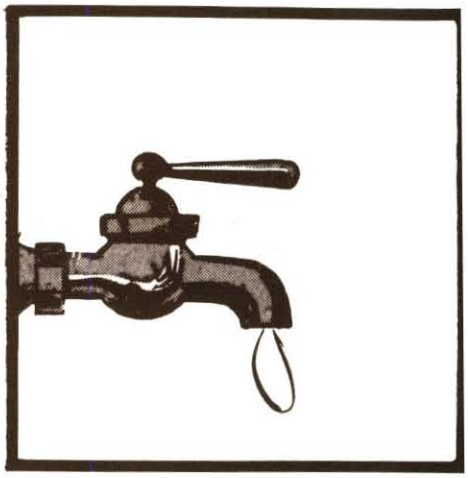
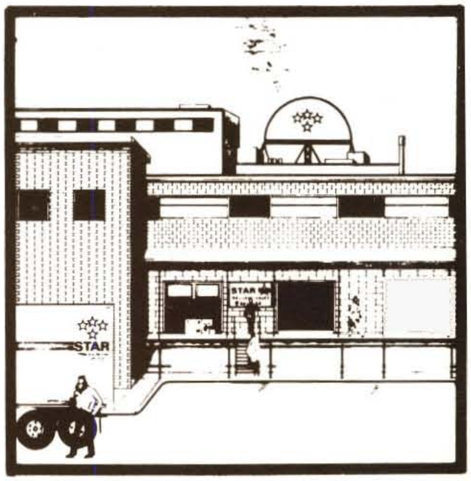
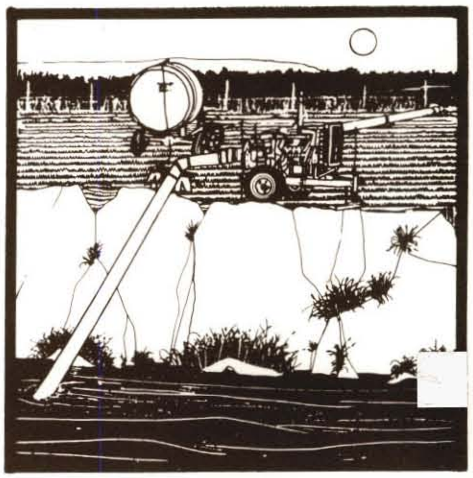




POLICY ISSUE STUDY
ON

WATER USE EFFICIENCY



State Water Planning and Review Process
Nebraska Natural Resources Commission

APRIL 1985

POLICY ISSUE STUDY
ON
WATER USE EFFICIENCY

STATE WATER PLANNING AND REVIEW PROCESS

WATER USE EFFICIENCY REPORT

REPORT
OF THE
NATURAL RESOURCES COMMISSION
TO
GOVERNOR ROBERT KERREY
AND
THE MEMBERS OF THE NEBRASKA LEGISLATURE

APRIL 1985

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STATE OF NEBRASKA
NATURAL RESOURCES COMMISSION
301 CENTENNIAL MALL SOUTH • P.O. BOX 94876 • LINCOLN, NEBRASKA 68509-4876 • PHONE (402)471-2081

The Honorable Robert Kerrey
Governor, State of Nebraska
State Capitol, 2nd Floor
Lincoln, Nebraska 68509

Dear Governor Kerrey and Members of the Legislature:

This report entitled "Policy Issue Study on Water Use Efficiency" has been reviewed and approved by the Natural Resources Commission. It is one of a series of studies of Commission studies of water policy issues.

Four policy alternatives and numerous subalternatives related to efficiency of water use in Nebraska are analyzed in this report. The Commission's recommended course of action is also provided and can be found in the blue pages immediately preceeding the summary.

It is the hope of the Natural Resources Commission that this report will be helpful in making policy decisions, and, if necessary, statutory changes. The Natural Resources Commission is prepared to answer any further questions you may have.

Sincerely,

Vincent J. Kramper

Vince Kramper, Chairman
Nebraska Natural Resources Commission

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Foreword

This is the final report of the *Water Use Efficiency Policy Issue Study*. It provides alternative policies for addressing efficiency of water use in Nebraska and is being forwarded to the Governor and Legislature for action as deemed appropriate. It is one of a series of water policy studies being conducted as part of the State Water Planning and Review Process.

The base document for this report was prepared by a task force of seven representatives from state agencies and two representatives from the University of Nebraska-Lincoln. Most of that document was prepared directly by the Water Resources Center, which also served as lead agency for the study. However, the final report and recommendations were the responsibility of the Natural Resources Commission.

The members of the task force were:

Donn Rodekohr	Water Resources Center-UNL (Lead Agency)
Bob Kuzelka	Conservation and Survey Division-UNL
Jerry Wallin	Natural Resources Commission
Gerald Chaffin	Game and Parks Commission
Tom Lamberson	Department of Water Resources
David Chambers	Department of Environmental Control
Bill Lee	Department of Health
John Alloway	Department of Agriculture
____________	Policy Research Office

Numerous other individuals have contributed substantially to the production of this report. These include Bob Burns, Sue Miller, Brad Gustafson, Ann Bleed, Danita Bright and Karen Stork, Water Resources Center; Dr. James Gilley, Department of Agricultural Engineering, UNL; Dr. Bruce Johnson, Dr. Raymond Supalla, and J. David Aiken, Department of Agricultural Economics, UNL; and Steve Gaul and Jay Holmquist, Natural Resources Commission. Deon Axthelm and John Addink surveyed and analyzed many of the techniques and were assisted by Paul Fischbach, Dean Eisenhauer, DeLynn Hay, Darrell Watts, Jerry Eastin, Elbert Dickey, and Norman Klocke, all of the University of Nebraska.

A Commission Special Committee monitored task force progress and prepared the draft of the Commission comments and recommendations for the study. Members of the committee were Richard Hahn, Mike Shaughnessy, and Milton Christensen.

At issue in this study is whether the benefits of installing water use efficiency techniques are sufficient to warrant legislative or administrative action. This report deals with (a) techniques to improve the efficiency of using water for agricultural, municipal, domestic, industrial, and power generation purposes, and (b) policy alternatives that may promote the adoption of these techniques.

Following initial consideration of the task force report the Commission released it for public review on July 12, 1982. A public hearing was held on August 8, 1984 in Grand Island. There were limited comments at that hearing.

The Public Advisory Board provided the Commission with a number of recommendations on the report. In addition written comments were received from the Corps of Engineers and a former Commission member. All of the above comments are on file at the office of the Commission and are available for review.

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Comments and Recommendations of the Natural Resources Commission

The Commission believes that efficient use of our water resources is an important responsibility and a keystone of continued prosperity for our state. These recommendations describe some of the policy actions our state government can take to provide benefits through improved water use efficiency. In general these recommendations and this report do not examine these benefits from the standpoint of individual water users. The fact that inefficiently used water returns to the aquifer or flows to downstream users may diminish irrecoverable loss of water to the state. However, from the standpoint of the individual irrigator those factors may not be immediately important. In those cases energy costs, chemical and fertilizer leaching, and soil erosion through inefficient application of water can cause substantial financial losses no matter what the impact on water supplies in the state.

Minimizing irrecoverable loss of water is in both the short term interests of individual water users and the long term interest of future generations who must continue to use Nebraska soil and water resources. Past research and educational efforts combined with recent increases in pumping costs help lead us to believe there are no widespread gross inefficiencies in water use. However, that does not mean that there is not room for improvement. Nebraska has been a world leader in irrigation technology and irrigation scheduling research. The Commission feels the state must retain these distinctions while vigorously pressing for more actual field application of the knowledge we have acquired.

Nebraska water resources are not privately owned but are a public resource which individuals may put to beneficial use in the interests of themselves and the people of the state. Courts have long held that the state's water must not be used in a wasteful manner. The constant improvement in crop varieties, irrigation technologies, and knowledge of water needs has given "efficiency" somewhat of a changeable definition. We feel it is the state's responsibility to see that individuals have the latest available information on how to use water efficiently. However, it remains the individual's responsibility to efficiently use the state's resource. How that responsibility is carried out has some impact on the current economic health of the state and may be meaningful in regard to the availability of our water resources to future generations. It is a responsibility that must be shared by agricultural, municipal, and industrial users. Although irrigation accounts for the vast majority of water consumption in Nebraska, municipal and industrial users can achieve monetary savings through implementation of conservation measures.

A portion of inefficiently used water is evaporated, transpired, or leaves the state as stream runoff. Another portion remains as soil moisture, moves back to the aquifer or is utilized by downstream water users. The amount of water entering each of these respective categories varies with soils, weather and other factors, including the amount inefficiently used. Little research has been done in Nebraska on what portion of the water makes its way back to the aquifer or is utilized by downstream users. Nor has sufficient research been done on the degree to which irrigators currently make efficient use of water. This has resulted in differences of opinion among some water researchers on the degree to which water use efficiency measures may affect aquifer life. While we strongly believe that water use efficiency measures have the potential for extending the life of the aquifer we simply don't know how great that potential is. However, there is little dispute that water use efficiency measures have substantial impact on energy costs, amounts of chemicals and fertilizers leaching to the groundwater, and soil erosion.

This report does not contend that every "inefficient" use of water is to the state's detriment. Indeed, it points out that in some situations inefficient use has resulted in groundwater recharge which is a significant asset to the state. In other cases the inefficiently used water may have flowed out of Nebraska in any event.

The following paragraphs provide our specific recommendations on the policy alternatives included in the report. It is our hope that they will receive serious consideration in upcoming legislative sessions.

Alternative #1 Make No Changes in Existing Administrative or Statutory Policies Related to Water Use Efficiency

Recommendation: The Commission does not recommend adoption of this alternative. Current policies do encourage efficient use of water, have provided for some excellent research on water use efficiency and have resulted in a significant educational effort. However, there is room for improvement beyond what the current policies encourage.

Alternative #2 Increase Research and Educational Efforts Related to Improving Water Use Efficiency

Recommendation: The Commission strongly supports adoption of this alternative. While we believe educational and especially research efforts of the past have been highly successful, we do see opportunities to expand those efforts. Adoption rates for efficient techniques can be improved. We believe that a portion of the increased educational assistance should specifically be targeted to providing on-farm technical advice; for instance how to make efficient techniques work on different types of soils. Because many factors that contribute to water use efficiency are site specific, there are some water users who would like to improve techniques but would hesitate without good technical advice for their specific situation. Providing additional specialists in these techniques is one way to improve that situation.

Lack of data and research on two topics has been of particular concern to us in making our recommendations on this report. Little data is available on the volume of water used by irrigators. Even more disturbing is the lack of available information on the degree to which efficiency measures influence aquifer life. Site specific research in areas of groundwater depletion might help establish what percentage of inefficiently used water is recoverable within the area.

Alternative #3 Provide Either Economic Incentives for Installing Efficient Water Use Techniques or Disincentives for Excessive Use of Water

Recommendation: Alternative 3A would earmark a portion of the existing Nebraska Soil and Water Conservation Fund for Water Use Efficiency practices or earmark an increase in the fund for such practices. The Commission recommends adoption of this alternative. We intend to develop a formula for distribution of funds and water use efficiency measures will be a factor in that formula. We also urge legislative action to increase appropriations to the fund.

Alternative 3B would establish water use efficiency as one of the criteria for determining priorities for Natural Resources Development Fund funding. It would also increase or earmark Development Fund appropriations to fund projects or programs improving efficiency. We believe water use efficiency measures should be a criteria used in establishing priorities for funding from the Development Fund. However, we do not believe that projects where it is not possible to incorporate efficiency measures should be penalized.

We also feel that a portion of the Development Fund should be earmarked for projects or programs improving water use efficiency. We will revise our guidelines to see that such earmarking occurs. We recommend increased Legislative appropriations to the Development Fund to help carry out these types of projects.

Alternative 3C would allow natural flow appropriators to expand crop acres served by an appropriation. We find this alternative to be appealing in theory. However, we have serious reservations as to whether it could be administered in practice. Although we cannot recommend its implementation at this time, we feel this idea should be studied for potential future application.

Alternative 3D would require water users to pay a water use charge, exempting self-supplied domestic and livestock watering uses. We support adoption of this alternative for water use efficiency purposes if it is implemented in a manner which charges a fee only once water usage increases above a certain volume on a per acre basis. We recognize that this alternative could have considerable administrative expense and for agricultural users might have to be restricted to groundwater control or management areas. We feel that a general fee on the total volume of water used would not have a significant impact on excess usage.

In one respect we do see a need for a more general water use charge. As a method for raising funds for water projects use fees to all water users it does make sense.

Alternative #4 Encourage The Installation of Efficient Water Use Practices by Regulation

Recommendation: Alternative 4 would authorize the Department of Water Resources to administer new and existing appropriations at something less than the 1 cfs to 70 acres provided under existing law. It would also authorize the establishment of efficiency standards for new conveyance systems.

The Commission does not recommend administration of new or existing appropriations at less than the 1 cfs to 70 acres provided under current law. We feel that the 1 cfs to 70 acres allowed for new appropriations is a reasonable rate and amounts that high are often needed. We also believe there would be severe constitutional problems in changing existing appropriations since appropriations constitute property rights.

We feel there is some value in establishing efficiency standards for new conveyance systems. Such standards could be implemented through either the Department of Water Resources or the new Water Management Board. However, we also recognize that in some cases inefficiencies in conveyance systems can be a benefit to the state through the recharge of groundwater.

Alternative 4B would expand the types of controls that can be required by natural resources districts in groundwater control or management areas. Items on the expanded list could include irrigation scheduling, reuse systems, system modifications, residue management, alternative cropping and hybrid selection, and/or windbreaks. The Commission does not recommend adoption of this alternative. We believe that including these measures would be impractical and would probably carry government too far into the daily operation of individual farms. For instance, irrigation scheduling depends on a great many individual factors of which only the individual farmer may have knowledge. NRD monitoring of each operation to ensure compliance with scheduling requirements scheduling would take tremendous manpower. On the other hand alternatives such as alternative cropping and hybrid selection, while perhaps easier to monitor, would result in an even larger government hand in basic farming decisions. To our minds such intervention is unjustified. Control and management areas can better accomplish water use efficiency goals through tough implementation of allocations. This leaves it to the landowner to decide what management practices should be employed to best utilize his allocation.

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Summary

The *Water Use Efficiency Policy Issue Study* was conducted as part of the Nebraska State Water Planning and Review Process. It is one of the eleven studies which analyze Nebraska's water policy issues. The study was conducted to determine what, if anything, the Legislature can do to promote or improve the efficiency of water use throughout the state. At issue is whether the potential benefits of improved water use efficiency warrant the adoption and implementation of state-wide policies to promote efficient use, and if so, what those policies are.

The purpose of the study was to provide information about the background of water use efficiency in Nebraska (Section I) and to present alternative techniques (Section II) and policies (Section III) which may be implemented to improve efficiency within the state.

As used in this study, improved water use efficiency refers to the maintenance of given water-related benefits, while reducing the amount of water applied or diverted to produce those benefits. For example, irrigation scheduling is a technique employed to monitor more closely the actual water needs of a crop, to pump or divert the amount of water more closely attuned to those needs, and consequently to minimize the amount of water "wasted," without reducing yield.

In this study of water use efficiency, the necessity of water use in the prolonged sustenance of agricultural and industrial productivity is accepted as a given, and the study is focused on policy alternatives designed to ensure that those benefits do not require more water than is technologically necessary.

SECTION I: BACKGROUND OF WATER USE EFFICIENCY IN NEBRASKA

Water use efficiency has been a major concern for Nebraskans throughout most of the state's history, but the context in which the concern is expressed today has shifted dramatically over the last thirty years. In contrast to the role water use efficiency played in the social and economic development of preceeding generations, it is today regarded as a potential aid in preserving an established and properous way of life and for ensuring the most equitable distribution of limited resources among competing interests and succeeding generations.

While water use efficiency may be viewed initially as intrinsically good, pragmatically it is a means to an end, rather than an end in and of itself. Along with the desire for an equitable and environmentally sound use of the state's surface water supplies, concerns as to the economic, social and cultural effects of groundwater depletions have provided, in part, the impetus for this study of water use efficiency.

However, improved water use efficiency should not be automatically regarded as an easy answer to complex state-wide water resources problems. In considering alternative techniques and policies, four significant factors need to be kept in mind. First, due in part to a prevailing conservation ethic and to the natural regulating function of energy and other production costs, this report does not assume the presence of widespread gross inefficiency. Second, improved water use efficiency does not always mean a corresponding reduction in withdrawals. Water which is "saved" on one field, for instance, can sometimes be used to irrigate another field. Third, though a reduction in withdrawals can mean a local, on-site water savings, it may or may not mean a corresponding water savings for the state. And finally, the successful voluntary application of water use efficiency techniques depends on their economic feasibility. Regardless of the hydrologic impact of implementing water use efficiency practices, it is the present and long-term economic impact which is crucial to the local operation, and the aggregate economic impact which can have state-wide social significance.

LEGAL AND INSTITUTIONAL FRAMEWORK

It is well established in both case law and state statutes that an appropriation permit does not entitle the holder to appropriate more water than that which can be put to beneficial use. It is primarily through this beneficial use limitation that Nebraska surface water

law addresses the water use efficiency issue.

What is meant by the term "beneficial use" has not been explicitly defined by the Legislature or state courts. With regard to irrigation, the Nebraska Supreme Court has stated that "many elements must be considered in determining whether water has been put to beneficial use, one is that it shall not exceed the least amount of water that experience indicates is necessary in the exercise of good husbandry for the production of crops." The Court has recognized that the amount needed for the production of crops will vary depending on climate, location, soil, and the type of crop grown.

One issue is whether the Legislature can require existing surface water appropriators to reduce their water use by increasing their water use efficiency under the concept of beneficial use or through some other legal theory. It appears the legal ability to reduce quantities of water used by appropriators to enforce water use efficiency requirements pursuant to the beneficial use doctrine has been limited somewhat by the Nebraska Supreme Court.

The legal authorization to transfer surface water rights will enable appropriators to transfer water rights to land better suited for irrigation and may promote improved water use efficiency. Whether this law will also enable appropriators to apply water "saved" through the use of improved irrigation practices on additional lands is unclear at this time.

Concerning groundwater law, landowners in Nebraska generally are entitled to the reasonable and beneficial use of groundwater underlying their land. What constitutes a reasonable and beneficial use, however, has never been addressed by the State Supreme Court or the Legislature, but probably includes use without waste. Whether "waste" in this context means "unnecessary waste" is unclear.

Three alternatives are available under the Ground Water Management and Protection Act (GMPA) to administratively require a higher degree of irrigation water use efficiency: (1) irrigation runoff control requirements, (2) groundwater control area regulations, and (3) groundwater management area regulations.

PUBLIC PERCEPTIONS

Four surveys were conducted to obtain water user perceptions of water use efficiency issues. These surveys may shed some light on public attitudes regarding water use efficiency issues. If alternatives are "targeted" to resolve both the physical and institutional problems as perceived by water users, the chances for effectively dealing with these issues may be improved.

The following inferences can be drawn from these surveys which might guide the development of policy alternatives that encourage greater efficiency in water use: (1) Because a major barrier to attaining efficiency seems to be the high cost of improvements, state and local governmental financial incentives may be helpful in alleviating some burdens. In fact, financial incentives appear to be perceived by water users as the keystone of public actions taken to improve efficiency. (2) Although educational programs may assist water users in becoming better stewards of natural resources, the respondents believed that these programs should not be relied upon as the sole methods of promoting wiser resource use. (3) Government regulations may be publicly acceptable in some instances, perhaps only when problems appear especially imminent. If regulations are to be imposed, local governments (i.e., natural resources districts) were judged by survey respondents as perhaps the best level for implementation. (4) Natural resources districts also were felt to be appropriate agencies to deliver governmental, educational and technical services to water users.

SECTION II: WATER USE EFFICIENCY TECHNIQUES, ASSOCIATED IMPACTS AND PRESENT LEVEL OF ADOPTION

In the following two sections of the report, two different kinds of impacts are described — local, on-site impacts of alternative techniques (Section II), and statewide, aggregate impacts of alternative policies (Section III).

To the individual user, the goal of any efficiency technique may be to reduce withdrawals and thus make the operation more profitable, today and into the future. The impacts at this local level are fairly straightforward. Included under each technique in Section II is a brief discussion of the expected impacts of implementing the technique on a local level.

CONVEYANCE SYSTEMS

A conveyance system is any means of carrying water from the point of diversion (stream, reservoir or well) to the point of on-site use. The conveyance system efficiency techniques identified in this report include:

(1) Lining - Lining a canal is a technique aimed at improving the canal's efficiency by reducing the amount of water lost through seepage. Concrete or other impervious lining material is installed within the waterway to prevent the water from seeping out of the canal, laterally into the adjacent fields or downward into groundwater storage.

(2) Use of pipelines or Surface Barriers - Pipelines provide a means of completely enclosing a water conveyance system to avoid both seepage and evaporation of water occurring in an open system. Chemical or mechanical barriers placed on water surfaces can reduce evaporation from impoundments or canals.

(3) Management Techniques - Improved management techniques can improve the efficiency of water conveyance systems, primarily by use of flow measures and/or flow regulating techniques.

(4) Vegetation Control Along Canals - Vegetation growing near a canal or ditch can transpire water that may have come from the water in the canal or ditch, thus reducing the available supply. A weed control program can effectively minimize excessive vegetation in and along ditch banks and can be accomplished by mechanical or chemical means.

ON-SITE IRRIGATION SYSTEMS

The agricultural techniques discussed are designed to increase the efficiency with which both precipitation and irrigation water are used. These on-site techniques include:

(1) Reuse Systems - Reuse pits are generally used on groundwater irrigated lands to capture water which would otherwise runoff the end of a field. The system usually consists of a pit or collection reservoir located below the irrigated area, a pump, and a pipeline to deliver water either back to the distribution system or to irrigate additional lands.

(2) Land Shaping - Land shaping is a technique to reshape the surface of a field to either control or increase the water flow. It can involve increasing slopes, flattening slopes, or the construction of terraces, grassed waterways, or other conservation structures.

(3) Shorter Rows - By shortening the length of run, less water need be applied with each irrigation due to a reduction in infiltration at the top of the field.

(4) Irrigation Scheduling - Irrigation scheduling is the practice of determining as accurately as possible the precise water needs of a crop, and then controlling the amount and timing of water application to meet those needs without overwatering. Irrigation scheduling does not employ deficit irrigation, that is, applying less water than the crop requires.

(5) Flow Management - Flow management devices can be used to control and measure the amount of water delivered and applied to a field. Examples of farm water control and regulating structures are checks, drops, divider boxes and reservoirs. Examples of flow measurement devices include Parshall flume wiers, orifice plates, and flow meters.

(6) Residue Management - Residue management involves the use of tillage practices which leave residue on the land surface or, in some cases, the application of mulches onto the land surface.

(7) System Modification - System modification refers to changes made within existing irrigation systems to improve the efficiency of those systems.

(8) System Conversion - System conversion refers to changing from one irrigation system to another. The two main methods of irrigation application in Nebraska are gravity flow and sprinkler. Other methods include drip, subsurface and drop nozzle systems.

(9) Windbreaks - Windbreaks are designed to minimize the effects of the wind on crops. They may be of the slat fence design (e.g., a snow fence), trees planted in rows or strips of annual grass. A slat fence can be used in the summer as a temporary windbreak structure. Wind shelter can significantly reduce ET, especially during periods of strong winds accompanied by warm temperatures. Also, soil moisture in the spring may be increased because of captured snow.

(10) Alternative Cropping and Hybrid Selection - Alternative cropping involves the use of a crop type with a lower ET requirement than other crops. Hybrid selection refers to choosing a less water intensive variety of the same crop.

The following three techniques are still in the experimental states and are not presently applicable.

(11) Anti-transpirants - Anti-transpirants are film forming substances that block the loss of water vapor from leaf surfaces, thus limiting transpiration. Various film materials such as long chain alcohols, silicone materials, latex, waxes and plastics have been researched.

(12) Reflectants - Reflectants are materials applied to crop leaf surfaces which reflect incoming solar radiation. Materials such as kaolinite, diatomaceous earths, aluminum silicates, and lime have been used by researchers as reflective materials with limited success.

(13) Mechanical Application of CO_2 - Mechanical application of carbon dioxide is a potentially viable method of increasing the amount of CO_2 in the microclimate of a cropped field.

MUNICIPAL, INDUSTRIAL AND POWER DISTRIBUTION SYSTEMS

Municipal water use is divided into distribution and residential uses. To improve water use efficiency in the first category, upgrading of the distribution system (control of underground leakage) has the advantage of being cost effective in that it reduces both pumping and water treatment costs. The following methods are available to improve water use efficiency in the residential use category: (1) toilet flushing control, (2) showering control, (3) laundry and cleaning controls, (4) plumbing maintenance, (5) dual or recycling systems, (6) lawn irrigation scheduling, and (7) landscaping practices.

Industrial water use can be divided into three major classifications: (1) non-contact cooling, (2) process and related uses, and (3) sanitary or miscellaneous uses. Industries vary greatly in water requirements, both between types of industry and within the same industry. Therefore, it is difficult to say that a product requires a specific quantity of water. However, the greatest opportunity for improved industrial water use efficiency occurs where greater recycling of the water may be possible.

There are three primary types of power generating plants: (1) hydroelectric, (2) thermoelectric-steam cycles, and (3) combustion turbine plants. After a review of the literature, it appears the potential for improved water use efficiency within the power industry is limited for the following reasons. First, the level of efficiency of any plant is dictated primarily by its type and design. The design is dictated by such factors as the availability of adequate water supplies, geologically or topographically suitable sites, the capital costs of plant construction, and environmental requirements for discharge permits. Second, once a power plant is built, it is generally not economically feasible to convert to another system of generating or cooling. Thus, efficiency considerations are relevant in the construction and design of new plants, but conversions of existing plants to more efficient systems are usually cost prohibitive.

SECTION III: POLICY ALTERNATIVES WHICH MAY PROMOTE THE ADOPTION OF WATER USE EFFICIENCY TECHNIQUES

The primary goal of any of the policies presented in Section III of this report is to promote the adoption of water use efficiency techniques within the state. An assessment of the state-wide aggregate impacts of alternative policies is difficult, as the complex relationships which exist between the source of supply and the destination of water after it is used do not always allow individual reductions to be additive. The state-wide, aggregate, long-term impacts of improved water use efficiency, as well as any social/economic, legal or institutional impacts resulting directly from the policy itself, are addressed in Section III of this report.

POLICY ALTERNATIVES PRESENTED

Alternative 1 Make no changes in existing administrative or statutory policies related to water use efficiency.

This alternative would allow existing incentives and constraints to control the rate by which efficiency techniques and practices are adopted. This alternative proposes that no new legislation be enacted and existing legislation not be modified.

Alternative 2 Increase research and educational efforts related to improving water efficiency.

This alternative would promote the development of new techniques and the refinement of existing techniques through research, and promote the adoption of existing techniques through expanded education and demonstration programs.

Alternative 3 Provide either economic incentives for installing efficient water use techniques or disincentives for excessive use of water.

Alternatives 3A-1 and 3A-2 would modify administration of the Nebraska Soil and Water Conservation Fund (NSWCF).

Alternative 3A-1 Earmark a portion of the existing NSWCF for water use efficiency practices.

The purpose of this alternative is to accelerate the implementation of water use efficiency techniques by designating a portion of existing NSWCF funds for these techniques.

Alternative 3A-2 Increase state appropriations to the NSWCF earmarked for eligible water use efficiency practices.

