the more regular food particles to remain as a fixed bed. Air quality is of minimum concern in harvest and post-harvest raw product cleaning. Mechanical motion may be used to improve the efficiency of air separation providing no product damage takes place.

The removal of smear soil, insect fragments, plant exudates, or other incidental contaminants by means of air scouring alone does not seem feasible at the present time. The energy needed to release this type of soil from the surface of the food can best be supplied by mechanical means combined with a limited amount of water or possibly another liquid. Krochta and Bellows (1974) discuss minimum water cleaning approaches.

Pneumatic Transport

Pneumatic transport is widely used for handling small dry food particles, powders, packaging materials, frozen foods, and more recently raw and blanched particulate foods. Successful applications have overcome the problems of product damage, microbial contamination, dehydration, product delivery, and air cleaning for discharge or recycling.

Pneumatic transport of high moisture particulate foods presents several major materials handling problems not encountered in conventional water fluming. Water cushions, suspends, and continuously cleans the particles and the conveying equipment. Moist food particles can be damaged during pneumatic transport by impacting in the transport pipe at bends and during discharge. Each time the particle contacts the pipe surface a layer of food material may be deposited. This food material is subject to microbial growth which will further contaminate the food and the downstream transport tube.

Although the system may be self-cleaning in operation, shutdowns must be followed by a thorough washing to reduce microbial buildup. This may be difficult to accomplish without special provisions for cleaning remote parts of the system. Provision must be made for discharging the product from the system and possibly cleaning the air. Positive air locks, cyclone separators, or other mechanical systems can represent an extensive investment and a complex cleaning problem.

With these problems in mind, Wolford (1972) describes microbial studies on negative air pressure conveying (NAPC) systems for transporting blanched cut vegetables in frozen food plants. Fig. 1, taken from this article, illustrates the basic system. Blanched peas, cut green beans, cut corn, lima beans and diced carrots can be conveyed successfully. The system consists of 4- to 6-in diameter tubes which are open at the inlet. The transport tubes are attached to a cyclone separator while a vacuum pump is used to establish air flow. The primary advantage of the system is to reduce water usage normally required by hydraulic conveying. Pneumatic transport may have an economic advantage over other mechanical means for long distance transporting. A plant handling 5 tons of peas per hour can

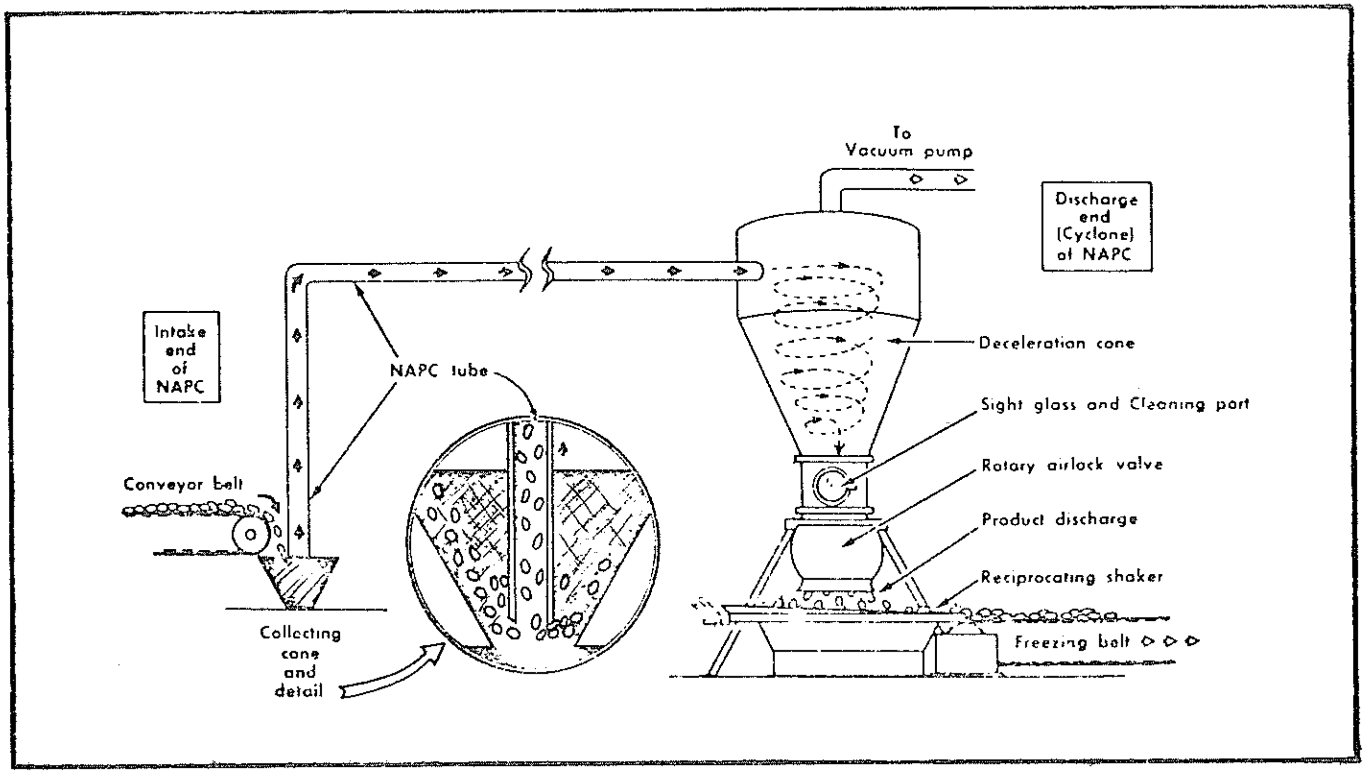

Figure 1. Negative Air Pressure Conveying System (Wolford 1972)

save the use of 20,000 gallons of water per hour. Wolford (1972) does not mention power requirements and relative capital costs. A rigid sanitation schedule must be maintained to minimize microbial buildup.

A processor faced with the need for effluent reduction through flume replacement should consider pneumatic conveying as an alternative to reduce length of flow streams and mechanical transport by vibrating conveyors or belts. Effective sanitation procedures must also accompany the use of any of these pieces of equipment.

Heating and Cooling

While the potential is great for reducing water use by substituting air in heating and cooling applications, lower values of heat capacity and density greatly reduce the effectiveness of air. A volume of air over 3,000 times as great as water is needed for equal heating or cooling effectiveness. Heat transfer equipment using air is significantly larger than that using water. This becomes obvious in Fig. 2, where surface heat transfer coefficients in a tubular heat exchanger are compared at various flow rates (pressure drops). Water is more effective by a factor of 30 at 15 lb. force per ft^2 pressure drop. No mass transfer is assumed to take place in these considerations. Heating with steam-air mixtures and evaporative cooling, where mass transfer does take place, will greatly increase the rate of heat transfer while minimizing water use. This can be discussed in relation to specific processing applications.

Blanching

Blanching in air-steam mixtures, in steam-combustion product mixtures, and in air alone has been reported by Mitchell et al. (1968), Ralls et al. (1973) and Brown et al. (1972), respectively. All of these methods are essentially effluent-free; however, as the ratio of steam to air is reduced, more and more product dehydration takes place during the blanching process. Brown et al. (1972), using a centrifugal fluidized bed with air velocities between 1500 and 3100 ft/min., and air temperatures between 220°F and 260°F, were able to blanch carrot dice in 8.4 minutes at the minimum conditions and 2.1 minute at the maximum velocity and temperature used. Weight reductions of the order of 50% were encountered under these blanching conditions. Mitchell et al. (1968) indicated that blanching in a steam-air mixture was equivalent to water blanching for peas, while the hot gas blancher concept developed by Ralls et al. (1971) has been used successfully to blanch snap beans for canning.

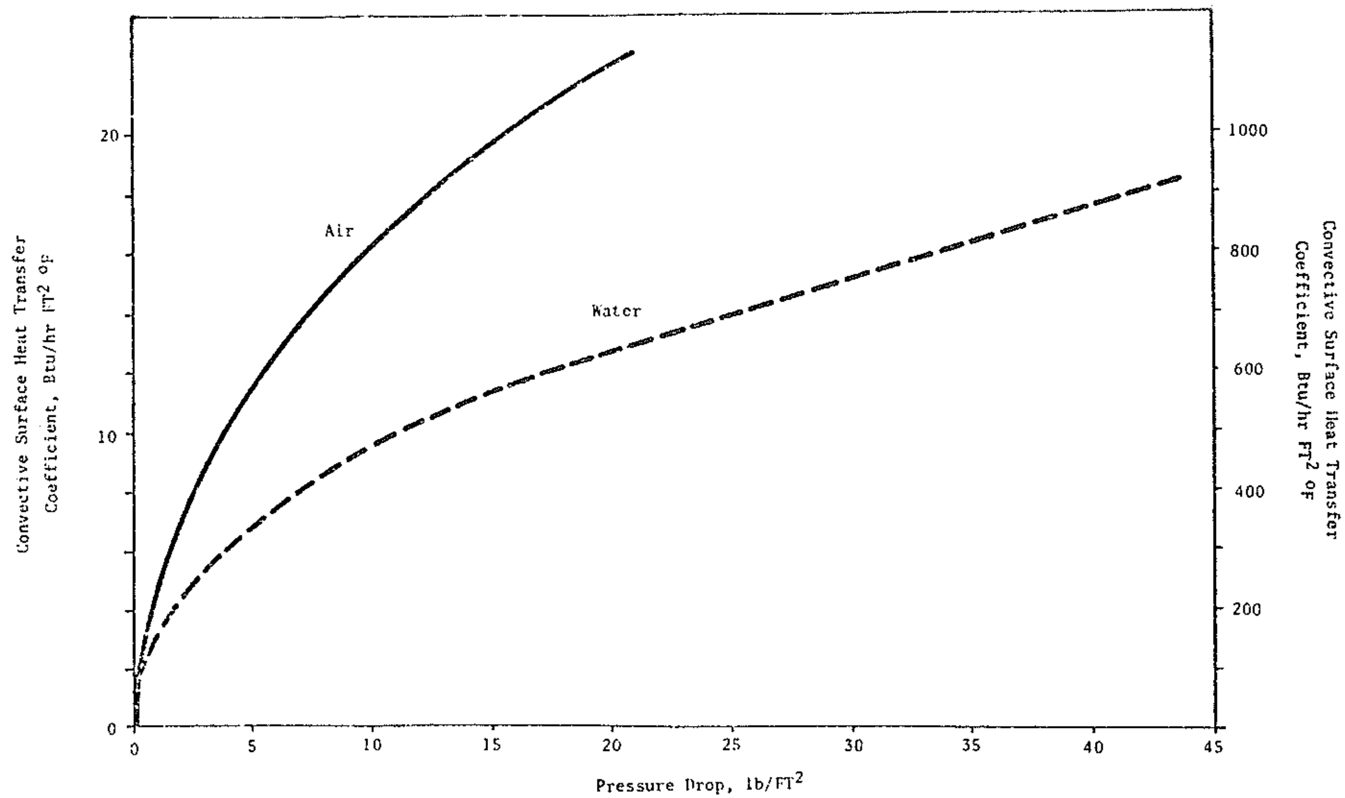

Figure 2. Surface Heat Transfer Coefficients vs pressure drops for air and water in a 2-in diameter tubular heat exchanger.

Can Sterilization

Methods have been developed to use air or hot gases as a substitute for steam or water in thermal processing. These include direct flame heating, high velocity air heating, and the use of deep fluidized beds to achieve over-pressures necessary for larger containers, Casimir (1970) cites the work of Ecklund and coworkers who developed a hot air can sterilizer in Sweden. Rolling motion, together with air at 293°F circulating at 33 ft/sec., gave a center temperature of 253°F in canned milk in 15 minutes.

Flame sterilization of cans, originally proposed by Beauvais et al. (1961), has achieved commercial use world-wide with small containers for non-acid foods and with larger containers for acid products. Small containers allow processing at internal can temperatures above 212°F since they can withstand pressures up to 15 psig if properly designed. Larger containers can only be heated to temperatures at or slightly above 212°F.

A novel fluidized bed retort has been described by Jowitt and Thorne (1971) and Thorne and Jowitt (1972). Heat transfer is increased by heating and cooling the cans in a fluidized bed of sand or other granular high density material such as hematite. Air pressures corresponding to saturated steam processing temperatures are achieved by the use of fluidized beds of sufficient depth.

Results show that process times are only slighly longer than those necessary for saturated steam processing and contrary to expectations, can abrasion from the fluidizing medium is negligible.

Cooling

Air is most effectively used in cooling in conjunction with water by direct contact evaporative cooling of food materials. Indirect evaporative cooling and cooling towers are not considered here. Weight loss is always a problem during evaporative cooling of processed foods since the cooling air can never have a water vapor pressure greater than that of the product surface.

Considerable work is needed to determine the best conditions for evaporative cooling in terms of product weight loss, effluent strength and volume, and equipment design. Currently, a number of processors are using fluidized beds for cooling vegetables after blanching and prior to freezing. Little data are available on weight loss resulting from evaporative cooling. However, Bomben et al. (1973) showed that evaporative weight loss for any product was closely related to the amount and method of water application during cooling. Flume cooling and spray cooling were studied.

Coffelt and Winter (1973) studied the effect of air velocity, relative humidity, and temperature on the rate of cooling of blanched potato cubes. Results showed that air at 70°F and 50% relative humidity and having a velocity of about 10 ft/sec. could cool 11/16-in. potato cubes from 190°F to 90°F in 5 minutes. Higher relative humidities reduced the effective rate of cooling slightly, while higher air velocities improved cooling rates. Air-water sprays gave cooling rates equivalent to those of air alone. Unfortunately, no data were taken on weight loss for each cooling condition. Water sprays applied at the correct time during cooling would reduce some of the evaporative weight loss (Winter, 1973).

Summary

Air appears to be a useful alternative fluid to water for certain cleaning, transport, and heat transfer operations. Data available in the literature are of limited use in evaluating the economic benefits of installing, for example, a pneumatic transport system in preference to mechanical conveyors or evaporative vegetable cooling over flume or spray systems.

While reduction in water use and hence effluent volume is an immediate benefit, savings in product solids lost through leaching and reduced capital costs are possible.

Optimum applications for air appear to be: precleaning; transport over long distances; and in conjunction with a small quantity of water, evaporative cooling.

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Michigan Agricultural Experiment Station Journal Article No. 6600.

WATER POLLUTION ABATEMENT THROUGH RAW MATERIAL SELECTION

Hugh J. S. Shane*

On the North American Continent, effluent control is now being applied to the textile industry. As a result of this, the textile processor is now faced with acquiring a new technology, as well as additional expense in capital and possibly personnel. A review of the regulations, present and pending, in terms of BOD, COD, dissolved and suspended solids, alkalinity and possibly toxicity, defines the limits that one is allowed to work within. It does not, however, tell the processor how to achieve the required production and yet stay within these regulations.

I propose, therefore, to outline in this discussion, some of the experiences of the textile companies in the United States and to view some of the suggestions of the authorities in that country as to the nature and type of effluent discharges from various textile processing plants, in terms of the process area and in terms of the fibre being processed. The authorities in the U. S. are in active communication with the industry in an endeavour toward finding the most workable solution to the effluent problem. I also propose to outline the advantages and disadvantages of some products currently used, from the effluent control point of view.

If we examine the products currently being used in the manufacture, and process, of textiles, we find they are many and varied. *Chart One* tabulates products normally found in the desizing, keiring, bleaching, mercerizing and dyeing processes, in the most general form. *Chart Two* indicates the chemicals found in specific dyeing processes, while *Chart Three* illustrates those products associated with both printing and finishing.

To become more specific, if we list woollen processing as a group, those compounds and chemicals listed under *Chart Four* embrace most of what we find in this area.

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CHART ONE - COTTON GOODS MANUFACTURING

Desizing - Commercial enzymes
- Starch (cornstarch, etc.), sizing compound
- Starch substitutes, sizing compounds
- Polyvinyl alcohol, sizing
- Carboxyl methyl cellulose, sizing compound
- Various salts
- Various penetrants (nonionic wetting agents)
- Gelatin
- Glues
- Gums
- Polystrene
- Polyacrylic acid

Bleaching/ Mercerizing/ Dyeing - General:
- Chlorobenzenes
- Biphenyl
- Orthophenyl phenol
- Indigo
- Acetic acid
- Sulphites
- Benzyl alcohol
- Sulphuric acid
- Sodium busulphite
- Sodium dichromate
- Starch
- Glycerol
- Chromates
- Potassium bichromate
- Formaldehyde
- Muriatic acid

Keiring - Sodium hydroxide
- Sodium silicate
- Pine oil soap
- Fatty alcohol sulphates
- Various wetting agents including miscellaneous polymers, amides, sulphates, sulphonates
- Methanol
- Ethanol
- Isopropanol
- Sodium tripoly phosphate
- "Calgon", softener
- Tetrasodium pyrophosphate
- Trisodium phosphate

CHART TWO - SPECIFIC DYEING CHEMICALS

Developed Dyes - Dye substance
- Penetrants (wetting & dispersing agents)
- Sodium chloride
- Sodium nitrate
- Hydrochloric acid
- Sulphuric acid
- Beta naphthol, developer
- Sulphated soap
- Fatty alcohol

Direct Dyes - Dye substance
- Sodium carbonate
- Sodium chloride
- Wetting agents
- Soluble oils
- Sodium sulphate

Naphtol Dyes - Dye substance
- Caustic soda
- Soluble oils
- Alcohols
- Various soaps and synthetic detergents
- Soda ash
- Sodium chloride
- Various bases
- Sodium nitrate
- Sodium nitrite
- Sodium acetate

Sulphur Dyes - Dye substance
- Sodium sulphide
- Sodium carbonate
- Sodium chloride

Vat Dyes - Dye substance
- Caustic soda
- Sodium hydro-sulphite
- Soluble oils
- Gelatine
- Perborate
- Hydrogen peroxide

Other Dyeing Chemicals
- Various thickeners
- Various hygroscopic substances
- Various dyeing assistants

CHART THREE - PRINTING/FINISHING

Melamine
Glyoxal compounds
Triazirdly phosphine oxide (APO), fire retardant
Tetrakis (hydroxymethyl) Phosphonium chloride (THPC), fire retardant.
Acrylate copolymers, soil releaser
Methacrylate copolymers, soil releaser
B-2 gum
Wheat starch
Pearl cornstarch
"Brytex" gum No. 745
KD gum
Slashing starch
Carboxymethyl cellulose
Hydroxyethyl cellulose
Tallow soap
Acetic acid
Cream softeners (cationic and nonionic)
Formaldehyde
Varicus bisulphites
Glycerin
Sodium hydrosulphite
Urea
Glucose
Gelatin
Caustic soda
Soda ash
Ammonia
Potassium carbonate
Trisodium phosphate
Sodium perborate
Sodium silicate
Liquid soda bleach
Hydrogen peroxide
Sodium chloride
Sodium dichromate
Sulphuric acid
Hydrochloric acid

CHART FOUR - WOOLLEN GOODS PROCESSING

Scouring
- Chiefly detergent scouring divided as to soap - alkali process and natural detergent process
- Soap - Alkali Process:
  - Sodium carbonate
  - Soda ash
- Neutral Detergent Process:
  - Nonionic detergents of the ethylene oxide condensates

