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No single factor has had greater influence on the development of the transboundary region of Mexico and the United States than water. I am certain that the progress which has occurred has been more dependent on water than any other single resource, except perhaps the human drive and resourcefulness of the men and women who developed the region. A statement by Dr. Philip Handler, former President of the National Academy of Sciences,[1] illustrates the worldwide importance of water: "It may yet prove that it is the world's fresh water supply that will really determine the number of Homo Sapiens (mankind) in the next century." This astute observation is doubly true for the arid regions of the world such as along the transboundary region of Mexico and the United States.

People who live in the arid parts of the world are always aware that water is the very life blood of the region. They know that there may be periods of several years when the supplies are relatively adequate, but the inevitable shortages which are certain to come with natural climatic cycles will again confront them. But some forget this fact. For example, on the national scene in the United States memories of severe water shortages are short, and as a result, it is difficult to achieve a sustained water resources research and planning effort. The view in the United States seems to be changing and there is now a growing sense of national concern because the water supply deficiencies in most of the states in the nation are quite acute. There is again fear of pending droughts throughout the country. I am told that most of the 48 contiguous states have water deficiencies at this time. For the past thirty or more years, there has been congressional concern about the national water problems, and yet the issue fades in importance and then again emerges.

To illustrate, Senator Domenici of New Mexico, when introducing proposed legislation entitled "The National Water Resources Policy and Development Act of 1981,"[2] stated that there is a backlog of needed but

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1. P. Handler, *On the State of Man*. Address presented at Annual Convocation of Markle Scholars, The Homestead, VA. (Sept. 29, 1974).

2. CONG REC S1804–10 (daily ed. Mar. 5, 1981) (statement of Sen. Domenici).

unbuilt water projects. Senator Domenici lamented the fact that it takes a generation—26 years—to move a typical water resources project in the U.S. from the point of authorization to the time when construction begins, and then the construction may take another decade. He spoke of the many water problems which must be solved in the United States including the massive depletion of underground water supplies. A classic example is that occurring in the high plains of Texas and New Mexico and the rest of the Great Plains of the United States. Senator Domenici stated, "It is not an exaggeration that we may face disaster unless we take initiative in seeking new and innovative approaches."

One can scarcely exaggerate the potential importance of water as a resource issue. Water is essential to food production. It is also essential to the development of some of the energy resources of the United States. Recently, an advisory council to the U.S. Department of Agriculture sensed an immediate urgency concerning water problems and concluded that "water is potentially the most limiting resource to U.S. agriculture." While recognizing the importance of reducing U.S. federal budgets, that advisory council stressed its serious concern and said that the need for water research was so great that if only one priority area for increased research funding could be provided, that priority area should relate to research in water resources.

Those of us who have worked in water resources have always felt a sense of urgency concerning the importance of water to our future well being. We never understood why all did not recognize what was so imminently apparent to us.

Resource Limits of the Earth

As a first issue, let me comment on the resource limits of the Earth. This limit to the resources of Earth dictates an ultimate limit to the number of humans that the Earth can support. While we may not know what these limits are, we know we are closer to them today than we were yesterday. And, tomorrow we will be still closer. The relentless pressure of exponential worldwide population growth brings us to the grim reality of present and future physical shortage of resources. Fortunately, one of these resources, water, is renewable. However, water is by no means without limit and we know of no major way to accelerate the natural renewing process of the hydrologic cycle—notwithstanding some relatively minor effects of weather modification and perhaps desalination of saline water. However, pollution can destroy the supply for most uses. Also, some supplies have accumulated slowly over geologic time, as is the case already mentioned for the groundwater supplies beneath the high plains of West Texas and Eastern New Mexico. These groundwater sources are not renewable and once used, like mineral reserves, are gone forever.

In analyzing the available water supply, one must recognize that it takes great quantities of energy to make some water supplies available. In the past we failed to recognize the energy factor, and talked of obtaining quantities of potable water from the sea through desalination. We now realize what an objective analysis would have told us all along—under the best circumstances, fresh water from the sea would be extremely energy costly and, therefore, very, very expensive. Pumping from deep groundwater also requires great amounts of energy. We must realize that there is no energy source, not even fusion, that will now provide free or unlimited energy.