The purpose of this alternative is to further encourage installation of efficient water use practices through increased financial incentives.

Alternatives 3B-1 and 3B-2 would modify the administration of the Nebraska Resources Development Fund (NRDF).

Alternative 3B-1 Establish water use efficiency as one of the criteria for determining priorities for NRDF funding.

The purpose of this alternative would be to establish water use efficiency as a criterion to be used by the NRC in establishing priorities for the annual funding of approved Resources Development Fund projects.

Alternative 3B-2 Increase and earmark NRDF appropriations to fund projects or programs improving water use efficiency.

The purpose of this alternative would be to accelerate the rate of adoption of efficiency techniques by increasing NRDF appropriations and earmarking these increased funds for those projects and programs which have improved water use efficiency as an objective.

Alternative 3C Authorize natural flow appropriators to expand crop acres served by an appropriation.

This alternative would allow natural flow appropriators to expand irrigated acres served by the appropriation if it can be shown that the net amount of water in the stream would be unchanged.

Alternative 3D Require water users to pay a water use charge, exempting self-supplied domestic and livestock watering uses.

The purpose of this alternative is to reduce withdrawals by increasing the cost of water.

Alternative 4 Encourage the installation of efficient water use practices through regulation.

Alternatives 4A-1, 4A-2 and 4A-3 would modify surface water administration.

Alternative 4A-1 Authorize DWR to administer new natural flow appropriations at a lower withdrawal rate.

The purpose of this alternative is to encourage new natural flow appropriators to adopt water use efficiency techniques by limiting the rate at which streamflow may be diverted to something less than the 1 cfs per 70 acres provided under existing law.

Alternative 4A-2 Authorize DWR to administer existing natural flow appropriations at a lower withdrawal rate.

The purpose of this alternative is to encourage existing natural flow appropriators to adopt water use efficiency techniques by reducing the rate at which water may be diverted from a stream to something less than the 1 cfs per 70 acres provided under existing law.

Alternative 4A-3 Authorize DWR to establish efficiency standards for new conveyance systems.

The purpose of this alternative is to regulate the efficiency of new surface water conveyance systems. This alternative would authorize DWR to establish water use efficiency standards as conditons on the issuance of new permits for storage, storage use and natural flow appropriations. These standards could incorporate the recognition of conveyance system contribution to useable groundwater supplies.

Alternative 4B Expand the types of controls that can be required by NRDs in a control or management area.

This alternative would expand the list of authorized controls to include the agricultural water use efficiency techniques that relate to groundwater use. These could include irrigation scheduling, reuse systems, system modifications, residue management, alternative cropping and hybrid selection, metering, and windbreaks.

IMPACTS OF ALTERNATIVES PRESENTED

Where the "policy impacts" include the projected adoption of any water use efficiency technology, the local physical/hydrologic, social/economic and environmental impacts follow directly from the implementation of the various techniques. These impacts can translate into state-wide, aggregrate, long-term impacts.

Various physical/hydrologic and environmental impacts may also have indirect social/economic impacts on the state. As an example, nitrate contamination of underground water supplies can have negative economic impacts on a community.

The state-wide social/economic impacts relate primarily to possible changes in net income, which can translate into higher or lower taxable incomes (and thus higher or lower state revenues) or into more or less available income (and thus into a stronger or weaker economic base for the community).

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Introduction

Within the past few decades, demands upon Nebraska's water resources have greatly increased, causing widespread concerns among Nebraskans. The potential conflicts between these growing demands and the increasing scarcity of reserves in the greater High Plains region have spawned a renewed interest in how efficiently these water supplies are being used.

As a result, the Legislature in 1978 directed the Natural Resources Commission and cooperating agencies to examine water use efficiency, along with other water-related issues, as part of a larger State Water Planning and Review Process. This series of policy issue studies was established to provide the Legislature and the citizens of Nebraska with information and alternative methods of addressing important water policy issues and area-wide or state-wide water resources problems. The *Water Use Efficiency Policy Issue Study* is one of this series.

STATEMENT OF THE ISSUES

This policy issue study has been conducted to determine what, if anything, the Legislature can do to promote or improve the efficiency of water use throughout the state. At issue is whether the potential benefits of improved water use efficiency warrant the adoption and implementation of state-wide policies to promote more efficient use, and if so, what those policies are.

Water use efficiency can best be understood and addressed within the larger context of water conservation. Generally, water conservation measures can be divided between supply-side and demand-side practices. Supply-side conservation practices are designed to increase the total amount of water available for use within a basin by supplementing and/or preserving existing water supplies (storage and diversion projects, weather modification, etc.). Demand-side practices, on the other hand, seek to increase the potential use to which this total amount of water can be put by reducing the amount of water necessary for each use (irrigation scheduling, system modification, etc.). Technologies and practices which improve water use efficiency belong to this second category.

As used in this report, **improved water use efficiency refers to the maintenance of given water-related benefits, while reducing the amount of water applied or diverted to produce those benefits**. For example, irrigation scheduling is a technique employed to monitor more closely the actual water needs of a crop, to pump or divert an amount of water more closely attuned to those needs, and consequently to minimize the amount of water "wasted," without reducing yield.

As so defined, the scope of this study differs from one strictly addressing the supply-side issue of water preservation. Hypothetically, the pursuit of maximum water preservation could best be served by the adoption of policies which encouraged or enforced a return to dryland agriculture. The result would be an effective curtailment of groundwater withdrawals, but with a subsequent curtailment of current production levels as well.

In this study of water use efficiency, the necessity of water use in the prolonged sustenance of agricultural and industrial productivity is accepted as given, and the study is focused on policy alternatives designed to ensure that those benefits do not require more water than is technologically necessary.

PURPOSE AND LIMITATIONS OF THE STUDY

The purpose of this water use efficiency policy issue study is to provide information about the background of water use efficiency in Nebraska and to present alternative techniques and policies which may be implemented to improve efficiency within the state.

It has not been within the scope of this study to assess the precise level of present efficiency — rather **this report assumes that not every water use is as efficient as it could be, and that more efficiency is possible to attain**.

It has not been within the scope of this study to address the relative efficiencies of various uses as they relate to one another. The study has only sought to describe the amount of increased efficiency which may be possible within the context of each existing use.

The scope of this study has been further limited to an evaluation of the improved efficiency potentials of withdrawal uses only — agricultural, industrial, municipal and off-stream power generation. It has not been within the scope of this study to address the efficiency of non-withdrawal uses such as navigation, recreation, instream hydroelectric power generation or fish and wildlife habitat.

OBJECTIVES OF THE STUDY

Although the goal of promoting water use efficiency might be to obtain the optimum benefit to the state as a whole per unit of water used, any program to increase water use efficiency must begin on a single-unit basis — an individual farm, a company, a community, a power plant, etc. For this reason, this study set out to examine alternative techniques and policies for improving water use efficiency on a single-unit basis, and then to assess the impacts of improved efficiency on local, regional, and state-wide levels.

The objectives of the study were as follows:

(1) to describe the various physical, hydrologic, socio-economic, environmental, legal and institutional factors which must be considered in assessing the impacts of new techniques and policies;

(2) to describe water use efficiency techniques, evaluate the impacts of their implementation, and estimate the present level of their adoption; and

(3) to outline policy alternatives open to the Legislature which could promote the adoption of those techniques.

ORGANIZATION OF THE REPORT

This report is divided into three sections which correspond, respectively, to the three objectives of the study as outlined above.

Section I of the report (Chapters 1, 2, 3, 4 and 5) provides information on the background of water use efficiency in Nebraska. Chapter 1 presents a social and historical perspective on why water use efficiency is being studied and what it is hoped improved efficiency might achieve. Chapter 2 presents a brief discussion of Nebraska's water supplies and the state's present water use. Chapter 3 describes the existing legal and institutional framework within which alternative policies should be considered, and Chapter 4 present the results of four surveys conducted to obtain water user perceptions of water use efficiency issues. Chapter 5 briefly describes the hydrologic, social/economic and environmental concepts used in Sections II and III to discuss impacts of improved water use efficiency.

Section II of the report (Chapters 6, 7 and 8) describes techniques, their associated impacts and present levels of their adoption. Chapter 6 presents the available techniques which can improve the efficiency of water conveyance systems, describes the various hydrologic, environmental, social and economic impacts of their implementation, and assesses the present level of their adoption. Chapters 7 and 8 describe the techniques, associated impacts, and present level of adoption of agricultural, municipal, industrial and power systems.

Section III of the report (Chapter 9) provides a discussion of alternative policies which may promote water use efficiency in the state. Four policy alternatives are presented for consideration by the Legislature for possible use in promoting water use efficiency in Nebraska. Presented with each is a brief description of the policy alternative; legal and institutional aspects of implementing the policy; the projected response of existing water users to the policy; and a discussion of various policy impacts which could be expected to result from the policy's implementation.

Six appendices and a glossary of terms used in the report are also included following Section III.

SECTION I:
BACKGROUND OF WATER USE EFFICIENCY IN NEBRASKA

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Chapter 1

Social and Economic Dimensions

It is the purpose of this chapter to describe the social and economic background of water use efficiency in Nebraska. Included are a brief social and historical perspective on why water use efficiency is being studied and a discussion of what water use efficiency can and cannot be expected to achieve.

While water use efficiency may be viewed initially as intrinsically good, pragmatically it is a means to an end, rather than an end in and of itself. The techniques and policies presented in this report have been evaluated as to how effectively they can improve water use efficiency. But a complete evaluation of their impacts upon the state cannot be made without reference to the larger benefits water use efficiency is hoped to achieve.

Water use efficiency has been a major concern for Nebraskans throughout most of the state's history, but the context in which the concern is expressed today has shifted dramatically over the last thirty years. Throughout most of that history, agricultural dependence upon a climate characterized by sparse and unpredictable precipitation and unreliable streamflows made the efficient use of limited water supplies an indispensable component of the state's agricultural production methods.

From the very beginning, an inadequate supply of water throughout the state was perceived to be one of the major barriers to successful settlement of the region. Over a century and a half ago, Maj. Stephen H. Long traversed the entire length of the state of Nebraska and described it as "**an area of desolate sands and unvaried sterility — thousands of acres of dreary plain**". As one who did more than any other explorer to fix upon Nebraska the reputation that it lay in the Great American Desert, Maj. Long reported:

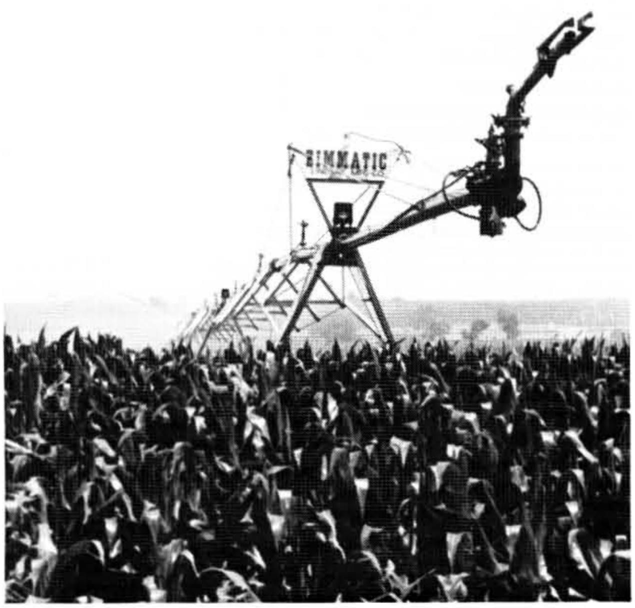
"In regard to this extensive section of the country, I do not hesitate in giving the opinion, that it is almost wholly unfit for cultivation, and of course uninhabitable by a people depending upon agriculture for their substance. Although tracts of fertile land considerably extensive are occasionally to be met with, yet the scarcity of wood and water, almost uniformly prevalent, will prove an insuperable obstacle in the way of settling the country."[15]

If Major Long could retrace his footsteps today, he would find, to say the least, a phenomenal transformation effected upon these "desolate sands."

Encouraged by the Homestead Act and lured by widespread railroad advertising both here and abroad, immigrants poured in from the east in the latter half of the nineteenth century. In those days before irrigation brought relative prosperity and stability to the region, the state's semiarid, western climate rendered even the most determined settler's hold upon agricultural subsistance tenuous in the best of times, impossible in the worst. Conventional "dryland" farming methods employed successfully east of the 100th meridian did not work so well west. Whole communities blossomed over night, only to dissipate just as quickly during periods of frequent and prolonged drought. In the late 1880's and early 90's, a drought struck the Nebraska plains which would test the resolve of all her residents. In 1894, in the midst of a Populist crusade for more silver money, the Callaway Courier of July 13th proclaimed, "**We need rain worse than an increase of**

the currency....The settlers are going out, and most of them do not contemplate returning; the cause is failure of crops on account of lack of rain."

While the successful, early establishmnt of farmsteads and rural communities on the plains of Nebraska can perhaps best be attributed to the temerity and fortitude of the immigrant populations, the dramatic increase in economic vitality and standard of living in the state over the past fifty years can also be attributed to federal assistance in expanding surface water storage and diversion projects, the discovery and tapping of the Ogallala Aquifer, and the subsequent widespread development of irrigation. Over eight million acres of Nebraska cropland are today estimated to be under irrigation, almost 90 percent of which is irrigated with groundwater pumped to the surface from a reserve undreamt of in Stephen Long's day.



According to the U.S. Department of Commerce *High Plains Study*, the expansion of irrigation made possible by the Ogallala Aquifer (70 percent of which lies under Nebraska soils) has been primarily responsible for the growth of the region into an important part of the national economy.[52] The relative abundance of water supplies enjoyed today by the state's agricultural, industrial and domestic interests has almost antiquated the notion that water use efficiency is an indispensable component of our economic survival. In contrast to the critical role it played in the social and economic development of preceding generations, water use efficiency is today regarded as a potential aid in preserving an established and prosperous way of life and for ensuring the most equitable distribution of limited resources among competing interest and succeeding generations.

Taken as a whole, the prospects for Nebraska's irrigated agriculture are bright, with irrigated acreage projected to expand to over 13 million by the year 2020. Bentall has estimated that there remains as much groundwater within the state today as there was before pumping began during the Dust Bowl of the 1930's.[5]

What these state-wide figures do not reflect, however, are local depletion rates, which in some areas of Nebraska are significant. Despite the state's overall abundance, the *High Plains Study* has projected that nearly 1.5 million acres now irrigated in Nebraska will revert back to dryland agriculture over the same next 40 years due to excessive pumping and consequent depletion of the aquifer. Fears as to the economic, social and cultural effects of such losses of irrigated agriculture upon local farming operations and rural communities have bred concern as to what, if anything, the state can do to stem these depletions. And along with the desire for the most equitable and environmentally sound use of the state's surface water supplies, these concerns have provided, in part, the impetus for this study of water use efficiency.

However, improved water use efficiency should not be automatically regarded as an easy answer to complex, state-wide water resources problems. In considering alternative technologies and policies, four significant factors need to be kept in mind.

First, due in part to a prevailing conservation ethic and to the natural regulating function of energy and other production costs, this report does not assume the presence of widespread gross inefficiency.

Second, improved water use efficiency does not always mean a corresponding reduction in depletions. Water which is "saved" on one field, for instance, can sometimes be the source of water used to irrigate another field.

Third, as discussed more fully in Chapter 5, though a reduction in withdrawals can mean a local, on-site water savings, it may or may not mean a corresponding water savings for the state. Though improved water use efficiency can have significant local and regional hydrologic impacts (which may be of state-wide importance), the quantity of water within the state as a whole is not projected to be altered.

Finally, the successful voluntary application of water use efficiency techniques depends on their economic feasibility. Regardless of the hydrologic impact of implementing water use efficiency practices, it is the present and long-term economic impact which is crucial to the local operation, and the aggregate economic impact which can have state-wide social significance.

Chapter 2

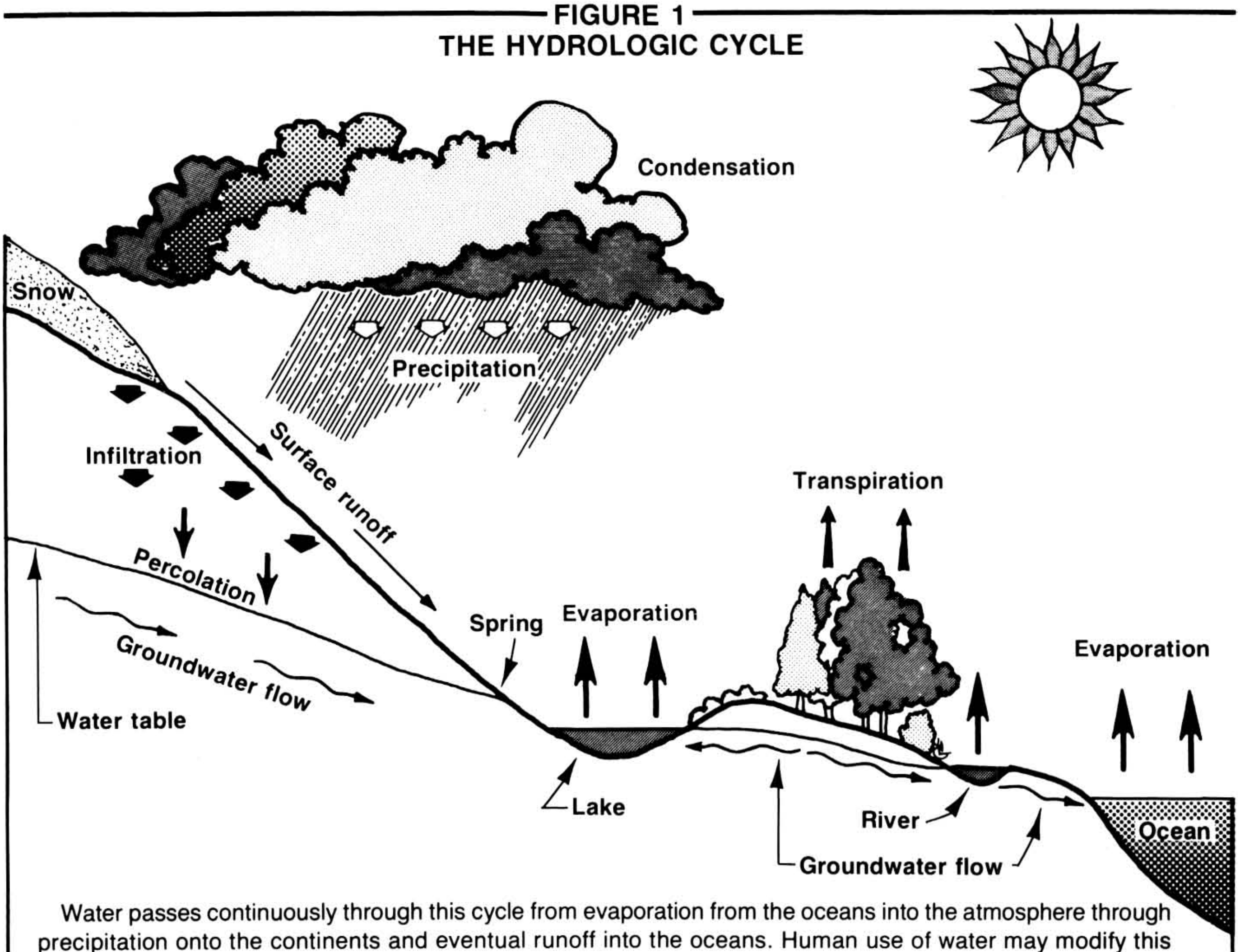
Physical/Hydrologic Dynamics

It is the purpose of this chapter to describe the hydrologic context in which the impacts of water use efficiency techniques are evaluated. Included are a description of the various inter-related components of the hydrologic cycle and a description of Nebraska's surface and groundwater supplies and current level of use.

THE HYDROLOGIC CYCLE

The fundamental concept in the study of water is the hydrologic cycle (Figure 1). The cycle is the conceptual model that relates the interdependence and continuous movements of all forms of water through the vapor, liquid, and solid phases.[43]

FIGURE 1
THE HYDROLOGIC CYCLE



Water passes continuously through this cycle from evaporation from the oceans into the atmosphere through precipitation onto the continents and eventual runoff into the oceans. Human use of water may modify this cycle at virtually every point.

Source: OTA Report [43]

The components of the hydrologic cycle are:

Precipitation: Water added to the surface of the earth from the atmosphere. It may be either liquid (e.g., rain and dew) or solid (e.g., snow, frost and hail).

Evaporation: The process by which a liquid is changed into a gas.

Transpiration: The process by which water vapor passes through a living plant and enters the atmosphere.

Infiltration: The process whereby water soaks into, or is absorbed by, the surface soil layers.

Percolation: The downward flow of water through soil and permeable rock formations to a water table.

Runoff: The portion of precipitation that moves along the land surface by gravity in sheet flow or in surface channels.

The watershed, or river basin, is the fundamental geographic unit of hydrology. It is also the fundamental unit within which technologies to affect water use efficiency generally are assessed. A watershed is a land area surrounded by highlands that cause precipitation falling within the watershed's bounds to flow toward its center to form rivers, streams, ponds or lakes.[43]

PRECIPITATION

Average annual precipitation in Nebraska is estimated at 86 million acre-feet. Regionally, however, the mean annual precipitation varies markedly. In fact, greater climatic variation exists west to east across the state than from eastern Nebraska to the Atlantic coast.[10] In extreme southeast Nebraska, precipitation averages 33 inches as compared with 15 inches annually in portions of the Panhandle.

The primary use of precipitation in Nebraska is for agriculture. Because of limited and highly variable precipitation patterns, considerable irrigation development has occurred across much of the state. However, the relative dependence upon irrigation does vary from area to area. For example, it is not uncommon for natural rainfall patterns to be adequate (or nearly so) for portions of south central and eastern Nebraska; thus, irrigation serves primarily a supplemental role. In contrast, in the more precipitation deficient areas of western and northern Nebraska, the crop dependency upon irrigation water is high in virtually every cropping season.

The timeliness of precipitation during the growing season is a key factor influencing agricultural productivity in any given year. Thunderstorm activity is common throughout the state during the summer

months, with large amounts of rainfall frequently occurring within short time intervals. Interspersed between such events may be extended periods of dry weather and hot winds which can lead to crop stressing. Thus, water use efficiency implies proper management under conditions of temporary excesses as well as moisture deficits, even in those years when precipitation is near normal.

The state receives approximately 86 million acre-feet of water per year by precipitation and approximately one million acre-feet of water by surface flow into the state. Surface flows out of the state are estimated to be about seven million acre-feet annually. And the state loses most of the remaining 80 million acre-feet to the atmosphere through evaporation and transpiration.[5] The remainder percolates into aquifers, either replacing groundwater withdrawals or adding to that already in storage.

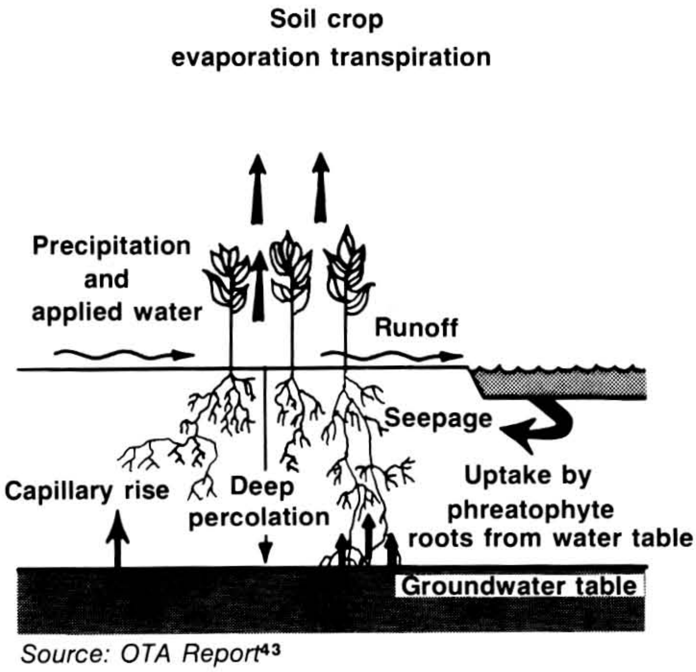
It has been estimated that approximately 14 million acre-feet of water was withdrawn (from surface and groundwater supplies) in Nebraska in 1980[32]. This water was used in the following categories: irrigation (75.2 percent), cooling water for thermoelectric power generation (20.6 percent), rural domestic and livestock watering (1.3 percent), municipal supplies (2 percent), and self-supplied industrial (0.4 percent).

EVAPORATION AND TRANSPIRATION

The term "evapotranspiration" is used to designate the loss of water from the soil by evaporation and from plants by transpiration (Figure 2).[43] The daily rate of transpiration varies with soil water availability, crop and climatic conditions.

FIGURE 2
THE ROLE OF SOIL IN THE HYDROLOGIC CYCLE

Precipitation or applied water infiltrates the soil surface and is used by a growing plant or is lost through evaporation, percolation, or surface runoff. Some water is also added to the soil profile through capillary rise.



Source: OTA Report[43]

Evapotranspiration (ET) exceeds annual precipitation throughout the state. Precipitation in the form of light showers can rapidly evaporate from soil and plant surfaces when temperatures and wind velocities are high and humidity is low.[31] In such instances, little if any moisture contributes to the crop root zone or livestock water supplies.

INFILTRATION AND PERCOLATION

The amount of water on the surface of a watershed which infiltrates into the soil is determined by the permeability of the soil (its ability to receive or transmit water). The permeability of the soil is determined both by the type of soil and by the amount of water already present in the soil.

After initial infiltration, soil water can move downward, upward, and laterally in response to different physical and biological conditions. Water generally moves downward and laterally in response to gravity and the "pull" of unwetted or drier soil particles, although water can also move upward by the process of capillary rise. Upward movement of water occurs where the water table is near the surface, or where fine-textured soils are present that can conduct water upward for considerable distances.

Some infiltrated water will be retained near the surface by capillary forces. Some will move by gravity flow either toward adjacent stream channels where it will appear as either seepage or discharge, or more commonly, downward by percolation to the water table where it will enter into groundwater storage.[43]

Groundwater may result from a number of processes: (a) infiltration of precipitation; (b) seepage through the banks and beds of surface water bodies such as ditches, rivers, lakes and oceans; (c) groundwater leakage and inflow from adjacent aquifers; and (d) artificial recharge from irrigation, reservoirs, water spreading, and injection wells.[43]

There is "misinformation, misunderstanding and mysticism" about groundwater that credits it with occurrence in underground rivers, pools and veins. Groundwater does not occur in pools or channels of the kinds commonly seen on the surface, with a few exceptions, such as in some limestone or basalt formations. Instead, it is found usually in small open spaces, or interstices, of subsurface geological formations of rock or unconsolidated sediment.[43]

Groundwater represents a vast and largely unmeasured natural storage reservoir. Although nearly all rock formations contain some water, formations that yield significant quantities of water are known as "aquifers." The subsurface layers of the earth, below the soil moisture zone, comprise a great reservoir through which water moves very slowly. Its journey underground may be extremely brief or very long. This reservoir acts as a vast natural regulator in the hydrologic cycle, comparable in its effects to the oceans. It absorbs some fraction of the rainfall and snowmelt that would otherwise reach streams and rivers very rapidly as surface runoff, and it maintains streamflow during dry periods when no surface runoff occurs.[43]

Agricultural practices can improve soil-water supplies in several ways. They can help to: increase the amount of water moving into the soil; increase the amount of water retained in the soil; and decrease the amount of water lost in surface runoff, evaporation, and deep percolation.[43]

SURFACE RUNOFF

Where precipitation exceeds infiltration and evapotranspiration, runoff will occur. Water that infiltrates into the soil or percolates to groundwater may ultimately re-appear at the surface as runoff at some point distant from that at which it fell as precipitation. This will be determined by the amount of transpiration losses, which depletes soil water, and by the transmissivity of the rock formations at a given location.[43]

The water supply available in this state in any year is determined partly by the annual hydrologic cycle, but it also includes water that was part of the cycle in geologic history. Most of the runoff is a product of the recent cycle, but some of the groundwater has been in storage much longer.