Pre-Scouring and Washing
- Quadratos - $Na_6P_4O_{13}$
- Olive Oil
- Nonionic emulsifiers for oiling
- Fulling by Alkali Fulling using:
  - Soaps
  - Detergents
  - Sod ash
  - Sodium carbonate
  - Sequestering agents
- Fulling by Acid Fulling using:
  - Sulphuric acid
  - Hydrogen peroxide
  - Metallic catalysts including:
    - Chromium
    - Copper
    - Cobalt
    - "Nopco 1656", soluble fatty ester
    - "Supertex E", fatty acid soaps, solvent cresylic

Dyeing
- General:
  - Sulphuric acid
  - Acetic acid
  - Ammonium sulphate
  - Glaubers salt
- Metallized, Wood Dyeing:
  - Dye Substance
  - Glaubers salt
  - Ammonium acetate
  - Diammonium phosphate
  - Bottom Chrome, Wool Dyeing:
    - Dye substance
    - Calsolene oil
    - Sodium dichromate
    - Potasium bitartrate
    - Acetic acid
    - Diammonium phosphate
    - Ammonium acetate
    - Leveling salts

Blend Dyeing:

- Surfactants
- Sodium sulphate
- Dye substance
- Various dye carriers
- Levelling agents

Other Dyeing and Printing Compounds:

- Starch
- Chrome, as $Na_2Cr_3O_7$
- Monochlorobenzene (C_6H_5Cl)
- Proteins (albumin)
- Glycerine
- Formaldehyde

Finishing

- Various carbohydrates
- Enzymes
- Dieldrin, mothproffing compound

CHART FIVE - SYNTHETIC GOODS PROCESSING

General (For all categories below)

Anti-static oils
Various lubricants
Various sizing compounds
Polyvinyl alcohol
Styrene-base resins
Polyalkylene glycols
Gelatin
Polyacrylic acid
Polyvinyl acetate

Nylon (Derived from hexamethylene diamine and adipic acid)
- Scouring:
  - Various soaps
  - Anti-static compounds
  - Fatty esters
  - Tetrasodium pyrophosphate
- Dyeing:
  - Sulphonated oils
  - Dye substances
  - Sodium nitrite
  - Hydrochloric acid

Acetates (Derived from cellulose acetate fibres)
- Bleaching:
  - Chlorine
  - Hydrogen peroxide
  - Synthetic detergents
- Scouring and Dyeing:
  - Anti-static compounds
  - Sulphonated oils
  - Various detergents
  - Various softeners
  - Aliphatic esters

(Dye types include: dispersed dyes, dispersed-developed dyes, acid dyes, and naphthol dyes)

Polyesters (In "Fortrel" polyester, derived from dimethyl terephthalate, an ester, or terephthalic acid, ethylene glycol, methyl alcohol)
- Scouring:
  - Nonionic synthetic detergents
  - Dyeing and Dye Carriers:
    - Phenylphenol
    - Phenylmethyl carbinol
    - Salicylic acid

Benzoic acid
Bi-phenyl chloro-benzenes

Acrylics-Modacrylics (Derived from acrylonitrile being reacted with a comonomer in the presence of a suitable catalyst)

Scouring:
- Anti-static compounds
- Lubricants
- Sulphonated oils
- Synthetic detergents
- Various soaps
- Pine oil
- Formic acid

Dyeing:
- Various wetting agents
- Various phenolic compounds
- Copper sulphate
- Hydroxy ammonium sulphate
- Various retarding agents (cationic, anionic and nonionic)
- Aromatic amines

Bleaching:
- Chlorite
- Sodium nitrite
- Acetic acid
- Oxalic acid
- Nitric acid
- Bisulphites
- Proprietary bleaches

Rayon (Derived from 100% regenerated cellulose via viscose process)

Sizing and Desizing:
- Same compounds as used in cotton goods sizing and desizing
- gelatin

Scouring and Dyeing:
- Soluble oils
- Synthetic detergents
- Anti-static compounds
- Lubricants
- Hydrogen peroxide
- Salts
- Electrolytes

Chart Five indicates the products associated with synthetic goods processing.

Herein we have described a formidable list of organic and inorganic compounds with wide coverage of pH reactivity, possible product to product synergism and without a doubt, toxicity.

If we then look at the findings, in the United States, on the effluents from various processing plants we come up with the following characterization of the wastewaters and the suggested method of control *(Chart Six)*, all of which are approached in terms of effluent plant installation.

The U. S. authorities, with the full knowledge that the textile industry in the United States must perform its function, have drawn up suggestions for the establishment of effluent limits for discharges based on the application of the best practical control technology currently available. They collected their data by a study of various textile mills throughout the country. From this they drew up a *Schedule A,* which reflects their best technical judgments of the effluent levels which can be achieved, by the application of the highest level of control technology, now considered practical and available for the industry. The *Schedule A* values are based on the totality of experience with this technology, including demonstration projects, pilot plants and actual use, which demonstrates that it is technologically and economically reliable - *Chart Seven A*. The best available treatment should be achieved by 1983, while the best practical technology is required by July, 1977.

While the *Schedule A* would obviously apply to new plants, with existing companies, such effluent control levels could not necessarily be achieved within the given time profile. For this reason they also produced a *Schedule B* which represents the minimum acceptable effluent levels. Under their recommendations no plant should achieve less pollution reduction than the *Schedule B* values (*Chart Seven B*). The *Schedule B* is in fact a borrowed time situation as the permit permitting this condition has a limited life after which, the position at that particular mill is reviewed.

Faced with regulations such as these, textile processors in the United States have looked hard at where, by product deletion, they can meet these requirements, particularly those of low existing BOD 5, low COD and low phenolic or aromatic contents.

CHART SIX - CHARACTERIZATION OF WASTEWATERS		
TEXTILE OPERATION	WASTEWATER CHARACTERISTICS	SUGGESTED METHOD OF TREATMENT
Wool Processing Mill	Color - Brown Grease Content - High Alkalinity - High (pH 10)	Solvent extraction of grease and suint.; Screening. Dissolved air flotation. pH adjustment. Equalization. Chemical coagulation. Settling. Aerated lagoon.
Cotton-Synthetics Integrated Mill	Color - High BOD - High COD - High Alkalinity - High	Caustic recovery and reuse. Equalizing pond. pH adjustment. Bar and fine screens. Chemical coagulation and sedimentation. Carbon adsorption. Biological oxidation.
Carpet Integrated Mill	Color - High COD - High Temperature - High Latex Emulsion - High Solvent Content - High	Equalization. Fine screening. Chemical coagulation and sedimentation Carbon adsorption. Biological Oxidation

CHART SEVEN - SCHEDULE B

Recommended Effluent Guidelines - Textile Industry
(Milligrams of Pollutant Per Litre of Water Discharged)

Mill Type	Nature of Production	Gals/lb	BOD_5	COD	TSS	Alk***	Cr^t	Cr^{+6}	Phenolics	Sulphide
Wool Scour and Finish (Integrated)	Fin. Wool	35	68	206	34	205	.25	.005	.25	.5
Wool Finish......................	Fin. Wool	25	72	230	38	216	.25	.005	.25	.5
Greige Goods - Woven & Knitted Goods..........................	Greige Goods	5	72	264	72	168	.25	.005	.25	.5
Finishing - Woven Products of Cotton, Synthetics* and Blends..	Fin. Cloth	16	60	270	60	337	.25	.005	.25	.5
Finishing**-Knitted Products of Cotton, Synthetics* & Blends....	Fin. Cloth	11	54	251	65	196	.25	.005	.25	.5
Integrated Woven Goods (Includes manufacture of Greige Goods)....	Fin. Cloth	20	47	247	53	294	.25	.005	.25	.5
Carpet - Dying and Finishing, excluding secondary backing....	Pri. Backed Carpet	20	41	205	35	47	.25	.005	.25	.5
Integrated Carpet................	Pri. Backed Carpet	22	43	226	43	54	.25	.005	.25	.5
Yarn Dyeing - All Yarns..........	Yarn	18	27	133	27	54	.25	.005	.25	.5

* Principally includes nylon, rayon, acrylics, acetates, polyesters.

** May include Direct Knitting

***as $CaCo_3$

CHART SEVEN - SCHEDULE A

Recommended Effluent Guidelines - Textile Industry
(Milligrams of Pollutant Per Litre of Water Discharge)

Mill Type	Nature of Production	Gals/lb	BOD_5	COD	TSS	Alk***	Cr^t	Cr^{+5}	Phenolics	Sulphide
Wool Scour and Finish (Integrated)	Fin. Wool	35	27	103	27	58	.25	.005	.25	.5
Wool Finish......................	Fin. Wool	25	29	110	29	72	.25	.005	.25	.5
Greige Goods - Woven & Knitted Goods.........................	Greige Goods	5	36	120	48	72	.25	.005	.25	.5
Finishing - Woven Products of Cotton, Synthetics* and Blends..	Fin. Cloth	16	45	173	45	120	.25	.005	.25	.5
Finishing**-Knitted Products of Cotton, Synthetics* & Blends....	Fin. Cloth	11	44	174	54	87	.25	.005	.25	.5
Integrated Woven Goods (Includes manufacture of Greige Goods)....	Fin. Cloth	20	42	156	42	108	.25	.005	.25	.5
Carpet - Dyeing and Finishing, excluding secondary backing....	Pri. Backed Carpet	20	27	114	30	30	.25	.005	.25	.B
Integrated Carpet...............	Pri. Backed Carpet	22	33	125	33	38	.25	.005	.25	.5
Yarn Dyeing - All Yarns..........	Yarn	18	17	73	17	27	.25	.005	.25	.5

* Principally includes nylon, rayon, acrylics, acetates, polyester.

** May include Direct Knitting.

***as $CaCo_3$

From the dyer's point of view one biggest area of hazard is the carriers which are usually aromatic in nature, often toxic and certainly detectable in the wastewater effluent.

Some carriers, however, are biodegradeable. For instance, those based on Crisotinic Acid. With high temperature processing equipment, carriers are less and less in demand, and only those with good migrating properties, at temperatures of around 130°C are required on this modern equipment. Fortunately the Crisotinic Acid types have excellent leveling properties under these conditions. Unfortunately, however, Crisotinic Acid itself is in short supply in the United States, and formulated products based upon this active are quite expensive, ranging from 95¢ to $1.55 per pound.

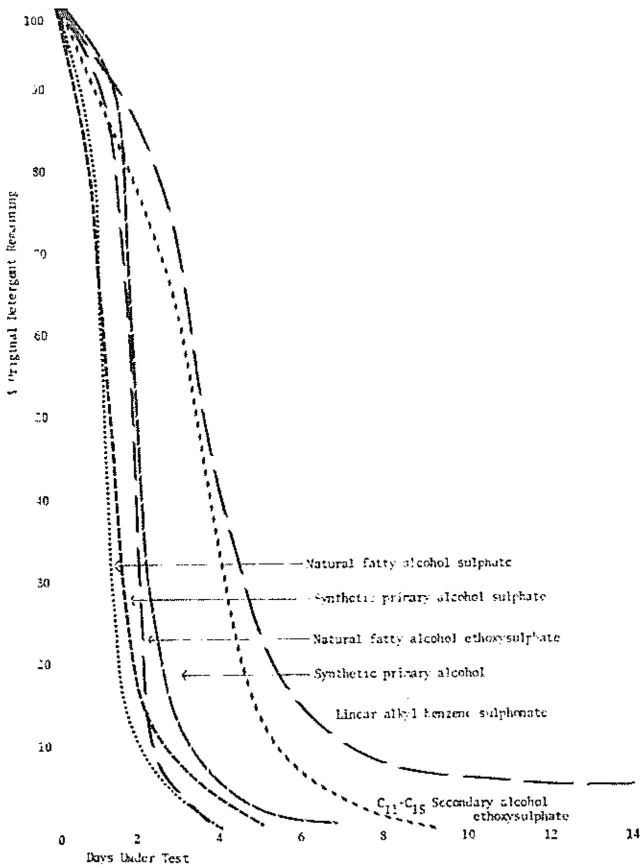
The wet processor has probably a much greater capacity to control his BOD and COD than, for instance, the weaver or the finisher.

A dyer has before him today a choice of biodegradeable preparation agents, detergents, wetting agents, dye bath auxiliaries and post dyeing softening agents than can be selected, in relation to performance, to give him exactly what he needs as regards his BOD.

Charts Eight A and *Eight B* illustrate the relative biodegradeability of a number of dye bath auziliaries, and detergents, considered generically. *Chart Eight A* shows the biodegradeability of anionic compounds, all of which appear to be satisfactory. The slowest degradeable product in this group is the Linear Alkyl Benzene Sulphonate, which is often used as the active in some lower priced dye bath leveling agents.

Chart Eight B shows the same method for nonionics. In this case, it is very apparent that from a biodegradeable point of view, the Alkyl Phenol Ethoxylate is a less satisfactory performer. Many textile auxiliaries are based on these compounds.

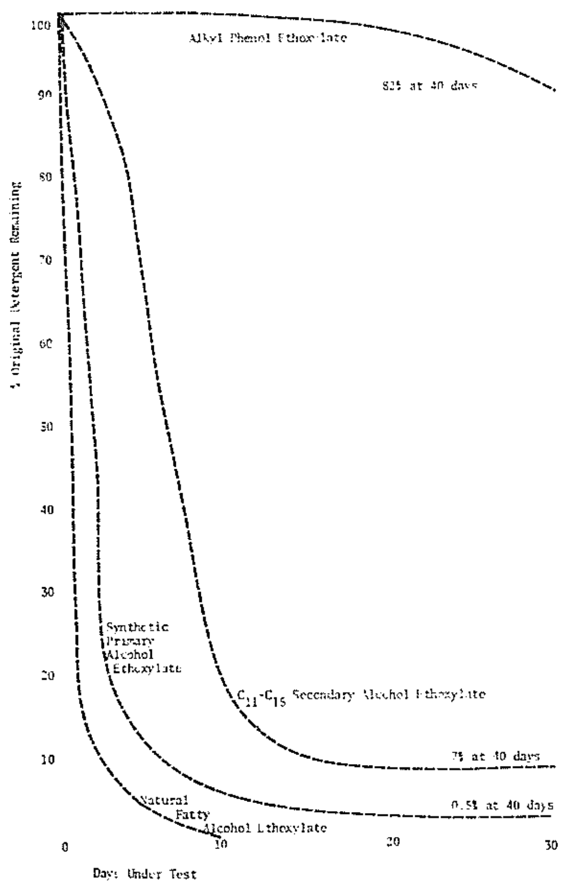
When considering the allowable BOD from your dyehouse or plant effluent, it is advisable to consult your chemical supplier for the specific BOD's of your chemicals supplied. These figures will probably be given on readings obtained from acclimated cultures. This practice is fair, because if these products are in your lagoon, those acclimated cultures will, in fact, develop and grow anyway, while the other commoner cultures will die off through lack of nutrition, unless they also find some media on which to feed. It is also suggested that you work closely with your auxiliary supplier on the question of your effluent as a whole. He should be in a position to give



Type	Product	Average % Biodegraded
Ethoxysulphates	Linear alkyl phenol ethoxysulphate	68
	Natural fatty alcohol ethoxysulphate	99
	Secondary alcohol ethoxysulphate	98
	Synthetic primary alcohol ethoxysulphate	99
Sulphates	Synthetic primary alcohol sulphate	99
	Natural fatty alcohol sulphate	99
Sulphonate	Linear alkyl benzene sulphonate	95

CHART EIGHT A

BIODEGRADABILITY OF ANIONICS BY WPRL AERATION SCREENING TEST



Product	Average % Biodegraded
Alkyl Phenol Ethoxylate	30
Synthetic Primary Alcohol Ethoxylate	97
Secondary Alcohol Ethoxylate	86
Natural Fatty Alcohol Ethoxylate	96

CHART EIGHT B

BIODEGRADABILITY OF NONANIONICS BY WPRL AERATION SCREENING TEST you first class guidance on how his product will perform from the BOD and COD point of view in your lagoon. Where a particular product with a specific end use application has an unsuitable BOD or COD, then your auxiliary supplier should formulate specifically to maintain the application requirements you have to satisfy in addition to meet your effluent needs.

A major area of problem appears to lie with some synthetic sizing compounds. Polyvinyl Alcohol, and CMC, Carboxy Methyl Cellulose, are both products that have low BOD values yet very high COD. In the United States these are causing considerable concern. From the point of view of efficiency in sizing they have, in many instances, substituted for starch and starch derivatives, which are biodegradeable, but which appear to perform over-all less satisfactorily.

The Americans have not yet resolved the problem of PVA and CMC.

The manufacturers of woollen carpets have also had to restrict certain product use. I refer in particular to the Dieldrin Moth Proofer which was the basis of many mothproofing formulations and which is now being totally withdrawn from the market, because of its high toxicity to marine life. It is my understanding that the Mitin FF product of Ciba-Geigy is one of the few remaining products that can be safely used in this area.

Trisodium Pyrophosphate, Monosodium Phosphate, TSP and other P_2O_5 donors are now used in dyehouses today as alkalis in scouring processes and for pH control in dye bath operations.

Under the first sweep by the government, the detergent manufacturers have been directed to reduce the phosphate content of household detergents to 5% as P_2O_5 by the end of 1972 and you may assume that industry will also be subjected to a close scrutiny in this area as well. Textile processes will therefore require modification so that other alkalis can be substituted and other buffering techniques evolved to reduce the consumption of phosphates.