In the transboundary region one energy source is abundant. That is solar energy from the bright sunshine. However, we are not close to having an economically feasible solar powered water pumping system.[3] Experimental solar powered irrigation pumps are operating in two transboundary states—Arizona and New Mexico. These systems utilize tracking solar collectors which concentrate the sun's energy. However, they are expensive and estimates of life cycle cost for start-up dates of ten years hence show that costs are likely to be nearly twice as great as for conventional electrical systems.

The World Bank is looking at the possibility of using photovoltaic cells to power irrigation pumping systems. Even with projected breakthroughs in photovoltaic cell technology, the costs of pumping water with solar energy will be great. There is reason to be hopeful, even if the capital cost of solar pumping systems is great, because of the availability of free solar energy. Nonetheless, I predict that we are more than ten years away from reliable, cost effective solar pumping systems. Considering these factors, to ignore the energy supply and cost in our water planning would indeed be folly.

I believe two examples are useful in illustrating the importance of water from now to the year 2000. These examples relate to the transboundary resource needs of both nations—the theme of this conference. These are, first, "water and food," and, second, "water and energy."

Water and Food

Let me start discussion of this issue by indicating the power of exponential population growth. If the world population at the time of Christ had been only a single couple and the population doubled every 35 years, as it does now with the existing annual two percent population growth, the present population would be 107,000,000,000,000,000 (107 million

3. Lukins, *Preliminary Economic Analysis of Solar Irrigation Systems for Selected Locations*, SANDIA LABORATORIES PAPER SAS D-77-140 3 (1977), and Newkirk, *Solar Technology Applications: A Survey of Solar Powered Irrigation Systems*, LAWRENCE LIVERMORE LAB UCID-17510-Rev. 1, 45 (1978).

billion or 107 $\times$ 10^{15})—or about 25 million times the present world population. Some countries have a growth rate of 3.5 percent per year. At that 3.5 percent annual growth rate, a single couple could create the present world population in less than 650 years. These mind boggling figures are examples of exponential growth. It is no wonder that Malthus in 1798 felt that the power of population growth was so superior to the power to produce food that the world was destined to face massive starvation.[4]

Although water is a key to producing the food necessary to feed mankind, without some sort of worldwide control of population growth there can be no satisfactory answer. There is not enough fresh water on Earth to indefinitely meet the ceaseless demand of an exponentially growing population.

The importance of irrigation to our food supply is so well documented that it should be unnecessary to mention it. Nonetheless, this basic fact is often not recognized. The irrigated lands of the world exceed 200 million hectares—about 15 percent of the cropland of the world. Yet, this irrigated land produces 30 percent of the world's food. The Food and Agriculture Organization of the United Nations estimates that there were 5 million hectares of irrigated land in Mexico in 1978 and the growth in irrigated area in the past decade averaged more than 150,000 hectares of new irrigation per year. The United States in 1978 had about 16.7 million hectares of irrigation and although growing, the growth rate is less than in Mexico. Some of that expanded irrigation has likely been in the transboundary region placing further stress on the already overtaxed transboundary water supplies.

In the near future, on a worldwide basis, we do not have sufficient land resources to meet the food needs of a growing world population unless high crop yields can be achieved.[5] In the developing nations even now there is greater dependence on the new high yielding varieties of rice and wheat—the so-called "green revolution." For success, this "green revolution" requires that greater emphasis be made on the production inputs of fertilizer, pest control *and* irrigation. If the "green revolution" has seemed to slow during recent years, it is from lack of sustained attention to the essential resource inputs, rather than the exhaustion of opportunities for increased food production. For example, the potential caloric yield from photosynthesis is about 550,000 kcal per hectare per day of vegetative growth. The portion of that caloric yield which is edible by humans ranges from about 230,000 kcal per hectare per day for grain crops to about 450,000 kcal per hectare per day for root crops. The

4. Thomas R. Malthus: AN ESSAY ON THE PRINCIPLE OF POPULATION AS IT AFFECTS THE FUTURE IMPROVEMENT OF MANKIND (1798). (Facsimile reprint, 1926).
5. Poleman, *World Food: A Perspective*. 188 SCIENCE 604–10 (1975).

average world yields, and even the maximum record yields achieved, are much less than the potential.