SURFACE WATER SUPPLY AND USE IN NEBRASKA

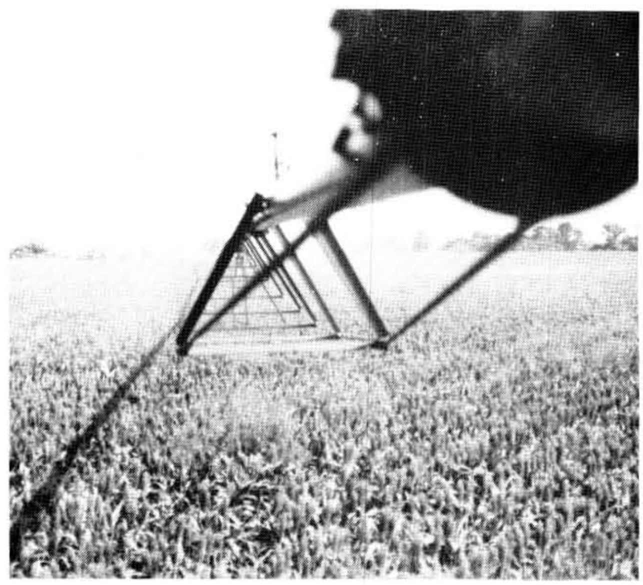
Rivers and streams represent a major portion of the state's surface water. The sources of streamflow are: (a) inflow from adjacent states; (b) overland runoff; (c) releases from reservoirs; and (d) natural seepage, or outflow, from groundwater.[5] The groundwater contribution to streamflow is called a stream's base flow and typically remains fairly constant throughout the year. The Niobrara, North Loup, Middle Loup, and Dismal rivers are noted for their steady flow.[5]

In contrast, those streams relying heavily upon surface runoff will experience highly variable seasonal flow and even interrupted periods. Most of the streams and tributaries of this type are located in eastern Nebraska where overland runoff is greatest due to fine textured soils, hilly terrain, and relatively higher precipitation levels. The Big Blue, Little Blue, and the Big Nemaha and Little Nemaha rivers are examples of the above. Such streams present particular problems in the form of potentially serious flooding as well as

unreliable water sources for domestic, industrial, and agricultural uses (the occurrence of high flows usually does not coincide with high water demands).

The state's principal surface reservoirs (surface acreage of more than 100 acres) have a combined storage capacity of approximately three million acre-feet.[5] Generally, actual storage is significantly less. In addition to the principal reservoirs, there are about 600 man-made reservoirs with surface areas less than 100 acres, 29,000 farm ponds, 300 floodwater retention structures and 300 grade stabilization structures. Most of these smaller bodies exist primarily to retard runoff and control flooding, but also serve other uses such as livestock watering and recreation.

Surface water withdrawals in the state are primarily for irrigation. In 1980, gross surface water withdrawals totaled 5.8 million acre-feet. The distribution by use was: irrigation (49.5 percent); cooling water for thermoelectric power generation (48.6 percent); municipal water systems (1.3 percent); rural domestic and livestock watering (0.4 percent) and self-supplied industrial (0.1 percent).[32]



Irrigation, the primary use of surface water, usually involves impoundments for retaining streamflows for use during the irrigation season. Nearly 60 percent of the acreage under surface water irrigation in water year 1975 was served by either a federal irrigation project or a public power and irrigation project involving impoundments.[5]

In the case of surface water development projects, water use efficiency is adversely affected by water loss in the system en route to the land to be irrigated. However, some of this water loss eventually may augment the groundwater supply and may then be pumped from wells for irrigation and other uses. For example, the water table has risen as much as 90 feet beneath project lands in Gosper, Phelps, and Kearney counties, allowing considerable groundwater irrigation in addition to the project's surface irrigated lands. But groundwater recharge and rising water tables are not always beneficial. Water-logging of cropland and adverse effects of increased flow upon some streams can result (e.g., increased streambank erosion).

Rural domestic use of surface water is relatively minor. However, the accessibility of streams, lakes, and water impoundments for watering purposes is often important for the production of livestock. This is particularly true of range areas. A more comprehensive assessment of livestock watering is given in the *Instream Flows Policy Issue Study.*

As previously noted, only a few Nebraska municipalities utilize surface water in their water systems. The Omaha municipal system is the largest, pumping about 60 percent of its supply from the Missouri River with a supplemental supply coming from well fields near the Platte River.

Thermoelectric power generating plants withdrawing surface water mainly for cooling purposes used an

estimated 2.8 million acre-feet in 1980. Between 80 and 90 percent of this amount was withdrawn from the Missouri River and discharged back to the river.[32]

Relative to other uses, industrial withdrawals are minor. Surface water withdrawals for self-supplied industrial use in 1980 amounted to approximately 8,000 acre-feet.[32]

GROUNDWATER SUPPLY AND USE IN NEBRASKA

Significant groundwater supplies underlie most of Nebraska, resulting in the widespread availability of high-yielding wells. It has been estimated that the ground and surface water systems in Nebraska contain approximately two billion acre-feet of water. This is equivalent to a body of water over 40 feet deep over the entire surface area of the state. Obviously, most of this volume represents water in aquifers (water bearing strata) below the surface. The groundwater area with the greatest volume of storage is the Sandhills region. It is not uncommon for portions of the Sandhills to be underlain with as much as 800 feet of saturated material, equivalent to a water depth of 150 feet or more. Wherever impermeable parent materials area close to the surface, groundwater supply will be limited. This is true in the shale and clay areas of the extreme northwest and portions of the glacial till area of northeastern Nebraska. Availability of high quality groundwater is also limited in parts of south eastern Nebraska.

Currently, approximately 93 percent of the groundwater withdrawn in the state is used for irrigation. It was estimated that in 1980, groundwater irrigation accounted for slightly more than half of the total water usage in Nebraska.[32] The effect of groundwater pumping on the reserves of a particular locality is a function of numerous variables which are further discussed in Chapter 5.

Dryland agriculture has some impacts on groundwater conditions. Cropping and tillage practices designed to retain surface water and promote soil infiltration can, on occasion, result in some aquifer recharge.

Municipal withdrawals of groundwater are estimated at just over three percent of the total groundwater withdrawn.[32] Nearly half the municipal withdrawals occur in southeastern Nebraska, most of which can be attributed to Omaha and Lincoln (please refer to the *Municipal Water Needs Policy Issue Study Report*). Both of these cities utilize well fields near the Platte River. It is noteworthy that these users are pumping a groundwater supply which depends greaty upon Platte River flows, of which a significant amount represents base flow out of the Sandhills region some 250 miles away. This illustrates clearly how the conjunctive aspects of the state's water resources intricately relate regions and uses. The efficiency of distribution systems is also discussed in the *Municipal Water Needs Policy Issue Study.*

Rural use of groundwater for domestic and livestock supplies equals approximately two percent of the total groundwater withdrawn.[32] In most areas of the state, municipal wells yield adequate water supplies both in terms of quantity and in quality. However, in some localities, problems of quantity and/or quality have resulted in the development of rural water districts.

Self-supplied industry utilizes roughly two percent of the total groundwater withdrawn, which, in 1980, equalled approximately 46,000 acre-feet.[32] In that same year, another 28,000 acre-feet of groundwater withdrawn was used for thermoelectric power generation (approximately 0.4 percent of the total groundwater withdrawn).

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Chapter 3

Legal/Institutional Framework Present Laws and Existing Institutions

It is the purpose of this chapter to discuss the existing laws and institutions as they relate to the promotion and/or regulation of efficient water use in Nebraska.

SURFACE WATER LAWS

Before one can use or store water from a stream, appropriation permits must be obtained from the Department of Water Resources (DWR). A permit to divert water directly from the stream for irrigation or any other use is called a natural flow or direct flow appropriation. A storage appropriation must be obtained before water may be stored in a reservoir, and a storage use appropriation permit is necessary before stored water may be used. Neb. Rev. Stat. 46-233, 241, 242 (R.R.S. 1943). It is well established in both case law and state statutes that an appropriation permit does not entitle the holder to appropriate more water than that which can be put to beneficial use. *Enterprise Irrigation District v. Willis*, 135 Neb. 827, 832, 284 N.W. 326 (1939); Neb. Rev. Stat. 46-229 (Supp. 1983); Neb. Rev. Stat. 46-231 (Cum. Supp. 1982). It is primarily through this beneficial use limitation that Nebraska surface water law addresses the water use efficiency issue.

BENEFICIAL USE

Nebraska law provides that the "right to diver unappropriated waters of every natural stream for **beneficial use** shall never be denied except when such denial is demanded by the public interest." Neb. Rev. Stat. 46-204 (Cum. Supp. 1982). What is meant by the term "beneficial use" has not been explicitly defined by the Legislature or state courts. With regard to irrigation, the Nebraska Supreme Court has stated that "many elements must be considered in determining whether water has been put to beneficial use, one is that it shall not exceed the least amount of water that experience indicates is necessary **in the exercise of good husbandry** for the production of crops." *Enterprise*, **supra** at 832 (emphasis supplied); see also Neb. Rev. Stat. 46-231 (Cum. Supp. 1982). The Court has recognized that the amount needed for the production of crops will vary depending on climate, location, soils, and the types of crop grown.

> "In other words, the duty of water may be defined as such a quantity of water necessary, when economically conducted and applied to the land without **unnecessary loss**, as will result in the successful growing of crops... The duty of water is a complicated question of fact which must be determined in accordance with the prevailing custom in the locality where it is used." *Enterprise,* **supra** at 833, 836 (emphasis supplied).

This concept of unnecessary loss, more commonly referred to as the unnecessary waste doctrine, applies generally throughout the Western states. I Hutchins, *Water Rights Laws in the Nineteen Western States* at 489-503, 506-14, 545-56 (1971). In this context, the unnecessary waste doctrine recognizes that some waste of water is inevitable in surface water projects (i.e., conveyance losses from unlined irrigation canals and laterals, evaporative losses, etc.) and in gravity irrigation. This means, then, that a considerable degree of inefficiency is legally allowed. Irrigators traditionally have not been required to use the most efficient methods available. *Tulare Irr. Dist. v. Lindsay-Strathmore Irr. Dist.*, 3 Cal. 489, 45 P.2d 972 (1935). See *Hutchins,* **supra**, at 644-50.

The Legislature has established by statute the maximum amount that can be appropriated by a natural flow appropriator, thereby setting an upper limit on the beneficial use limitation. In 1911 the Legislature enacted a law limiting the rate of withdrawal for natural flow appropriations to one cfs per seventy acres irrigated, not to exceed three acre-feet per acre per year. Neb. Rev. Stat. 46-231 (R.R.S. 1943). This does not apply to storage use appropriations.

This provision was established when irrigation methods were less sophisticated than they are now. The three acre-feet allocation allows irrigators to irrigate fully (when water is available) without having to irrigate efficiently. In the absence of complaints of downstream appropriators, an irrigator as a practical matter can withdraw as much water as he can even though this exceeds the amount authorized in his appropriations during water shortages it limits withdrawals to the rate authorized in the appropriation, generally one cubic foot per second per seventy acres. Often this will increase streamflow to downstream appropriators such that their rights are satisfied. DWR does not enforce the three acre-feet limitation. Therefore, the three acre-feet allocation does not have any impact on the degree of irrigation water use efficiency. However, administration of the rate of withdrawal requires a certain degree of efficiency.

An important issue is whether legislators can require existing surface water appropriators to reduce their water use by increasing their water use efficiency under the concept of beneficial use or through some other legal theory. See Aiken, "Interrelationships Between Water Allocation and Water Quality Management Policies" (UNL Dept. of Ag. Econ. Staff Paper No. 5, 1980). Based on the *Enterprise* case cited previously, it appears the legal ability to reduce quantities of water used by appropriators to enforce water use efficiency requirements pursuant to the beneficial use doctrine has been limited somewhat by the Nebraska Supreme Court.

In that case the Bureau of Irrigation (predecessor agency to the Department of Water Resources) attempted to limit a Scotts Bluff county appropriator's annual natural flow appropriations to three acre-feet per acre irrigated. The appropriation had been acquired in 1889, before the 1911 three acre-feet natural flow irrigation appropriation limitation had been established. The irrigator's appropriation of 3.5 acre-feet per acre had been acquired when the only legal limitations on the quantity of a natural flow appropriation were: (1) no more water could be diverted and appropriated than could be applied to a beneficial use, and (2) that the quantity of water appropriated could not exceed the capacity of the diversion works.

State officials asserted that the three acre-feet per acre irrigated natural flow limitation established the maximum quantity that could be beneficially used for irrigation and should be applied retroactively. The state produced experts who had experimentally grown the same crops grown by the irrigators, and concluded that three acre-feet per acre was an ample quantity of water for irrigation in the region.

However, the Court felt the state's experiments were conducted under very different conditions than those faced by the local irrigators, suggesting that those differences might have accounted for the differences in water use. The Court also noted that there was not direct evidence that the irrigators had wasted water or were not otherwise using the water beneficially. The Court then concluded that the water had been put to a beneficial use "**in the ordinary and recognized methods of applying irrigation water in that section of the state**" and went on to state that, "(n)either is it contemplated nor required that each appropriator should use the latest and most approved scientific method in applying irrigation water to the land." *Enterprise,***supra** at 330, 336 (emphasis supplied).

The Court had this to say regarding the limits of the state's authority to take actions affecting established water rights.

> "While vested water rights may be interfered with within reasonable limits under the police power of the state to secure a proper regulation and supervision of them for the public good, any interference that **limits the quantity of water** or changes the date of its priority **to the material injury** of its holder is more than regulation and supervision and extends into the field generally referred to as a deprivation of a vested right." Id. at 834 (emphasis added).

The Court concluded that the law establishing the three acre-feet per acre irrigated limitation could not be retroactive without unconsitutionally infringing on vested property rights. Accord *Heminghaus v. So. Calif. Edison Co.*, 200 Cal. 81, 252 P. 607, 6212 (1926).

Interestingly, the *Enterprise* case was the same decision in which the Nebraska Supreme Court noted with approval from an earlier decision:

> "It is the evident purpose of the (appropriation) law, taken as a whole, to enforce and maintain a strict economy in the use of the waters of the state. It has been and is the policy of the law in all arid states and territories to require and enforce an economical use of the water of the natural streams. The urgent necessity of the situation compel this policy by the very force of the circumstances. One of the main objects of the system of (appropriative) administration of public waters prescribed throughout the arid regions is to restrain unnecessary waste, and to provide for an economic distribution of that element so necessary to the very existence of agriculture in those regions. This is also the policy of the state

of Nebraska in its regulation of the use of the waters of the state, and the law should be construed so as to effect a reasonable, just, and economical distribution of for irrigation purposes. The court will take judicial notice of the fact that there are hundreds of areas within the state susceptible of irrigation, to every acre which there is water enough to supply, and it is obvious that a construction of the law that will best distribute the use of the waters is to be preferred, if such construction is not inimical to any constitutional inhibitations or limitations." *Enterprise,* **supra** at 328-29, quoting *Farmers' Canal Co. v. Frank*, 72 Neb. 136, 100 N.W. 286, 294 (1904).

This quotation indicates the Court recognized that there are many claims on the limited water resources and that courts should construe the law wherever possible to effect the widest distribution of water. Yet, in spite of this recognition, the Court deferred to local irrigation practices and refused to sanction a legislative act it felt would result in a "material injury" to the holders of existing rights.

The *Enterprise* opinion does not necessarily present an absolute bar to legislatively requiring existing surface water users to adopt improved irrigation practices. Judicial attitudes toward the acceptable limits of the state's police power have changed considerably since 1939, the year the *Enterprise* decision was handed down. In 1939, the Court felt the evidence showed that applying the three acre-foot limitation would result in material injury to the appropriators involved and was therefore unconstitutional. Whether the Court, siting in the 1980's or 1990's and presented with a different set of facts, would be as likely to find a law requiring the use of improved irrigation practices by existing users unconstitutional is open to question.

APPROPRIATION TRANSFERS

A common feature of prior appropriation law is the appurtenancy doctrine: any water right acquired may be applied only to the land described in the appropriation permit. The appropriator acquires the right to use a specific rate of flow on a specific tract of land. I *Hutchins,* **supra**, at 489-91, 454-68. Water saved through improved irrigation practices cannot be used on additional land without obtaining and additional apprpriation which normally would have a later priority date. *Salt Water Valley Water Users' Ass'n v. Kovacovich*, 3 Ariz. App. 28, 411 P. 2d 201 (1966). See Dickinson, *Installation of Water Saving Devices as a Means of Enlarging an Appropriative Right to Use Water*, 2 Nat. Res. Law 272 (1969); 46 Ore. L. Rev. 243 (1967). Because an additional appropriation is required and because water is allocated on the basis of "first in time is first in right," the irrigator is likely to lose the water he has saved to intervening appropriators. See Aiken, *The National Water Policy Review and Western Water Rights Law Reform*, 59 Neb. L. Rev. 327, 331n25 (1980).

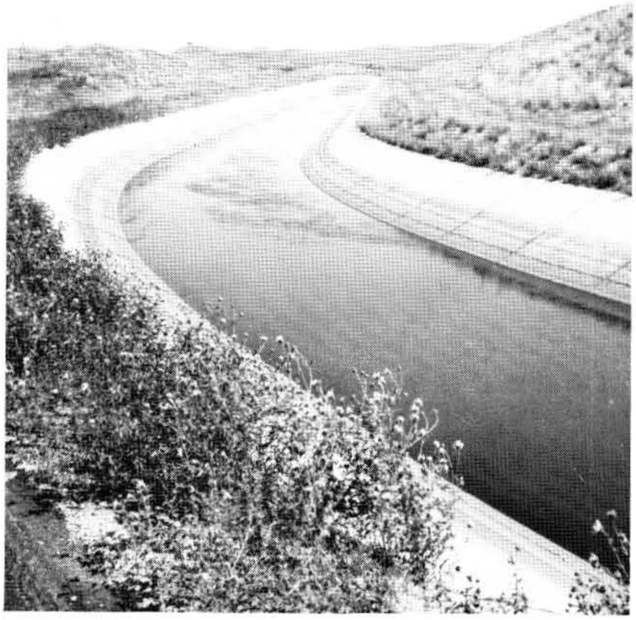
The justification for prohibiting the use of water saved through improved irrigation practices is the protection of downstream appropriators. As noted above, when water is used for irigation, some is evaporated and some is transpired by the crop. Some ultimately returns to the stream as return flow, either as overland runoff or as deep percolation to the groundwater aquifer which is feeding the stream. If an appropriator is allowed to increase the number of acres he can irrigate with a fixed quantity of water, this will result in reduced return flow. In other words, the consumptive use of water may be increased at the expense of downstream appropriators and instream flow users.

Under a law enacted by the Nebraska Legislature in 1983 and amended in 1984, surface water appropriations may be transferred to another site within the same river basin for use with DWR approval if the new use is in the same preference category as the original use and certain other requirements are met. Neb. Rev. Stat. 46-290 to -294 (Supp. 1983). The requested change in location must not harm any other appropriator or objecting riparian, the water to be withdrawn must be from the same source of supply, the change in location must not diminish the supply of water otherwise available, and the transfer must be in the public interest.

The legal authorization to transfer surface water rights will enable appropriators to transfer water rights to land better suited for irrigation and may promote improved water use efficiency. Whether this law will also enable appropriators to apply water saved through the use of improved irrigation practices on additional lands is unclear at this time. The Department of Water Resources has not been presented with an application involving this type of transfer and has not yet ruled on the issue.

SURFACE WATER APPROPRIATIONS FOR UNDERGROUND STORAGE AND RECOVERY

In 1983 the Nebraska Legislature passed LB 198, authorizing surface water appropriators to store water underground and granting the appropriator the right to charge for the recovery of that water. Two types of storage were recognized in the act — intentional and incidental. Intentional storage includes recharge accomplished as a planned result of a project through the leakage of water from canals and reservoirs in addition to the use of injection wells, infiltration basins and other reasonable methods. Incidental storage occurs as an indirect result of an existing project and includes seepage from reservoirs, canals and laterals and the deep percolation of water applied to irrigated lands. Neb. Rev. Stat. 46-296 (Supp. 1983). Only appropriators having rights perfected as of the effective date of the act may obtain rights for water stored incidentally. **Id**. at 46-226.01.



In this act the Legislature explicitly recognized that the seepage of water from reservoirs, canals and laterals and the over application of water on irrigated lands can be a beneficial use of surface water since it can recharge groundwater supplies. To the extent it can be shown that the storage of groundwater has occurred, the Legislature has condoned the "inefficient" use of surface water. See, **Id.** at 46-295. It has even gone a step further and encouraged project operators to include the seepage of surface water into new project designs by authorizing the operators to charge landowners who benefit from the recharge. **Id.** at 46-299.

MISCELLANEOUS PROVISIONS

There are a variety of other relatively minor statutory provisions which may encourage improved surface water use efficiency to some degree. Any person storing or using water via a ditch, canal or reservoir must install a measuring device at the request of DWR. Neb. Rev. Stat. 46-256., See also Neb. Rev. Stat. 46-258, -261. However, measuring devices have been required to facilitate appropriation adminstration, not to monitor water use efficiency requirements. Owners of irrigation ditches or canals must maintain their embankments to prevent water waste. Neb. Rev. Stat. 46-265. Owners of power or irrigation ditches, canals or laterals must construct and operate the ditches, etc. to prevent water from overflowing onto a public road. Neb. Rev. Stat. 46-266. Violation of this requirement is a misdemeanor (0-$100 fine upon conviction). Neb. Rev. Stat. 28-106(1).

GROUNDWATER LAW

REASONABLE BENEFICIAL USE

Landowners in Nebraska generally are entitled to the reasonable and beneficial use of groundwater underlying their land. Neb. Rev. Stat. 46-656, *Olson v. City of Wahoo*, 124 Neb. 802, 248 N.W. 304 (1933). See generally Aiken, *Nebraska Ground Water Law and Administration*, 59 Neb. L. Rev. 917 at 975-86 (1980). What constitutes a reasonable and beneficial use has never been addressed by the State Supreme Court or the Legislature, but probably includes use without waste. Whether "waste" in this context means "unnecessary waste" as described above is also unclear.

GROUND WATER MANAGEMENT AND PROTECTION ACT

Three alternatives are available under the Ground Water Management and Protection Act (GMPA) to administratively require a higher degree of irrigation water use efficiency: (1) irrigation runoff control requirements, (2) groundwater control area regulations, and (3) groundwater management area regulations.

Irrigation Runoff Controls. Each person using groundwater for irrigation must control or prevent irrigation water runoff. Neb. Rev. Stat. 46-664(1). Natural resources districts (NRDs) are required to adopt regulations to control groundwater irrigation runoff, and are authorized to enforce runoff control regulations. **Id**. at 46-664(2), (3). Runoff controls typically are enforced on a complaint basis. If a landowner is receiving unwanted irrigation runoff from another person's property, he can complain to the NRD. The NRD will investigate the complaint to determine whether improper runoff has occurred. If so, the NRD will so inform the irrigator. If the irrigator does not voluntarily comply with NRD runoff regulations, the NRD can hold a hearing to determine whether runoff controls have been violated. If a violation has occurred, the NRD can order the irrigator to comply with runoff control requirements. A common irrigation runoff control practice is to install a reuse pit to catch runoff before it leaves an irrigated field. Typically NRDs will share the cost of reuse pit installation with the irrigator. State and federal cost sharing assistance may also be available.

Although not part of the GMPA, road damage caused by irrigation runoff, spray from sprinkler irrigation systems, or other irrigation practices is a misdemeanor (0-$100 fine upon conviction). Neb. Rev. Stat. 39-703, 28-106. An irrigator would not be guilty, however, if the road damage resulted from equipment malfunction or if the damage would not have occurred under normal weather conditions. Sprinkler irrigation systems must be equipped to automatically shut off the end-gun if the system sprinkles the road. Neb. Rev. Stat. 39-703.01. Violation of the end-gun shutoff requirement is a misdemeanor ($100-500 find upon conviction). Neb. Rev. Stat. 28-106(1).

Groundwater Control Areas. Groundwater control areas may be designated by the DWR director (at NRD request) if the director determines that groundwater development and use have caused or are likely to cause groundwater depletion or pollution. Neb. Rev. Stat. 46-658. Once a control area has been designated, the NRD may, with DWR approval, restrict groundwater withdrawals. **Id.** at 46-666. In adopting and approving groundwater controls the NRD and DWR must consider whether the controls will "encourage a high degree of water use efficiency." **Id.** at 46-666(2), (3). Establishing groundwater allocations (i.e., restricting groundwater withdrawals) in groundwater control areas is a powerful tool available to NRDs to require improved irrigation water use efficiency. To date, however, only three control areas have been designated, and only one is enforcing groundwater allocations. See 59 Neb. L. Rev., at 962-67.

NRDs are authorized to establish different groundwater allocations for irrigators depending on the type of irrigation system they use. However, this two-tiered allocation system may only be in effect for five years. Neb. Rev. Stat. 46-666(5) (Supp. 1983). This authorization was added to the law in 1983 at the urging of the Upper Republican NRD, the one NRD to enforce groundwater allocations in its control area. Before the use of the two-tiered allocation system was authorized, the Upper Republican NRD had adopted allocations high enough to allow gravity irrigators to maintain full irrigation if they used efficient practices. However, the NRD felt the allocations were overly generous to sprinkler irrigators since their systems generally are more efficient than gravity systems. Consequently, the sprinkler irrigators were under little, if any, pressure to improve their efficiency. The Upper Republican NRD has now put a two-tiered allocation system into effect and set its groundwater allocations for sprinkler systems at a lower level than for gravity systems.

As noted earlier, the two-tiered allocation system must end after five years. At that time the NRD will be faced with the difficult decision on whether to establish its single allocation for all groundwater irrigators at a level which requires both sprinkler and gravity irrigators to adopt efficient practices, which will put gravity irrigators at a possibly severe disadvantage, or whether to return to a higher allocation which allows gravity irrigators to continue full irrigation using efficient practices but does not require improved efficiency for those using sprinkler systems.

Groundwater Management Areas. The GMPA was amended in 1982 to allow NRDs to establish groundwater management areas after preparation of a groundwater management plan. The act was amended again in 1984 to require all NRDs to prepare groundwater management plans by January 1, 1986. The plans must contain, among a number of items, a "groundwater aquifer life goal"; i.e., the "definite or indefinite period of time which (a NRD) establishes as its goal for maintenance of the supply of water in a groundwater reservoir at the time a groundwater management plan is adopted." Neb. Rev. Stat. 46-657(13). If a management area is established, the NRD must adopt groundwater regulations, including restrictions on use, to implement the reservoir life goal. These restrictions may include groundwater allocations to require improved irrigation water use efficiency. No management plans have been completed, and no management areas have been established at this writing.