As you saw from the A & B Schedules, chromates, and copper contamination are all areas of concern in the United States. It should be remembered that many dyestuffs contain a metal ion such as copper or chromium and these will eventually come under scrutiny as well. *Chart Nine* shows the empirical formula of some dyestuff types and from this you will see, for instance, that Direct Blue 218 has copper as has Brown 95 and Blue 86, while Acid Black 52 is a chromium donor. These are but a few of

CHART NINE

Dye Name	Empirical Formula
Disperse Dyes:	
Yellow 42	$C_{18}H_{16}O_2N_2S$
Yellow 3	$C_{15}H_{15}O_2N_3$
Yellow 54	$C_{18}H_{11}O_3N$
Blue 3	$C_{17}H_{17}O_2N_2$
Blue 7	$C_{18}H_{18}O_6N_2$
Red 60	—
Mordant Type:	
Black 11	$C_{20}H_{13}O_7N_3S$
Acid Dyes:	
Orange 7	$C_{16}H_{12}O_4N_2S$
Black 52	$C_{20}H_{11}O_7N_3SCr$
Yellow 17	$C_{16}H_{12}O_7N_4S_2Cl_2$
Orange 24	$C_{20}H_{18}O_5N_4S$
Black 1	$C_{22}H_{16}O_9N_6S_2$
Blue 113	$C_{32}H_{23}O_6N_5S_2$
Green 25	$C_{28}H_{22}O_8N_2S_2$
Blue 25	$C_{20}H_{14}O_5N_2S$
Yellow 151	—
Yellow 38	$C_{28}H_{26}O_8N_4S_3$
Black 80	$C_{36}H_{26}O_{11}N_8S_3$
Blue 45	$C_{14}H_{10}O_{10}N_2S_2$
Direct Dyes:	
Yellow 28	$C_{28}H_{20}O_6$
Blue 6	$C_{32}H_{24}O_{14}N_6S_4$
Blue 218	$C_{32}H_{20}O_{16}N_6S_4Cu_2$
Yellow 4	$C_{26}H_{20}O_8N_4S_2$
Red 81	$C_{28}H_{21}O_8N_5S_2$
Yellow 50	$C_{35}H_{28}O_{13}N_6S_4$

Red 23	$C_{35}H_{27}O_{10}N_7S_2$
Brown 95	$C_{31}H_{20}O_9N_6S$ Cu
Black 38	$C_{34}H_{27}O_7N_9S_2$
Yellow 11	$C_7H_7O_5N$ S
Blue 86	$C_{32}H_{16}O_6N_8S_2Cu$
Yellow 12	$C_{30}H_{28}O_8N_4S_2$
Yellow 106	——
Black 80	——

Basic Dyes:

Brown 4	$C_{21}H_{24}N_8$
Green 4	$C_{23}H_{25}N_2Cl$
Violet 1	$C_{24}H_{28}N_3Cl$
Yellow 11	$C_{21}H_{25}O_2N_2Cl$
Blue 3	$C_{22}H_{30}O_2N_3Cl$

Vat Dyes:

Blue 43	$C_{18}H_{14}O_2N$
Orange 1	$C_{24}H_{12}O_2Br_2$
Green 1	$C_{36}H_{20}O_4$
Yellow 2	$C_{28}H_{14}O_2N_2S_2$
Brown 3	$C_{42}H_{23}O_6N_3$
Green 3	$C_{31}H_{15}O_3N$
Blue 6	$C_{28}H_{13}O_4N_2Cl$

Sulphur Dyes:

Black 1	$C_6H_4O_5N_2$

the selections of dyestuffs available today, and, I can foresee a need that the dyer has available to him chemical compositions of his dyestuffs so that he can again determine his best choice. The color index is very valuable for this purpose. Dyestuff discoloration in wastewater is presently the subject of much intense research and development. The American Association of Textile Chemists and Colorists are greatly concerned on this matter and a study headed by the AATCC is presently underway to address this problem.

In the United States it is considered important that measures be taken to limit or control the long-term discharge of caustic wastes and dyes, especially printing pastes. It has been suggested that additional separate disposal or reuse of excess printing pastes should be adopted. Similarly, recovery of wool grease and suint have been included in the treatment models that have been set up for wool processing. It has also been recommended that improved control over wet process operations be implemented. For instance, the use of Redox potential measurements to permit reduced excess chemical use in sizing, desizing, bleaching, dyeing, finishing, etc.

Again, in the U. S., it has been suggested that control should be exercised on water usage to reduce needs in processing and spillage as well as leaks and continuously running water hoses. Improved housekeeping is strongly underlined with the use of retaining sills, splash boards and special waste collection containers, etc.

Much attention has been given to wastes resulting from printing operations, in that excess pastes should be separated from the printing room wastewaters and the pastes collected manually, or automatically, into barrels or other suitable containers. These pastes should not be allowed entry to floor drains in the print rooms or the screen cleaning/repair rooms. The viscous printing pastes clog drain lines, sewers and treatment floor apertures and further settle out on the sides of aeration basins and in other areas where least desired. While print pastes may exhibit considerable toxicity, conversely certain pastes have extremely high BOD's from 200,000 mg/l to more than 400,000 mg/l. It has been suggested that the collected mass should be incinerated with strict caution in preventing air pollution or should be partially refined for recovery of varsol and other hydrocarbons.

For wool processing, recovery of wool grease and suint as referred to earlier, are essential in achieving the effluent limits. Recovery of wool grease by solvent systems and conversion into lanolin was practiced when the lanolin market was favorable. Today Calcium Chloride cracking or acid cracking and centrifuging are possible alternatives.

Solvent processing operations show potential for replacing wet processing in the future, in the opinion of some environmentalists. Some textile experts cite increased process efficiencies and decreased in-plant waste loads since solvent systems require little or no water. Solvent systems have been used for a number of years in wool scouring and processing. It is the opinion of some that application is now highly probable in the scouring, desizing, dyeing and finishing of all types of cotton and synthetic goods. It is claimed that solvent systems can achieve desizing, dyeing and finishing in shorter times compared to the conventional aqueous systems. Soluble natural impurities are collected at the solvent purification stills as an oily semi-solid, rather than being wasted. Highly alkaline and detergent-soap laden wastewaters, particularly from cotton scouring and desizing, may be largely eliminated and fresh water requirements reduced up to 96%. Solvent residues may be reclaimed, incinerated, etc. Some solvent systems for desizing, sizing, dyeing and finishing have been more extensively used overseas, but are relatively new in North America. Solvent recovery is thought to be presently incorporated into two or three plants in the United States. The economics of solvent systems will become increasingly favorable with a rise in wastewater treatment costs.

Outside of product selection, proper handling and disposal of spent dye baths and the associated dye rinse and washwater represents a major problem to the textile industry in terms of high levels of BOD, COD, toxic substances and intense color in these wastewaters. In-plant modifications to reduce effects of dyes and the color in resulting wastewaters may include continuous steam dyeing instead of batch dyeing; the oxidation of vat dyes by steaming in lieu of dichromate fixing; and indeed the re-use of dichromate solutions; the reclaiming of first rinses for makeup of new baths; the direct recovery and re-use of concentrated dye solutions. In dyeing synthetics or cotton-polyester blends, the Thermosol Process has been advocated for minimizing amounts of dye chemicals and waters used.

Pressure becks in place of atmospheric dyeing equipment also require less carrier material as well as permitting the choice of alternative carriers having low hazard ratings.

Other suggested routes to reduce waste in both product and water is by the use of continuous scouring in place of pressure keiring. Combined scour-desize and scour-bleach baths are also deemed desirable. Scour rinses may also be used or reused as desize rinses. Highly concentrated spent solutions of keir, mercerizing and desize liquors should be segregated from other plant wastes. These liquors may then be treated separately; more preferably these liquors can be dried and therefore re-used for keiring or mercerizing makeups, be incinerated, or undergo other appropriate disposal in the near dry state, although this method would be very expensive.

In conclusion, it would appear that as pressures mount for cleaner effluents, not to mention atmospheric emissions from your industrial plants, that the chemical suppliers, must continue to work in close accord with the processor, to meet the stringent requirements laid down for the industry.

Full illustrated text of paper delivered at CATCC, Quebec Section, symposium, January, 1973.

WATER USES AND WASTES
IN THE TEXTILE INDUSTRY

John J. Porter, Donald W. Lyons, and William F. Nolan*

Approximately 13 trillion gallons of water are discharged by U. S. industry each year. The textile mill products industry discharges about 135 billion gallons or 1% of the total. The relative quantity of water used by the textile industry seems small, but when one considers that the textile industry is concentrated in four or five states in the Southeast on inland water supplies, the water use is quite significant.

Another very important factor to consider is the rate at which this growing waste stream is changing in composition. Due to new products introduced onto the market, a waste stream that may have once been homogeneous and biodegradable can become heterogeneous and inert.

The lint from textile manufacturing and finishing is a noticeable part of the suspended solids in textile waste. In the case of natural fibers, biological degradation will occur when the fiber is retained with the sludge in the treatment plant. However, this is not true for most synthetic fibers which are comparatively inert. The buildup of synthetic fibers in a treatment plant using mechanical aeration can cause damage to pumps and aerators unless special precautions are taken to remove fibers from the waste stream as it enters the plant. Generally, this is done by screening the waste stream as it enters the treatment plant. In some cases, this may be a difficult operation because a screen system fine enough to remove fibers 15 μ in diameter may easily clog or remove suspended solids that are suitable for biological treatment. Synthetic fibers can amount to 5-10% of the weight of the sludge.

Effluent Characterization

A number of mechanical operations have to be performed to convert textile fibers into fabrics. The fibers must be combined into yarns and then the yarns into fabrics. After fabrics are manufactured, they are subjected

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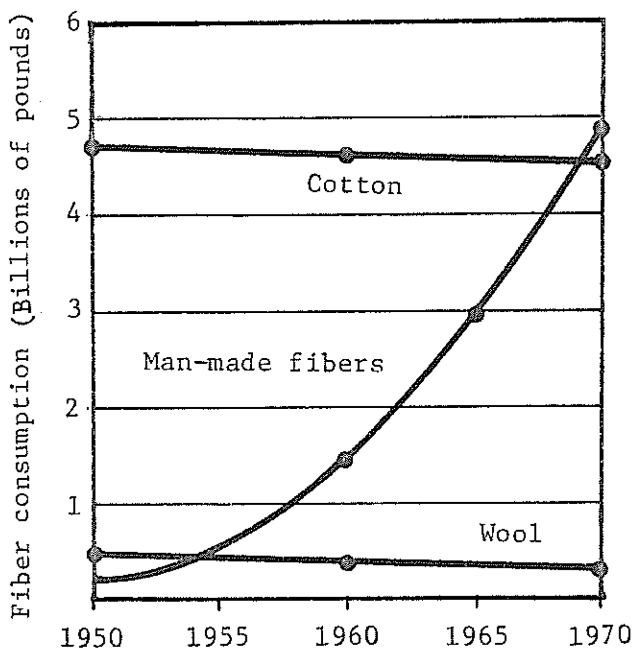
Figure 1. Textile fiber consumption in the U. S.



Source: Textile Organon, 40, 191, 1969.

to several wet processes collectively known as finishing, and it is in these finishing operations that the major waste effluents are produced.

Cotton

The consumption of cotton fibers by textile mills in the United States exceeds that of any other single fiber (Figure 1). Slashing is the first process in which liquid treatment is involved. In this process, warm yarns are coated with "sizing" to give them abrasive resistance to withstand the pressures exerted on them during the weaving operation. The principal slashing polymer used before 1960 was starch which was easily degraded biologically and should present no problem to the conventional waste treatment plant other than BOD loading.

Development of many synthetic fibers in the 1950's and their use in blended fabrics created the need for new sizes which were more compatible with the hydrophobic fibers. Some of those which are still in use are polyvinyl alcohol (PVA), carboxymethyl cellulose (CMC), and polyacrylic acid.

If an average size concentration of 10% is assumed to be present on woven fabrics, which constitute 70% to 80% of the fabrics produced, approximately 400 million lb of size per year are currently entering textile finishing waste streams. Since PVA and CMC are resistant to biological degradation, conventional treatment methods would not be expected to alter their chemical structure. While the polymer may be partially removed from the waste water by adsorption on the sludge, it is quite questionable whether this is an effective method of treatment.

The operation of desizing removes the substance applied to the yarns in the slashing operation, by hydrolyzing the size into a soluble form. There are two methods of desizing--acid desizing and enzyme desizing. In acid desizing, the fabric is soaked in a solution of sulfuric acid, and in enzyme desizing, complex organic compounds produced from natural products or malt extracts are used to solubilize the size. Due to the unstable nature of these organic compounds, the whole bath must be discarded after each batch. Desizing contributes the largest BOD of all cotton finishing processes--about 45%.

Scouring follows desizing. In this process, cotton wax and other noncellulosic components of the cotton are removed by hot alkaline detergents or soap solutions. In most modern plants, scouring is done in conjunction with desizing rather than as a separate operation. Caustic soda and soda ash along with soaps and synthetic detergents and inorganic reagents are used to remove the noncellulosic impurities. The waste liquor will have a 0.3% alkaline concentration.

A few of the major chemical manufacturers are now offering solvent processes to the textile industry for scouring where little water is used. In these cases, nonflammable chlorinated solvents are used, and the projected solvent recovery is between 90% and 97%. However, nearly 1 ton of solvent per day per range will reach the atmosphere or waste stream.

Bleaching, the next process, removes the natural yellowish coloring of the cotton fiber and renders it white. The three bleaches most commonly used for cotton are sodium hypochlorite, hydrogen peroxide, and sodium chlorite. The bleaching process contributes the lowest BOD for cotton finishing.

Mercerization gives increased luster to cotton fabrics, but more importantly, imparts increased dye affinity and tensile strength to the fabric. The process uses sodium hydroxide, water, and an acid wash. The effluent from the overall process has a high pH and also a high alkalinity if the caustic material is not recovered. After mercerizing, the goods are sent to the dye house or color shop. The dyeing process is carried out in an aqueous bath with pH variations of 4 to 12.

In the color shop, the goods are printed with colored designs or patterns. The color is imparted to the fabric from rolling machines which contain the printing paste. This paste contains dye, thickener, hygroscopic substances, dyeing assistants, water, and other chemicals. The pollution load from the color shop comes mainly from the wash-down rinses (used to clean the equipment in the shop) and the cloth rinsings and is rather low in both volume and BOD. When a mill does both printing and dyeing, the BOD contribution of the combined processes is 17%, and the total BOD load comes from the process chemicals used.

Dyes have to be more and more resistant to ozone, nitric oxides, light, hydrolysis, and other degradative environments to capture a valuable portion of the commercial market. It is not surprising, therefore, that studies on the biological degradation of dyestuffs yield negative results when dyes are designed to resist this type of treatment. The range of pollution loads of the various cotton textile wet-processing operations are listed in Table 1.

Federal Water Pollution Control Administration estimates for BOD, suspended solids, total dissolved solids, and volume of waste water for 1970-82

Table I. Pollution effects of cotton processing wastes

Process	Wastes, ppm		
	pH	BOD	Total solids
Slashing, sizing yarn	7.0-9.5	620-2,500	8,500-22,600
Desizing		1,700-5,200	16,000-32,000
Keiring	10-12	680-2,900	7,600-17,400
Scouring		50-110	
Bleaching (range	8.5-9.5	90-1,700	2,300-14,400
Mercerizing	5.5-9.5	45-65	600-1,900
Dyeing:			
Aniline Black		40-55	600-1,200
Basic	6.0-7.5	100-200	500-800
Developed Colors	5-10	75-200	2,900-8,200
Direct	6.5-7.6	220-600	2,200-14,000
Naphthol	5-10	15-675	4,500-10,700
Sulfur	8-10	11-1,800	4,200-14,100
Vats	5-10	125-1,500	1,700-7,400

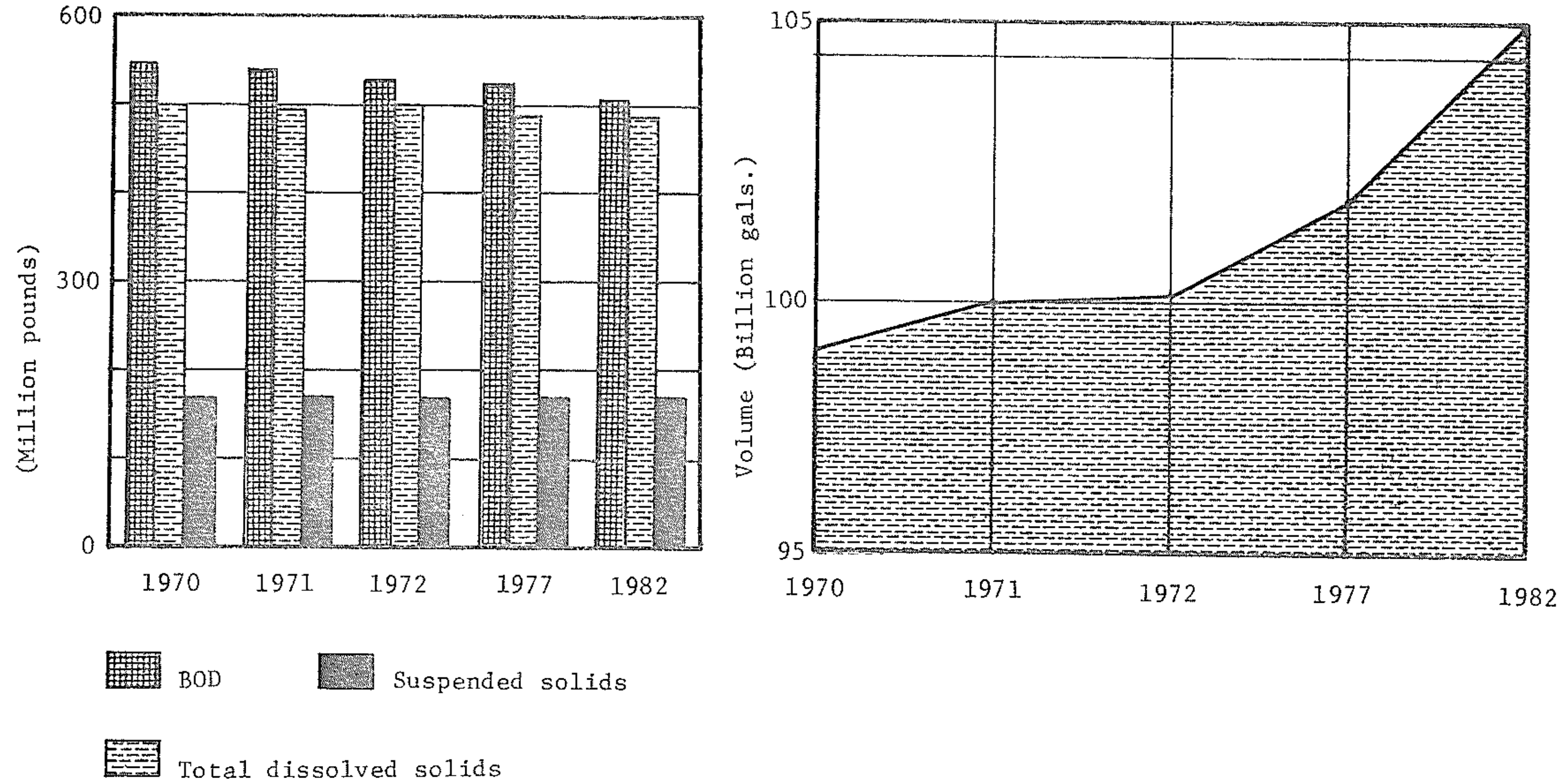


Figure 2. Projected wasteload for cotton finishing wastes.

are shown in Figure 2. The gradual decrease of the gross pollution load in coming years is based on these assumptions: new machinery, which tends to produce less pollution per unit of cloth due to water reuse and countercurrent flow designs; trends in process modification, new chemical manufacture, and better housekeeping will continue; a larger percentage of the wastes will be treated due to increased efficiency of treatment facilities; and increased state, local, and federal pressure.

Wool

Wool fiber consumption is the smallest of the three groups, and the trend seems to be toward less demand in the future on a percentage basis. Scouring is the first wet process that wool fibers receive. This process removes all the natural and acquired impurities from the woolen fibers. For every pound of scoured woolen fiber, 1-1/2 lb of waste impurities are produced; in other words wool scouring produces one of the strongest industrial wastes in terms of BOD by contributing 55-75% of the total BOD load in wool finishing.

Depending on whether the fabric is classified as woolen or worsted, the remaining wet processes will vary. Burr picking and carbonizing are steps to remove any vegetable matter remaining in the wool after scouring and before dyeing.

The volume of waste water generated by dyeing, either stock or piece goods, is large and highly colored, and many of the chemicals used are toxic. The BOD load is contributed by the process chemicals used, and represents 1-5% of the mill's total BOD load. Although the following mixing and oiling step does not contribute directly to the waste water volume, the oil finds its way into the waste stream through washing. The percentage contribution to total BOD load of this process varies with the type of oil used.