However, the potential high yields depend on more than high yielding seeds. There must also be proper fertilization, control of insects and pests, and good water management. Ample water is absolutely essential for high yields. Either adequate natural rainfall or irrigation is necessary and in the Mexico–U.S. transboundary region, irrigation is usually required.

In the United States, there have been great increases in the food production per hectare. I am sure the same is occurring in Mexico. However, in reference to U.S. food production the National Academy of Sciences gives a warning in reporting that the spectacular productivity breakthroughs of the last several decades may not ever be repeated and reduced to practice.[6] Improvements will occur, but the progress will be more difficult as the biological limits to productivity are approached. Water is most certainly one of the keys to further productivity increases. But, the fact that there is a limit to yields should also be noted.

Water and Energy

Now I shall speak of another important issue related to water resources—that being its requirement in developing alternate energy sources.

The U.S. dream of a few years ago of energy independence has waned and we now admit that the goal was not achievable in the short time frame stated. In the past, we did not heed the signals related to energy supply depletion in the U.S. and energy costs have soared creating some serious economic problems. Twenty-five years ago a foresighted geologist named Hubbert had predicted that U.S. oil production would peak between 1966 and 1971.[7] Actually, it peaked in 1970. Use of oil in the U.S. has exceeded domestic supply since about 1960, and for natural gas since about 1967.[8] While I personally think the future importance of water in relation to food production exceeds its importance in relation to energy, the question is academic since both water and energy are necessary. Water is absolutely essential for many things and the ability to develop alternate energy sources is one of them.

Calculations have been made regarding the amount of water required to develop and transport alternate energy sources.[9] As is frequently the

6. NATIONAL ACADEMY OF SCIENCES, AGRICULTURAL PRODUCTION EFFICIENCY 199 (1975).

7. Hubbert, *Energy Resources*, RESOURCES AND MAN 157–242 (1969).

8. STAFF OF SENATE COMM. ON INTERIOR & INSULAR AFFAIRS, 93d CONG., 2d SESS., REPORT ON WATER AND ENERGY SELF-SUFFICIENCY (Dreyfus and Cooper, Serial No. 93-51 (92-87) (1974)).

9. NEBRASKA WATER RESOURCES RESEARCH INSTITUTE, *The Role of Water in The Energy Crisis*, PROCEEDINGS OF A CONFERENCE 219 (Stork, Ed. 1974); and UNIVERSITIES COUNCIL ON WATER RESOURCES, *Energy, Environment and Water Resources*, PROCEEDINGS 1974 UCOWR ANNUAL MEETING 382 (1974).

case in water resource problems, there are critical regions where the needs will be great and the supply inadequate. The Colorado River Basin is most assuredly one of the most critical of the basins. The Northern Great Plains region of the U.S. is another area which is critical in terms of the water supply for the region. In both areas about 90 percent of all existing water resources are for irrigation. The analysis of these two areas which have potential for new fossil energy development, principally from coal and oil shale, shows that over a million acre-feet annually would be needed in the Colorado Basin and nearly three-quarter million acre-feet would be needed annually from the Northern Great Plains (Montana, Wyoming, North Dakota and South Dakota). In both areas, irrigation will be the principal competitor for any so-called "uncommitted water supplies." I doubt that agriculture can compete for water on a purely economic basis and, therefore, a most serious problem for food production may exist. Essentially the same situation exists in both basins in terms of problems of competition for water between food production and energy production interests.

There will likely be similar future competition for water in the watersheds of transboundary regions of the U.S. and Mexico.

There is a general belief by many that adequate water supplies are available for the United States to develop alternate energy supplies. However, I have seen little evidence to demonstrate that adequate analysis has been made of the impact of diverting water from irrigation uses to energy purposes. The sociological and economic effects of a shift in water use must be studied.

SUMMARY

In addressing the subject of the role of water from now to the Year 2000 in relation to Mexico–U.S. transboundary resource needs and issues, I chose two examples to illustrate: "water and food" and "water and energy." I believe these issues are important and among the many good reasons why our management of Earth's life blood, water, will be increasingly important. This is particularly true in the transboundary region of Mexico and the United States.