OTHER STATE LAWS

NEBRASKA SOIL AND WATER CONSERVATION ACT

In 1977, the Legislature established the Nebraska Water Conservation Program (changed to the Nebraska Soil and Water Conservation Program in 1983) to provide up to 75 percent cost-share assistance to private landowners to help them install on-farm water

conservation practices. Neb. Rev. Stat. 2-1581 (R.R.S. 1943). Eligible practices under the act include irrigation reuse pits, grassed waterways, small water impoundments, windbreaks, terraces, terrace outlets and diversions. Almost $7.4 million has been appropriated for the program by the Legislature for FY 1978-79 through FY 1984-85.

NEBRASKA RESOURCES DEVELOPMENT FUND

The Nebraska Natural Resources Commission (NRC) is authorized to provide grants and/or loans (loans are required if the project or program generates revenue) from the Nebraska Resources Development Fund to projects or programs undertaken by state agencies or political subdivisions to promote, among other things, soil and water conservation. Neb. Rev. Stat. 2-3272 (R.R.S. 1943). Eligible projects related to improving water use efficiency include irrigation project system rehabilitation.

NEBRASKA ENVIRONMENTAL PROTECTION ACT

Over-irrigation can result in groundwater pollution through the leaching of water soluble agricultural chemicals into groundwater supplies. Groundwater pollution is prohibited by the Nebraska Environmental Protection Act. Neb. Rev. Stat. 81-15061(1); -1502(21). Implementing these provisions has led to an agreement to require irrigation scheduling in the proposed Norden reclamation project. See Aiken, *National Water Policy* at 333.

INSTITUTIONAL FRAMEWORK

This portion of the chapter will discuss the programs offered by governmental agencies to promote water use efficiency. Ultimately control for the efficient use of water falls to the individual and there exists a range of flexibility in choice of techniques. Programs of a number of governmental agencies and private interests guide the decisions of the individuals and are at least as significant as formal regulations in affecting water usage. These programs can be divided into several components including: (1) data collection; (2) research and technology development; (3) technology transfer and technical assistance; and (4) financial assistance.

DATA COLLECTION

The most basic need in the development of any investigation or program is an understanding of the present condition. As such, data gathering is accomplished by all agencies and university units as well as private industrial concerns. However, several governmental agencies have major programs in this area. A few examples of such programs are provided below.
water and related resources and deveops a soil and water conservation program based on the appraisal. It has primary responsibility for the national cooperative soil survey; heads a national inventory and monitoring activity; and makes and coordinates snow surveys for water supply forecasting. The water-related activities of the U.S. Geological Survey (USGS) include collecting, evaluating and distributing water quantity, quality, and use data, generally in cooperative agreements with state agencies. In cooperation with the State Department of Water Resources, they help conduct the stream gaging program. USGS measures groundwater levels, movement and supply, and samples wells and streams for water quality parameters. They also inventory water use and publish several reports.

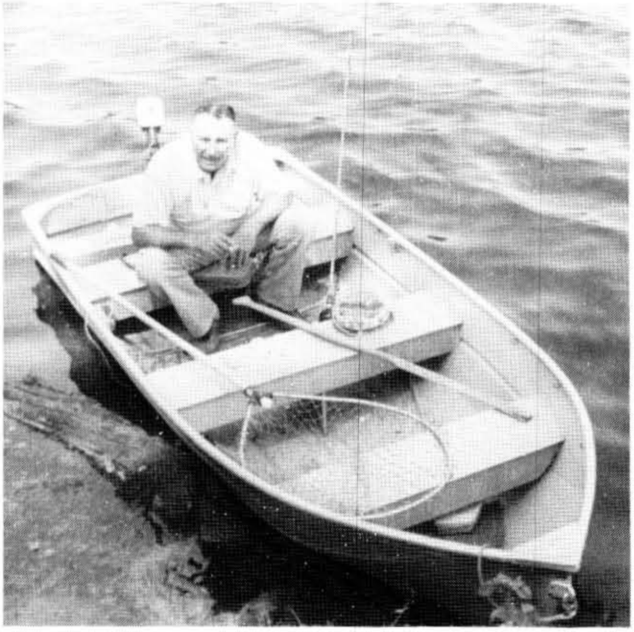
The Natural Resources Commission administers a data bank through which natural resources information of various types is available to state, federal and local agencies, professionals and the general public at minimal cost. The Department of Water Resources registers all groundwater wells and the Conservation and Survey Division publishes information on water supply, quality, and usage.

RESEARCH AND TECHNOLOGY DEVELOPMENT

Research for the development of new technologies is carried out by governmental agencies, university departments and private industry. In addition to product development or redesign, research is also concerned with the possibilities for and effects of water use.

The U.S. Geological Survey conducts research in hydraulics and hydrology as well as water-related mineral, energy or land resources research programs. The Bureau of Reclamation has a program investigating weather modification, and the Fish and Wildlife Service activities include operating cooperative fish and widlife reserach units at universities.

The Game and Parks Commission conducts studies to determine the quantity and quality of water needed to sustain Nebraska's fish and wildlife.



In those areas where groundwater supplies are dwindling, the Department of Water Resources may conduct hearings and investigate the need to establish a control area. The UNL Conservation and Survey Division, the Natural Resources Commission and the Department of Environmental Control are required to give testimony at these hearings.

University researchers and private industrial concerns conduct research including the development of new water-conserving plant hybrids and improvements in irrigation equipment design or practices. Seed companies have developed ornamental plants and grasses more adapted to arid climate landscaping, and new water saving devices for the home are available in the hardware stores.

Natural resources districts are presently working with the Soil Conservation Service (SCS) on a study to determine the economic consequences related to soil erosion.

TECHNOLOGY TRANSFER AND TECHNICAL ASSISTANCE

Nearly all water-related governmental agencies and many private concerns offer some technical assistance or programs of technology transfer to promote new products or methods.

The Soil Conservation Service plans and carries out a soil and water conservation program in cooperation with federal and state agencies and natural resources districts; provides technical assistance to individuals, groups, organizations and units of government (including designing dams, ponds, terraces, sediment basins, increasing irrigation efficiency and other soil and water conservation practices). In addition the SCS provides assistance to owners and operators of rural land to install and maintain best management practices and gives technical assistance for participants in the conservation credit program of the Farmers Home Administration. The SCS also provides technical assistance in land use planning to communities and units of government and helps them obtain needed technical data on land, water and related resources. The Corps of Engineers and the Bureau of Reclamation provide engineering, economic and hydrologic expertise in the development of water and power projects.

Through its staff the Natural Resources Commission (NRC) is responsible for soil and water conservation, comprehensive water resources planning, flood prevention and control, and watershed protection. NRC has the authority to develop water resources projects dealing with water quantity and quality, but acts primarily as a funding agency. The Department of Environmental Control (DEC) is the designated state agency for implementation of the state's 208 water quality plan. The plan encourages the prevention of runoff and influences land management practices which may thereby affect water usage. The Department of Health (DOH) reviews plans and specifications for new construction, issues permits and trains operators for public water systems. Although the primary concern for these permits is to protect water quality, system design is also reviewed.

Natural resources districts provide technical assistance in various conservation programs, primarily windbreaks. They also work closely with the local SCS offices in providing assistance on terracing, reuse piits and other land shaping projects. In districts where control areas have been established, NRD staff assist local operators with irrigation scheduling programs. The NRDs also carry out educational and informational programs designed to increase awareness within the districts of conservation programs and practices available (i.e., public service announcements and newsletters).

The Cooperative Extension Service is charged with delivering research information to the people of the state. County extension agents, along with district and state specialists, use individual conferences, public meetings, field days, publications and the mass media to disseminate information.

FINANCIAL ASSISTANCE

The ability to adopt and apply new techniques may require financial resources, and government agencies often administer loan and grant programs providing financial assistance. The following is an example of these programs.

The Agricultural Stabilization and Conservation Service (ASCS) funds practices designed to help farmers conserve water and prevent erosion. Under the Agricultural Conservation Program, ASCS pays up to 75 percent of the cost of building dams, terraces, waterways, irrigation measures and other practices which help prevent erosion and keep sediment out of streams. In some cases the Soil Conservation Service provides financial assistance. The Bureau of Reclamation is not only a technical, but also a financial assistance agency. Water-related activities of the Bureau include developing water and related resource projects (especially irrigation projects), and administering small reclamation project loans. The Fish and Wildlife Service conducts many water-related activities including administering cost-sharing funds for state-led fish and wildlife management.

The Natural Resources Commission administers the Water Conservation Fund (a cost-sharing program for terraces, waterways, small dams, etc.) and the Nebraska Resources Development Fund. These funds provide grants and loans to fund practices which help conserve water and prevent erosion.

In addition to state and federal cost-sharing assistance programs, local natural resources districts also provide financial assistance for conservation practices. For example, during a recent 12-month period, NRDs invested $1.8 million for cost-sharing programs throughout the state.

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Chapter 4

Constraints on Improved Water Use Efficiency as Perceived by Nebraska's Water Users

It is the purpose of this chapter to present the results of four surveys conducted to obtain water user perceptions of water use efficiency issues. These surveys may shed some light on public attitudes regarding water use efficency issues. If alternatives are "targeted" to resolve both the physical and institutional problems as perceived by water users, the chances for effectively dealing with these issues may be improved.

Included are:

(1) A non-scientific public opinion survey of Nebraska's water managers conducted by the Nebraska Water Resources Center;

(2) A scientific public opinion survey of School Creek Watershed residents (northern Clay and northwestern Fillmore counties) regarding a number of issues and concerns, including water use efficiency, sponsored by the Upper Big Blue Natural Resources District, conducted by Selection Research, Inc. (SRI);

(3) A scientific, state-wide public opinion survey conducted in 1981 regarding various conservation planning issues in Nebraska, including water use efficiency, sponsored by the Nebraska Association of Resources Districts (NARD) and the Soil Conservation Service, conducted by SRI; and

(4) A scientific public opinion survey conducted in 1980 of 700 Sandhills residents regarding natural resources issues in that part of the state, sponsored by the Natural Resources Commission and NARD and conducted by SRI.

WATER USE EFFICIENCY SURVEY

(Neb. Water Resources Center)

In January, 1980, the Nebraska Water Resources Center conducted a non-scientific public opinion survey by mail to determine what factors either encourage or discourage efficient water use among Nebraska's water managers. The survey respondents were stratified into four groups: farm managers, surface irrigators, manufacturers, and energy producers.

By and large, respondents from all stratified groups felt that water was a "**very important**" factor to the success of their operations.

The extent to which various factors were perceived as restricting water use differed among the four user groups. "Availability of water" seemed to restrict the operations of surface irrigators more than any other user group. Governmental regulations at the federal, state and local levels did not appear to appreciably affect the water use of any group. "Energy costs" seemed to "somewhat restrict" water use of farm managers, but affected the other groups to a lesser degree. Overall, water quality and technical limitations did not emerge as having an appreciable impact. Two respondents in the manufacturing group cited "water costs" as somewhat restrictive. In summary, none of the factors was cited as obvious restrictions for any group, except for water availability — cited as ranging between severely and somewhat restrictive for surface irrigators.

For all groups, "non-governmental" factors (defined by the respondents as energy/water costs, supply, etc.) were cited most often as influencing changes to improve efficiency. A number of farm managers also marked "federal incentives." Whereas some farm managers and surface irrigators felt that government incentives (i.e., cost-sharing) had a role in water use efficiency decisions, some manufacturers felt that "government discouragement" (e.g., regulations, financial disincentives) was an incentive to adopt conservation practices.

The majority of farm managers and surface irrigators indicated that changes could be made to improve the efficiency of their water use; however, most manufacturers felt that changes could not be made. Energy producers were about evenly divided, with the majority indicating that changes could be made.

When asked what precluded efficiency changes from being implemented, "non-governmental" factors comprised the single item cited most often by each group. However, an absence of governmental incentives — especially federal — was an apparent concern of farm manager respondents.

In summary, the cost of pumping water appears to be the major incentive for more efficient water use, and the cost of new technologies appears to be the major deterrent. Government incentives appear to be helpful in assisting users to become more efficient; but, according to many, may not be extensive enough to be effective.

SCHOOL CREEK WATERSHED SURVEY

(Upper Big Blue Natural Resources District)

In April, 1980, the Upper Big Blue Natural Resources District contracted with Selection Research Center, Inc. (SRI) to conduct a survey of School Creek Watershed residents (northern Clay and northwestern Fillmore counties), "to assess the community's opinions on a number of Upper Big Blue issues and concerns." Major conclusions of the survey with respect to water use efficiency include:

(1) "The soil and water conservation elements are the most preferred of the NRD programs and should be advocated in NRD materials."

(2) "There is no strong support for large water control dams as compared to small farm ponds as a means of water control. There is a strong belief, however, in NRD programs of soil conservation, water pollution control, irrigation scheduling, flood control, and groundwater recharge. If other technical data show that large dams would more effectively and efficiently achieve the goals of these programs, an education program through newsletters and newspapers would be necessary to win public support."

STATEWIDE STUDY FOR CONSERVATION PLANNING

(Neb. Assoc. of Resources Districts/Soil Conservation Service)

In the Spring of 1981, SRI, under joint contract with the Nebraska Association of Resources Districts (NARD) and the USDA Soil Conservation Service (SCS), conducted a survey centering around various issues related to conservation planning in Nebraska. Listed below are summary statements supported by the research which may be appropriate for consideration in the development of water use efficiency policy alternatives.

(1) A large majority of Nebraskans believe that programs and activites designed to help Nebraskans conserve natural resources are going to be of greater importance five years from now than they are today (1981).

(2) The primary natural resource concerns of today center on energy cost, cost of applying conservation practices to land, groundwater quantity, surface water supply, and soil erosion. The major concern is maintaining the groundwater supply. Twenty-four percent of the respondents felt there should be regulation of wells and irrigation.

(3) Almost 80 percent of Nebraskans believe that it is appropriate to use tax dollars to encourage conservation of resources and are more likely to belive that too little rather than too much is being spent for conservation.

(4) Of the conservation programs and activities that are currently funded by tax dollars, Nebraskans feel that those dealing with monitoring groundwater supply and quality, tree planting, conservation education, and conservation tillage are the most important.

(5) Although conservation and education programs and activities are important to farmers and ranchers, conservation technical information and education specific to their land is less likely to encourage them to apply conservation practices on their property than better market prices for their products, simpler procedures for participating, increased cost share dollars, or low interest loans.

(6) Simplifying procedures for farmers and ranchers to participate in conservation programs and activities is likely to encourage participation, especially among smaller farmers and ranchers. This controllable alternative (as opposed to increased market prices for agricultural products which are not controllable) has the lowest cost of the alternatives presented.

(7) Sixty-one percent of the farmers and ranchers say they are somewhat likely or very likely to apply conservation practices on their land in the next five years. The land affected by those practices would be approximately 53 percent of their total land holdings, averaging 388 acres per farmer.

(8) Metro residents have as high a concern for the future of Nebraska natural resources as rural residents and are more willing to pay, through taxes, for conservation programs than are rural residents.

SANDHILLS RESIDENTS SURVEY

(Natural Resources Commission/Natural Association of Resources Districts)

In 1980, SRI, under contract with the Natural Resources Commission and the Nebraska Association of Resources Districts, conducted a public opinion survey of 700 Sandhills residents regarding natural resources issues in that part of the state. Specifically, the purposes of the study were: "to assess the perceptions and attitudes held by the residents of the Sandhills region regarding existing or potential problems concerning groundwater quality and quantity, wind and water erosion, surface water quality and quantity, wildlife habitat, and general area economy; evaluate opinions on desired land use or degree of...development; analyze public sentiment concerning public policy alternatives which address problems caused by irrigation development." Few items of the survey related specifically to water use efficiency; however, other facets were analyzed which are appropriate for consideration in the development of policy alternatives, namely, public opinions on institutional arrangements for water resources management.

The SRI anaysis of respondents' attitudes on regulation concluded that:

> "...it seems people will accept local regulations on Sandhills natural resources, but are not sure of the specific means of control. This can be considered either good news or bad news. From the positive perspective the study results indicate that Sandhills residents would be accepting of local regulation. The bad news is that no specific programs can be implemented that will have immediate appeal unless an effort is first made to increase acceptance by stressing the local nature of the program/problem being handled by a local organization. This effort would most likely be along the lines of educational programs addressing relevant concerns...."

CONCLUSIONS AND INFERENCES OF SURVEY RESULTS FOR DEVELOPMENT OF WATER USE EFFICIENCY POLICIES

Even though most of the surveys analyzed in this section addressed a wider scope of resource issues than just water use efficiency, some tentative conclusions can be made which may assist in the development of alterntive legislative and administrative policies dealing with water use efficiency concerns. These conclusions are listed below:

(1) According to the survey of water managers (Water Resources Center) the availability of water seemed to be the greatest constraint in achieving water use efficiency among surface irrigators. For farm managers, manufacturers and energy producers, however, water availability was cited as constraining, but not to the degree experienced by surface irrigators. Other factors (e.g., energy costs or regulations) seemed to "somewhat" restrict the attainment of efficiency.

(2) "Non-governmental" factors (i.e., energy costs, cost of equipment and improvements) were cited most often as constraining water users from improving efficiency, according to the WRC water managers survey. Other factors, such as governmental incentives and disincentives, did not appear to appreciably affect efficiency improvement decisions.

(3) According to the NARD/SCS survey, the major natural resources concern among Nebraskans is maintaining the groundwater supply. Twenty-four percent of the respondents felt that wells and irrigation should be regulated. Respondents felt that tax-funded programs monitoring groundwater quantity and quality are important.

(4) The NARD/SCS survey also found that 80 percent of Nebraskans believe that it is appropriate to use tax dollars to encourage resource conservation and are more likely to believe that too little is being spent for conservation.

(5) The SRI Sandhills survey found that if regulation were necessary to protect the area's natural resources, local government (especially NRDs) is the most appropriate arena to implement a regulatory program.

(6) The School Creek Watershed Survey (Upper Big Blue NRD) indicated that a clear majority of respondents felt that programs relating to water use efficiency — especially conservation education and irrigation scheduling — are appropriate functions of natural resources districts. The SRI Sandhills survey found that 70 percent of the respondents felt that irrigation scheduling was

an effective means for promoting water use efficiency.

From these generalizations, some inferences can be drawn which might guide the development of policy alternatives that encourage greater efficiency in water use. The major inferences are:

(1) **Financial incentives**. Because a major barrier to attaining efficiency seems to be the high cost of improvements, state and local governmental financial incentives may be helpful in alleviating some burdens. In fact, financial incentives appear to be perceived by water users as the keystone of public actions taken to improve efficiency.

(2) Although **educational programs** may assist water users in becoming better stewards of natural resources, these programs should not be relied upon as the sole methods of promoting wiser resource use.

(3) **Government regulation** may be publicly acceptable in some instances, perhaps only when problems appear especially imminent. If regulations are to be imposed, local governments (i.e., natural resources districts) were judged by survey resondents as perhaps the best level for implementation.

(4) Natural resources districts also were felt to be appropriate agencies to deliver governmental, educational and technical services to water users.

Chapter 5

Introduction of Terms and Concepts

It is the purpose of this chapter to introduce the terms and concepts used in Sections II and III of this report to describe the impacts of improved water use efficiency. Two different kinds of impacts are described — local, on-site impacts of alternative techniques (Section II) and state-wide, aggregate impacts of alternative policies (Section III).

To the individual user, the goal of any efficiency technique may be to reduce withdrawals and thus make the operation more profitable, today and into the future. The impacts at this local level are fairly straightforward and are addressed, generally, in Section II of the report.

An assessment of state-wide impacts is more difficult, as the complex relationships which exist between the source of supply and the destination of water after it is used do not always allow individual reductions to be additive. Generally, these state-wide impacts are addressed in Section III under the discussion of alternative policies which may promote state-wide efficiency among a large number of water users.

CONCEPTS USED IN DESCRIBING IMPACTS OF ALTERNATIVE TECHNIQUES

Included under each technique in Section II is a brief discussion of the expected physical/hydrologic, social/economic, and environmental impacts of implementing the technique on a local level.

PHYSICAL/HYDROLOGIC CONCEPTS

Physical/hydrologic impacts of water use efficiency techniques are discussed primarily in terms of the components of the hydrologic cycle described in Chapter 2. Before discussing the physical/hydrologic impacts, however, it is necessary to define several other terms as well.

First, it would be well to reemphasize the definition of water use efficiency. As used in this report, water use efficiency refers to the maintenance of given water-related benefits, while reducing the amount of water applied or diverted to produce those benefits.

Consumptive use is the portion of water that is stored, withdrawn, or diverted from its source that is evaporated, incorporated into a product, or reduced in quality to the point where the water is unfit for future use. This term commonly refers to a class of water use that returns relatively less water to the source than others. Neither this classification nor the opposite is absolute.

Productive consumption is that portion of consumptive use that is required to maintain a desired level of output. The amount of productive consumption is subject to change with changes in technology.

Non-consumptive use is the amount of water that is used in a stream or lake, or withdrawn or diverted and returned to the source, without substantially reducing the supply of water or degrading the quality of the water to the point it cannot be reused. This term commonly refers to a class of use that generally changes the quantity of water in the source very little. Some uses are considered non-consumptive because they occur in streams, lakes and reservoirs. These include generation of hydroelectric power, navigation and

recreation. Other non-consumptive uses require diversion or withdrawal of the water from the source, but the percentage of return remains relatively high. In

Nebraska, some hydroelectric power plants are considered to be in this category.

Recoverable loss is that water which is lost to the current users, but which can be recovered and used at a later time or by another user in the state. It is essentially an economic loss to the user.

Irrecoverable loss is that water which is lost to the current user, and which cannot be recovered and used at a later time or by another user in the state.

Evapotranspiration is an irrecoverable use of water. A certain amount of ET is essential for plant growth and crop production; however, excessive or unnecessary ("luxury") ET represents an irrecoverable loss.

Deep percolation may or may not be recoverable. It is recoverable when the water is available for future pumping at a reasonable cost. However, if the water proceeds to a depth that is beyond feasible pumping, or it becomes a carrier for dissolved solids or gases which make it unfit for future use, or if it is located in such an area that it cannot be pumped (i.e., under a city), then deep percolation is an irrecoverable loss.

Runoff can also be either a recoverable or an irrecoverable loss. In those cases where the runoff water enters a stream or impoundment and is available for use, then runoff is classified as recoverable. Runoff losses are irrecoverable to the state when the water becomes a carrier of dissolved solids and gases that make it unfit for future use or when the water fows out of the state. Water treatment facilities may reduce the pollutant load to the point that the water is again useable. Water flowing out of the state may not necessarily be lost to the hydrologic basin, but may be a loss to the state.

Return flow is water in excess of a water user's needs or water that has served a use and is returned to some natural watercourse. Examples are excess water that has passed through an irrigation district's main canal system and must be disposed into a stream, or effluent from an industrial plant or municipality that eventually is returned to the stream.

Conveyance system is any means of carrying water from the point of diversion or withdrawal to the on-site use. For example, the facilities used to divert and transport water from a stream or aquifer to a farm comprise the conveyance system.

On-site use takes water from the conveyance system and applies it for some intended purpose. The on-site delivery system includes the connection to the conveyance system, individual distribution system, application system, and the outflow system.

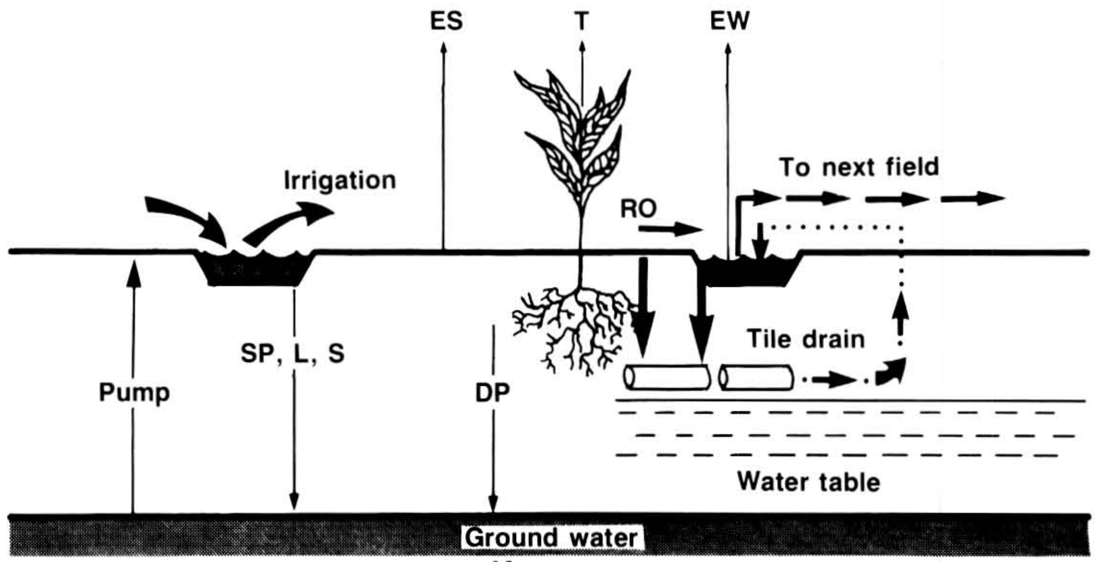
DESTINATION OF WATER

Water to be used for any purpose in Nebraska can be tapped from three sources: precipitation, groundwater or surface water. Efficiency techniques will have differing hydrologic and economic impacts depending on the source of the water.

Once water is applied on a field, it may proceed to four different destinations (Figure 3).[43] The first destina-

FIGURE 3

WATER DESTINATIONS IN A CROPPED FIELD



Key

Recoverable losses:
S — Seepage
L — Leakage
SP — Operational spills
RO — Surface runoff
DP — Deep percolation

Irrecoverable losses:
EW — Evaporation from open water
ES — Evaporation from soil
T — Transpiration

Source: OTA Report [43]

tion of water is an aquifer. If the transmissivity of the soil is such that deep percolation takes place, groundwater recharge may result. The length of time required to actually recharge the aquifer is variable depending upon the depth to the aquifer, transmissivity of the soil, and whether or not the vertical movement of the water is impeded by impervious layers of soil. Unlike deep percolation, seepage and leakage may result in saturation of the upper layers of the soil, without necessarily contributing to aquifer recharge, for a considerable length of time, if ever. An example of this situation in Nebraska would be the seepage occurring from the Farwell irrigation canals, resulting in a saturation of the upper layers of soil. Geneally, as previously mentioned, deep percolation seepage and leakage are throught to be recoverable; however, in some cases, making use of that water is not always easily accomplished.

The second possible destination of water is a body of surface water. A portion of that surface water may be evaporated directly or transpired by vegetation. Some will seep or percolate into the soil. Runoff water which becomes confined to a definable canal or stream may contribute to the needs of a downstream user, and also may help to meet instream flow needs. The reuse of this runoff water may require pumping or the quality of the water may be impaired. Nevertheless, runoff water has the potential of being reused and is generally considered recoverable.

The third destination of water is the atmosphere. Water can be evaporated from both soil and open water surfaces or it can be transpired through plant surfaces. The combination of these two processes is called evapotranspiration (ET), defined above as the process whereby water passes into the gaseous state as water vapor. Although ET cannot be recovered through conventional means, not all water that returns to the atmosphere is "wasted." Some, such as crop ET, is required to produce the desired benefit. Evaporation from plant and soil surfaces can have a necessary cooling effect on plants and raise the relative humidity in the field, reducing the crop's transpiration rate. However, some ET can be either unwanted or unnecessary, and can be reduced without hurting production. Reductions in unwanted ET are generally associated with weed control. Reductions in unnecessary ET (sometimes called "luxury" ET) are associated with reducing the amount of water available to a crop, as a plant will transpire more water than it needs to produce a crop if extra water is available. It can be very difficult for an irrigator to apply the exact amount of water necessary for production, although irrigation scheduling is designed to improve the accuracy of these applications.