Fulling or felting is another operation that does not directly contribute to the waste stream, until the process of chemicals are washed out of the fabric. It is estimated that 10-25% of the fulled cloth's weight is composed of process chemicals that will be washed out in this process and discarded.

Wool washing after fulling is the second largest source of BOD, contributing 20-35% of the total. This process consumes 40,000-100,000 gallons of water for each 1,000 lb of wood fabric, and analyses show that wool, once thoroughly washed, will produce little or no BOD on being rewashed. Carbonizing the fabric or stock of fibers (with strong acid to remove cellulose

Table II. Pollution loads of wool wet processes

Process	pH	BOD, ppm	Total solids, ppm
Scouring	9.0-10.4	30,000-40,000	1,129-64,448
Dyeing	4.8-8.0	380-2,200	3,855-8,315
Washing	7.3-10.3	4,000-11,455	4,830-19,267
Neutralizing	1.9-9.0	28	1,241-4,830
Bleaching	6.0	390	908

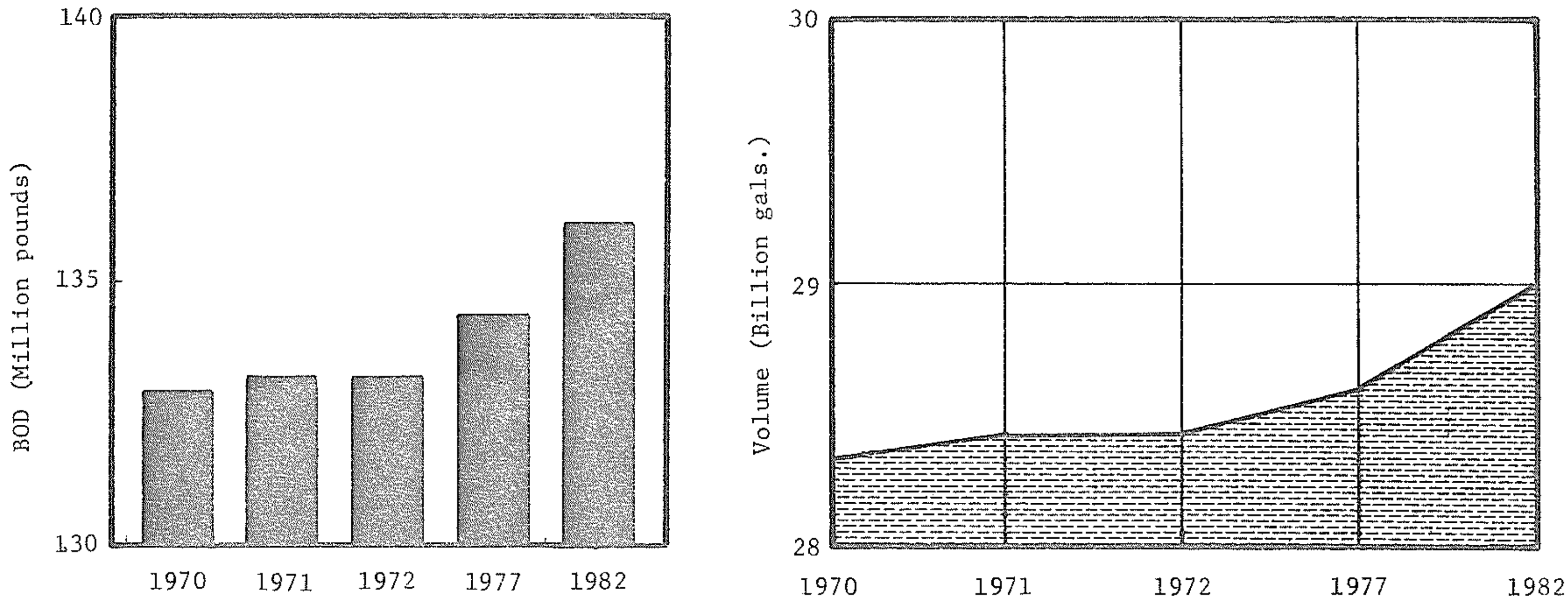


Figure 3. Projected wasteload for woolen finishing wastes.

impurities followed by a soda ash wash) contributes less than 1% of the total BOD load.

Wool is bleached if white fabric or very light shades of colored cloth are required; however, the amount of wool fabric bleached is rather small. With hydrogen peroxide and sulfur dioxide, bleaching the BOD contribution is usually less than 0.5%, and optical brighteners, which use organic compounds, contribute about 1% of the total BOD. In processing woolen fibers, five sources of pollution load exist--scouring, dyeing, washing after fulling, neutralizing after carbonizing, and bleaching with optical brighteners. The average values of the pollution load of each of these processes is shown in Table II. The waste water volume for woolen finishing wastes is shown in Figure 3.

Synthetics

This category of textile fibers has two broad classifications: cellulosic and noncellulosic fibers. The two major cellulosic fibers are rayon and cellulose acetate; the major noncellulosic fibers are nylon, polyester, acrylics, and modacrylics. Different processes to produce synthetic fibers result in varying pollution loads (Table III).

The first process in which synthetic fibers are subjected to an aqueous treatment is stock dyeing (unless the fabric is to be piece dyed). When stock dyeing is used, the liquid waste discharge will vary from about 8 to 15 times the weight of the fibers dyed. Due to the low-moisture regain of the synthetic fiber, static electricity is a problem during processing. To minimize this problem, antistatic oils (polyvinyl alcohol, styrene-based resins, polyaklylene glycols, gelatin, polyacrylic acid, and polyvinyl acetate) are applied to the yarns and become a source of water pollution when they are removed from the fabrics during scouring.

Since the manufacture of synthetic fibers can be well controlled, chemical impurities are relatively absent in these fibers; and if synthetics are bleached, the process is not normally a source of organic or suspended solids pollution.

In finishing rayon, one of the synthetic fibers, scouring and dyeing are usually done concurrently in a single bath. If scouring and dyeing are the only finishing processes given rayon fabrics, an equalized effluent of 1445 ppm BOD and 2000-6000 ppm salt contained in approximately 5000 gallons of water for each 1000 lb of fabric processed will be produced.

Table III. Pollution load of synthetic wet fiber processes

Process	Fiber	pH	BOD, ppm	Total solids, ppm
Scour	Nylon	10.4	1360	1882
	Acrylic/modacrylic	9.7	2190	1874
	Polyester		500-800	
Scour & Dye	Rayon	8.5	2832	3334
	Acetate	9.3	2000	1778
Dye	Nylon	8.4	368	641
	Acrylic/modacrylic	1.5-3.7	175-2000	833-1968
	Polyester		480-27,000	
Salt Bath	Rayon	5.8	58	4890
Final Scour	Acrylic/modacrylic	7.1	668	1191
	Polyester		650	

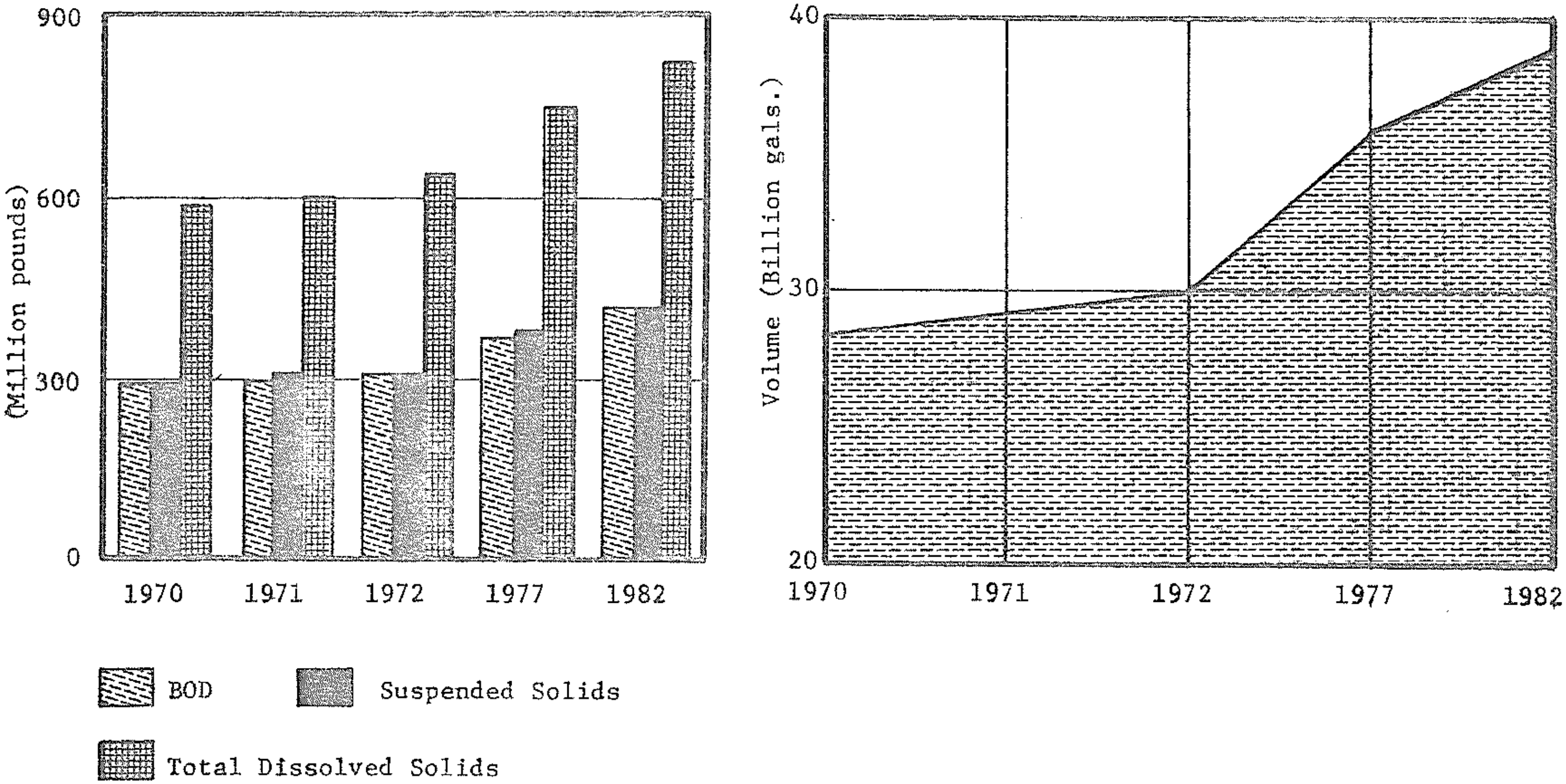


Figure 4. Projected wasteload for synthetic fiber finishing.

For acetate fibers, the wastes from scour and dye baths average 2000 ppm and 50 lb of BOD for each 1000 lb of acetate fabric. Typically, the bath contains antistatic lubricant desizing wastes, which contributes 40-50% of the BOD load; the sulfonated oil swelling agent, which accounts for 30-40% of the BOD load; the aliphatic ester swelling agent, which amounts to 10-20% of the BOD discharged; and the softener which has negligible BOD content.

These processes produce a composite waste of 666 ppm of BOD for each 1000 lb processed; the volume of water required to treat this amount of cloth averages 9000 gallons. If bleaching is substituted for dyeing, the BOD of the discharge of the scouring and bleaching bath is approximately 750 ppm.

Nylon differs from other synthetics in that approximately 1% of the fiber dissolves when scoured. Soap and soda ash are used in the scouring process which averages 1360 ppm and 34 lb of BOD for each 1000 lb of cloth processed. The substances present in the bath contribute the following percentages to the total BOD of the bath; antistatic-sizing compound (40-50%), soap (40-50%), and fatty esters (10-20%).

When nylon is dyed, sulfonated oils are used as dye dispersants. These dye dispersants contribute practically all of the process's BOD, which amounts to an average of 600 ppm and 15 lb for each 1000 lb of cloth dyed. However, the BOD contribition of scouring is roughly 80%, the remaining BOD being contributed by the dyeing process.

Another group of synthetic fibers are the polyesters whose scour wastes average 500-800 ppm of BOD. Processing 1000 lb of polyester fabric will produce 15.5 lb of BOD of which 90% is contributed by antistatic compounds used for lubrication sizing. Because of the high concentrations at which they are used and the inherent high rate of BOD, the emulsifying and dissolving agents used in polyester dyeing will produce high BOD loads. The rinses in polyester finishing are usually low in BOD. But, the processing of polyester uses an average of 15,000 gallons of water per 1000 lb of fiber. Projected gross wasteload for synthetic fiber finishing is shown in Figure 4.

Acrylics and Modacrylics

Although these two fiber types have different physical and chemical properties, they are both subject to the same finishing techniques. The waste from the first scour averages 2190 ppm and 660 lb of BOD per 1000 lb of processed fiber. The chemical components of the bath are the antistatic compound, which accounts for 30-50% of the BOD, and the soaps used to accomplish this process. When using acid dyes, the dye baths average 175 ppm and 5.3 lb of BOD per 1000 lb of fabric, the total BOD load coming from the dye carriers.

The final scour averages 668 ppm and 20 lb of BOD for 1000 lb of cloth. This final scour is accomplished with synthetic detergents and pine oil, which together contribute practically all the BOD. The equalized discharges will have a BOD of 575 ppm and 120.9 lb in a volume of 25,000 gallons of wastewater for each 1000 lb of acrylic and modacrylic fabric processed.

Finishing

A treatment of a fabric that modifies its physical or chemical properties may be classified as finishing. Examples include permanent press finishes, oil repellents, soil release agents, low-crock polymers, abrasion-resistant polymers, fire retardants, lamination polymers, germicide and fungicide chemicals, to mention a few. A small number of these materials are biodegradable; however, most are not.

The polymers used for textile finishing are generally supplied to the finishing plant as emulsions which are sensitive to pH, salt, or agitation and may coagulate when they enter waste streams. Sewer lines may then become clogged with inert materials which have to be removed by hand. Although the bulk of the polymer emulsion can be coagulated and removed in a treatment plant, some of it remains emulsified and is not removed by biological treatment. For complete removal of the polymer emulsion, chemical treatment is sometimes necessary. However, this is an additional step which in itself could replace much of the need for biological treatment.

Most of the finishes used for wash and wear and permanent press fabrics are manufactured from urea, formaldehyde, melamine, and gloxal compounds. Some of these products are readily degradable by microbial action; others are not. The formaldehyde derivatives can react with themselves or other chemicals in the waste stream to form insoluble products that may be removed by sedimentation.

A class of finishing chemical that has come into prominence in recent years is fire retardants. Most of the commercial fire-retardant finishes are phosphorus- and nitrogen-containing compounds. One such compound, triaziridyl phosphine oxide (APO), could present a serious problem if it got into a natural stream. The chemical inactivity of APO would facilitate its hydrolysis in a waste stream and prevent the parent compound from reaching the discharge water of a treatment plant. Whether or not these initial hydrolysis products are toxic or harmful is not known. This points to the increasing need for the characterization of industrial waste.

In the future, waste streams from different processing operations will have to be isolated and treated by either chemical or biological methods. The choice of treatment will naturally depend on the composition of the stream. By using this approach, industry will have more latitude in choosing chemicals and processes for their inherent production advantages and not their effect on pollution.

REDUCING ENERGY REQUIREMENTS FOR SUPPLYING IRRIGATION WATER

Darrell G. Watts*

Introduction

It is well within current technological capability to achieve an overall reduction of 10 to 20% in the energy consumed annually for providing water for irrigation. The potential reduction is much greater. The barriers to attaining it are primarily human and not a lack of scientific information. The problem is twofold: (1) there is a need for a greatly expanded program of information dissemination to the principal water supply user, the irrigator; (2) farmers have a natural resistance to the change of status quo plus doubts about the economic advantages of the changes which must be made in irrigation practice if energy use is to be reduced. The current high price of fuel, the persisting local shortages and the alternatives of using less energy or not irrigating at all may, however, force change at a rapid pace.

Energy in relation to irrigation means energy for pumping water. Energy is needed for lifting water from wells, for providing pressure for sprinkler systems, for raising water to the high point of a field so that it can be used for surface irrigation. At the end of 1972 there were approximately 50 million acres of irrigated land in the United States. Ten million were sprinkled and 40 million surface irrigated (9). Essentially all sprinkled land requires the use of energy for pumping. As a very rough estimate, 50% of the surface irrigated land used pumped water, (reliable statistics are very difficulty to obtain). This means that probably over half of all irrigation agriculture in the United States requires a consumption of fossil fuels or hydro-power to provide a water supply.

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This past year irrigators only began to feel the pinch of the energy crisis. Fuel shortages occured in various areas. In the midwest, many growers turned to electricity as an alternative only to find a long waiting period before they could get connected. The short run energy supply picture for agricultural water supply is unclear. Even if the Federal Government is able to provide 100% of last year's requirements, local shortages could occur. This is especially true in states such as Nebraska where irrigation agriculture is rapidly expanding and the demand for fuel is increasing at a high annual rate.

Nebraska is currently the third state in the nation in terms of total irrigated acreage. By the year 2000 it could conceivably be first. Projections of the growth rate of irrigation suggest an increase in the state from the present 5 million acres up to 7.5 million acres by 1980 depending on the energy supply and a continued favorable economic climate for development. The most limiting factor could be the availability of energy for pumping water.

Using presently available technology there are several different procedures which can be used to reduce energy requirements for irrigation pumping. Some are common to all widely used irrigation methods while others are specific to a given method or general climatic zone. Perhaps none could be considered to have application throughout the entire irrigated region of the United States. However, the application of each one where appropriate would yield substantial improvement in the energy picture for agricultural water supply.

The suggested procedures include:

1. Increasing irrigation pumping plant efficiency.
2. Reducing water application.
3. Improved management of electric pumping plants.
4. Reuse of irrigation runoff water.
5. Improved irrigation system design.

Increasing Irrigation Pumping Plant Efficiency

There is one step which, if taken by all irrigation pump owners, could reduce energy requirements for pumping by 10 to 20% next year. That step would be the adjustment of all pumping plants to bring them up to field performance standards. This pertains to all nonelectric power plants and all deep well pumps, regardless of power plant type. Table 1 shows performance standards which have been established for deep well pumping plants. These are standards which have been generally accepted throughout the United States. They were developed and verified by several years of field and laboratory study (2, 12, 15). They are practical performance levels which can be obtained in the field when pump and power unit are in good condition and are properly adjusted.

Table 1. Performance standards for deep-well pumping plants

Energy source	Rated load hp-hr/gal for representative power units	Performance standard in whp-hr/gal[1]
Diesel	14.58[2]	10.94
Gasoline	11.54[2]	8.66
Tractor fuel	10.48[2]	7.86
Propane	9.2[2]	6.89
Natural gas	88.93[3] per 1000 cu. ft.	66.7 per 1000 cu. ft.
Electric	88 percent efficient	0.885 per kw-hr

[1] Based on 75 percent pump efficiency.
[2] Taken from Test D of Nebraska Tractor Tests Reports. Data corrected for 5 percent drive loss.
[3] Manufacturers' data corrected for 5 percent drive loss.
[4] Not corrected for drive loss. Assume a direct connection.