I opened this paper with a quote from a 1974 address by Dr. Philip Handler, former President of the National Academy of Sciences. I close with two more quotes from the same address "On the State of Man." The first quote is:

> "In the long term, the adequacy of the 'solution' to the energy problem will determine the future of our species."

And the other quote from Dr. Handler, in speaking of malnutrition, hunger, and the worldwide importance of food production, is:

"Nothing will work but food."

AGUA SU PAPEL DESDE HOY AL AÑO 2000

El agua es renovable pero tiene límites y no hay una fuente de energía que provea agua gratuitamente. No hay agua dulce suficiente en la tierra para cubrir, indefinidamente, la demanda de alimentos. El agua es también esencial para desarrollar fuentes de energía. En el área transfronteriza, el desarrollo de carbón y petróleo usará el agua que hoy se emplea para la irrigación.

INTRODUCCION.

El agua ha sido una de las mayores influencias en el desarrollo de la región transfronteriza de México y los Estados Unidos. Aún en esta árida región, en períodos en que los abastecimientos de agua son relativamente adecuados, la gente olvida la necesidad de seguir investigando y haciendo esfuerzos para planificar los recursos continuos de agua.

El Senador Domenici, de Nuevo México, ha advertido sobre un rezago de proyectos necesarios, pero no realizados. Ha lamentado los 26 años que requiere que un proyecto llegue a su construcción, además de la década que requiere su terminación. La disminución masiva de los recursos de agua en Nuevo México, Tejas y la Gran Planicie llevará al desastre a menos de que nuevos e innovativos enfoques sean iniciados.

Límites de Recursos de la Tierra.

La escasez física del agua puede dictar un límite último al número de seres humanos que la tierra puede alimentar. El agua es renovable, pero tiene límites, puesto que sólo efectos menores han resultado de los intentos de modificar su ciclo de renovación. Más aún, la contaminación puede destruir el abastecimiento actual para la mayor parte de sus usos y las fuentes de agua subterráneas no son renovables.

En el pasado no hemos dejado de apreciar el costo y la cantidad de energía necesaria para poder usar el agua por desalinización o bombeo. Hoy nos damos cuenta que no hay fuente de energía que proporcione agua gratis o en cantidad ilimitada.

En la región transfronteriza la radiación solar es abundante pero la energía solar todavía no es económicamente costeable. Los sistemas de seguimiento para acopio de energía solar, en Arizona y Nuevo México, cuestan el doble de los sistemas convencionales eléctricos y con la tecnología de celdillas fotovoltáicas, los costos de inversión siguen siendo altos.

Agua y Alimento.

El Departamento de Agricultura de los Estados Unidos ha llegado a la conclusión de que "el agua es potencialmente el recurso más limitante de la agricultura estadounidense" y ha urgido que se incremente la investigación sobre recursos de agua. Puesto que el mundo dobla su población cada 35 años, no hay suficiente agua en la tierra para satisfacer la incesante demanda de alimento en forma indefinida.

Las tierras irrigadas, aunque comprenden solamente el 15% de la tierra de labranza en el mundo, producen el 30% de sus alimentos. El incremento de la superficie irrigada ha pesado sobre un abastecimiento de agua ya sobreexplotada.

En en futuro próximo, las cosechas de alto rendimiento pueden compensar los recursos insuficientes de tierra para enfrentar las necesidades alimentarias. Las variedades de alto rendimiento de arroz y trigo, sin embargo, necesitan mayor dependencia de otros insumos de recursos, como fertilizantes, controles de plagas e irrigación. Una amplia dotación de agua es absolutamente necesaria para que el mundo llegue a la producción potencial de calorías.

Agua y Energía.

El agua es esencial para desarrollar fuentes alternativas de energía. Es, por lo tanto, crítico que las regiones donde habrá gran necesidad de agua y que tengan un abastecimiento inadecuado, sean los lugares para el desarrollo de nueva energía fosil, desde carbón hasta aceite de esquistos.

En la Cuenca del Río Colorado y en el Gran Llano, el 90% del agua existente se usa actualmente para la irrigación. Puede ocurrir la competencia por el agua en las regiones transfronterizas y es dudoso que la agricultura pueda competir con el desarrollo energético sobre bases económicas. Se requieren estudios sobre los efectos sociológicos y económicos de tal cambio en el uso del agua.