The fourth destination is soil moisture storage. Many of the efficiency techniques seek to increase this component. Capture of off-season precipitation, reduction of runoff and reduction of soil evaporation may increase the retention of moisture in the soil for crop use. However, it must be realized that soils have varying storage capacities, and runoff or increased evaporation will occur as the moisture in the soil approaches field capacity.

ON-FARM IRRIGATION EFFICIENCY

The physical/hydrologic impacts of water use efficiency techniques in Nebraska relate primarily to irrigated agriculture. The following discussion of on-farm irrigation efficiency and "water savings" has been included to illustrate the relationship of improved water use efficiency to state-wide water supplies.

Technologies that affect irrigation practices are often discussed in terms of their "on-farm" irrigation efficiency, defined as the ratio of water retained in the root zone after irrigation which is available for crop use to the total water applied in the irrigation.[13] On-farm irrigation efficiency can be improved in three main categories as shown in Table 1.[43]

TABLE 1

FACTORS REDUCING ON-FARM IRRIGATION EFFICIENCY

(1) Delivery System:

Inadequate water-measurement devices
Unlined ditches
Improper location or alignment of ditches
Obsolete systems
Inflexible delivery schedule

(2) Field Application System:

Improper land shaping
Improper relationships of slopes, length or run, border widths, discharge rates Improper design of sprinkler or drip system (pumping capacity, pressure, nozzle sizes)
Method of application not suited to soils or slopes

(3) Ineffective Water Management:

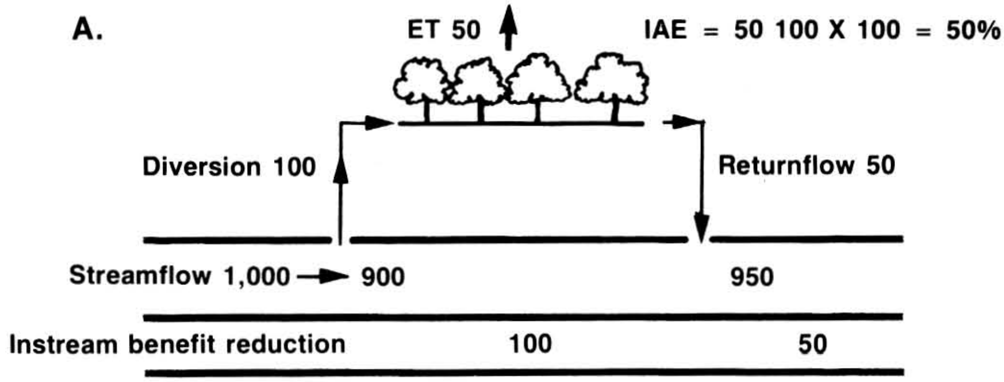
Improper timing of irrigations
Incorrect application amounts
Improper scheduling of water
Excessive use of inexpensive water to save labor cost

Source: Office of Technology Assessment, *Water-Related Technologies for Sustainable Agriculture in U.S. Arid/Semiarid Lands*[43]

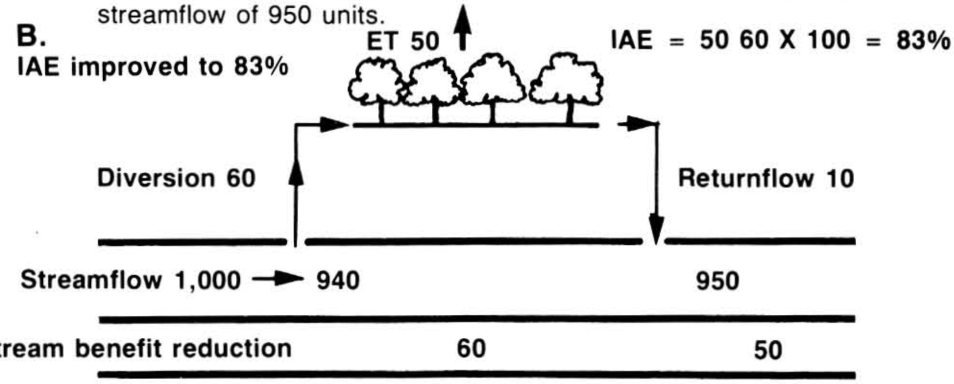
After irrigation water is applied, water that does not become a part of soil moisture supplies in one field (this component includes seepage, surface runoff, and deep percolation) can remain part of an area's total water supply. This water is usually available for reuse downstream, although pumping may be required and water quality may be changed significantly. These losses are termed "recoverable." Losses that result from evaporation from open water and from the soil surface, and from transpiration are called "irrecoverable" since they are lost except through the course of the hydrologic cycle.[43]

Surface runoff and deep percolation can be curtailed in several ways, resulting in higher on-farm irrigation efficiencies. In most cases, however, a roughly equal reduction in return flows occurs, and a small net water savings is realized (Figure 4).[43]

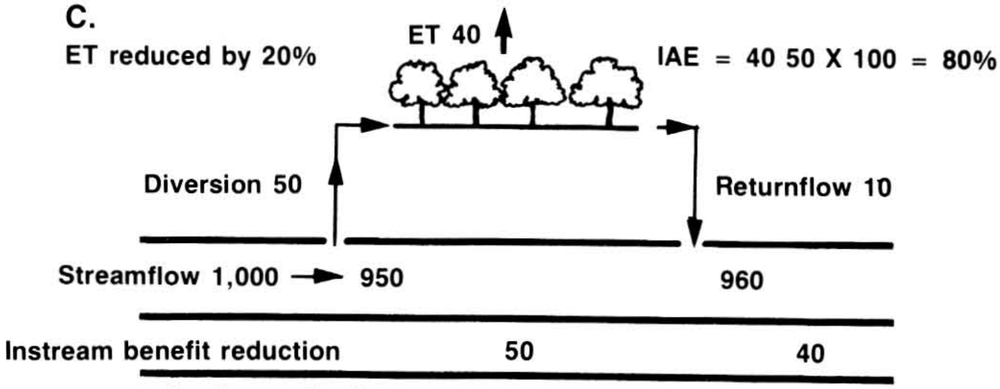
FIGURE 4
EFFECTS OF AGRICULTURAL WATER CONSERVATION ON STREAMFLOW



These illustrations show in a simplified way, the interrelations among water supply, gross demand, and return flows. In figure A, 100 units of water are diverted from a 1,000-unit supply of streamflow. 50 of the 100 units are lost as evapotranspiration (resulting in an onfarm irrigation efficiency of 50%). 50 units are returned to the water source as return flow, thereby yielding a final streamflow of 950 units.



In figure B, the farming area has improved its irrigation efficiency to 83%. Still meeting crop needs for water of 50 units, only 60 units of water (instead of 100 units) need to be diverted. Streamflow is reduced to 940 units between points of diversion and outflow and 10 units are returned to the sources. Final streamflow remains at 950 units.



In figure C, the evapotranspiration requirements of the agricultural area are reduced from 50 units to 40 units. Because ET is smaller, less water diversion is needed (50 units instead of 60 units). The smaller diversion results in a streamflow of 950 units between the points of diversion and returnflow; final streamflow is 960 units (instead of the 950 units in the other examples).

(ET = Evapotranspiration; IAE = Irrigation Application Efficiency)

Source: OTA Report[43]

In the case of irrigation water applied to a somewhat sandy soil, for example, water which is not used by the crop or evaporated from the soil surface would infiltrate, eventually percolating back to the aquifer. In this case, reducing groundwater withdrawals may have little effect on extending aquifer life. There could, however, be rather significant benefits in reduced energy needs and possibly in preventing nitrates from entering the groundwater. Another consideration would be the time it takes for percolating water to reach the aquifer because the water will be unavailable to the irrigator until it has reached the aquifer. In the same situation, reducing surface water diversions may reduce recharge to the aquifer which is a source of supply for other irrigators. In this example, benefits may accrue to the individual irrigator, but may not necessarily increase or extend the total available supply.

To assess the effect of irrigation water conservation on total water supplies, a study by the Soil Conservation Service looked at several irrigation water conservation measures, both on and off the farm, and evaluated their potential for reducing irrigation water demands in the 17 Western states. With no increase

in either irrigation acreage or volume of water provided to water-short areas, improved irrigation efficiencies reduced irrigation diversions by over 30 million acre-feet. However, the net increase of water available for reuse or additional use was estimated at only 3.3 million acre-feet.[25]

Other than saving some quantity of water, on-farm water conservation efforts have both benefits and negative consequences for an individual and for a wider area. Advantages of reducing recoverable losses include energy savings by reduced pumping requirements, plant-nutrient savings by reducing leaching losses, less nutrient pollution and salt emission to surface and groundwater, fewer plant disease and weed problems, less standing water from runoff where mosquitoes could breed, and increased instream flows in sections of rivers where water diversions are reduced. The disadvantage of reducing recoverable water losses is that less water is available for groundwater recharge and the creation of wetlands.[43]

Advantages for reducing irrecoverable losses include reduced demand for both surface and groundwater, energy savings from lowered pumping requirements, increased streamflow, additional water for other agricultural, municipal and industrial uses, and improved quality of subsurface water. The major disadvantages are reduced crop yields and the physical requirements needed to implement measures to reduce evapotranspiration losses.

Finally, physical, social, legal and economic factors often hinder adoption of practices that could improve on-farm irrigation efficiencies. These include:

(1) On-farm physical conditions that cannot be alleviated easily (e.g., sandy soils that have low retention capacities);
(2) Difficulties in identifying practices that reduce irrigation efficiencies because of current measurement techniques and services:
(3) Relative insignificance of water losses to an individual if water is inexpensive or cannot be used if saved;
(4) Questions over costs of practices relative to benefits derived from application; and
(5) Feasibility of integrating new practices into existing farm management practices.[43]

SOCIAL/ECONOMIC CONCEPTS

The implementation of water use efficiency techniques can have significant social/economic impacts on: (a) the surface or groundwater user, (b) other water users in the area, and (c) the state as a whole. Social/economic impacts involving the first two categories are discussed in Section II, while Section III addresses these impacts on a state-wide basis.

The social/economic impacts on the surface and groundwater user relate primarily to potential reductions in energy and/or labor costs associated with reduced withdrawals and to potential increases in operating costs associated with any capital expenditures required by the new technology.

The social/economic impacts on other water users in the area relate primarily to possible reductions in water available for reuse resulting from decreases in runoff or deep percolation. These decreases in runoff or groundwater recharge can translate into negative economic impacts for secondary water users who were previously dependent upon that water for their own operations.

ENVIRONMENTAL CONCEPTS

Improved water use efficiency can have significant environmental impacts. These impacts relate primarily to: (a) streamflow (fish and wildlife habitat and recreation); (b) soil conservation (water quality, preservation of productivity); and (c) percolation to groundwater (water quality, creation of wetlands).

Reduced diversions from surface water can increase the amount of streamflow between the point of diversion and the point of return flow, although streamflow below the point of return may not be significantly affected. Increased efficiency in a large conveyance system can reduce seepage to groundwater and to adjacent lands. Reduced groundwater recharge can reduce base flows to the stream; reduced seepage to adjacent lands can eliminate some artificially maintained wetland areas and thus decrease the amount of habitat these wetlands provide.

Soil conservation can result from reduced runoff. Reduced soil erosion can prolong the productivity of the land and reduce water quality problems resulting from sedimentation.

Reduced groundwater percolation can improve groundwater quality by also reducing the amount of chemical leaching. The water quality problems associated with such leaching can also affect streams where this water becomes part of stream base flow.

CONCEPTS USED IN DESCRIBING IMPACTS OF ALTERNATIVE POLICIES

The primary goal of any of the policies presented in Section III of this report is to promote the adoption of water use efficiency technologies within the state. The projected effectiveness of the policies in achieving this goal (Water User Response) is discussed along with a description of each policy alternative.

Also included under each policy is a brief discussion of the projected impacts of implementing the policy alternative. Where these "policy impacts" include the projected adoption of any water use efficiency technology, the reader is referred back to Section II where the various local hydrologic, social/economic and environmental impacts of the technology are discussed.

The state-wide, aggregate, long-term impacts of improved water use efficiency, as well as any social/economic, legal or institutional impacts resulting directly from the policy itself, are addressed in Section III.

The state-wide economic impacts relate primarily to possible changes in net income, which can translate into higher or lower taxable incomes (and thus higher or lower state revenues) or into more or less spendable income (and thus into a stronger or weaker economic base for the community). Reduced energy costs can also result in a state-wide benefit. Economic savings resulting from reduced petroleum demands will have impacts on the state's petroleum industry, although most of the supplies are imported, and thus the reduction could be seen as a net economic benefit to the state.

Various physical/hydrologic and environmental impacts may also have indirect social/economic impacts on the state. As an example, nitrate contamination of underground water supplies can have negative economic impacts on a community.

The environmental impacts of any policy will be a direct function of the techniques adopted, and the reader is referred to Section II for a description of these impacts on a local level. The possible state-wide, aggregate environmental impacts are discussed in Section III under the policy alternatives.

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SECTION II:

WATER USE EFFICIENCY TECHNIQUES, ASSOCIATED IMPACTS AND PRESENT LEVEL OF ADOPTION

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Chapter 6

Conveyance System Techniques, Associated Impacts, and Present Level of Adoption

It is the purpose of this chapter to discuss conveyance system techniques and describe their associated impacts and present level of adoption. A conveyance system, as defined in Chapter 5, is any means of carrying water from the point of diversion (stream, reservoir or well) to the point of on-site use. Conveyance systems can be either open canals or pipelines. The following discussion of improved conveyance system efficiency is applicable to all categories of water use.

The efficiency techniques identified include:

(1) lining of main canals;
(2) using pipelines or surface barriers;
(3) management techniques; and
(4) vegetation control among canals.

LINING OF CANALS

Lining a canal is a technique aimed at improving the canal's efficiency by reducing the amount of water lost through seepage. Concrete or other impervious lining material is installed within the waterway to prevent the water from seeping out of the canal, laterally into adjacent fields or downward into groundwater storage.

Lining will reduce seepage from canals and laterals and can effectively improve water distribution and management by improving the flow characteristics of the water within the canal, but canal lining does not prevent evaporation from the canal surface. The seepage rate of various lining materials has been determined. For example, the seepage rate of a compacted silty clay soil may range from 0.05 to 0.76 cubic feet per square foot of wetted perimeter of canal per day (averaging about 2.5 gallons). The seepage rate of a concrete lining averages about 0.08 cubic feet (0.6 gallon)[14]. Calculations for the approximate costs and the seepage that could be prevented in a supply canal 20 miles long sufficient capacity to carry 800 cubic feet per second (cfs), in Sherman County, Nebraska are presented in Table 2.

TABLE 2
ESTIMATED COSTS AND SEEPAGE REDUCTION OF FOUR DIFFERENT TYPES OF CANAL LINING.

Canal Type	Diversion (A-F)	Cost ($)	Seepage (A-F)	Seepage as % of Diversion*	Cost $/mile
Unlined	146,000	20,178,000	10,600	7.3	1,008,900
Earth lined	146,000	21,760,000	3,030	2.1	1,088,000
Membrane lined	146,000	24,339,000	0	0	1,216,950
Concrete lined	146,000	28,323,000	1,000	0.7	1,416,150

Source: *Fluid Mechanics.* Sixth Edition, 1975.

TABLE 3

WATER CONVEYANCE EFFICIENCY AND THE PERCENTAGE OF WATER LOSS IN MAIN CANALS AND LATERALS FOR THREE NEBRASKA IRRIGATION DISTRICTS

District	Conveyance (1) Efficiency	Losses (2) Canals	Laterals	Type of Canal
Farwell	46.3%	34.8%	18.9%	Earth
Sargent	46.8%	45.4%	7.8%	Earth
Ainsworth	64.8%	6.1%	29.1%	Concrete canal; earth laterals

(1) Conveyance efficiency is the ratio of the amount of water released from the reservoir (or, in the case of the Sargent unit, the amount of water diverted from the stream) to the amount of water delivered to the farm.
(2) Cacek includes return flow, seepage and evaporation in the term "losses".

The following study of the water conveyance systems in the Farwell, Sargent, and Ainsworth Irrigation Districts serves as an example of potential conveyance system efficiency. The three districts are shown in Table 3, developed from data collected by Cacek[8] over a three-year period. It should be noted that Cacek uses the term "losses" to include return flow, seepage and evaporation. Cacek's terminology is retained throughout the pertinent discussion of the Districts' systems.

Of the three districts, the Ainsworth Unit is the most efficient in its distribution of water because Ainsworth has a concrete lined canal while Farwell and Sargent have earthen canals. The amount of water leakage was similar at both Farwell and Sargent. It should be noted, however, that the Farwell and Sargent units have taken steps to install concrete or impermeable canal linings since Cacek's study.[8]

Most of the Ainsworth "losses" result from return flow rather than seepage. Approximately 70 percent of the water "lost" through the canal is return flow while 30 percent is lost due to seepage or evaporation. In contrast, the other two districts lost a substantially greater percentage of water through seepage and evaporation.

IMPACTS

The primary hydrologic impacts of canal lining relate to (a) reduced seepage from the canal which, in turn, (b) allows the system to divert less water from the source while delivering the same amount of water to the user, and (c) can increase the capacity to deliver water to the end users. Reducing seepage can also decrease groundwater recharge (downward seepage) and water logging of soils (lateral seepage).

If the recharged groundwater can be recovered through pumping, canal seepage can be regarded as a positive hydrologic impact and canal lining as having a negative hydrologic impact to the area. If the canal is lined, diversions can be reduced and more water can remain in the stream or river. This can have positive impacts on the stream between the point of diversion and the point of return flows, but may have little effect on the stream below the return flow. However, the decrease of water stored in aquifers or the soil could reduce baseflow which could cause a more cyclic streamflow. It must be remembered that decreasing the amount of water "lost" to seepage does not necessarily increase the available supply. In some cases it may be desirable to allow seepage from unlined canals to maintain or increase the groundwater level.

However, in other instances, lands near canals may be subject to water logging which may have a negative impact on agricultural production. Canal lining may have a corresponding positive impact to the users. Lands near canals often can only be reclaimed by lining the canal or by draining the land.

The social/economic impacts of canal lining relate primarily to (a) construction costs, (b) reduced costs of draining water logged soils, (c) lowering of water tables in the area, with reduced potential for pumping recharged groundwater, and (d) reduced maintenance costs.

The U.S. Bureau of Reclamation cost estimates for 1984 for various types of lining materials are shown below.

Lining Material	Range of Estimated Cost Per Cubic Yard
Concrete	$39.00-95.00
Compacted Earth	1.90- 5.30
Membrane (existing canal)	6.40- 9.00
Membrane (new canal)	5.50- 8.00

It should be noted that these estimates reflect excavation and topping costs involved in lining new or existing canals as well as the cost of the lining material.

Though relatively expensive, lining may be feasible when water is in short supply, is expensive, or when seepage causes drainage problems. Accurate measurements of water losses in the canal systems are necessary for determination of the feasibility of lining a canal. Lining reduces maintenance time, increases water delivery efficiency, and prevents bank erosion and weed growth.

The economic feasibility of lining a canal depends not only upon the value of the water, but also upon other economic tradeoffs. Where water is recharging the aquifer and being used for groundwater irrigation, the appropriator may choose to provide this supplemental water supply and charge the groundwater irrigators. Where seepage causes water logging problems, the tradeoff may be between the cost of draining the land versus the cost of canal lining.

The environmental impacts of canal lining relate primarily to (a) increased streamflow between the point of diversion and the point of return flow, (b) possible decreases in off-season stream base flow, (c) decreased wetlands and other wildlife habitat, and (d) varying effects on water quality.

Canal seepage can sometimes be seen as having a positive environmental impact if it results in the development of a significant wetland. Reductions in seepage and reclamation of water logged lands could also result in decreased wildlife habitat, such as marshes which are dependent on canal seepage. In some cases, this habitat may be transferred from the canal to land along the stream. The location of a wetland must also be considered in evaluating its importance to the ecosystem.

Increased streamflow would allow for greater dilution of chemicals in the waters. However, if the increased flows represent more water energy, the stream could experience some scouring, thus increasing the sediment load. Water quality may be improved since return flows are generally somewhat degraded by sediment, chemicals and nutrients.

PRESENT LEVEL OF ADOPTION

The use of lining to improve the efficiency of canals in Nebraska is very minimal.

USE OF PIPELINES OR SURFACE BARRIERS

Pipelines provide a means of completely enclosing a water conveyance system to avoid both seepage and evaporation of water occurring in an open system. Chemical or mechanical barriers placed on water surfaces can reduce evaporation from impoundments or canals.

IMPACTS

The hydrologic impacts of pipelines relate primarily to (a) reduce seepage, (b) reduced evaporation, and (c) better control of water delivered to the farm. Advantages or disadvantages of pipeline systems are very similar to those listed above for system lining, with the primary addition of reduced evaporation.

Evaporation from open water surfaces is very difficult to control, compared to other water losses in Nebraska. Total evaporation approximations from water surfaces in Nebraska range from 54 inches in the southwest to 40 inches in the northeast.[41] The exact surface area of the ponds and reservoirs and rivers in Nebraska is unknown. Furthermore, evaporation from free water surfaces varies from year to year. Bentall and Shaffer estimated evaporation from free water surfaces (including wet meadows) at about 1.9 billion gallons per day (gpd) for 1975.[5] In 1979, there were 18 major reservoirs, excluding Lewis and Clark Lake; 1,300 natural lakes in the Sandhills; 23 impoundments over 100 surface acres; 590 under 100 acres; and 29,280 (1970 estimate) farm ponds. River and stream surface areas are not quantified.

Crowe and Manges, in day tests on very small research test ponds in Oklahoma, found that certain floating barriers could reduce evaporation from 11 percent to 35 percent. When barriers were used in conjunction with chemical films, evaporation was reduced from 21 percent to 45 percent. Where chemical film alone was maintained by continuous chemical feed processes, a 36 percent reduction resulted. Wind was a major problem for barriers and films, although vertical barriers to suppress wind speeds had some beneficial effects.[12]

The evaporation control benefits of pipelines for large flows and the use of barriers to control evaporation on large water surfaces require proper design, maintenance and construction and, as always, their practicality needs to be evaluated in terms of water savings versus cost. Other benefits include better utilization of lands along conveyance systems and the elimination of safety hazards common to open systems.

Social/economic impacts of pipelines relate primarily to (a) capital investment, (b) reduced costs of draining wetlands, (c) lowering of water tables in the area with reduced potential for pumping recharged groundwater, and (d) reduced maintenance costs normally associated with canals.

Environmental impacts of pipelines are similar to those listed above under "Lining of Canals."

PRESENT LEVEL OF ADOPTION

Relatively few piped systems are installed to date. Where they have been installed, conveyance and distribution efficiencies greater than 95 percent have been attained.[8] The use of surface barriers to retard evaporation on reservoirs or canals in Nebraska is nonexistent.

MANAGEMENT TECHNIQUES

Managers of any water conveyance system must provide adequate water supplies to the on-site water users. This requires anticipating the water users' needs, coordinating delivery of water to users and maintaining adequate head (water height) in the system's canals or pipelines. This can require a high degree of skilled management, as peak demands can often be unpredictable from season to season or even week to week.

Improved management techniques can improve the efficiency of water conveyance systems, primarily by use of flow measuring and/or flow regulating techniques. Examples of these flow measuring and/or regulating measures are checks, drops, turnouts, diversion structures, inlets, and regulating reservoirs. The size of the discharge opening, such as a farm turnout, and the level of water in the conveyance system are factors which regulate the actual delivery of water to the users.

Water deliveries can be scheduled to allocate water according to crop use, rainfall, tillage practices, delivery system carrying capacity, and field irrigation characteristics. However, lag time between diversion and delivery and contracts between the supplier and consumer may restrict the flexibility of the system manager to schedule deliveries.

IMPACTS

The physical/hydrologic impacts associated with management techniques relate primarily to (a) more accurate identification of seepage areas within canals, and (b) improved distribution control.

The primary management technique identified was the use of metering to improve delivery schedules. For instance, more closely monitoring the water delivery system would allow the irrigation districts to more accurately identify seepage areas within the canals. Metering of the municipal system may alert municipal suppliers to leakage in the system. For many of Nebraska's communities, only the amount of water pumped is known. The amount of water actually used by customers can only be estimated. A more carefully regulated system might improve distribution of the water contracted by the users.

The social/economic impacts of improved management techniques relate primarily to increased operating costs due to the possible need for more employees to monitor the system.

The environmental impacts related to this technique are not easily quantified. They relate primarily to spills, return flows and seepage, all of which could be reduced.

PRESENT LEVEL OF ADOPTION

The Department of Water Resources requires measurement at the point of stream diversion and may require measurement at any spill. Within most canal systems, water is also measured at farm turnouts. Individual natural flow withdrawals are not measured unless the stream is being administered.

VEGETATION CONTROL ALONG CANALS

Phreatophytes are deep-rooted plants which obtain water from the water table or the soils just above it. If they grow near a canal or ditch, they transpire water that may have come from the water in the canal or ditch, thus reducing the available supply.

A weed control program can effectively minimize excessive vegetation in and along ditch banks and can be accomplished by mechanical or chemical means. Potential benefits of a routine weed control program are increased water delivery capacity due to reduced water consumption and less flow restriction. Vegetation control can be accomplished by mechanical or chemical removal of the vegatation. As noted earlier, lining is also an effective control of unwanted vegetation.

IMPACTS

The hydrologic impacts of vegetation control relate primarily to (a) reduction of transpiration from vegetation along the canal system, and (b) a possible increase in the flow rate of water, decreasing the lag time for water deliverly.

Vegetation along canals consists primarily of weeds, cattails, and perhaps Cottonwood or willow trees. Unlike areas in the southwest (where phreatophytes such as Salt Cedar and Water Hyacinths are major water consumers in canals) the problem is not as significant in Nebraska.

The social/economic impacts of vegetation control relate primarily to the operating costs of vegetation removal.

The environmental impacts relate primarily to (a) some reduction in wildlife cover, and (b) a possible increase in chemicals in the water if a chemical reduction method is chosen.

PRESENT LEVEL OF ADOPTION

Chemical spraying, mowing operations, and scouring are normally used to control canal vegetation in Nebraska.

Chapter 7

On-Site Irrigation System Techniques, Associated Impacts and Present Level of Adoption

It is the purpose of this chapter to discuss agricultural water use efficiency techniques and describe their associated impacts and present levels of adoption. These techniques are designed to increase the efficiency with which both precipitation and irrigation water are used. At the end of this chapter is a discussion of the methods used for estimating and comparing the efficiency of these agricultural techniques along with a group of tables which compare the efficiency of each irrigation system type and each conservation practice.

Irrigation water use represents 75.2 percent of Nebraska's total water use.[32] A task force report prepared by the Department of Interior and Agriculture and the Environmental Protection Agency entitled *Irrigation Water Use and Management* suggests a number of on-site techniques to increase efficiency.[25]

The on-site techniques discussed in this chapter include:

(1) Reuse systems
(2) Land shaping
(3) Shorten rows
(4) Irrigation scheduling
(5) Flow management
(6) Residue management
(7) System modifications
(8) System conversion
(9) Windbreaks
(10) Alternative cropping and hybrid selection
(11) Anti-transpirants
(12) Reflectants
(13) Mechanical application of CO_2

(1) REUSE SYSTEMS

A reuse system usually consists of a pit or collection reservoir located below the irrigated area, a pump, and a pipeline to deliver water back to the distribution system or to irrigate more land.[25] Reuse pits generally are used on groundwater irrigated lands to capture water which would otherwise run off the end of a field. Unused surface water canal diversions return to the system and are used by downstream appropriators, and thus reuse pits are not generally employed on surface water irrigated lands.