In a study conducted a few years ago 376 pumping plants were tested in Nebraska and compared with these standards (7). The results are summarized in Table 2. Less than 9% of the systems tested met the standard and less than 60% achieved 75% of the standard performance. The basic problem is that systems are frequently installed and receive minimum maintenance thereafter. Just like any other mechanical equipment, pumping plants need periodic adjustment by trained personnel to maintain operation at peak performance. Unfortunately, these units receive less maintenance than most any other comparable piece of equipment used in agriculture. No one would think of buying a new car and driving it for 10 years without maintenance. Many people will not hesitate to expect this type of performance from a pump. A thorough adjustment of pump and power plant requires about six hours by a trained technician and will cost less than $100. It is an excellent investment.

Table 2. Summary of performance tests on 376 deep well pumping plants

Percent of standard	Exceeding standard	90-100%	75-89%	50-74%	49% or less
Percent of pumping plants in each category	8.8%	14.9%	35.1%	32.2%	9.0%

A measure of possible energy savings from pumping plant adjustment may be obtained by applying the data of Table 2 to the present Nebraska situation. Table 3 shows the savings that could result if all irrigation pumping plants in the state were brought up to performance standards. These savings would result even with no other improvement in irrigation practices. Additional savings are possible with better water management.

Table 3*. Potential energy savings/year in Nebraska through pumping plant adjustment

Electricity	241,000,000 K.W. - hrs.
Diesel Fuel	17,600,000 gallons
L. P. Gas	27,900,000 gallons
Natural Gas	1.6×10^9 cubic feet
Gasoline	822,000 gallons

* Assumptions in computing tabulated values:

39,500 registered wells (1/1/73)
100 acres/well; 24.3% of area sprinkled & 75.7% surface irrigated.
135 feet lift to surface
70 psi at pump on sprinkler systems
18 inches gross water application for sprinklers
24 inches gross water application for surface irrigation
Type of power units: Gasoline - 1%; Diesel - 27%; Electric - 30%; Natural gas - 15%; L. P. gas - 27%

Reducing Water Application

Irrigation Scheduling

The most direct approach to reducing energy consumption by irrigation pumping plants is to pump less water. While this may seem obvious it is not so easy to implement in practice. Historically the farmer has substituted water for labor, finding it easier to put on "plenty" rather than doing a lot of hard physical labor to apply smaller quantities. With new developments in irrigation equipment good water control is easier to attain. The irrigator is more able to apply water when it is needed and only in the amounts needed. However, to determine "when" and "how much" requires, at the very least, weekly monitoring of soil moisture levels in the field.

A thorough job of irrigation scheduling requires additional calculations and data input beyond moisture monitoring. Most farmers either feel that they do not have the time or will not take the time to use a soil probe in the field for checking moisture or spend the time to install and read electrical resistance blocks. Furthermore many growers are not sure how to translate their findings in the field to specific quantities of water to be applied by their irrigation system.

Commercial irrigation scheduling services appear to have a strong potential for providing the grower with the day-to-day information he needs for properly operating his irrigation system. When an irrigation is correctly scheduled he irrigates at the time water is needed and, with proper equipment and guidance, applies the right amount. This usually reduces the quantity of water which is pumped during the growing season. These savings could amount to between 15 and 50% of the amount the grower normally pumps, depending upon his previous practices.

Commercial scheduling services have been successfully operating in Nebraska and Arizona for the last four years and are developing in the Pacific Northwest. A computer is used to make a daily water balance on each field that is scheduled. Meteorological data are used to estimate potential evapotranspiration which is then corrected for stage of growth of the crop. Information on rate and depth of rooting, soil water holding capacity on a given field, plus information on irrigation system capacity is used to determine when the grower should irrigate and how much should be applied.

The success of the "computer" approach depends upon the human element. The scheduling service sends a man to the field on a weekly basis to make a direct check of the actual soil water content. The field man uses the computer print-out as a guide but modifies it as field observations dictate and returns the revised data for reentry into the computer. Finally, he discusses the current situation with the grower while giving him the irrigation schedule for the coming week. Attempts to operate a scheduling service without field monitoring have not been very successful. If it rains, probing is required to see how much entered the soil. Furthermore, local variations in evaporative demand make it impossible to compute exact water use on every field. On the other hand, scheduling directly by field observation without the meteorological inputs and computer assistance works fairly well only in areas that have little or no growing season precipitation.

In Nebraska the commercial scheduling service has had good acceptance by both surface irrigators and those using sprinkler equipment. The company has received a repeat business of between 90 and 95% of its previous years' customers and is expanding rapidly. In 1974 almost 100,000 acres will be scheduled commercially within the state (3).

The potential of irrigation scheduling for reduction of pumping is illustrated by Figure 1 which shows a comparison of relative water application in 1973 between 32 nonscheduled irrigation systems and the average (rel. app. = 1.0) of 3 systems scheduled by a commercial service (16). All systems were in a two county area of southwest Nebraska.

Allowing an error of +10% and -20% (the latter to allow for a greater end of season moisture depletion than was obtained on the scheduled systems), it appears that, four systems may have been under-irrigated and eleven applied excessive amounts of water. This points out that scheduling does not automatically decrease water application. In this case some fields would have had additional water applied if they had been scheduled. Nevertheless, an overall average reduction in pumping of 12-15% would have been achieved on the 32 systems if irrigation scheduling had been used. On some systems the savings would have been dramatic.

Programmed Depletion of Soil Moisture

In areas where several inches of precipitation normally fall during the growing season a planned or "programmed" depletion of soil moisture can be used on deep rooted crops to avoid the application of several inches of irrigation water. It is especially useful on sprinkler irrigated fields where maximum water control can be exercised. Programmed depletion to reduce energy consumption can be used in areas where enough winter or spring precipitation occurs to refill the soil moisture reservoir after depletion the previous year. In general the soils should have an available moisture holding capacity of 1.5 inches/ft. or better and have a profile depth about equal to the principal rooting depth of the crop.

Current design practices for irrigation systems call for a capacity to apply water at a rate approximately equal to the peak evapotranspiration rate of the growing crop (1). Several years of field research at various locations in Nebraska having a wide range of growing season rainfall, indicate that under the conditions previously specified an irrigation system capacity equal to about one-half to two-thirds of the evapotranspiration rate is sufficient. During peak ET periods when water use exceeds application, the plants withdraw from stored soil moisture a quan-

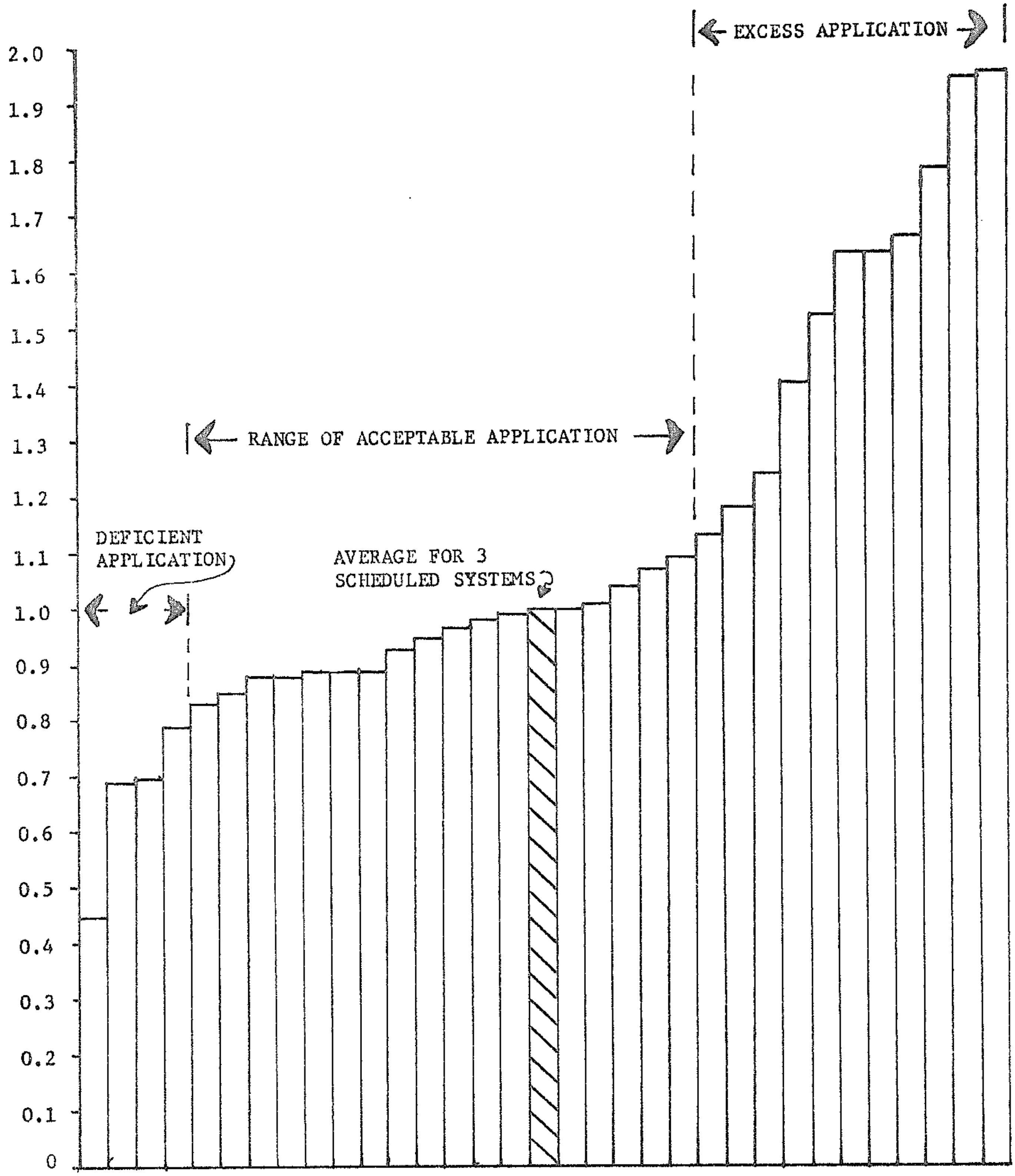

Figure 1. Comparison of relative water application on scheduled and non-scheduled irrigation systems.

tity equal to the difference between what is needed and what is applied as irrigation. The soil moisture reservoir is refilled by precipitation during the non-growing season.

To achieve "programmed" depletion of soil moisture irrigations systems must be designed to fit crop, soil, and climatic conditions in order to hold the maximum depletion of soil moisture within safe limits. Its application to the conditions of the northern and central Great Plains has been amply documented and demonstrated (8, 6, 11, 14). The concept is simple but growers have been reluctant to accept it because it is contrary to the traditional approach of maintaining a full or nearly full soil moisture reservoir.

Programmed soil moisture depletion is illustrated by Table 4 which shows 1971 research data for irrigated corn grown at North Platte, Nebraska (13). No statistical difference was found between yields on the three treatments, although treatment C received only a little over half of the irrigation of treatment A.

Table 4. Total water use and grain yields of corn on solid set sprinkler irrigated plots at the University of Nebraska North Platte Station for three quantities of irrigation in 1971

Irrigation Treatment[1/]	Rain	Irrigation Inches	Stored Moisture Change in Root Zone	Total Water Use Inches	Corn Yield Bu/A
A	12.5	16.1	-2.3	30.9	159
B	12.5	13.3	-3.7	29.5	160
C	12.5	8.5	-6.7	27.7	155

1/ A = .95 inch per irrigation, 2 applications per week, equivalent to a water application of .27 inch per day.

B = 1.48 inch per irrigation per week, equivalent to .21 inch per day.

C = .95 inch per irrigation per week, equivalent to .14 inch per day.

The water application of .95 inches per week on treatment C was sufficient to meet in full evapotranspirational demand for the first half of the growing season. During the latter half of the season the plants withdrew 6.7 inches of water from the soil profile to supply the difference between demand (which can exceed .3 inches per day) and irrigation application. The total water use figure is the sum of irrigation, plus the change in the stored soil moisture from beginning to end of the growing season, plus a rainfall amount of 12.5 inches. The total use probably included some deep percolation on treatments A and B.

By maintaining a moisture deficit in the root zone, more precipitation that falls during the growing season is retained and used. In contrast when high moisture levels are maintained by heavy irrigation as was the case for treatment A, more of the rainfall either runs off or percolates through the soil profile.

Depending on crop, soil and climate a programmed depletion of soil moisture can reduce the water application and associated energy requirements for pumping from 20 to 50%. Using this method in conjunction with irrigation scheduling a maximum saving of energy can be obtained. Scheduling procedures can assure proper water application during the first half of the growing season when root zones are shallow and only small water deficits can be tolerated. In areas of substantial summer precipitation, scheduling tells the grower when to resume irrigation if he receives enough rainfall to "erase" the moisture deficit during the peak water use period.

Improved Management of Electric Pumping Plants

Electricity is the energy source for over half of all irrigation pumping plants in the United States. It is preferred because it is convenient, in many areas inexpensive, and during a fuel shortage, a certain source of power.

Because irrigation is a very seasonal user of electricity it creates problems for the power suppliers. Power demand for irrigation normally occurs over a three to four month period each year which coincides with the time that air conditioning load is high. The wholesale power supplier must invest in generating equipment with a capacity sufficient to meet the peak demand, yet part of that capacity may go unused nine to ten months of the year. In some areas the retail power distributor must pay a penalty for having a high summer demand in relation to the winter load. For some this problem has become so serious that they can connect only a few additional irrigation customers per year.

Figure 2 shows the annual power demand over a five-year period for a retail public power district in Nebraska facing the irrigation load problem (10). There is a rapidly growing summer demand, a large differential between summer and winter loads and a very sharp summer peak as irrigation and air conditioner power demands coincide. The darkened area in Figure 2 indicates when the district has to pay a penalty to the wholesale power

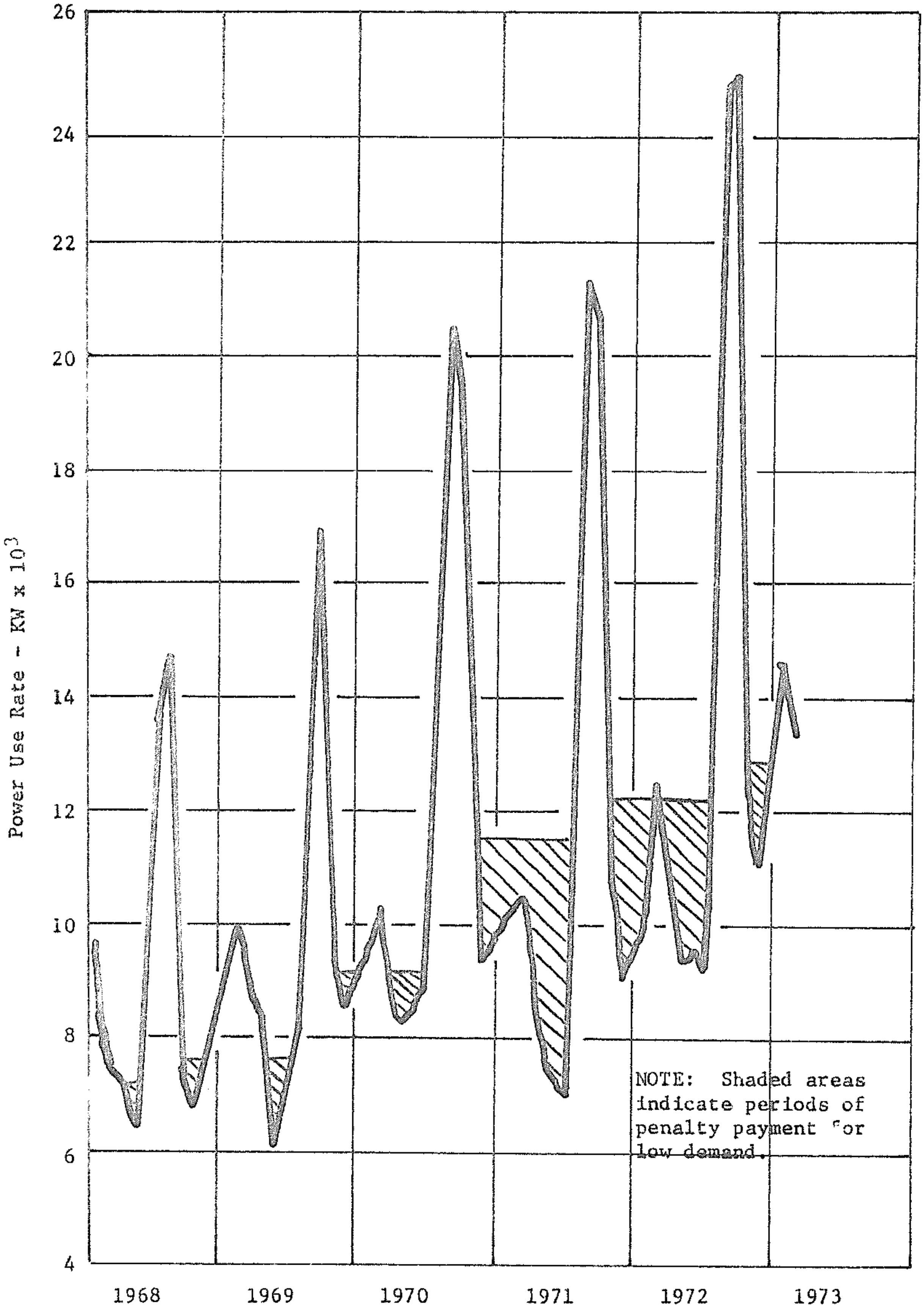

Figure 2. Five year power demand; Custer Public Power District, Nebraska.