IMPACTS

The primary hydrologic impacts of a reuse pit are: (a) reducing runoff, (b) increasing percolation, and (c) increasing irrigation management options.

A reuse pit captures excess water at the end of a field before it can runoff. This water would otherwise be lost

to the local operator, but might or might not become available to other areas.

If the reuse pit is unlined, seepage will occur at a rate determined by soil type, soil conditions and management factors. Rates for two small impoundments over a three-year period in York and Clay counties were 0.50 inches and 0.59 inches per day, respectively. Eleven irrigation reuse pits studied in Hamilton County showed a mean of 0.56 inches per day seepage rate, with a range of 0.12 to 19.20 inches/day.[16] Soil type and conditions and operation factors affect seepage. This seepage can recharge local groundwater supplies.

Water captured by a reuse pit increases the groundwater irrigator's management options. The operator can either pump the water back to irrigate the same field, which can reduce pumping, or he can use the water to irrigate additional lands.

The primary social and economic impacts relate to (a) increased capital investment in reuse pit construction, (b) reduced pumping costs made possible by reuse of captured water, (c) possible long-term increase in a farm's productivity due to reduced pumpage and increased groundwater recharge, and (d) possible negative impacts on downstream users depending on irrigation runoff.

The primary environmental impacts of reuse pits are (a) some reduction in soil erosion, (b) improved stream quality due to reduced runoff of soil sediment and agricultural chemicals, (c) possible increase in leaching of agricultural chemicals to groundwater due to increased seepage, and (d) possible decrease in fish and wildlife habitat because of reduce streamflows.

PRESENT LEVEL OF ADOPTION

Nebraska irrigation specialists estimate that 50 percent of the gated pipe systems and 25 percent of the open ditch systems in the state employ reuse pits.

(2) LAND SHAPING

Land shaping is a technique to reshape the surface of a field to either control or increase the water flow. It can involve increasing slopes, flattening slopes, or the construction of terraces, grassed waterways, or other conservation structures. Land shaping is most important in gravity flow irrigation systems.

IMPACTS

Establishing proper land grades for a field application system can allow better control and more uniform application of water.[25] The primary hydrologic impact of flattening the slope of a field is to decrease runoff and increase infiltration. The hydrologic impact of increasing a slope (used where water logging is a problem) is to decrease infiltration.

Because this technique primarily affects runoff and infiltration rates, the extent to which it reduces pumping or diversions depends on other management factors. For example, the proper slope can improve the effectiveness of irrigation scheduling by controlling excessive water logging and runoff. An increase in slope used in conjunction with a reuse pit could allow the irrigator to reduce withdrawals or diversions. For surface water irrigators, the primary effect is to change the timing of return flows.

The social and economic impacts of land shaping relate to (a) increased capital investment, and (b) decreased pumping costs due to more effective distribution of water.

The primary environmental impacts of land shaping relate to the potential reduction in soil erosion, improvement in water quality and possible reduced streamflows.

PRESENT LEVEL OF ADOPTION

It has been estimated that over 90 percent of all gravity flow irrigated lands have been treated with one form of land leveling or another, as well as 10 percent of the state's crop land under sprinkler irrigation.

(3) SHORTER ROWS

Another technique which has hydrologic impacts similar to land shaping is the use of shorter rows. By shortening the length of run, less water need be applied with each irrigation. Standards have been established by the Soil Conservation Service, USDA for lengths of run and flow rates for various grades and are given in the *Nebraska Irrigation Guide.*[51]

IMPACTS

The hydrologic impact of this practice is to reduce deep percolation at the upper end of a field. In some cases water logging problems at the lower end of the field may be reduced as well. Primarily, this practice improves the uniform infiltration of water throughout a field and may improve the feasibility of irrigation scheduling.

PRESENT LEVEL OF ADOPTION

Due to the difficulty of monitoring the adoption of this technique, no data are available for Nebraska.

(4) IRRIGATION SCHEDULING

Irrigation scheduling is the practice of determining as accurately as possible the precise water needs of a crop, and then controlling the amount and timing of water application to meet those needs without over-watering. Irrigation scheduling does not employ deficit irrigation, that is applying less water than the crop requires. However, in some instances, the scheduling is practices in a manner which applies water according to the stage of crop growth. It has been found that the crop may be able to survive with less water earlier in the development stage, but will require full irrigation during pollination. If water applications are timed to stage of crop growth, some "luxury ET" may be eliminated.

Non-scientific irrigation scheduling is usually limited to monitoring soil moisture with a shovel and evaluating crop stress levels with visual examination. Scientific irrigation scheduling seeks to improve the accuracy of these monitoring practices through the use of new technologies (soil probes, moisture blocks, tensiometers, automated weather data stations, etc.). The newest technologies involve the use of computers in monitoring, system control and the formulation of irrigation schedules; however, this technique is still largely in the developmental stage.

IMPACTS

The hydrologic impacts of irrigation scheduling relate to potential reductions in (a) groundwater or surface water withdrawals, (b) runoff, (c) deep percolation, and (d) evaporation from soil surfaces. Irrigation scheduling may allow less frequent applications of water, due to more effective timing and distribution of the water that is pumped.[20] Scheduling can reduce runoff, deep percolation and evaporation "losses," all of which can result from over-irrigating. Water which runs off or percolates may be recoverable either locally or within the state, but evaporation losses are not. The precise amount of evaporated water that could be potentially saved is not quantifiable, because an individual irrigator's situation and seasonal climatic conditions vary.

The social and economic impacts of irrigation scheduling relate to (a) reduced withdrawal costs, (b) possible inrease in management costs, and (c) possible negative impacts on downstream users dependent on upstream agricultural runoff.

The environmental impacts relate primarily to (a) reduced soil erosion, (b) reduced leaching of chemicals into groundwater supplies, (c) improved stream quality, and (d) changes in streamflow related to reduced withdrawals and runoff.

Programs resulting in reduction of irrigation water use in central Nebraska are good examples of the potential benefits of irrigation scheduling. In York County, where irrigation scheduling was used, the amount of water applied to crops was reduced from 24 to 15 inches. The study also showed that scheduling resulted in a 38 percent savings of energy and water pumping.[19] Excess irrigation results in higher production costs, leacher fertilizer, and possibly greater evaporation loss.

PRESENT LEVEL OF ADOPTION

Irrigation scheduling has increased considerably in the last ten years because of the rapid increase in costs of energy and fertilizer. The cost price squeeze for farmers in the past few years also promotes additional interest in irrigation scheduling.

It is currently estimated that approximately 2.6 million acres of cropland in Nebraska employ some form of irrigation scheduling technique.

(5) FLOW MANAGEMENT

Flow management devices can be used to control and measure the amount of water delivered and applied to a field. On-farm water control devices regulate the flow of water from the well or water delivery canal into the field. Examples of farm water control and regulating structures are checks, drops, divider boxes, and reservoirs. On-farm flow measurement devices monitor the amount of water which flows onto the farm. Examples of flow measurement devices are Parshall flume wiers, orifice plates, and flow meters.[25] Pipeline systems use various kinds of valves and divider accessories to regulate flow and flow meters to measure the flow.

IMPACTS

Control and measurement devices such as these do not increase water use efficiency except when used in conjunction with other techniques. However, they may encourage irrigators to reduce water use simply by increasing awareness of pumping rates and associated costs.

PRESENT LEVEL OF ADOPTION

Since the mid-1970's, over 20,000 flow meters have been sold in Nebraska, 5,000 to 10,000 of which were sold in a cost-share program in 1977.[34] It has been estimated that this represents about one-sixth of the groundwater withdrawals in the state. Surface water withdrawals from conveyance canals are required to be metered at the point of diversion. However, on-farm metering is not required, except in some groundwater control areas.

(6) RESIDUE MANAGEMENT

Residue management involves the use of tillage practices which leave residue on the land surface or, in some cases, the application of mulches onto the land surface. In this discussion, mulches and residue are equivalent. Regardless of whether the material was applied or resulted from cultivation practices, the end result, in terms of water conservation, is the same.

Conservation tillage is a broad term which refers to any tillage method which leaves at least 20 percent of the soil surface covered with residue after planting. Table 4 shows the residue covers obtained after various tillage practices under different crops. Ecofallow and other crop rotation programs may be combined with the reduced tillage systems to maintain weed and insect control. Conservation tillage and ecofallow systems generally are associated with dryland agriculture, but can have a significant impact in irrigation water management.

TABLE 4

MEASURED SURFACE COVER AND SOIL LOSS FOR VARIOUS TILLAGE SYSTEMS

Residue Type Tillage System	Residue Cover	Erosion	Erosion Reduction From Moldboard Plow
	Percent	T/ac	Percent
Corn Residue[1]			
Moldboard plow, disk, disk, plant	6.3	7.8	—
Chisel plow, disk, plant	34.6	2.1	73.7
Disk, disk, plant	20.6	2.2	71.9
Rotary-till, plant	26.4	1.9	75.9
Till-plant	33.6	1.1	86.4
No-till plant	38.9	0.7	91.9
Soybean Residue[2]			
Moldboard plow, disk, disk, plant	1.6	14.3	—
Chisel plow, disk, plant	7.2	9.6	32.5
Disk, plant	8.5	10.6	25.7
Field cultivate, plant	18.0	7.6	46.5
No-till plant	27.3	5.1	64.5
Wheat Residue[3]			
Moldboard plow, harrow, rod weed, drill	8.9	4.2	—
Blade plow three times, rod weed, drill	29.3	1.2	72.0
No-till drill	86.0	0.2	95.7

1 Nebraska tests after tillage and planting on a silt loam soil having a 10 percent slope, 2 inches water applied.
2 Nebraska tests after tillage and planting on a silty clay loam having a 5 percent slope, 2 inches water applied.
3 Nebraska tests after tillage and planting on a silt loam soil having a 4 percent slope, 3 inches water applied.

Source:
"Erosion Control With Residue," Dickey, Elbert C.; David P. Shelton; Paul J. Jasa; Thomas R. Peterson, in *Conservation Tillage Row Crop Production*, IANR SCS and NRDs, pp. 15-20.

IMPACTS

The hydrologic impacts of residue management practices relate to (a) reduced runoff, (b) reduced evaporation from soil surfaces, (c) increased soil moisture retention, and (d) increased soil retention of winter and spring precipitation moisture.

The social/economic impacts relate primarily to (a) reduced pumping costs, (b) increased initial capital investment in minimum-till or no-till equipment, (c) possible increases in herbicide costs due to reduce cultivation, (d) improved dryland crop yields during periods of drought, and (e) possible lengthening of aquifer life to the extent that the practice reduces evaporation from soil surfaces and reduces pumping.

Residue management under irrigation is estimated to have the potential of reducing crop water application by 10 to 15 percent through surface evaporation control.

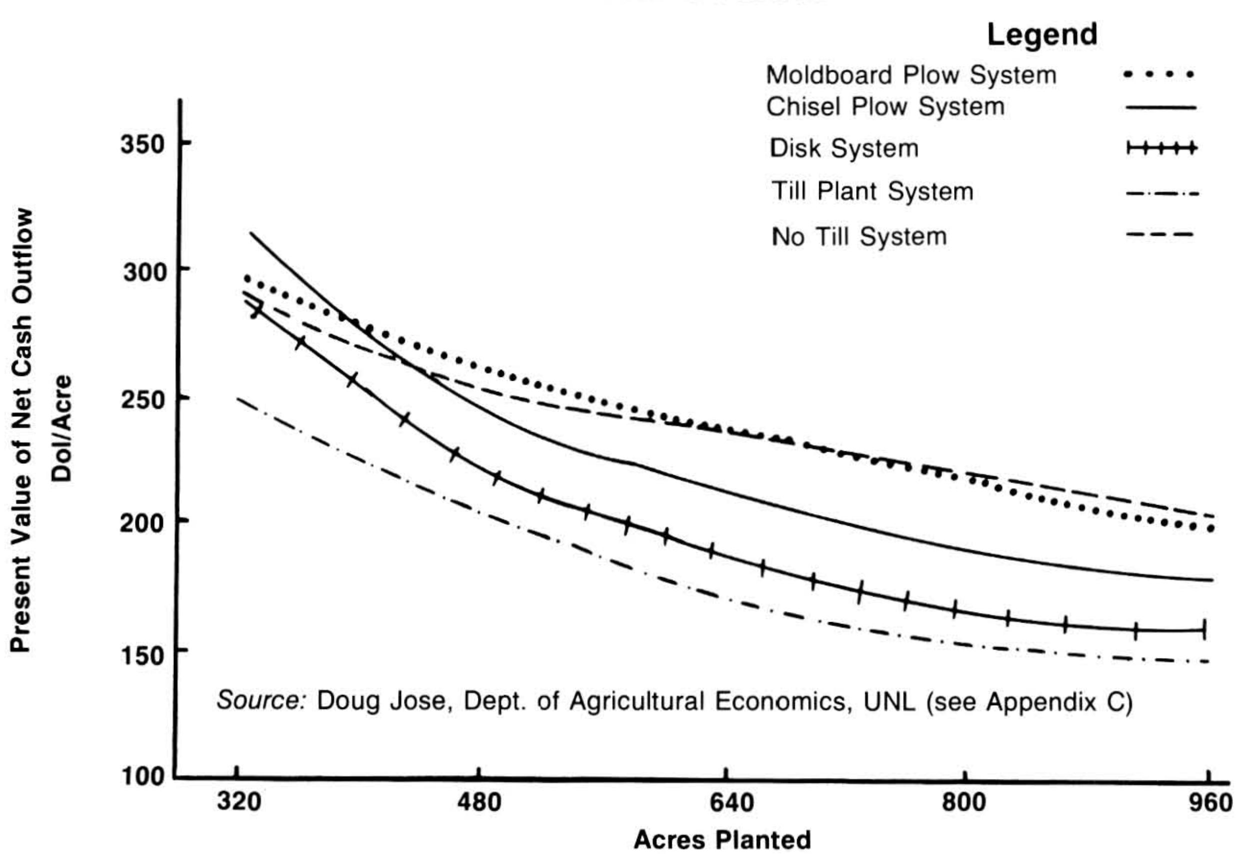
Little research has been directed toward determining how much evaporation has been reduced by mulch systems. The most recent research by Klocke[27] in 1980-81 attempted to separate and measure the components of plant transpiration and soil evaporation from a field of corn at the University of Nebraska-Lincoln Sandhills Agricultural Laboratory. Under the specified conditions, Klocke found that 33 percent of the total crop water use (ET) was due to soil evaporation. Research from Kentucky, Texas, and Wisconsin indicates soil evaporation can range from 6 to 47 percent of the crop water use.

Residue management systems can be most easily adapted to sprinkler systems. Problems of water movement down rows and management of water flow exist for furrow irrigation with crop residues.[17] To make conservation tillage practices compatible with furrow irrigation will require changes in cultural practices and irrigation management.[18]

Generally the test results have shown increased yields under the conservation tillage systems. However, variability in the results indicates that conservation tillage may reduce crop production, especially if weeds or insects become a problem. Differences in test results point up regional differences in climate and the need for adaption of cultural practices.

In addition to the need to adapt the tillage practice according to climate and soil, each operator will need to develop a system in accordance with his particular farming operation and budget constraints. H. Doug Jose, Extension Farm Management Specialist, University of Nebraska-Lincoln, has compared the cost effectiveness of several tillage operations. The no-till system is the most expensive with till-plant, disk systems, chisel plow and moldboard plow showing up respectively less expensive (Figure 5). (For a more complete discussion of these concepts refer to Appendix C.)

FIGURE 5
EFFECT OF FARM SIZE ON PRESENT VALUE OF CASH FLOW FOR 10-YEAR PLANNING PERIOD



Source: Doug Jose, Dept. of Agricultural Economics, UNL (see Appendix C)

The environmental impacts of residue management relate primarily to (a) decreased soil erosion, (b) improved stream quality due to less soil sediment and agricultural chemicals running off, (c) possible increases in insect and rodent populations in the field, and (d) possible increase in herbicide and pesticide applications and potential leaching of these chemicals into groundwater supplies. Residue management will decrease soil erosion due to both its protection of soil from the impact of raindrops and the reduction in runoff. A higher level of residue on the field during the season may increase the presence of insects and rodents, which may dictate the application of higher amounts of pesticides. During periods of heavy precipitation, leaching of chemicals to groundwater supplies may increase, although the reduction in runoff will have positive effects on stream quality.

PRESENT LEVEL OF ADOPTION

A tillage survey reported in *Farming Today* (Winter 1984) showed estimates made by State Agronomists of the Soil Conservation Service over a 14-state area. For Nebraska, it was estimated that four percent of the land was farmed under a no-till system and 44 percent was farmed with minimum tillage. The trend from 1982 to 1983 was a shift from conventional tillage (56 percent in 1982) to a reduced tillage system. In 1983 acreages under conventional tillage had been reduced to 52 percent.

(7) SYSTEM MODIFICATION

System modification refers to changes made **within existing irrigation systems** to improve the efficiency of those systems. The methods of irrigation application are gravity flow, sprinkler, drip, subsurface, and drop nozzles.

Within gravity flow systems, changes can be made from the use of unlined ditches or to a pipeline.

Within sprinkler systems, sprinkler heads can be renozzled, the sprinkler spacings can be contracted or expanded, or the sprinkler system pressure can be reduced.

Drip and subsurface irrigation systems are largely in developmental stages as they relate to cropland agriculture, and thus modifications within these systems are not pertinent to this discussion. They are, however, discussed in more detail under "System Conversion."

IMPACTS

The major hydrologic impact of modifying a pivot system from high pressure to low pressure is to reduce evaporation losses during the sprinkling operation. Estimated reductions in evaporation vary considerably; however, a five percent reduction appears reasonable. Improvements in the distribution patterns and application rate may also allow more effective use of rainfall. Side benefits may include reduction of energy requirements, and reduction in operation and maintenance costs.[25]

The major hydrologic impact of modifying an existing on-farm distribution system is to reduce seepage from the ditch to adjacent land or to groundwater; the impact of changing to the use of a pipeline is the same, with the additional reduction of evaporation. Both modifications of a gravity flow irrigation system increase the irrigator's control over his supply and allow more of the water pumped or diverted to actually be applied to the crop. Potentially, this practice could allow the surface water irrigator to reduce his diversion. In years when water is short, the suurface water irrigator could make fuller use of his appropriation. The groundwater irrigator could pump less water, increase the application to the field, or irrigate more land with the same well.

The social and economic impacts of system modifications relate to (a) potential reductions in pumping costs, (b) some capital investment in the change of equipment, and (c) possible long-term benefits from reduced evaporation losses and reduced pumping.

The environmental impacts of system modifications are minimal. However, low pressure sprinkler systems must be managed effectively to compensate for an increased potential for irrigation runoff and the accompanying water quality problems.

PRESENT LEVEL OF ADOPTION

Many center pivot systems have been converted to low-pressure, low-angle sprinklers and spray nozzles to reduce energy requirements, evaporation and drift. However, the low-pressure, low-angle sprinkler and particularly spray nozzles increase the application rate and the potential for water movement on the surface of many soils. This potential for increased runoff makes the system unsuitable for certain soil types.

James Gilley, Department of Agricultural Engineering, UNL, developed a methodology to determine on what soils a low-pressure system could be used without causing excessive runoff. Using this methodology, it was found that approximately 72.8 percent of the potential groundwater acreage in the state could use low-pressure impact head systems[42]. However, data on the number of conversions to low-pressure impact head systems is not currently available.

(8) SYSTEM CONVERSION

System conversion refers to **changing from one irrigation system to another**. The two main methods of irrigation application in Nebraska are gravity flow and sprinkler. Other systems are drip, subsurface, and drop nozzle systems.

Gravity flow systems, by definition, are any systems which utilize gravity in applying the irrigation water over the field. They generally rely on either ditch or gated pipe to convey the water to that end of the field with the highest elevation and then depend on gravity to carry the water down the rows and through the field.

Sprinkler systems (stationary, lateral move or center pivot) apply water to a field through pressurized, nozzled pipelines, stretches across the field and usually high above the crop.

Drip systems or drop nozzle systems utilize a more complex delivery apparatus to distribute water to the plants. A LEPA (Low Energy Precision Application) system distributes water directly to the furrow at very low pressure through orifice-controlled emitters at the end of tubes dropped from center pivot or lateral move irrigation equipment. Microbasin (furrow diking) is a land preparation technique used in conjunction with the LEPA system. Subsurface systems are submerged beneath the soil surface. All drip systems rely primarily on the capillary movement of water through soil the achieve effective irrigation of the field.

System conversion may be a valid alternative for improving water use and management where the existing irrigation system is poorly suited to the site conditions, and the desired degree of efficiency cannot be obtained by improving the system design. No one irrigation method is adaptable to all conditions, and conversion from one method to another should not be based on such a premise. The potential change in method should be based on evaluation of land slope, crops to be irrigated, water supply, water intake and holding capacity of the soil, labor, and other factors.[25]

IMPACTS

The hydrologic impacts of system conversions are directly related to the comparative efficiencies of the two systems. Estimates of the irrigation requirement under different types of systems presented later in this chapter show that conversion from an open ditch system without a reuse pit to a sprinkler could reduce irrigation application requirements from 27 inches per acre to 16 inches per acre. However, it should be noted that the same reduction could be obtained by a system modification which incorporated gated pipe and a reuse pit.

Conversion to gated pipe from a ditch system reduces evaporation and seepage, while the addition of a reuse pit allows the irrigator to recycle the used water. Changing to a center pivot decreases the application rate, and could also decrease runoff and any deep percolation associated with seepage. However, evaporation may be increased, unless the conversion was made to a low-pressure sprinkler system, in which case evaporation would be less likely to increase. Converting to a sprinkler system allows the irrigator better management of his water supply, reduces labor and may encourage the use of irrigation scheduling. Either the conversion or the modification would reduce pumping costs. Both have the potential to increase or extend supplies.

Conversions to drip irrigation systems can significantly increase water application efficiency, while reducing pumping energy consumption.[33] As with the re-nozzling techniques, the major impact is to reduce evaporative losses associated with the spray. It was reported that the only measureable water loss occurring during LEPA testing was evaporation from the ponded water in the micro-basins following irrigation. Pan evaporation measurements indicated these losses were less than one percent of the water applied in all tests.

Soil moisture measurements showed that deep percolation below the root zone did not occur. The furrow dikes eliminated runoff without re-diking except after three or four consecutive irrigations. Two to three percent runoff occurred on the fourth or fifth consecutive irrigation due to dike erosion. However, average application efficiency remained above 98 percent, not considering soil surface evaporation following irrigation. The drop-tube application of water without furrow diking had an average application efficiency of 87 percent. This points out the usefulness of furrow diking used in conjunction with the LEPA system to achieve higher application efficiency.[3] In addition, furrow diking improves utilization of rainfall.

PRESENT LEVEL OF ADOPTION

Land slopes, type of soils, or a requirement for frequent light applications have led to installation of sprinklers in order to improve irrigation efficiency. Conversion to a more efficient irrigation system is not always possible because in some cases gravity systems may be needed when large applications of water are required to maintain salt balance or sprinkling with low quality water would damage crop foliage (although these condition generally do not exist in Nebraska).

Many of the surface irrigation systems have been converted to center pivots to reduce labor time and to

increase uniformity of water application, although the precise number of conversions is unknown. Depending upon the agricultural economy and the investment and operating costs, the trend to change from gravity flow irrigation to center pivot use will probably continue.

(9) WINDBREAKS

DESCRIPTION

Windbreaks are designed to minimize the effects of the wind on crops. They may be of the slat fence design (e.g., a snow fence), trees planted in rows or strips of annual grass. A slat fence can be used in the summer as a temporary windbreak structure. Windbreaks have the following water use efficiency effects: (a) reduced ET; (b) reduced wind speed; (c) increased absolute air temperature during the day, decreased absolute air temperature at night; and (d) increased vapor pressure gradients. Wind shelter can reduce ET, especially during strong winds accompanied by warm temperatures. Also, soil moisture in the spring may increase due to captured snow.[35]

Tree windbreaks do contribute to ET and soil moisture depletion in the immediate vicinity of the windbreak, usually considered equal to the height of the windbreak. However, reduced crop ET and increased production has been found on the leeward side of the trees, up to 20 times their height. Production levels of corn, soybeans, and wheat have been improved by an average of 20 percent, 18 percent, and 5 percent respectively, through the planting of windbreaks[7]

IMPACTS

The physical/hydrologic impacts of windbreaks are (a) increased soil moisture storage on the leeward side; (b) decreased soil moisture storage directly under a tree windbreak; and (c) reduced soil erosion.

The primary social/economic impacts relate to acres taken out of production for planting windbreaks. However, long-term economic analysis of windbreaks indicate a payback period of about 12 years. In 1984 dollars, 15 acres of trees would cost about $2,700. However, one-half of this expense can be cost shared through various programs including the Agricultural Stabilization and Conservation Service (ASCS), NRDs, Game and Parks Commission, and the Nebraska Soil and Water Conservation Fund. The average effective life expectancy of a windbreak is 50 years. Over the long term, windbreaks show a net profit of $57,000 for each 160 acres protected.[7] Other social impacts include the aesthetic diversity that trees add to the "dreary plains" that Major Long recorded, and a potential supply of firewood.

Windbreaks add significantly to the habitat diversity of areas that are primarily devoted to the crop production. They also increase the amount of woodland habitat and reduce soil erosion. Tree windbreaks also reduce weather related stress on both livestock and wildlife.

PRESENT LEVEL OF ADOPTION

Data collected from 1970 through 1975 indicated that while the number of windbreaks is increasing, the total length and the total acreage covered by windbreaks is decreasing (see Table 5). As mentioned earlier, there are various programs that encourage the establishment of windbreaks.

TABLE 5

COMPARATIVE DATA ON THE LEVEL OF ADOPTION OF WINDBREAKS.

Year	Number of Windbreaks	Number of Acres	Length (in miles)
1970	32,630	84,159	7,661
1975	32,908	79,484	7,455

(10) ALTERNATIVE CROPPING AND HYBRID SELECTION

Alternative cropping involves the use of a crop type with a lower ET requirement than other crops. For example, the soybean ET requirement is about 23.0 inches, while corn is 26.5 inches.

Hybrid selection refers to choosing a less water intensive variety of the same crop. Hernandez studied two different sorghum varieties under certain conditions of water stress, one more drought tolerant than the other. He found that when coupled with various temperatures for a six-day period, transpiration was reduced, but yield of the drought resistant type of sorghum was not highly affected.

IMPACTS

The hydrologic, social/economic and environmental impacts of these techniques can be significant to the extent that they reduce water withdrawals. Individual farmers can employ such techniques voluntarily, and as irrigation costs rise and water supplies become increasingly scarce, it is anticipated that farmers will place more emphasis on crop selection as a water use reduction method.

PRESENT LEVEL OF ADOPTION

Precise figures concerning the usé of alternative cropping and hybrid selection are unavailable. The choice of using any particular crop or hybrid is not always made solely on the basis of the water requirements of that crop. Other factors such as equipment, market prices, and labor requirements are also important considerations in making cropping decisions. The development of more efficient yet productive hybrids is one area which could benefit from additional research funding.

(NOTE: The following three techniques are in the early experimental stages of development and are not applicable at this time.)