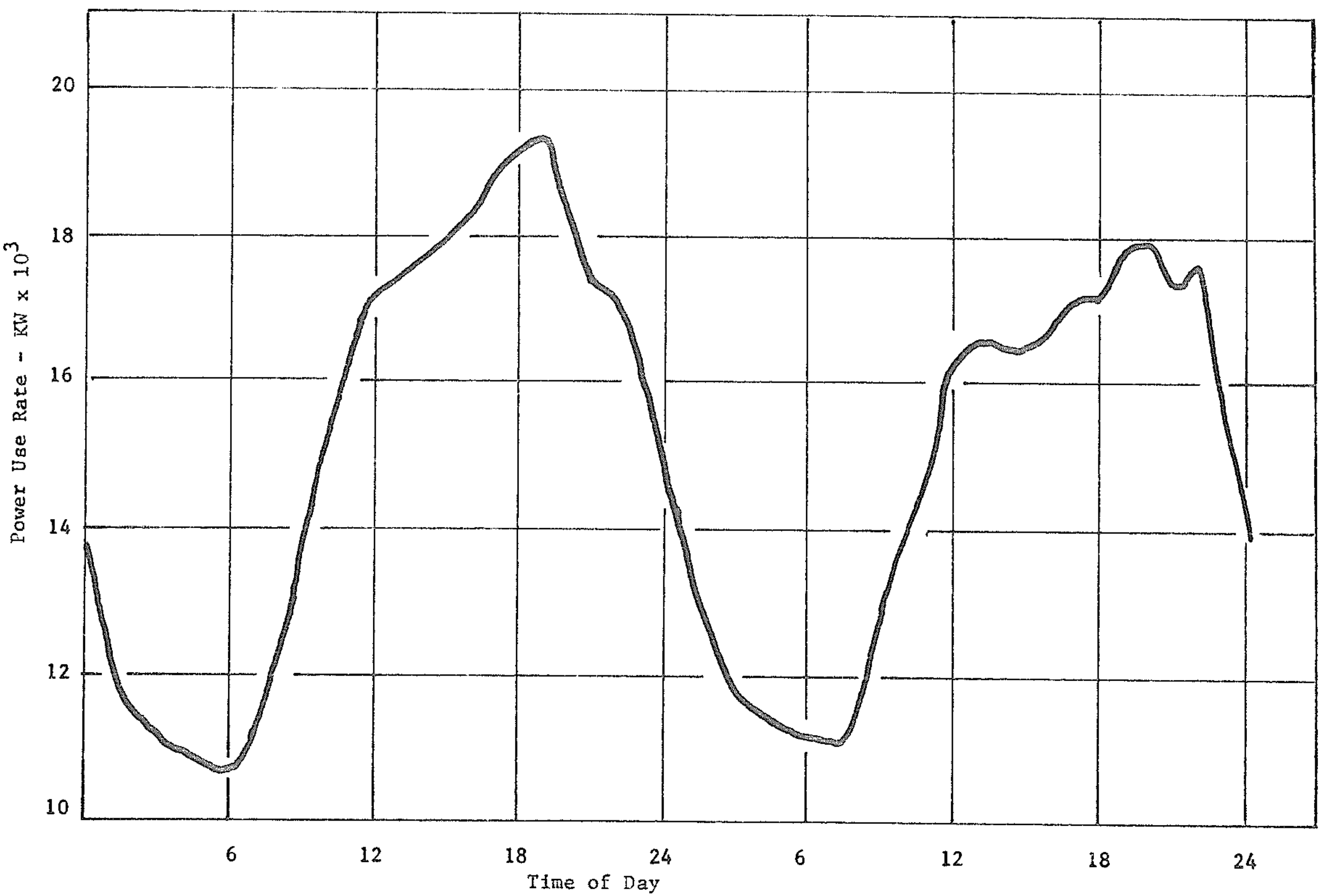

Figure 3. Hourly energy demand during "normal" irrigation operation.

supplier because the power use rate dropped below 65% of the summer peak. (The latter is determined as the peak one hour use rate on the peak day of the year, less a small irrigation load allowance by USBR). In order to hold the penalty within acceptable bounds, the utility district has severely restricted the number of new irrigation pumps it will connect each year. Other districts not on the penalty system have taken similar steps to limit new connections because of the danger of overloading their facilities during peak demand periods.

Part of the "peaking" problem is caused by the large difference between afternoon maximum power demand and the early morning minimum. This is shown by Figure 3, a typical hourly energy demand curve over a two-day period in the summer. Peaking occurs around 7:00 P.M. when domestic air conditioning and irrigation loads are all high.

Through application of irrigation scheduling a procedure has been developed for reducing the effect of the irrigation load on the peak power demand. The objective is to reduce the differential between daytime and nighttime demand during the summer. This can be done by turning off irrigation systems during daily peak use periods. This serves to reduce maximum daily peaks and thus reduces the overall summer peak, for a given total connected load. For a given transmission capability it becomes possible for electric utilities to connect additional irrigation customers.

The new procedure now being used in Nebraska makes use of the "excess" capacity of many irrigation systems. When proper use is made of stored soil moisture, thenormal system capacity of .3 to .4 inch per day is greater than necessary for medium textured soils in the Northern Great Plains. The average irrigation system need operate only 60 to 70% of the time. The systems can therefore be turned off during the early evening hours when domestic and air conditioning power uses are higher. Timeclocks or radio controls can be used to facilitate switching.

Application of the new management procedure was made this past summer on an experimental basis (17). Twenty-six irrigation systems with electric pumping plants all served by the same transformer substation were operated only between 11:00 P.M. and 3:00 A.M. the following day. Power was off to the systems during "peak use" hours for three separate periods totaling 28 days during the growing season. All systems were computer scheduled and field checked to assure that a high level of soil moisture was maintained prior to the period of off-peak operation. This assured adequate moisture in storage when systems were able to run only part time.

When the irrigation systems were under controlled operation, the daily peak was shifted from 7:00 P.M. to the early morning hours. The daily minimum occurred between 5:00 and 8:00 P.M., the normal peak demand period. By having a large number of systems under remote control and by varying the hours of operation, an almost uniform 24-hour power demand could be created.

Using this method of operation, a utility district with summer peaking loads may be able to serve a larger number of irrigators without expanding generating and/or transmission facilities. It is quite important, however, that growers participating in such a program use some form of soil water monitoring or irrigation scheduling.

Reuse of Irrigation Runoff Water

A well designed surface irrigation systems may have runoff losses which average 25 to 30% of all water applied (4). A poorly designed or managed system will have more. For normal furrow irrigation of row crops runoff is necessary to achieve a uniform water penetration in the soil profile. Where the water source is a well, the cost of collecting the runoff water and pumping it to the head of the field for reuse is often only a fraction of the cost of pumping the same amount of water directly from the well. The exact relationship is dependent upon the pumping lift from the well and the design of the return system.

Eighty percent of all irrigated land in the United States is served by surface or gravity irrigation. The portion of this land that requires a pumped water supply is not exactly known, but probably is at least one half of the total acreage or a minimum of 20 million acres. Installation of a reuse system on all of these lands having a substantial pumping lift could reduce total power consumption from 10 to 25% or more for the systems involved.

Increasing numbers of irrigation farmers are installing reuse systems because they make economic sense and are required in some cases for environmental protection purposes. This a conservation practice which should be vigorously encouraged and which can bring immediate returns in terms of energy savings.

Improved Irrigation System Design

Automatic Surface Irrigation Systems

Significant energy savings can be realized through modernization of present irrigation systems and application of recently developed equipment and design procedures on new ones. Because sprinkler irrigation has more readily lent itself to mechanization, the main thrust in new developments in water control has been in this area. The mechanization of surface irrigation has been much slower. Most irrigators still make 12 or 24 hour "sets" or water applications because it fits their labor schedule, regardless of whether the crop and/or soil conditions dictate this length of time. The result is excess water application, a part of which goes to deep percolation and the remainder to runoff.

Various procedures have been developed to solve this problem. They include reducing row length on light textured soils, shorter application times, and the use of the "cutback" furrow stream (using a high volume initial stream to give rapid water advance down the row with subsequent reduction in flow rate). They all work but so does the farmer in order to use them. It has been cheaper and easier to substitute water for labor, the latter being expensive and in many cases unavailable. The energy shortage increases the attractiveness of newly developed alternatives to present methods.

An automatic surface irrigation system has been developed which can provide greater than 90% water application efficiency (5). Figure 4 shows a schematic of the system. Gated pipe delivers water to the furrows. A reuse system is used to return runoff water to the head of the field and automatic valves are used to shift from set to set at whatever time interval is dictated by the soil conditions and system design. This may be as short a period as three or four hours! Rapid water advance assures a uniform application. The newly developed pneumatic valves are the key to the system. Energy savings of 50% or more may be realized in comparison to traditional approaches. The cost per acre, including land leveling, is comparable to that for the center-pivot irrigation machines, yet power consumption is much lower since only a low hydraulic head is required on a gated pipe as compared to the 60 to 90 PSI needed for standard sprinkler equipment.

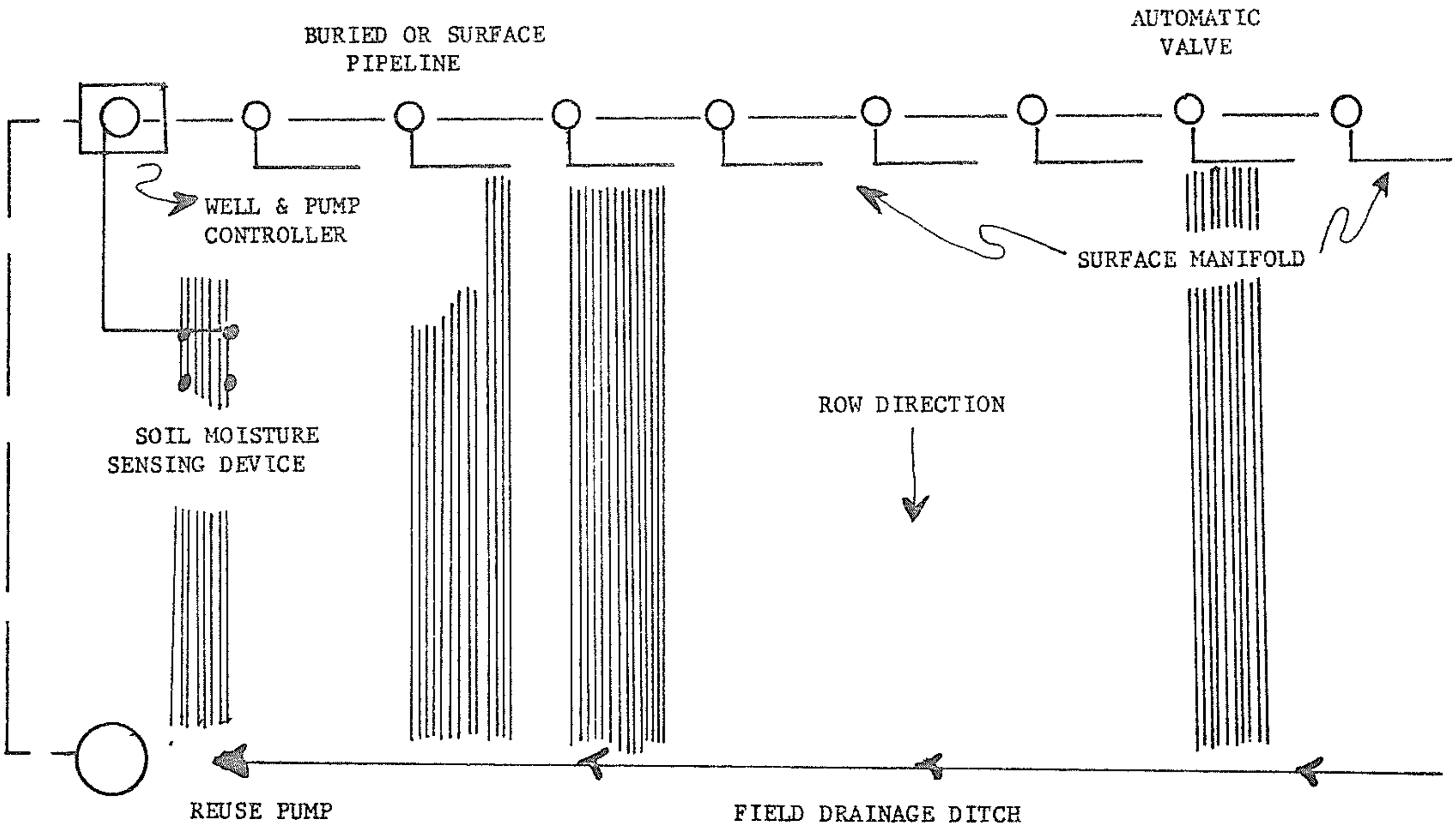

Figure 4. Schematic of automatic surface irrigation system.

Conclusions

Technology is available for obtaining a considerable reduction in the present rate of energy consumption for providing irrigation water. There is no single solution with universal application. The approach must be to fit various solutions to the soil, climatic and economic conditions of each region. The present problem is one of convincing the irrigator that the new methods will work in his situation. A serious roadblock to lowering energy use is a shortage of financial and manpower input to extension and demonstration programs in irrigation management. The high cost of available fuel and/or a shortage of it is going to force many water users to search for viable alternatives to present irrigation practices. The challenge is to clearly and convincingly present alternatives that will allow a reduction in energy consumption while maintaining a high level of production.

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CONSTRAINTS IN WATER MANAGEMENT ON AGRICULTURAL LANDS

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and Gaylord V. Skogerboe*

Introduction

Irrigation is one of the most important agricultural practices developed by man, with irrigation being practiced in some form since the earliest recorded history of agriculture. The economic base for many ancient civilizations was provided by irrigation. Indians of the western hemisphere were irrigating crops long before the discovery of the New World. Much of the economy of the western United States depends on irrigation, which has been the dominant factor in the development of land and water resources in the arid and semi-arid regions of the western states. Irrigation is practiced on about 10 percent of the total cropped land in the United States, but this land produces approximately 25 percent of the Nation's total crop value. Irrigation farming not only increases productivity, but it also provides flexibility which allows shifting from the relatively few dryland crops to many other crops which may be in greater demand. Irrigation contributes to strengthening other facets of a region's economy in that it creates employment opportunities in the processing and marketing of agricultural products.

Irrigation return flow constitutes a large portion of the flow in many streams of the western United States. Some degree of water quality degradation due to irrigation has been accepted as the price for irrigation development. However, as pressures on water resources increase, there is a mounting concern for proper control of such serious water quality deterioration.

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The water quality problems associated with irrigation return flows are of special concern because irrigation agriculture is the largest consumer of our Nation's water resources. As societies become much more complex and diversified and demands continuously increase and expand in scope and intensity, the use of scarce water resources and the preservation of the natural environment become much more important concerns in the planning and evaluation of development efforts. In any water resource development, three major problematic situations give rise to a continuous re-examination of the parameters of any water use system: 1) Continuously changing economic and social conditions, such as increasing population demands for more food, urbanization, and industrialization; 2) The strong presence of institutional constraints, the result of long historical and cultural practices, embodied in laws and judicial doctrines and in traditions reflecting the norms and practices of a given society and community; and 3) Increasing concern with adverse environmental impacts and consequences, which stems either from an already ecologically fragile environment (natural sources of pollution), or from man-made perturbation, such as the misuse of the land and the various forms of the despoliation of the water supply. Irrigated agriculture has to be viewed as an integral part of these larger socio-economic trends and of increasing awareness of new equations between technological intervention and ultimate ecological balance.

An irrigation system is a combination of physical facilities and the institutions by which the acquisition, distribution, use, and reclamation of water contribute to increased agricultural production in a given enterprise setting. Whether the goal is minimizing water quality degradation in receiving streams or maximizing agricultural production on existing croplands, the solutions are identical--improved water management practices. In order to achieve either of these two goals, then, the initial problem becomes the identification of constraints in improving water management.

Technological Solutions

An irrigation system can be subdivided into three major sub-systems: a) the water delivery system; b) the farm; and c) the water removal system. The water delivery system can be further subdivided into components; namely, a) the transport of water and pollutants from the headwaters of the watershed to the cross-section along the river where water is diverted to irrigation croplands, and b) the transport of water and pollutants from the river diversion works to the individual farm. The farm sub-system begins at the point where water is delivered to the farm, which is usually the point of highest elevation on the farm, and continues to the point where surface water is removed from the farm, which is usually the lowest elevation ground surface and terminating at the bottom of the root zone. The water removal sub-system consists of a) the surface runoff from the tail end of the farm, and b) water moving below the root zone.

There are a number of potential solutions for improving water management, thereby controlling the quantity and quality of irrigation return flow and increasing agricultural productivity. Using efficient practices in the delivery canals and pipelines, as well as improving on-the-farm water management, will minimize the problem in the water removal system. In most cases, the key element is to improve water management practices on the croplands.

The water delivery system can be improved by lining canals and laterals, using closed conduits for water transportation, providing adequate control structures, and installing flow measuring devices.

Improved practices that can be used on the farm include judicious use and application, or placement, of fertilizers, use of slow-release fertilizers, controlling water deliveries across the farm, use of improved irrigation application methods (e.g., subsurface application or trickle irrigation), control of soil evaporation, use of a pumpback system to allow recycling of surface return flows, erosion control practices (e.g., contour farming), and irrigation scheduling to insure that the proper amounts of water are applied at the times required by the plants.

In the water removal sub-system, open drains and tile drainage can be used to collect return flows, which can then be subjected to treatment on a large area or basin-wide basis, if necessary.

Water Law

For nearly a century, agricultural development has taken place in the western United States subject to the provisions of water allocation and distribution proclaimed by the state water codes under the appropriation doctrine. Individuals have governed their activities in accordance with their right to use appropriated water and have made investments according to the stability and quality of their right. In turn, irrigation systems resulted in social communities being established where its members were the direct recipients of the economic base made possible through the describable tures to the point where politicans find it politically desirable to attack the continued horrendous diversions of this scarce resource to a sector of society already subsidized in every way except outright dollar grants. Few have really analyzed the beneficial primary and secondary impacts of agriculture upon the total economy and the stability it has given to local and regional societies. True, the water right has allowed agriculture to continue in operation with little modification in management practices since the mid-1800's. Under the preference system of the appropriation doctrine, agriculture was even given a superior position to such uses as industry, recreation, etc. In a way, the water right has been a security blanket for the farmer; he has not had to compete on the open market for water because he acquired an early right to available supplies which were guaranteed him so long as he exercises his right.

The contemporary push is to compel the maximum use of water to gain the highest economic and social return. Technology has advanced far beyond present agricultural practices to develop new and better water management methods that have not been adopted due to legal, economic, and social constraints.

Therefore, in light of the water problem status and the role of water rights, two opposing principles must be given recognition in the pursuit of changes to implement technology. The first is to protect the current water right holders and recognize their interest in the vested appropriation. Second, changes must be adopted to encourage maximum use of available waters through incentives where possible, strict enforcement of the law where necessary, but, more importantly, through the personal initiative of water users and a recognition of their social responsibility.

Water Right Changes

Recommendations to resolve the water quantity and quality problems of river basins must, in reality, examine the river system as one hydrologic unit regardless of state boundaries. In so doing, the modifications and reinterpretations of the law must be designed to accomodate the overall goal of efficiency and effectiveness in water management. This will require coordination and cooperation by state and federal agencies presently working with water resources management.

Focusing upon the agicultural uses of water, yet cognizant of the multitude of other uses in river systems, the first step is to structure the water right around three sublevels of the irrigation flow system to integrate quantity and quality constraints in formulation of changes in the exercise of the appropriation. The three sublevels are 1) the water delivery system, 2) the farm and 3) the water removal system. In this manner, the various individuals and organizations holding water rights or transporting waters can effectively be included in any water management scheme.

The concept that is at the heart of the appropriation doctrine and which could make the most substantial impact in solving the legal and institutional constraints is the concept of beneficial use. This is a very nebulous concept which defines the measure and the limit of a water right. In general, beneficial use pertains to nothing more than the reasonableness of the diversion according to the use to which the water is to be applied. At the present, what is a beneficial use for acquiring a water right may depend on whether that particular use is one recognized by the state constitution or statutes. The concept must be conceived and directed not only to types of uses but to the nature of the use on the farm with respect to the user's needs. More importantly, this concept must be viewed with respect to the user's responsibility to other downstream users and the public interest.

A major change in the nature of a water right that would serve to protect the interests of the right holder and later water users would be to add the element of water quality. In so doing, the right holder would have the same assurance and likewise liability in the use of diverted water within the priority system for quality purposes as he now has for quantity flows. This change would be instrumental in encouraging practices to treat or dispose of highly polluted waste waters and encourage the proper application of water on the farm.

Significant to five appropriation doctrine states is the appurtenancy concept which ties water to land. This concept breeds inefficiency by promoting irrigation of certain lands that are not as productive as other available lands belonging to the right holder or other land owners wishing to purchase water rights. Elimination of this concept would allow the landowner to make a proper selection of land that would yield the highest agricultural returns to his operation.

A final doctrinal impediment in the exercise of water rights is the transfer restriction of rights within an irrigation system to other uses, or outside of the basin. This constraint may exist in the substantive water law or as a result of the organizational and administrative system of the state. There are few states that prevent the sale and transfer of water rights from within or without the present uses. States restricting transfers rely upon the appurtenancy concept to prevent such shifts. However, the law should be modified or changed to reflect state encouragement in the renting, leasing, transferring or selling of water rights to other uses and places so long as the vested rights of others are protected. Changes in the administrative and judicial system should be made to facilitate exchanges of water rights. Recognition of such a right and a change in the concept of beneficial use to include recreation, aesthetics, fish and wildlife and other beneficial uses would serve to nullify the fear of losing that portion of the water right not exercised by permitting the transfer of the unneeded portions to other uses within the system.

Removing these rigidities in the law to give the right holder greater freedom and flexibility will eliminate many of the irrigation problems perpetuated by the appropriation doctrine. Agricultural users are subject to constraints that other users are not, which is frequently passed over when comparing the use of water for agriculture to other uses.

Socio-Economic Issues

Improving irrigation management implies not only technological innovations and better interpretation of water law, but also other organizational improvements. Such organizational improvements include, for example, better irrigation scheduling which is very closely associated with the present negative aspects of western water laws. When we combine better information regarding soil moisture management in the root zone of the crops and more sensitive equations concerning application efficiency criteria, the farmer may still wish to use his full water right. It is assumed, at this point, that various positive incentives and resulting changing attitudes will allow a saving of water, and transfer of saved water to other uses of a comprehensive water resource development plan of a river basin.

A major problem in the overall management efforts is the lack of single management units in most of the irrigated valleys of the West, which are characterized by the existence of quite a number of fragmented irrigation companies and districts, with each company responsible for water delivery to only a part of the valley. In addition, separate institutions may be created to handle the water drainage system. In order to develop not only effective irrigation return flow quality control programs, but also to improve the overall efficiency of a water system in a given irrigated valley, it is imperative that the entire irrigation system should be coordinated on an integrated basis. The need is to move from private, single company oriented management units to what may be described as primarily valley-wide alternative. This brings forward a very difficult, but challenging water management problem, that is, an attempt towards consolidating separate small irrigation companies into single entities which would have advantages of size, economies of scale, and potential for comprehensive valley-wide development. Water quality degradation will be reduced if attempts are made to face the problem not only as an integrated approach of various units within a valley, but also as a much larger effort to integrate the particular valley with other surrounding systems. (This same goal could be applied to urban systems, where the consolidation of water supply and wastewater would greatly facilitate urban water management.)

Many other suggestions have been offered concerning the solution to problems of irrigation water management. Essentially, most of them can be summarized around a cluster of individual and community attitudes which seem to have consequences for the quality of a given water system supply. There exists a host of social practices, as well as traditional ways of irrigating and using the water, which directly degrade the quality of a given water supply system. The immediate solution and the attack against such practices can be easily perceived as a simple problem of social control. Perhaps, one of the immediate attacks to this problem would be to require that anyone degrading the quality of water pay the cost of treating this water. However, this approach treats the problem of water quality degradation from a symptoms points of view, rathering than addressing itself to the essential cause. It is not only difficult to assess penalties, but also to provide a very complex and expanded system of policing and mechanisms of law enforcement. The attack to the problem would be an attempt to reach the roots or the causes of the water quality degradation; that is, the kinds of social practices and the types of attitudes which would improve water use before degradation of water takes place. From the social point of view, in changing practices, and provided that there are also technological solutions to both natural and man-made pollution of water, the following major areas should be of major concern:

1. Priority of use (and the interpretation of legal doctrine);
2. Geographic area (and the increasing scope of planning);
3. Population affected;
4. Political units involved; and
5. Disciplinary scope (and the attempt towards a multidisciplinary systhesis).

To bring about changes in the organizational behavior of all types of units involved in water management, as well as effective response from individual irrigators, three major categories of policy decisions and social action must be made: first, strong incentives for efficient or new uses (economic benefits, redefinition of the doctrine of beneficial use, etc.); second, structural changes (such as new organizational arrangements, creation of inter- and intro-state agencies, appelate bodies, water brokerage--either private or public, etc.); and third, "regulatory counterincentives" (such as stricter enforcement, pricing policies, etc.). More than anything else, however, all the above changes or attempts for modification must be guided by a pervasive spirit of social consciousness and a new outlook of individuals and collectivities away from their small closed system of their particular community, to the larger and much more complex regional scene.

To be able to give answers to the above major areas of concern, we need to develop an assessment methodology which would enable us to identify in a systematic way potential causes and corresponding effects, a description of their characteristics, and possible consequences in the overall water system.

In trying to achieve effective water management, it should be kept in mind that alternatives offered should be evaluated under three different conditions of "effectiveness." Traditionally, the most widely used term has been that of *efficiency* which attempted to relate in simple economic benefit-cost analysis the relationship between resources (input) and proposed goals or attempted targets (output). An efficient system has been an easy one, that with minimal cost, and that cost has always been understood in terms of dollar values.

The term *effectiveness* has been used mostly in terms of organizational performance or the meeting of purely organizational goals, that is, the relationship between a given organization (thruput) and perceived goals (output). It has been also used in the context of the overall measure of achievement for a system, derived from its sub-system's performance or related to its interactions with other systems.

And last, but not least, the term *efficacy* is used, which attempts today to incorporate the meeting of social goals and a much more comprehensive relationship between input, thruput, and output. Efficacy, in other words, attempts to move beyond purely economic considerations, or criteria of organizational effectiveness, and tries to answer the question of how a particular system can efficiently, effectively, and guided by principles of social awareness, meet goals of a given society. The term of efficacy brings forward an increasing awareness of a whole number of intangible benefits to be accrued from a given water system that cannot be directly measured by existing economic or other quantitative criteria. Qualitative criteria and the consideration of social goals transcending purely utilitarian criteria provide us with the very difficult task of trying to strike a balance of fulfilling water use goals in expedient, technologically and economically feasible ways, to larger questions of social policies and attempts of environmental balance. This implies that any water management system, as well as any attempt for comprehensive water use development, would be also dependent on subjective models which are much more difficult to construct, yet they contain long-range policies for a social use of natural resources.

These kinds of considerations probably provide the answer to questions regarding the advisability of continuous water use development in the arid West under the adverse or fragile ecological conditions of the territory. It would have been easier to have water systems responding only to technological imperatives. However, the valleys of the West and the irrigation systems are not abstract simulation models responding to the whims of any experimentor. They include individuals and communities that have developed a pattern of life and whose welfare and future may even depend on inefficient water systems. Even a marginal or not particularly efficient agriculture fulfills the purpose of being a supportive social system for a number of individuals and part of the ongoing life of a number of Americans. It is not easy to dictate a social policy that would be based solely on criteria of efficiency and effectiveness without considering at the same time the so-called "human factor." And in many respects the human factor involves questions of inefficiency (and ineffectiveness) because the social costs of dislocation and disruption may be so high--when examined under criteria of efficacy--that they may dictate a policy of continuing present practices with little technological intervention.

The above discussion, however, does not mean that there is very little to be done with the irrigated valleys of the West or with any presently declared inefficient or ineffective water management system. It only points out that the problem of water quality management control is a complex one that requires considerations beyond accepted technical, economic, or even political constraints. Our effort for improving water quality management implies, therefore, a manyfold attack and a series of efforts aimed at improving project irrigation efficiency and effectiveness, under the larger rubric of efficacy and the achievement of larger social goals.

Conclusions

Whether the goal is minimizing water quality degradation in receiving streams or maximizing agricultural production on existing croplands, the solutions are identical--improved water management practices. Technology has succeeded in developing feasible solutions to improving irrigation water management, but the law has been slow to encourage or direct implementation. The villain of the western United States water problem is the property right concept of the appropriation doctrine. The most substantial impact in solving the legal and other institutional constraints inherent in the appropriation doctrine would be more stringent application of the beneficial use concept. In addition, water quality should be made a part of each water right. Also, the appurtenancy concept, which ties water to land, should be eliminated. Finally, water laws should be modified to encourage the renting, leasing, transferring or selling of water rights to other uses and places so long as the vested rights of others are protected. Improving water management also implies organizational improvements, such as the consolidation of fragmented irrigation and drainage districts into valley-wide single management units. All attempts for modifying water use must be guided by a pervasive spirit of social consciousness.

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ON THE NECESSARY AND SUFFICIENT CONDITIONS FOR A LONG-TERM IRRIGATED AGRICULTURE*

Charles V. Moore*

The objectives of this paper are: (1) to describe the physical factors involved in the plant-soil-water relationship, including the constituents of water quality and drainage in an irrigated agriculture, and (2) to discuss the economic interrelations of private and community investment in irrigation and drainage over time, for a sustained hydraulic agriculture.

Societies based on an irrigated agriculture have appeared and disappeared through several millenia of man's history. Analogous counterparts of the process continue in modern times. If manifestations of such failures are not to continue to repeat themselves, resource economists must evaluate the necessary and sufficient conditions for survival of an irrigated agriculture.

Water Quality and Irrigation

For years, water resource economists have been infected with the "water is water" syndrome, ignoring until recently the quality dimensions of this resource. The water that falls on the surface of the earth as rain is, for all practical purposes, pure H_2O. As it travels over and through the earth's crust, water picks up and carries in solution a portion of the minerals with which it comes in contact.

Pure rain water may degenerate in quality, while retaining nearly its same volume, as it passes through several nonconsumptive uses, or as it passes toward the sea or underground basin. Characterization of water quality may differ considerably, depending on the particular use intended. This paper is concerned primarily with irrigation; therefore, the quality of water as related to municipal and industrial uses will be excluded from the discussion.

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Demise of the early culture which, by all accounts, flourished for several centuries along the Tigris and Euphrates Rivers before the birth of Christ, has been attributed to a combination of three factors [Marr, 1967]. Salinization of the soil over time was certainly important. Another factor apparently was the gradual buildup of silt on the fields themselves. This raised the lands to a higher elevation than that of the canals, eliminating the head of water available to the irrigator. Finally, due to recurrent invasions and wars, there appears to have been a breakdown of the administrative structure required to organize the thousands of workers needed annually to repair and clean the silt and vegetative growth from the main canals and laterals.

Salinization of the soils in this area was not something that occurred over night, or even in one century. Although the records are not precise, it took an estimated 3,000 years from the time of the initial small stream diversions until the entire area was returned to its present state of salt flats and desert. The first recorded indication of the buildup of soil salts is inferred from the increased proportion of the land planted to highly salt-tolerant barley rather than to the less tolerant wheat crop. Gradual decline of yields of these crops over time supports this view. As more and more acreage went out of production and yields declined, so did the population and political power of the area [Marr, 1967].

This was not an isolated occurrence in world history. There is some evidence that similar, pre-Columbian disasters occurred in what is now the southwestern United States, as well as in the Middle East. In fact, an economy or culture based on irrigated agriculture which has survived over a few hundred years is really an exception, rather than the rule. Have contemporary project planners heeded these warnings as well as they might, so that modern technology can be brought to bear in solving the problems? Or, is our civilization to have the same unhappy destiny?

Salinization or salts in soils is without question the most prevalent problem in irrigated arid regions of the world. Under more humid conditions, soluble salts are generally carried through the soil and transported by streams to the ocean. Sometimes they accumulate naturally in inland areas. When this happens, the land may become unfit for commercial agriculture, such as the salt flats and playas of the Intermountain area in North America.

Productive soils may be salinized at different rates, depending on the amount of dissolved salts imported with the irrigation water. When water is applied to a crop, most of the moisture leaves the soil through evapotranspiration; but, the salts remain in the soil. If a portion of the irrigation water percolates past the plant's root zone toward the water table, soluble salts will be carried out of the zone. But if the water leaching beyond the root zone does not contain as much of the dissolved salts as entered with the irrigation water, the net result is salt accumulation within the soil, creating what is often referred to as an unfavorable salt balance.

The deleterious impact of salinization upon quality of a soil or an irrigation water depends on variables other than salt per se. Bernstein [1967], in his paper, "Quantitative Assessment of Irrigation Water Quality," considers three factors or conditions affecting water quality determinations--salt tolerance of crops, soil permeability, and drainage. Salt tolerance of crop plant species, i.e., their response to varying degrees of soil salinity, has been studied extensively at the U. S. Salinity Laboratory at Riverside, California. This work, using the electroconductivity (EC) of the soil saturation extract[1] as a measure of salinization, has been summarized by Bernstein [1967]. Figure 1 indicates that salt tolerance of selected crops to soil salinity values between EC[2] of 0 to 21. Barley and Bermuda grass are highly salt tolerant. Little or no yield reduction will occur until EC values of about 10 prevail; then a rapid yield reduction can be expected.[3] Bernstein [1967] states, "Since there is approximately a tenfold range in salt tolerance, one might expect, roughly, a comparable range in permissible salt contents of irrigation waters." However, the degree of soil water salinity is dependent on the proportion of the irrigation water evapotranspired relative to the fraction of the water which is leached past the root zone.

Soil permeability and water infiltration rates are factors in soil salinity in that they influence the irrigator's ability to manage the amounts of water needed to meet both the evapotranspirational losses and the water required to carry the excess salts past the root zone. The permeability of some soils may be so low that water stands in the field for several days after irrigation. In this event, damage to the crop will often occur from poor aeration and scalding.

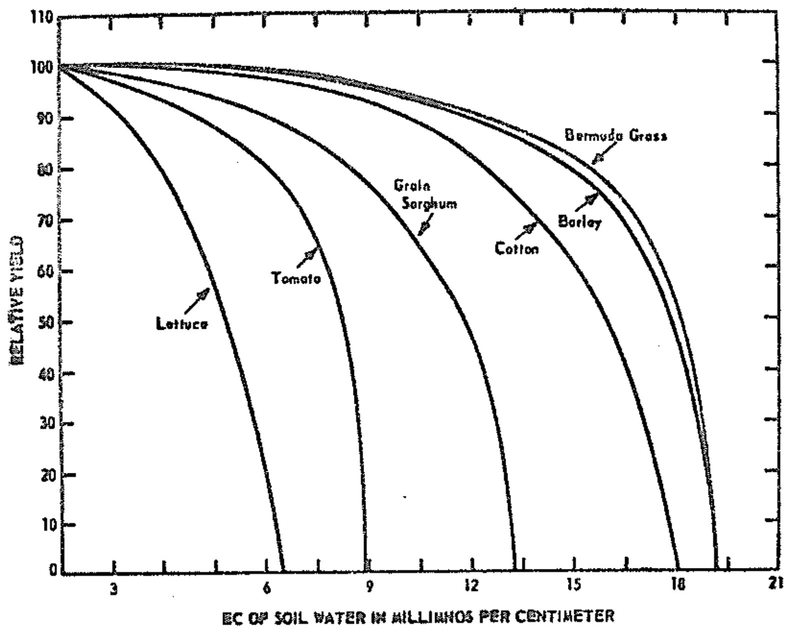

Figure 1. Salt tolerance of selected crops from Bernstein [1964].

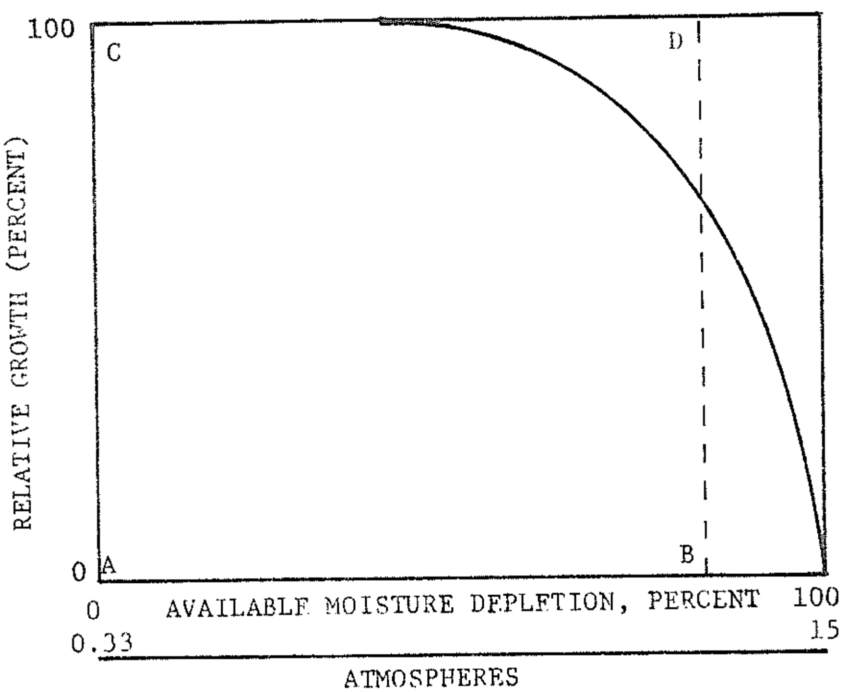

Figure 2. Plant growth in relation to available soil moisture.

For an irrigation system to be successful, provision must be made for percolation of some water below the root zone to leach away the yield-depressing salts. Adequate drainage must also be available to prevent a rise in the water table, and thus forestall an upward movement of salts by capillary action. If subsurface drainage is not available naturally, it must be supplied by artificial means, such as buried drain tiles.

Using Bernstein's [1967] definition of the leaching fraction as:

$$LF = \frac{D_d}{D_i}, \tag{1}$$

or the ratio of the depth of drainage water D_d to the total amount of irrigation water percolated into the soil D_i, then $D_d = D_i - D_e$, where D_e equals the amount evapotranspired. In other terms, if $D_i = I_t$ and $D_e = E_t$, where I and E are the average infiltration rates and evapotranspiration rates, respectively, over time t, then

$$LF = 1 - \frac{Et_c}{It_i} \tag{2}$$

where drainage is not limiting and t_c and t_i are duration of the irrigation cycle and irrigation application, respectively.

If the drainage rate is limiting, then the difference in value between infiltration and evapotranspiration cannot exceed drainage without causing waterlogging. If O is the average drainage rate per day without a rising water table, the $LF = O/E + O$. Therefore, there is an upper limit to the leaching fraction which limits the salt content of usable irrigation water. This is best shown by an example:

if E = 0.3 inch per day

and O = 0.1 inch per day,

$$\text{then } LF = \frac{0.1}{0.3 + 0.1} = 0.25 \tag{3}$$

Once the upper limit of LF is calculated, the suitability of an irrigation water can be determined by the ratio of its conductivity to that of the drainage water:

$$LF = \frac{EC_i}{EC_d} \text{ or } EC_i = LF \times EC_d \tag{4}$$

where EC_d is the maximum permissible electroconductivity of drainage water. If the maximum permissible electroconductivity of the soil water is 3 millimhos (this level reduces lettuce production by 25 percent, see

Figure 1), the EC of the irrigation water cannot exceed EC = 0.25 x 3.0 = 0.75.