(11) ANTI-TRANSPIRANTS

Anti-transpirants are film-forming substances that block the loss of water vapor from leaf stomata, thus limiting the transpiration from plants. Various film materials, such as long chain alcohols, silicone materials, latex, waxes, and plastics have been researched. Certain chemicals have been investigated as stomata closing materials.

IMPACTS

Researchers report very limited success in use of certain anti-transpirants under laboratory conditions. One broadleaf tree transpiration control trial resulted in a 12 percent reduction in water use[45]

PRESENT LEVEL OF ADOPTION

Commenting on the status of anti-transpirants, Rosenberg said, "Thus, the literature reports a general lack of field success in the use of anti-transpirant materials, while greenhouse results have been more encouraging".[45]

(12) REFLECTANTS

Reflectants are materials applied to crop leaf surfaces that reflect incoming solar radiation. Researchers have had limited success using kaolinite, diatomaceous earths, aluminum silicates, and lime as reflective materials. The problem is keeping photosynthesis working optimally, while reducing evapotranspiration and heat flux. Certain crops, such as soybeans, may be better candidates for reflectant application than others.[45]

IMPACTS

The hydrologic impact of this technique, if it were successfully developed, would be a reduction in evaporation and/or transpiration. Thus, water use could be reduced.

The social/economic and environmental impacts would follow from any significant reductions in irrigation withdrawals.

PRESENT LEVEL OF ADOPTION

Reflectants may be found in the future that will reduce the energy load on the crop, while interfering less with photosynthesis. Thus, reflectants are potentially capable of reducing water use, but, at present, are not available for general field crop application.

(13) MECHANICAL APPLICATION OF CO_2

Mechanical application of carbon dioxide (CO_2) is a potentially viable method of increasing the amount of CO_2 in the micro-climate of a cropped field. Increasing the CO_2 concentrations can have a beneficial effect of crop yields by both increasing photosynthetic activity, while decreasing transpiration. Laboratory experiments have shown such increases.

Apart from mechanical applications, the CO_2 content of the atmosphere is said to be naturally increasing because of increased industry and other activities. Rosenberg indicates that because of "the increasing concentration of CO_2 in the atmosphere, there should be, also, an increase in net primary photosynthetic productivity in most cultivated species of crops.... The water use efficiency...is favored...by increasing CO_2 concentration in the ambient air".[45]

IMPACTS

The hydrologic, social/economic and environmental impacts of this technique would be similar to those listed above under "Reflectants."

PRESENT LEVEL OF ADOPTION

Techniques for applying CO_2 to field crops may be found in the future, although this currently poses distinct problems because of wind conditions. For the near future, any benefits derived from reduced transpiration and increased water use efficiency that may occur will depend on natural increases in atmospheric CO_2 concentrations.

ESTIMATING AND COMPARING THE IMPROVED EFFICIENCY POTENTIALS OF THESE TECHNIQUES

The potential of each irrigation system type and each conservation practice for improving water use efficiency was estimated after considering research results and consulting with irrigation specialists in Nebraska. Crop water use data were derived in the same manner. Calculations were made only for those agricultural practices which show promise in the near future and for which reasonable data were available. The results of these calculations are shown in Tables 6 and 7.

TABLE 6

SPRINKLER IRRIGATION SYSTEMS--PRESENT IRRIGATION WATER USE AND POTENTIAL REDUCTIONS USING VARIOUS CONSERVATION MEASURES FOR CROPS GROWN IN NEBRASKA (DATA IN ACRE-INCHES)

	CORN	SOYBEANS	SORGHUM	ALFALFA	WHEAT	BEANS	SUGARBEETS	POTATOES	BARLEY
Average ET	26.5	23.0	23.0	33.0	17.0	19.0	30.0	21.0	17.0
Average rainfall during growth season	14.3	14.3	14.3	16.2	12.1	11.1	16.2	11.1	12.1
Net irrigation required	12.2	8.7	8.7	16.8	4.9	7.9	13.8	9.9	4.9
Present gross irrigation water application based on 75% efficiency	16.3	11.6	11.6	22.4	6.5	10.5	18.4	13.2	6.5
Gross water requirement if following measures were practiced:									
Mulching only	12.7	8.5	8.5	NA	4.3	8.0	14.4	10.4	4.3
Renozzling to low angle, low pressure (sprinkler modification)	15.5	11.0	11.0	21.3	6.2	10.0	17.5	12.5	6.2
Irrigation scheduling management	14.7	10.4	10.4	20.2	5.8	9.5	16.6	11.9	5.8
Gross water requirement with combinations of measures:									
Mulching & sprinkler modification	12.1	8.1	8.1	NA	4.1	7.6	13.7	9.9	4.1
Mulch & irrigation scheduling	11.4	7.6	7.6	NA	3.9	7.2	13.0	9.4	3.9
Sprinkler modification & irrigation scheduling	13.9	9.9	9.9	19.2	5.6	9.0	15.7	11.2	5.6
Mulch, sprinkler modification & irrigation scheduling	10.9	7.3	7.3	NA	3.7	6.8	12.3	8.9	3.7

TABLE 7

SURFACE (GRAVITY) FLOW IRRIGATION SYSTEMS--PRESENT IRRIGATION WATER USE AND POTENTIAL REDUCTION BY IRRIGATION SCHEDULING AND MANAGEMENT PROGRAM FOR VARIOUS CROPS GROWN IN NEBRASKA (DATA IN ACRE-INCHES)

	CORN	SOYBEANS	SORGHUM	ALFALFA	WHEAT	BEANS	SUGARBEETS	POTATOES	BARLEY
Average ET	26.5	23.0	23.0	33.0	17.0	19.0	30.0	21.0	17.0
Average rainfall during growth season	14.3	14.3	14.3	16.2	12.1	11.1	16.2	11.1	12.1
Average net irrigation required	12.2	8.7	8.7	16.8	4.9	7.9	13.8	9.9	4.9
Present gross application for:									
Gated pipe with re-use system[1]	16.3	11.6	11.6	22.4	6.5	10.5	18.4	13.2	6.5
Gated pipe--no re-use system[2]	22.2	15.8	15.8	30.5	8.9	14.4	25.1	18.0	8.9
Open ditch with re-use system[3]	18.8	13.4	13.4	25.8	7.5	12.2	21.2	15.2	7.5
Open ditch--no re-use system[4]	27.1	19.3	19.3	37.3	10.9	17.5	30.7	22.0	10.9
Application requirement with irrigation scheduling 7 management for:									
Gated pipe & re-use system	14.7	10.4	10.4	20.2	5.8	9.4	16.6	11.9	5.8
Gated pipe--no re-use system	20.0	14.2	14.2	27.4	8.0	13.0	22.6	16.2	8.0
Open ditch with re-use system	16.9	12.1	12.1	23.2	6.7	11.0	19.1	13.7	6.7
Open ditch--no re-use system	24.4	17.4	17.3	33.6	9.8	15.7	27.6	19.8	9.8

[1] 75% efficiency
[2] 55% efficiency
[3] 65% efficiency
[4] 45% efficiency

The calculations indicate that improving water use efficiency through the implementation of various available techniques can result in the reduction of water withdrawn and, in many cases, save water that would otherwise be irrecoverable. It should also be noted that the calculations reflect the average state-wide conditions and may not necessarily be appropriate for application of agricultural techniques to reduce gross irrigation requirements may have a substantial effect on a regional basis. In addition to the regional effects of reducing water demands, it is conceivable that operating costs for both the end user and the delivery system may be lower and also could result in lower capital costs over time.

ASSUMPTIONS

An early attempt was made to estimate effective rainfall and use this figure as a base for these calculations. However, effective rainfall is difficult to document because of variability of the storms from one area of Nebraska to another. The decision was made to use the composite average rainfall data for three representative sites — Scottsbluff, North Platte and York — from 30 years of climatic records of the National Weather Service. The use of this rainfall figure does appear to correspond to irrigation water application amounts commensurate with current on-farm water application, e.g., 16.3 inches to 22.0 inches for corn. Soil moisture availability at the beginning of the crop growing season is a factor in determining the amount of irrigation water applied during a growing season. Accurate soil moisture figures on a state-wide basis were not available. Therefore, the soil moisture component was not used in the calculations. However, the use of total rainfall estimates in place of effective rainfall estimates may substitute, in part, for the lacking soil moisture component. Caution is advised in using the results because of this substitution. However, a comparison of the relative efficiencies of various practices should be valid.

SUMMARY OF TABLES

Tables 6 and 7 evaluate the theoretical effectiveness of on-farm water use efficiency techniques. The average evapotranspiration rates for different crops and the estimated efficiency of the various irrigation systems were derived from consultation with irrigation specialists at the University of Nebraska. Table 6 presents a comparison between several methods under sprinkler systems and Table 7 presents a comparison of the various methods using gravity flow irrigation.

Comparisons were made of the effectiveness of the various techniques in reducing water use. For example, if a gated pipe operation incorporates irrigation scheduling, improved management and a reuse system, Table 7 indicates that a theoretical reduction of 7.5 inches of water per acre per year may be possible (from 22.2 inches to 14.7 inches). Adding only irrigation scheduling and improved management would reduce water use from 22.2 to 20.0 inches. Smaller comparisons can be made for other combinations of techniques.

Mulching or residue management under sprinkler irrigation (see Table 6) is of special note. Combined with sprinkler modification and irrigation scheduling and management, water use can be reduced, potentially, to 10.9 inches from a gross application of 16.3 inches. This may seem to be a discrepancy, as the net irrigation requirement listed in the table is 12.2 inches. However, when mulches are used, the evaporation portion of the evapotranspiration is reduced by an estimated 10 percent; thereby, also, reducing the net irrigation requirement to 9.55 inches.

Potential efficiency improvements were estimated for spray and drift losses (5 percent), evaporation from soil surfaces (10 percent of ET), and system improvement and management (10 percent). These are considered to be conservative estimates.

Combinations of several techniques were found to nearly always have much greater possibilities of increasing water use efficiency than installing single practices.

Determinations of the effect of various water use efficiency techniques on total water use in the state are more difficult than for an on-site (irrigation field) unit. Rainfall differences are pronounced; crop water use, water use reduction techniques and effectiveness, cropping patterns, and irrigation methods all vary from year to year, and thousands of irrigators are involved. These variations make the estimation of potential statewide reductions misleading, as accurate state-wide information is not available, especially within the limitations of this study.

Chapter 8

Municipal, Industrial and Power Distribution and Application Techniques, Associated Impacts and Present Level of Adoption

It is the purpose of this chapter to discuss availble techniques for improving the efficiency of water in municipal, industrial, and off-stream power generation systems along with associated impacts and present level of adoption of these techniques.

MUNICIPAL SYSTEMS

Municipal water use represents approximately 2 percent of Nebraska's total water use[32] and can generally be catagorized into (a) distribution and storage, and (b) residential use. Many of the efficiency techniques considered for residences are applicable to other purposes, such as small industry and commercial establishments, construction and public works, and personal and public services.

The impacts and present levels of adoption of all municipal distribution and residential water use efficiency techniques are presented together after all the techniques have been described.

DISTRIBUTION

Not all the water introduced into the conveyance system can be expected to actually reach the service connections. A wide range of "unaccounted for" water in Nebraska municipalities (10 to 40 percent) has been estimated by reviewing information gathered by the UNL Conservation and Survey Division in the Municipal Water Use Data Collection project. However, there is not enough information available for many of the communities to determine the exact amounts, and such "unaccounted for" water could not be summarized for the report.[32] In an unmetered system, there is no accurate way to determine distribution losses; however, reasonable estimates can be made based on per capita consumption, comparison of night-time versus day-time pumping rates, or with leak detection instruments.[6]

Even when the metered ratio (the amount of water sold compared to the amount purchased) indicates a high level of "unaccounted for" water, factors other than leakage may be involved. Hudson[24] suggests six possibilities that can affect the metered ratio of distribution losses: (a) inaccurate master meters, (b) inaccurate industrial and commercial meters, (c) inaccurate domestic meters, (d) unauthorized use, (e) use from hydrants, and (f) unmetered but authorized uses.

Of the physical methods available, upgrading of the distribution system (control of underground leakage) has the advantage of being cost effective in that it reduces both pumping and water treatment costs.[23]

RESIDENTIAL USE

Residential water use can be divided into two use categories — in-house and outdoor uses. In-house uses include cooking, drinking, bathing, cleaning, and disposal of wastes. Outdoor uses include car washing, private swimming pools, and lawn and garden watering.[36] Reduction in the demand for municipal water may be accomplished in several ways and at several stages throughout the system. These methods of reduction include the following:

In-house: (1) Toilet flushing control,
(2) Showering control
(3) Laundry and cleaning controls,
(4) Plumbing maintenance
(5) Dual or recycle systems,

Outdoor: (6) Lawn irrigation scheduling, and
(7) Landscaping practices

System conversion to conservation measures in the home not only may reduce the need to pump water, but also may reduce the outflow at the sewage disposal plant. The losses due to in-house uses are considered recoverable since the used water may be available for downstream uses.

Task force No. 9 of President Carter's Water Policy Initiatives on *"Water Conservation in Housing Assistance Programs"*[21] reported that the average daily water usage in residences is about 70 gpcd (gallons per capita per day) and predicted that this amount could be reduced by as much as 15 percent within a ten-year period and perhaps more over a longer time frame. Several authors [23, 46, 49] have estimated potential reduction in use ranging from 32 percent to 70 percent (see Appendix table E-5.) Estimates used in the report are based on reductions discussed by Sharpe.[46] These possible areas of **in-house** reductions are:

Toilet Flushing: A 15 percent reduction in toilet flushing has been obtained by the use of displacement bottles in the tank. Plastic dams were reported to reduce water usage by 29.8 percent per flush. Flush mechanism devices can reduce demand by 40 percent while devices with a two-cycle flush mode reduced usage by 51 percent. However, installation ease, cost, and overall performance made the displacement bottles more acceptable for general use.[23, 46]

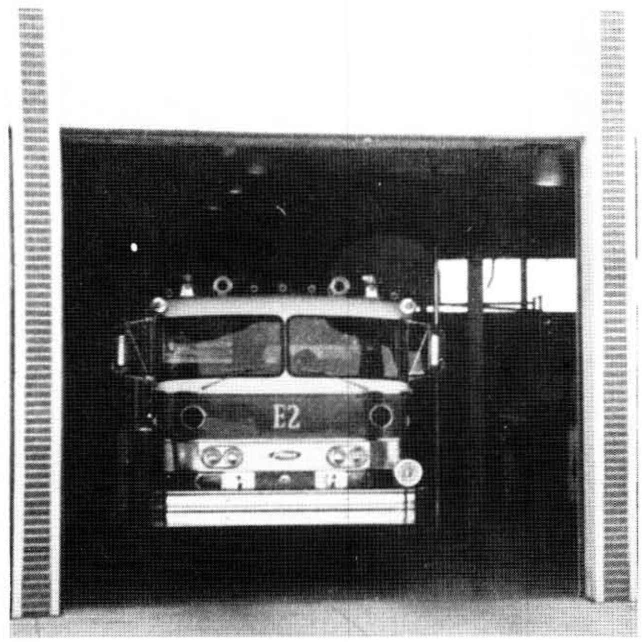
Showering: Because showering habits vary, a wide range in possible reduction of water usage for this activity has been found in the literature. Sharpe[46] discussed reduction ranging from 15 percent to 42 percent. Selecting the proper restriction device is important. Low-flow and low-pressure showerheads may encourage the bather to take a longer shower and thus defeat the purpose of the water-saving device. Showerheads are available that give an acceptable shower with a two gpm flow ration at 50 psi service pressure. Such a device installed in a dormitory a Gettysburg College (Pa.) in 1979 resulted in an average reduction in water use of 24 percent.[46]

Laundry and Cleaning: Faucet aerators and pressure reducing valves are reported to have a reduction potential of 20 percent to 50 percent. Up to 40 percent water reduction can be realized by using wash cycle adjustment for load size.[46]

In addition to the installation of water saving devices a further reduction in demand could be realized by preventing loss due to leaks at the point of connection and plumbing within the buildings. This is a highly variable amount; but, Antosiak and Job[3] indicate that water conservation practices which are "simply good housekeeping...could reduce water use by 50 percent."

Many of the practices which are available to home owners, such as flow restrictors and toilet tank displacements, could also be adopted by businesses, industries and institutions or public buildings.

Dual Systems or Recycling Systems are individual household water recycling systems (referred to as gray water systems) which collect the waste water from clothes washers or showers for use in flush toilets or lawn watering. Savings of up to 39 percent of the total water used in a household have been achieved.[9] Dual water systems will distribute both a potable and non-potable grade of water. The non-potable supply is considered safe and poses no immediate health hazard if inadvertently consumed, but is not of the quality as the potable supply. The quantity, quality and pressure in each system are related to the functions of their respective intended use. The non-potable water is used for lawn and garden watering, car washing, toilet flushing or other municipal needs such as street cleaning, fire protection and possibly industrial needs.[50]



In **outdoor uses**, several methods are availble to a municipality to encourage reduction in the amount of water necessary to maintain a well kept lawn, including irrigation scheduling and the planting of grasses which have lower water requirements.[50]

As with irrigation scheduling for agricultural crops the home owner can be encouraged to apply only the amount of water required by the landscape (grass or trees) and in such a manner as to prevent runoff, deep percolation or excessive evaporation.[50] Irrigation scheduling practices use low-flow watering devices and automation of the watering system. The average sprinkler applies one inch per hour, but an impact head could reduce this flow rate to 0.3 inches per hour. An automated system with a timer may reduce application rates by 25 percent to 50 percent.[20]

Lawn watering is known to comprise a relatively large percentage of municipal water use, but little data exist on lawnwater application rates in Nebraska. Barnes[4] found that summer versus winter demand gives a reasonable estimate of outdoor residential usage. This same study found that lawn watering accounted for 60 percent to 90 percent of total residential use in Laramie and Wheatland, Wyoming. He stated that 30 to 40 percent is commonly cited as the proportion of total municipal water use attributable to lawn watering. It has been shown that the landscape of the average American home uses approximately 70 percent of the total water utilized in the residence.[23] The average winter usage (November-April) was tabulated for six Nebraska muncipalities and compared to the average summer use (May-October, see Appendix E). These cities showed that a range of 30 percent to 47 percent of total municipalities examined showed a range of 124 to 259 gallons/capita/day (gpcd) summer increase over winter use for the six month period; or 78 gpcd annual average.

Cotter and Croft[11] report that home owners in a New Mexico study applied 50 percent more water than calculated plant requirements. A similar study by Barnes[4] found Wyoming residents over-watering by 125 percent to 175 percent of the landscape water requirement. No studies are available for any Nebraska cities.

Landscaping with indigenous or native vegetation is a developing practice in Arizona, Nevada, and California. This type of landscaping includes plants and grasses as well as other native or low water consuming vegetation (such as wildflowers). Other decorative ground cover such as rock or wood chips may be included in the landscaping practice. Little if any irrigation water is required for the vegetation, as the normal rainfall for the region will sustain growth for all but a very few exceptionally dry periods.[9] Not only would this practice conserve the amounts of water required but also would reduce the maximum seasonal and peak hourly day demands.

IMPACTS

The hydrologic impacts of municipal and residential water use efficiency techniques relate primarily to potential reductions in water withdrawals.

While encouragement of such practices could be important to a water supplier, the potential reduction as a percentage of state-wide demand is believed to be rather small. The 1975 estimated water usage reported by Bentall and Shaffer[5] was compared against the calculated demand if the aforementioned conservation techniques for municipalities had been in place. It was found that the overall reduction would likely be no more than three percent of the state-wide water requirements for all activities (excluding power generation).

The water reductions which could be obtained in lawnwatering practices or changes in landscaping are not well documented for Nebraska, but savings of up to 50 percent are cited in the literature as a reasonable estimate. A comparison of the reductions which might be realized among the various practices is shown in Table 8.

TABLE 8

COMPARISON OF ESTIMATED POTENTIAL REDUCTION OF WATER USAGE IN VARIOUS HOUSEHOLD ACTIVITIES

Activity	Percent Reduction		
	Howe (23)	Sharp (46)	Stone (49)
Toilet	41 to 56%	up to 30%	12 to 27%
Shower	20 to 34%	50 to 70%	0 to 32%
Laundry	20 to 27%	——	0 to 2 %
Faucet	——	50	0 to 2 %

The social/economic impacts relate primarily to (a) the cost of water to the consumer, and (b) the costs of sewage treatment. The cost per unit of water used for the consumer may actually increase, as municipal systems must still finance existing systems designed for largers demands. However, if reduced demand eliminates the need for new municipal withdrawals, storage and delivery systems, the long-term costs of water could be reduced. The costs of sewage treatment would also be varible, depending on the type of existing sewage treatment plant in use. Reduced municipal water use would decrease the amount of water reaching the plant which may create problems in the treatment process. However, if the reduced water use makes construction of larger treatment plants unnecessary, long-term savings may be realized.

The environmental impacts relate primarily to sewage treatment, as discussed above, and will also be highly variable depending on municipal system.

PRESENT LEVEL OF ADOPTION

The present level of adoption of residential water use efficiency practices fluctuates primarily according to the cost of the water. During a water shortage crisis, pricing mechanisms are generally recognized as a method used by suppliers to reduce water demand. Afifi and Bassil report that: "Waste by customers is encouraged by flat rates and by low rates for high volume during peak periods....".[1]

INDUSTRIAL SYSTEMS

Self-supplied industrial water use represents 0.4 percent of Nebraska's total water use[32], and the three major classifications of industrial water use are:

(1) non-contact cooling,
(2) process and related uses, and
(3) sanitary or miscellaneous uses.

The greatest opportunity for improved industrial water use efficiency occurs where greater recycling of the water may be possible. However, Koller and Brewer[28] state: "The hard core of the industrial market for municipally supplied water is made up of the small water users.... Those (plants) have little opportunity to recycle." This report looks only at the recycling opportunities for self-supplied industrial water use.

According to Sherwani[47], "There is very little data available on cost, pattern of water use and water technology of self-supplied industries." Furthermore, industries vary greatly in water requirements both between types of industry and within the same industry. It is difficult to say that a product requires a specific quantity of water. Kollar and MacAuley[29] have reported average or typical water use requirements for various industries. Although these numbers must be viewed rather carefully, they do represent a valuable comparison of relative water needs among different industries and types of usage within the industry. This table is presented in Appendix E.

Kollar and MacAuley[29] have estimated potential reduction in demand if maximum feasible recycling were employed (see Table 9). They note that, "Good judgement should be exercised in interpreting these ratios, since they represent overall (national) averages for these industries."

TABLE 9

WATER INTAKE REQUIREMENTS; AVERAGE PLANT VERSUS HIGH RECYCLING PLANTS AND PERCENT REDUCTION IN WATER USAGE.

	INTAKE			RECYCLING RATE	
INDUSTRY	1973 Industry Ave.	Maximum Feasible Reduction Best Available Technology	% Potentail Reduction	1973 Industry Ave.	Maximum Recycle Rate, BAT.
Industrial Inorganic Chemical	4,750 gal/ton	470 gal/ton	90.1	3.08	31.20
Meat Packing Plants	2 gal/lb.	.5 gal/lb.	77.3	1.66	6.67
Beet Sugar Refineries	11,100 gal/ton	6,200 gal/ton	44.1	2.98	5.38
Hydraulic Cement	830 gal/ton	180 gal/ton	78.3	1.63	7.41
Petroleum Refining	289 gal/bbl.	55 gal/bbl.	81.0	6.38	33.30

(Taken from Kollar and MacAuley, 1980)

There may also be opportunity for industry to reduce evaporative losses through improvement or redesign of systems where steam is used for power generation, as a catalyst or for cleaning. The use of water in industry is not well documented, and no attempt is made in this report to estimate the extent to which evaporative losses could be reduced.

IMPACTS

The hydrologic impacts of improved industrial water use efficiency relate primarily to (a) reduced withdrawals for self-supplied industries, and (b) reduced demand on municipal water supplies where those industries are dependent on municipal systems.

Social/economic impacts relate primarily to (a) reduced pumping costs for self-supplied industries, and (b) variable effects on water fees charged for municipal water use (see discussion under "Municipal Systems").

Opportunities exist for water conservation in industry, but, as Antosiak and Job caution, "Across the board regulations for industry to conserve water are not desirable because the effects (impacts) of water conservation in each individual industry's manufacturing process may vary. In addition, the costs of installing necessary equipment may outweigh the benefits in some cases, while in others industrial water conservation efforts may use more energy than normal operations. Thus, decisions concerning industrial water conservation should be made on a case-by-case basis.[3]"

Environmental impacts of industrial water use efficiency are similar to those described above under "Municipal Systems."

PRESENT LEVEL OF ADOPTION

Water use per unit of production and present recycling rates for Nebraska's industries are not compiled. For this report, it is assumed that Nebraska industries use no more or less water than the national average and can reduce their present demand by the same percentage as suggested by Kollar and McAuley.[29] Table 10 shows the estimated reduction as calculated for the five major water users which provide their own supply.

TABLE 10

INDUSTRIAL WATER REDUCTION POTENTIAL.

INDUSTRY	Estimated 1979 Use (million gallons/yr)	Potential Reduction percentage	Estimated Demand Using Maximum Feasible Recycling (million gallons/year)
Industrial Inorganic Chemical	6,967.12	90.1	690
Meat Packing	4,228.89	77.3	960
Beet Sugar Refining	2,743.70	44.1	1,533
Hydraulic Cement	1,118,72	78.3	242
Petroleum Refining	1,051.20	81.0	200
Total	16,109.63		3,625

1979 Industrial Water Use adapted from: *An Inventory of Public, Industrial, and Power-Generating Water Use in Nebraska* Nebraska Water Survey Paper #54.

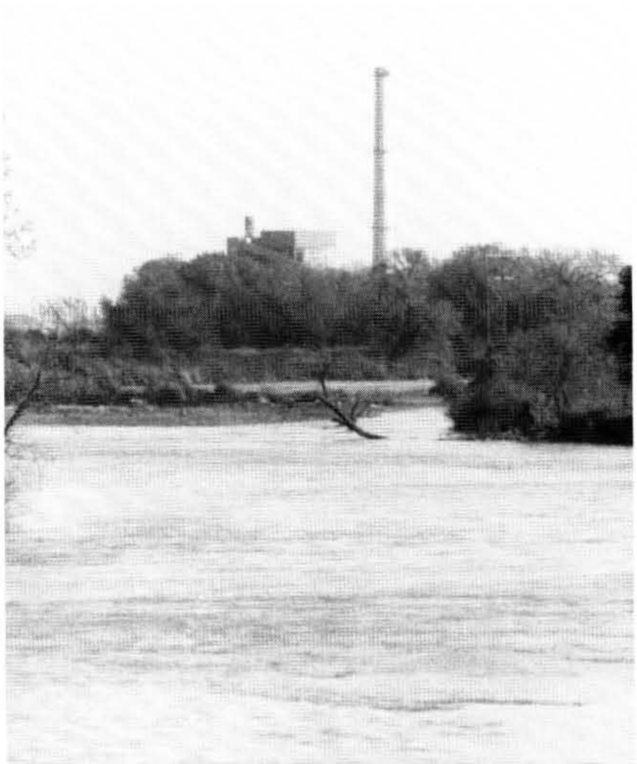
**NOTE:* Based upon available technology and may not necessarily be economically feasible in Nebraska.