However, if field tile drainage increases the average rate to O = 0.15 inch per day, then an irrigation water of EC = 1.0 can be used successfully without loss of yield.

Effect of Soil Moisture Stress on Plant Growth

Although very little direct quantitative information is available on plant growth as influenced by soil salinity and soil moisture in combination, some tentative suppositions must be made if a wide range of irrigation water qualities are to be analyzed.

Most plant scientists agree, in general, that plant growth within an irrigation cycle is a function of total soil moisture stress in the active root zone. Moore [1961], drawing on the work of Hagan [1955] and others, used the inverted soil-moisture-release curve to describe the relative rate of growth between field capacity and the permanent wilting point (see Figure 2). If it can be assumed that each irrigation cycle is independent of all others (no hysteresis), the production response may be described as a series of irrigation regimes. Weights may be attached to individual irrigation cycles to take into a ccount the effect of soil moisture stress during critical periods of plant growth (tillering, boot state, and flowering).

If the crop is reirrigated at a moisture depletion percent of 80, then the area under the curve between 0 and 80, as a fraction of the rectangle ABCD in Figure 2, will give the index of relative growth for one irrigation cycle. This can be represented mathematically as:

$$I\theta_i = \frac{\int_0^{\theta_i} g(x)\,dx}{\theta_i \times 100} \qquad (5)$$

where I is the fraction of potential growth for one irrigation cycle, and θ_i, is the moisture depletion percent at which the irrigation cycle is terminated with a new irrigation application.

A Model Combining Quality and Quantity of Water

Growth retardation from the part of moisture stress due to salinity alone is related primarily and directly to the osmotic pressure of the soil solution. Because the electrical conductivities of soil solutions are highly correlated with their osmotic pressures, the simple conductivity measurements can be used. The relationship between osmotic pressure in atmospheres and electrical conductivity is given approximately by:

$$OP = 0.36(EC_e \times 10^3) \text{ [Reeves and Fireman, 1967]} \tag{6}$$

Assuming that moisture stress (whether it results from a physical reduction in soil moisture or from the osmotic pressure of dissolved salts) is additive with respect to reducing growth rates and yields, then it is possible to construct a theoretical response surface for quality and quantity of water.[6]

Figure 3 is an idealized representation of the production response surface, depicting for three salt tolerance groups the effect of different irrigation regimes and water qualities for one soil type. At the left-hand edge of the surface (zero EC) is a curve similar to the moisture-release curve shown in Figure 2. Relative growth curves for varying soil conductivities appear as traces for the medium tolerance group, beginning on the horizontal axis and extending upward and over the response surface. For detailed research purposes, the specific response curve for any crop in question should be used. This grouping for a medium tolerance group is used to illustrate a first approximation. The traces parallel to the base in Figure 3 represent isoquants, i.e., lines of equal production. The slope of these isoquants indicates the marginal rate of substitution between water quality and water quantity.

Assuming that the effects of moisture stress and of electroconductivity of the saturated soil after irrigation are additive, combining:

$$G_j = f(x) \tag{7}$$

where G_j is the crop response to soil moisture depletion, with

$$G_k = g(s) \tag{8}$$

where G_k is the crop response to the salt content of the soil, to obtain

$$G_{jk} = F(xs) \tag{9}$$

the net response for one irrigation cycle can be represented as the double integral

$$G_{ri} = \int_0^{\theta_i}\int_0^{e_s}\theta_{jk}dx\ ds \tag{10}$$

where θ_i is the soil moisture at the time the crop is reirrigated, and e_s is the conductivity of the soil water in the root zone at the end of the irrigation cycle.

The index of growth within an irrigation cycle would be the definite integral of equation (1) over the volume of the cubic defined as (θ_i) (e_s) (100) or

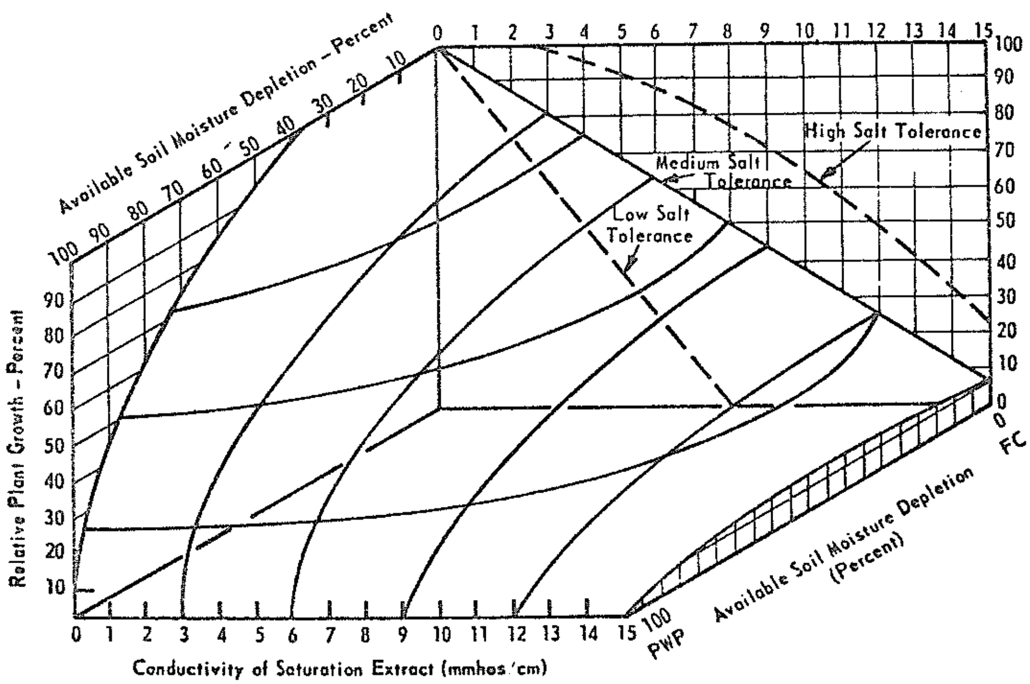

Figure 3. Hypothetical crop response surface.

$$I_{\theta_i e_s} = \frac{\int_0^{\theta_i} \int_0^{e_s} \theta_{jk} \, dx \, ds}{(\theta)(e_s)(100)} \qquad (11)$$

To obtain the total growth for the entire season, G_{ri} is summed for each irrigation cycle, i. For a particular crop, G_{ri} can be weighted to reflect the effects of critical periods in the development of the plant, such as germination, flowering, seed development.

A major problem in this synthesized approach is that the variables are not stated in terms of quantities of water applies, but rather in terms of soil-moisture tension, electroconductivities, and relative yields. The situation is further complicated by the fact that the leaching efficiency of a small water application may be greater in terms of units of salts removed from the root zone per unit of water applied, than that of a deep water application. However, for purposes of simplifying the presentation, we will assume there is a related surface, stated in terms of actual quantities of water applied, associated with the surface shown in Figure 3.

This second surface would necessarily take into account the water lost due to surface evaporation, the water required to achieve uniform wetting throughout a field, and the leaching efficiency of different depths of water application with respect to salt removal.

Summary of the Physical Factors Affecting Water Quality Considerations

Thus far only the physical factors associated with crop response to the qualitative and quantitative dimensions of irrigation water have been considered. An attempt has been made to show that there are physical limitations to the use of certain irrigation waters in certain locations. That is, due to the physical conditions of climate, soil permeability, drainage (natural or artificial), the salt tolerance of the crops adaptable to a specific location, irrigation water of a given quality may or may not be usable. These limitations are not absolute, and there is a degree of substitutability among them. For example, artificial tile drainage can be substituted for natural drainage, or the quantity of water can be substituted for quality of water using a higher leaching fraction. Also, crops with a higher salt tolerance can be used to replace sensitive crops as the quality of water deteriorates. In the concept of a long-run, steady state, these physical factors can be used to describe the limitations to the possibility of a long-term, irrigated agriculture. In the parlance of logic, the physical factors can be termed the necessary but not sufficient conditions for a long-term agriculture.

Other Constituents of Water Quality

Major attention has been given to salt concentration as a measure of irrigation water usability. However, other constituents are also important and, in certain localities, may be of overriding importance. An example is sodium, which can cause an alkali buildup under certain situations. Crops, especially those of woody plants, can accumulate harmful levels of sodium in the leaves when the exchangeable sodium percentage (ESP) of the soil is as low as 5 percent [Bernstein, 1967]. Sodium also affects soil properties by causing dispersion of the soil particles, with a resultant drastic reduction in the infiltration rate. Sodic soils are usually treated by adding gypsum or other acid-forming amendments. Little is known about the effect of boron and other trace elements which may be present in local irrigation waters in sufficient quantity to create toxic conditions for plants. As little as one ppm boron can be toxic to some plants.

Economic Considerations of Irrigation Water Quality

Assume a production function based on the above description of physical variables as follows:

$$y = f(W_1\ W_2,\ R, D, L, K) \qquad (12)$$

where output y is some function of f, of W_1, defined here as the quantity of "pure" water, W_2 is the electroconductivity of W_1, R is average rainfall, D is the drainage variable, and L and K are labor and capital, respectively.

A'priori, a high inverse intercorrelation between W_2 (water quality) and drainage could be expected. As the EC of the irrigation water increases, drainage would necessarily also increase, although in the short run, D could approach zero. Perhaps this last statement should be elaborated. If an individual farm or field on a farm is being considered, irrigated crops could be grown for a short period of time with no drainage. However, with low-quality water, this time could be surprisingly short. For example, the depth of irrigation water applied, (D_i), of known EC_i that will contain sufficient salt to increase the EC of the soil in one foot of the root zone (D_s) by an amount (ΔEC_i), is calculated by the equation:

$$D_i/D_s = \frac{d_s}{d_w}\ (SP/100)\ (\Delta EC_e/EC_i) \quad [USDA, 1954] \qquad (13)$$

where d_s/d_w is the ratio of the densities of the soil and water, and SP is the saturation percentage. Letting $EC_i \times 10^6 = 1{,}000$, $d_s = 1.2$ gm cm^{-3}, $d_w = 1$ gm cm^{-3}, SP = 40, and $\Delta EC_e \times 10^6 = 4{,}000$, then $D_i/D_s = 1.9$. This means that less than two feet per acre of reasonably good quality water contain sufficient salt to change a one-foot depth of salt-free soil to a saline condition in one year, if there is no leaching.

If the production function is developed for an irrigation project or district service area, investment in a district-wide drainage system must be included in the drainage variable. Subsurface drainage water from higher elevations may accumulate in low-lying areas on farms at lower elevations, or as perched water tables down slope. It may be impossible to remove the drainage water from a farm without a district-wide system of interceptor drains or collecting drains. Corrective measures require community action. The interdependency with respect to drainage in the Imperial Valley of California for example, involves two levels of hierarchy--the private farmer and the community of farmers represented by the irrigation district. Just as in the of joint action being required to obtain a supply of water, the economic feasibility of on-farm drainage requires collective action to remove the effluent from the district.

Drainage of a large geographic area, such as the Central Valley of California, the Indus Plains of Pakistan, or the Gangetic Plan in India, may require group action of an aggregate of communities. A good example of communal participation is the Master Drain for the San Joaquin Valley. This points to a problem of sequential decisions at different levels of hierarchy, both private and public, before a necessary physical condition can be met. A study of the optimal timing for these decisions would be an interesting investigation, because of the interdependency and the external diseconomies involved, but such is not a part of this paper. Where an aggregate of communities must act jointly to solve a drainage problem due to irrigation return flows re-entering the source of supply and reducing its quality dimension, account must be taken of the external diseconomies inflicted on the downstream users. A system of trade-offs based on welfare criteria must be established in order to minimize the total cost for the entire river basin [Kneese, 1964, Chap.3].

Rainfall is included as a variable because it may be sufficient to supply the leaching requirement. If rainfall is sufficient during the winter months to reduce the salt content of the root zone to zero each year, irrigation water of a much lower quality could be used during the summer than would otherwise be possible. However, in an area such as the Imperial Valley of California, where the rainfall averages less than two inches a year, leaching must be accomplished using low-quality Colorado River water.

Rainfall during the crop growing season can contribute to the leaching requirement, and to evapotranspiration as well. Such rainfall, although it complicates the analysis, does not preclude a solution to the analytical problem. Also, when water from two or more sources, with differing water qualities are used, account must be taken of the timing and quality of each source. A simple average conductivity for the entire season may give erroneous results.

Water Quality and Conservation

In the terminology of resource conservation, irrigated agriculture becomes a flow resource with a critical zone [Wantrup, 1952]. This is not a simple flow resource situation which provides a good or service in many time periods, but a bundle of highly interrelated, complementary flow resources. Irrigation water is a flow resource, a certain amount of which becomes available each year. The soil root zone also can be considered as giving off a flow of services, in that each year the soil can be used as a reservoir for holding moisture and nutrients, and as an adhesive force which keeps a plant in place.

To conserve this bundle of resources above its critical zone, the use rate of the resource must not be so high that in any one time period the salt content of soil moisture in the root zone passes the critical level, causing the productivity of the resource bundle to be irretrievably lost. This point would occur when reclamation of the salinized soil was no longer economical. In the ancient civilizations of Mesopotamia, the critical zone was passed; and the land reverted back to desert when the salt content of the soil extract became too great, although for several centuries this had been a highly productive area.

In the United States there was a case where an irrigation project came to the brink of the critical zone. The sole source of water for the Imperial Irrigation District of California is the flow of the Colorado River. Here, irrigated acreage increased rapidly in the first two decades of this century. Symptoms of waterlogging and salting-up began to appear in the 1920's. By the 1930's the problem was serious, and some 50,000 acres with poor natural drainage temporarily went out of production. Soil Conservation Service engineers recommended extensive field tiling and a broad network of collection ditches to remove the excess saline water from individual farms and the district service area. However, farm product prices at this time were quite low due to the economic depression, and farmers were unwilling to make the large capital investments that appeared necessary. Lands in the district continued to revert to desert. During the 1940's, agricultural income improved, and along with it willingness to invest in drainage, both privately and collectively. By 1966, almost 13,000 miles of tile drains had been installed, covering over 300,000 acres in the district. The district has also dug over 1,400 miles of open ditch to carry the effluent from the tile drains to the New and Alamo Rivers, through which it flows into the Salton Sea [Smith, 1966].

The Imperial Valley case indicates the importance of factor and product prices, as well as the necessary physical conditions. It can be asserted that if the physical factors specify the necessary conditions, then economic factors can be used to describe the sufficient conditions for a long-term irrigated agriculture. Attaching product prices and factor prices to the production function, a present-value profit equation can be written:

$$\pi_{pv} = B_i \sum_{n=1}^{n} \sum_{j=1}^{m} P_i Y_i f(X_{11}, X_{12}, \ldots, X_{nm}) - c_{ij} X_{ij} \qquad (14)$$

where π_{pv} is the present value of a future stream of income summed over inputs (X_{ij}) and time, P_i and C_i are product and factor prices, respectively, and B_i is the appropriate discount factor.

Theoretically, it would be possible to calculate a maximum π which optimized the use rates of each resource in each time period. However, the problem is not to determine an optimum, but rather to specify conditions for Survival implies establishing a critical minimum conservation use rate of the resources. Survival also would mean that the present value of the future stream will always be greater than unity. Stated in this form, survival also implies that π for each subplanning period must be positive. The length of the subplanning period can exceed one year, but cannot be so long that the critical zone resources involved can, at any one time, become "trapped" in the critical zone.[5]

The previously described "salt" problem of the Imperial Valley was not anticipated when the project was initiated. If the additional drainage investment required had been included in the original project feasibility analysis, the benefit-cost ratio would not have been so favorable. As the quality of the Colorado River continues to deteriorate, there is some question as to how long an irrigated agriculture can be maintained in the Valley. With the present technology and fixed water supply, there is an upper limit to the substitution between water quality and quantity. As this limit is approached, more salt-tolerant (lower-valued) crops must be included in the crop mix. Lower-valued crops, along with greater investment in drainage, reduce the value of the profit equation. This is, the Valley is faced with an increasing cost function and a decreasing revenue function over time.

Ignoring for a moment the impact on the profit equation created by substituting more-tolerant for less-tolerant crops in the cropping pattern, the Imperial Valley experience points out the risk involved in using long-term average prices to determine project feasibility. Long-term average prices, without consideration of the variance about the mean, ignore the possibility that product prices can assume values below those expected, for a number of years in succession. For resources without a critical zone, this does not present the hazard that could be encountered with a critical zone resource. The irreversibility of critical zone resources necessitates greater care to insure against the probability of premature project failure. For example, if the depression of the 1930's had continued for an additional 10 years, El Centro might now be called Mesopotamia West.

Thus far, the precise definition of the expression "long-term irrigated agriculture" has not been made. In fact, using an exact number of years such as 200 or 1,000, would have little meaning. A workable definition would be a planning horizon where all structures and facilities had become worn out or obsolete, in other words, when all costs with respect to planning have become variable costs. If the maximum design life of the structure included in a project is 100 years, then the planning period should be at least 101 years. The additional year beyond the design life forces consideration of, in the original project, the design of replacement structures. For example, this approach would have forced the designers of Shasta Dam to consider in their original design the "new" Shasta Dam that will be required when Shasta Reservoir has been silted-in due to the turbulence constituent of water quality. In another case, what additional facilities should be constructed in the Central Arizona Project to replace presently planned structures to minimize the impact of Colorado River water containing 1,500 ppm of dissolved salts sometime in the next century?

If the present value of a dollar 100 years in the future at a 3 percent discount rate is only $0.052 and at a 6 percent discount rate only $0.029, concern for the economic viability of future generations dwindles rapidly beyond the century planning period. Possibly the present value of future incomes and costs, 100 years from now is so small, or predicting technological change is so uncertain, they can be ignored. However, concern for the survival of a productive use of a rapidly growing world population requires a longer-run outlook.

Summary

An attempt has been made to show that the necessary conditions for a long-term irrigated agriculture can be described in terms of specified physical factors: salt tolerance of crops, soil permeability, climate, and drainage. For a given location, there is a range of substitutability among these factors. The sufficient condition, however, must be defined in terms of the economic considerations involved in long-term survival. A resource with a critical zone implies that conservation must not drop below the critical minimum level any time during the planning period if the critical zone is a true "trapping state." For the sum of the stream of benefits from a project to be at a survival level for the entire planning period, the resource must be maintained above the critical zone for each subperiod.

Footnotes

1 The salt content of a soil or water can be estimated by passing an electrical current through a sample of water or through a water extract of soil sample [USDA, 1954]. This electrical conductance is expressed in millimha/ca or EC x 10^3.

2 Unless otherwise indicated, electroconductivity in this paper will be expressed in millimhos/cm or EC x 10^3.

3 Pincock has used these data to estimate the possible effects of a deteriorating water quality in the Welton-Mohawk Irrigation Project in Arizona [Stewart and Pincock, 1967].

4 An early attempt to measure this relation was made by Wadleigh [Wadleigh, Gauch and Magstad, 1964], using guayule plants and water with various salt concentrations under three different irrigation regimes.

5 It would be possible to visualize a very large π for the first time period and zero for the remaining time periods where $\pi_{pv}/N > 0$.

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