Municipal and industrial wastewater reclamation procedures are highly developed, and reuse of treated wastewater is possible with today's technology. Recycling can be accomplished if the costs of recycling are competitive with water from other sources.[48] Both the costs of water reclamation and environmental considerations dictate whether water will be reclaimed and reused. Examples of water reuse systems can be found in areas of water shortage.[2]

POWER GENERATION SYSTEMS

Power generation water requirements represent 20.6 percent of Nebraska's total water use[32], and there are three primary types of generating plants: (a) hydroelectric, (b) thermoelectric-steam cycles, and (c) combustion turbine plants.

Hydroelectric facilities include both on-stream and off-stream plants. At on-stream plants, all or a portion of the natural streamflow flows through the turbines and returns to the river, with essentially no consumptive loss of water. Off-stream hydroelectric power plants can also



be generally considered non-consumptive, excepting that water which may be lost during conveyance to the plant from a distant source. These conveyance system losses are covered in Chapter 6.

Thermoelectric-steam cycle plants rely on steam pressure to generate electricity. While the actual generating operation is relatively non-consumptive, separate water systems are also employed to cool the steam after it has passed through the generating turbines, and these systems can be water consumptive. Six main cooling systems exist, including once-through cooling systems, cooling lake systems, wet cooling towers, dry cooling towers, wet/dry cooling towers, and spray pond cooling. These systems vary in the amount of water diversions necessary, the amount of water consumed, and in the cost of construction. In Nebraska only once-through cooling systems and wet cooling towers are in use.

The *Water and Energy Policy Issue Study*, published in 1984, provides a thorough description of both hydroelectric and thermoelectric power plants, along with information on their water diversion requirements, water consumption rates and instream flow impacts. For further information on these systems, the reader is referred to this study.

Combustion turbine plants, generally used for peaking power, do not have large water requirements and were not examined in this study.

Generally, the power production techniques used in Nebraska are the state-of-the-are available in the industry, and are as efficient as the industry as a whole. After a review of the literature, it appears the potential for improved water use efficiency within the power industry is limited, for the following reasons:

First, the level of efficiency of any plant is dictated primarily by its type and its design. The design is dictated by such factors as the availability of adequate water supplies, geologically or topographically suitable sites, the capital costs of plant construction, and environmental requirements for discharge permits.

Second, once a power plant is built, it is generally economically infeasible to convert to another system of generating or cooling. Thus, efficiency considerations are relevant in the construction and design of new plants, but conversions of existing plants to more efficient systems are usually cost prohibitive.

IMPACTS

The hydrologic impacts of choosing a more water efficient power plant relate primarily to (a) possible reductions in water withdrawals from either streamflow or groundwater, and (b) possible reductions in evaporative losses.

Where power plants depend on surface water diversions, canal systems and storage reservoirs, the impacts of improved efficiency within these conveyance systems are discussed in Chapter 6. Within thermoelectric plants, the choice of cooling systems has an impact on potential evaporative losses. Once-through cooling systems require larger diversions, but lose less water to evaporation than wet cooling towers or reservoir systems, which require less water diversion.

The social/economic impacts of choosing a more water efficient power plant or cooling system relate primarily to the capital costs associated with water withdrawals, both of which are ultimately passed on to the power users.

The environmental impacts of choosing a more water efficient power plant relate primarily to (a) possible increases in streamflow below the point of diversion where the plant is dependent on surface supplies, and (b) reductions in thermal pollution.

PRESENT LEVEL OF ADOPTION

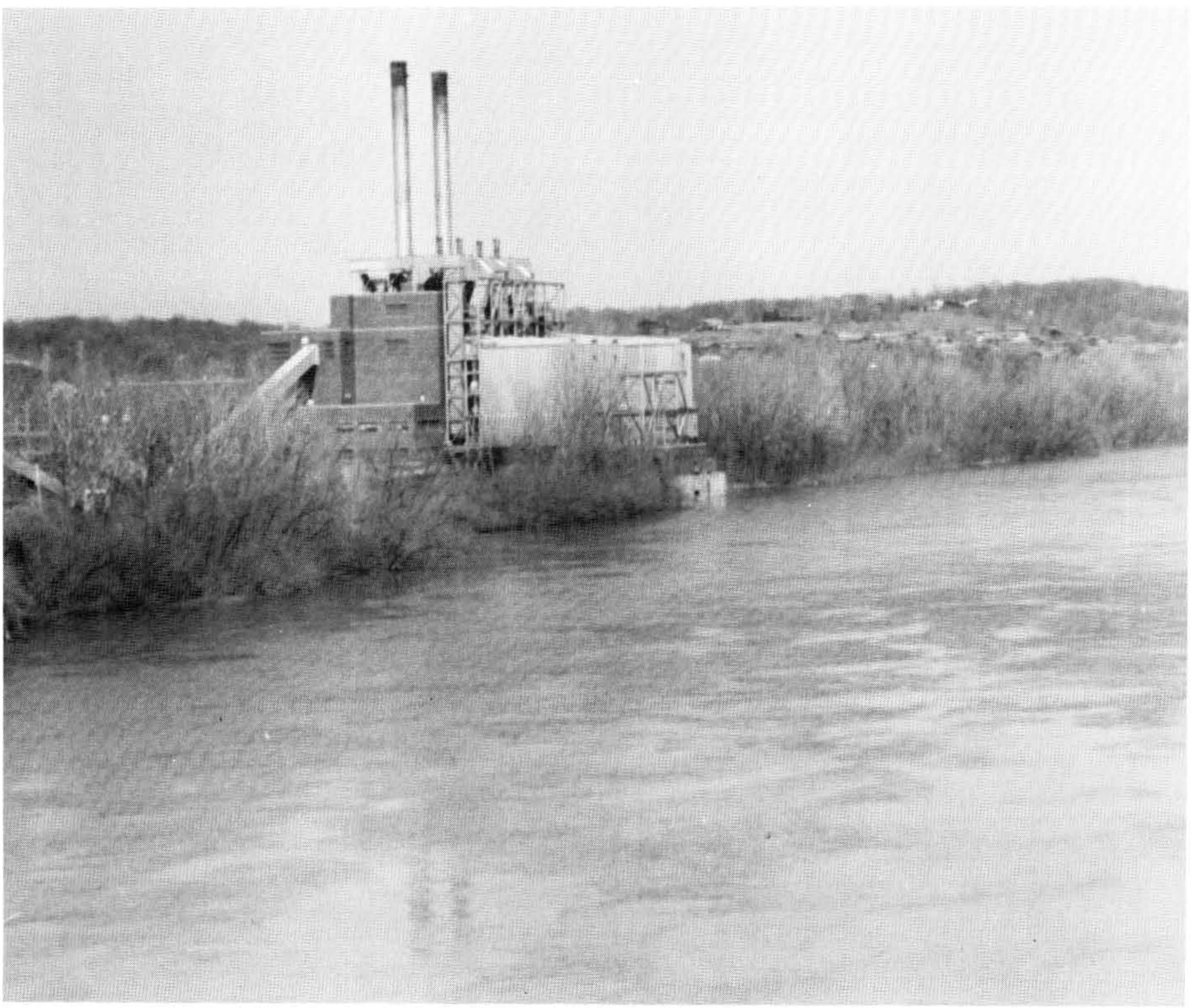
Given their present facilities, hydroelectric power production in Nebraska has been judged to be close to maximum possible efficiency in water use.[30]

In thermoelectric power plants in Nebraska, once-through cooling systems are nearly always preferred on large river systems. Once-through cooling systems are simple, inexpensive, and they consume relatively small amounts of water, although they require large diversions. Thus, once-through cooling systems are used primarily at power plants along the Missouri River and to a lesser extent along the Platte River. Fifteen Nebraska power plants use once-through cooling systems.

Where sites are not hydrologically, geologically or topographically favorable for once-through cooling, a wet cooling tower is used. These towers require smaller diversions but consume more water. Most of the water that was originally diverted from the river or from groundwater evaporates and is not returned to the source. Six power plants in the Platte River Basin use wet cooling towers.

According to the *Water and Energy Policy Issue Study*, if new power plants use once-through cooling, diversions for power generation will be about 1.5 times greater in the year 2000 than they are today; consumption will be about two times greater. If, on the other hand, new power plants use wet cooling towers, diversions in 2000 for power generation will be about the same as today but consumption will be about three times greater.

Research continues for more water efficient methods of steam cooling and alternative techniques for electrical generation, but for the near future, hydroelectric plants (where feasible), and thermal plants with once-through or wet evaporative cooling towers will likely remain the choices for new plants, as alternative methods are not felt to be economically feasible at this time or in the near future. A combined system of wet/dry evaporative cooling, however, may show promise in the years ahead.



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SECTION III

POLICY ALTERNATIVES WHICH MAY PROMOTE THE ADOPTION OF WATER USE EFFICIENCY TECHNIQUES

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Chapter 9

Policy Alternatives Presented for Consideration

It is the purpose of this chapter to identify, describe and analyze policy alternatives which could promote the adoption of improved water use efficiency techniques discussed in Section II. Presented with each is a brief description of the policy alternative; legal and institutional aspects of implementing the policy; the projected response of existing water users to the policy; and a discussion of various policy impacts which could be expected to result from the policy's implementation.

Given the purpose of these policy alternatives, the primary "impact" of each alternative relates to how effectively it promotes the adoption of the techniques presented in Section II. An evaluation of each policy's effectiveness in achieving this goal is discussed under "Water User Response." Where these policy alternatives are projected to promote the adoption of any water use efficiency technique, the reader is referred back to Section II where the various local physical/hydrologic, social/economic and environmental impacts of the techniques are discussed.

However, these local impacts can have state-wide social and economic effects which are described in more detail under the "Impacts" of each policy alternative. Certain social or economic impacts stemming directly from the policy itself are also discussed where applicable. Also, in some cases there will be a definite administrative impact associated with implementing the alternative.

Four policy alternatives are presented as follows:

Alternative 1. Make no changes in existing administrative or statutory policies related to water use efficiency.

Alternative 2. Increase research and educational efforts related to improving water use efficiency.

Alternative 3. Provide either economic incentives for installing efficient water use technologies or disincentives for excessive use of water.

Alternative 3A. Modify administration of the Nebraska Soil and Water Conservation Fund (NSWCF).

Alternative 3A-1. Earmark a portion of the existing NSWCF for water use efficiency practices.

Alternative 3A-2. Increase state appropriations to the NSWCF earmarked for eligible water use efficiency practices.

Alternative 3B. Modify administration of the Nebraska Resources Development Fund (NRDF).

Alternative 3B-1. Establish water use efficiency as one of the criteria for determining priorities for NRDF funding.

Alternative 3B-2. Increase and earmark NRDF appropriations to fund projects or programs improving water use efficiency.

Alternative 3C. Authorize natural flow appropriators to expand acres served by an appropriation.

Alternative 3D. Require water users to pay a water use charge, exempting self-supplied domestic and livestock watering uses.

Alternative 4. Encourage the installation of efficient water use practices by regulation.

Alternative 4A. Modify surface water administration.

Alternative 4A-1. Authorize DWR to administer new natural flow appropriations at a lower withdrawal rate.

Alternative 4A-2. Authorize DWR to administer existing natural flow appropriations at a lower withdrawal rate.

Alternative 4A-3. Authorize DWR to establish efficiency standards for new conveyance systems.

Alternative 4B. Expand the types of controls that can be required by a NRD in a control or management area.

POLICY ALTERNATIVE #1

MAKE NO CHANGES IN CURRENT ADMINISTRATIVE AND STATUTORY POLICIES RELATED TO INCREASING WATER USE EFFICIENCY.

DESCRIPTION

The purpose of this alternative is to allow existing incentives and constraints to control the rate by which efficiency techniques and practices are adopted. This alternative proposes that no new legislation be enacted and existing legislation not be modified.

Several reasons for implementing this alternative might include:

(a) if it is determined that the efficiency of water use within the state does not need to be significantly improved;

(b) if it is determined that the efficiency of water use within the state needs to be improved, but that existing legislative and regulatory controls or incentives are adequate (existing laws are discussed in Chapter 3);

(c) if it is determined that the efficiency of water use within the state needs to be improved, that existing legislative and regulatory controls or incentives are not promoting improved efficiency, but that the potential improvements in efficiency are taking place naturally in response to economic restraints, private sector technology promotion and social pressure both on local and state levels.

WATER USER RESPONSE TO ALTERNATIVE #1

Water use efficiency techniques and practices are adopted in response to many influencing factors, including the financial cost of the technique, practical adaptability of the technique to local situations, potential economic returns from adopting the technique, and governmental laws and regulations restricting the use of water. Legislative policies can affect each of these factors to varying degrees.

IMPACTS OF ALTERNATIVE #1

As this alternative proposes no change in existing policy, it will have no effect on the current rate at which efficiency techniques are being adopted. Therefore, it can be projected that present trends of water use will continue, as well as any physical/hydrologic or environmental impacts resulting from these present or projected water use patterns.

Generally, if no changes are made in existing laws or regulations, as proposed by this alternative, the following water use patterns are projected to occur.

Agriculture. According to the *High Plains Study*[52], the status quo or baseline situation would probably result in the following key responses:

(1) an increase in acres irrigated with groundwater and surface water;

(2) reduction in the average amount of water applied per acre of about 30 percent in the case of gravity irrigation systems and about 10 percent for sprinkler systems; and

(3) a proportional increase in the acreage devoted to crops with a lower water requirement.

These responses are based on the assumption that the profitability of irrigated agriculture will increase over the long term.

The agricultural water use efficiency techniques (Chapter 7) which are most likely to be adopted are irrigation scheduling, conservation tillage, reuse pits, and system modifications and conversions (unlined ditches to gated pipe, gated pipe to sprinklers, high pressure to low pressure sprinkler systems, etc.).

Conveyance Systems. Within surface water conveyance systems (Chapter 6), techniques most likely to be adopted include canal lining, system modification, and conversion to pipelines. However, because of the high cost, lining will occur primarily in those areas where canal seepage prevents water suppliers from meeting their contractual water demands. In other areas water logging may become a serious problem, and drainage costs or social and legal pressures could dictate that the canals be lined. In addition, existing law allows surface water project operators to charge those benefitting from recharged groundwater resulting from unlined canals. This may serve as a financial incentive to keep the canal unlined.

Municipal. Techniques to improve municipal water use efficiency (Chapter 8) are adopted primarily in response to the price of water, which in turn, is determined by the cost of withdrawal and distribution. Beyond these economic restraints, little incentive exists to improve municipal water use efficiency, especially where water supplies are not threatened by streamflow or groundwater depletions.

Self-supplied Industry and Power Generation. Techniques to improve industrial and power generation water use are adopted according to the physical and economic feasibility of the technique, as well as the need to comply with water quality regulations. These incentives will continue to promote a high level of efficiency within these uses.

The state-wide social/economic impacts of Alternative #1 relate primarily to the possible "opportunity costs" incurred by not implementing a beneficial policy. If policies exist which could potentially enhance the state's economic base, not implementing those policies could be regarded as having a negative impact on the state.

For a thorough description of these present trends, and the impacts of making no changes in current policy, the reader is referred to the other policy issue study reports on *Groundwater Reservoir Management, Supplemental Water Supplies, Instream Flows, Municipal Water Needs, Water Quality, Selected Water Rights, and Water and Energy.*

POLICY ALTERNATIVE #2

INCREASE RESEARCH AND EDUCATIONAL EFFORTS RELATED TO IMPROVING WATER USE EFFICIENCY.

DESCRIPTION

The purpose of this alternative is two-fold: (1) to promote the development of new technologies and the refinement of existing technologies through research, and (2) to promote the adoption of existing technologies through expanded educational and demonstration programs.

Research and educational programs can either be implemented alone or in conjunction with incentive or regulatory policies. Obviously, until the techniques are developed and water users understand how to implement them, any incentive or regulatory policy to promote their adoption will be ineffective.

Examples of research and educational areas which may benefit from additional funding include development of less water intensive crops, cropland mulching, alternative cropping patterns, and collection and storage of crop water use data.

IMPLEMENTATION

This alternative may be implemented by (a) increasing legislative appropriations for water use efficiency research and educational programs; and/or (b) redirecting existing research and educational programs to place greater emphasis on improving water use efficiency.

WATER USER RESPONSE TO ALTERNATIVE #2

Expanded research and educational efforts could lead to an increased rate of adoption of improved efficiency techniques if water users believed such practices to be profitable. The factors which most dictate adoption are economic considerations (cost of implementation and potential returns on investment) and legal restraints (surface and groundwater withdrawal restrictions), both of which may be intensified during periods of drought or other water shortage.

Agriculture. It is anticipated that groundwater users will be more receptive to research and educational efforts than surface water users because the cost of groundwater withdrawals is approximately five times the cost of surface water withdrawals. Therefore, potential economic savings are greater for groundwater users. Also, reductions in surface water withdrawals will not increase the amount of water available for use in following years, whereas reductions in groundwater withdrawals may.

Municipal, Industrial, Power. In many other states, water-related educational programs are directed primarily toward municipal users. In Nebraska, these efforts could be effective in areas which experience periodic water shortages, but throughout most of the state, municipal water supply is not perceived to be a problem. Thus, educational programs would not likely produce any significant response. Within industrial and power generation uses, research and development takes place in large part within the industry, and thus state-sponsored programs would not be projected to have any significant impact.

IMPACTS OF ALTERNATIVE #2

An expanded research program could lead to the development of new and the refinement of existing technologies, the impacts of which are difficult to assess. An expanded educational effort should lead to the accelerated implementation of existing technologies, the local physical/hydrologic and environmental impacts of which would be as listed under each technique in Chapters 6, 7 and 8.

On a state-wide level, the *High Plains Study* reported that educational programs would secure voluntary adoption of water use efficiency techniques only to the point that they are perceived to be profitable, but that this level of adoption would not significantly reduce groundwater depletion rates. The improved efficiencies adopted voluntarily, according to this study, would reduce pumpage substantially, but would affect net depletions only slightly because much of the excess pumpage associated with over-irrigation ultimately returns to the aquifer.[52]. However, if a 10 percent reduction in ET were realized, then there might be a substantial impact on those areas where over-irrigation is occurring.

The social/economic impacts of this alternative relate directly to the benefit/cost ratio of research and education appropriations—economic returns to the state. Educational efforts to promote some new techniques may have a favorable benefit/cost ratio.

POLICY ALTERNATIVE #3

PROVIDE EITHER ECONOMIC INCENTIVES FOR INSTALLING EFFICIENT WATER USE TECHNIQUES OR DISINCENTIVES FOR EXCESSIVE USE OF WATER.

ALTERNATIVES 3A-1 and 3A-2 CONCERN MODIFYING ADMINISTRATION OF THE NEBRASKA SOIL AND WATER CONSERVATION FUND (NSWCF).

The stated legislative intent in creating the NSWCF is "that it is in the public interest of this state to financially assist in encouraging water and related land resource conservation measures on privately owned land and that this will produce long-term benefits for the general public." The NSWCF is available to provide cost sharing to landowners to increase on-farm water storage and conservation. This fund is administered by the Natural Resources Commission (NRC). Landowners may receive up to 75 percent state cost-sharing on eligible soil and water conservation practices, which include construction of terraces, sedi-

ment control structures, reuse pits and planting windbreaks. The NRC has the authority to expand this list to include other water use efficiency practices. As a condition of receiving NSWCF cost-sharing, landowners must agree not to remove or modify the practice for 10 years without NRC approval.[39]

Appropriations for the NSWCF have grown steadily from $500,000 in 1978 to $1.4 million in fiscal year 1984-85. From its inception in 1978, approximately $7.3 million has been appropriated to the NSWCF. Approximately $1.5 million has been spent on terracing projects, and $350,000 on reuse pits as of July 1, 1983. No figures are available for windbreaks. On the average, approximately 40 percent of this fund has been obligated and spent for water use efficiency related practices.

POLICY ALTERNATIVE #3A-1

EARMARK A PORTION OF THE EXISTING NSWCF FOR WATER USE EFFICIENCY PRACTICES.

DESCRIPTION

The purpose of this alternative is to accelerate the implementation of water use efficiency techniques. At the present time approximately 40 percent of the NSWCF is utilized for those projects listed as improving water use efficiency but is variable from year to year. If a portion of this fund were designated for funding these practices, more water use efficiency practices may be implemented.

IMPLEMENTATION

Implementing this alternative could require legislation designating a portion of the NSWCF for water use efficiency practices, or the NRC could accomplish this through administrative action.

POLICY ALTERNATIVE #3A-2

INCREASE STATE APPROPRIATIONS TO THE NSWCF EARMARKED FOR ELIGIBLE WATER USE EFFICIENCY PRACTICES.

DESCRIPTION

The purpose of this alternative is to further encourage installation of efficient water use practices through increased financial incentives. Water use efficiency practices which are presently eligible under NSWCF guidelines are reuse pits, terrace construction, windbreaks, and water impoundments (e.g., for the purpose of recharge).

IMPLEMENTATION

Implementing this alternative would require increased legislative appropriations to the NSWCF and earmarking those appropriations for water use efficiency techniques.

WATER USER RESPONSE TO ALTERNATIVES 3A-1 AND 3A-2

Increasing appropriations to the Nebraska Soil and Water Conservation Fund would allow increased participation in the program.

Earmarking a portion of the NSWCF would ensure that the designated water use efficiency techniques would be installed by those utilizing the fund. In order to have a significant impact, the proportion earmarked may have to be greater than the 40 percent currently being used for water use efficiency. Because the NRDs also have the discretionary authority to limit the practices applicable within their borders, alternative 3A-1 (earmarking a portion of the current level of funding) may prevent some operators within certain NRDs from utilizing those earmarked funds. Alternative 3A-2, which increases NSWCF funding and earmarks a portion of these increased funds, would not affect the present level of non-earmarked funds available.

Practices encouraged would be the installation of reuse pits, terrace construction (land shaping) and the planting of windbreaks. The impacts of installing these practices are discussed in Chapter 7.

IMPACTS OF ALTERNATIVES 3A-1 AND 3A-2

The impacts of these alternatives would depend on response to the incentives. If the alternatives succeed in accelerating the adoption of eligible water use efficiency techniques, the primary physical/hydrologic impact would be a reduction in runoff and improved snow management. For a more complete discussion of the local physical/hydrologic impacts of installing reuse pits, land shaping and windbreaks, refer to Chapter 7.

The primary social/economic impact of these alternatives could be an increase in state expenditures, if participation in the funding program is increased. However, the installation of efficiency techniques may result in improved revenues for water users, and it is possible that the money disbursed by the NSWCF could result in greater spendable and taxable income, especially over the long term.

The environmental impacts of implementing these alternatives would be variable. In areas where overland runoff is the primary source of streamflow, water quality may be improved, although the total stream volume may be diminished. There may be a greater potential for stream bank erosion because reduced sediment loads increase the potential energy of the streamflow. If windbreaks are planted, habitat diversity will increase.

ALTERNATIVES 3B-1 AND 3B-2 CONCERN MODIFYING THE ADMINISTRATION OF THE NEBRASKA RESOURCES DEVELOPMENT FUND (NRDF).

The NRDF makes state financial assistance available for development of supplemental water supplies, conveyance system improvements, and other such projects sponsored by local governmental units. Project applications are evaluated by the NRC staff to determine whether: (1) the proposed project would conflict with any state land plan; (2) the proposal is economically and financially feasible; (3) the proposal is technically feasible; (4) adverse environmental impacts are minimized; (5) the applicant is qualified to implement the proposal; (6) any loan request can be repaid and that adequate operation and maintenance are provided during the loan's term; (7) the proposal is coordinated with other state programs; and (8) money is available from the NRDF. Precise expenditures for these projects which presently relate to water use efficiency cannot be determined.[40]

From fiscal year 1974-75 to fiscal year 1984-85, almost $20 million has been appropriated to the NRDF, of which $18,045,934 has been allocated. Interest rates on loans made through this fund are based on current bond rates, which at this writing, is approximately 9.87 percent. There is a $10 million ceiling on funds that may be provided to individual projects by the NRDF after February 15, 1985.

POLICY ALTERNATIVE #3B-1

ESTABLISH WATER USE EFFICIENCY AS ONE OF THE CRITERIA FOR DETERMINING PRIORITIES FOR NRDF FUNDING

DESCRIPTION

The purpose of this alternative is to establish water use efficiency as a criterion to be used by the NRC in establishing priorities for the annual funding of approved Resources Development Fund projects. Each year, the NRC reviews approved projects for which funds are requested for the next fiscal year. Based on this review, the Commission or NRC staff establishes a priority list used to determine which projects will receive funds out of the next fiscal year's appropriation if those appropriations are not sufficient to fund all the projects for which funds are requested. A tentative priority list is arrived at by evaluating projects based on a multiple criteria point system that includes, but is not limited to, consideration of the economic return on the project, urgency of need, environmental impact, public support,

and needs addressed by the project. The Commission may alter the list arrived at through the assignment of points if it desires.

Water conservation is one of the needs addressed for which points can be obtained under the existing system, but the definition of this term is different (water recharge and the use of practices that enhance the continued use of the water resource) than the definition of water use efficiency used in this study.

IMPLEMENTATION

This alternative could be implemented by the Commission by revising the Resources Development Fund Project Assessment Criteria it uses for the annual priority setting process or the Legislature could direct the Commission to consider water use efficiency in the priority setting process. To clearly include water use efficiency considerations in the priority setting process, the definition of water conservation could be reworded, or a separate category for water use efficiency added. If the Commission desired, it could also allow a greater number of points to be earned for projects which improve water use efficiency than other types of projects.

POLICY ALTERNATIVE #3B-2

INCREASE AND EARMARK NRDF APPROPRIATIONS TO FUND PROJECTS OR PROGRAMS IMPROVING WATER USE EFFICIENCY

DESCRIPTION

The purpose of this alternative is to accelerate the rate of adoption of efficiency techniques by increasing NRDF appropriations and earmarking these increased funds for those projects and programs which have improved water use efficiency as an objective. Under existing statutes, state grants and loans are available to public entities (irrigation districts, NRD's, municipalities, etc.) from the Nebraska Resources Development Fund for water resources development. Grants and loans may be made to improve public water conveyance systems, among other things. Loans are made to revenue generating projects, while grants are made for non-revenue producing projects or portions thereof.

IMPLEMENTATION

Implementing this alternative would require increased state financial appropriations to the NRDF and designating them for projects specifically designed to improve water use efficiency.

WATER USER RESPONSE TO ALTERNATIVES 3B-1, 3B-2

These financial incentives will (a) encourage existing water suppliers to consider water use efficiency projects to improve present systems; and (b) encourage the incorporation of water use efficiency as a consideration in the design of new systems. Assuming that this encouragement is sufficient, the techniques that may be adopted include canal lining, conversion of lateral ditches to pipelines, and surface barriers. For a full discussion of these techniques, the reader is referred to Chapter 6.

Municipal water distribution systems may be able to utilize some of these incentives through the NRDF. By doing so they may be able to upgrade their water distribution systems and to repair leaks.

IMPACTS OF ALTERNATIVES 3B-1 AND 3B-2

If these alternatives accelerate the rate of adoption of eligible techniques, the primary physical/hydrologic impact will be a reduction in system seepage, e.g., canal, reservoir, or municipal distribution system. For a more complete discussion of these impacts, refer to Chapter 6.

Improvements in conveyance systems can result in changes in the location and timing of streamflows. In areas where system seepage is significant, base streamflow may decrease. Problems associated with water-logged land, such as in the Farwell area, could be reduced.

The primary social/economic impact of these alternatives may be possible increases in state expenditures. However, a major economic impact on the water supplier could be the cost of lining a supply canal which will be passed on to the water users. Conveyance system improvements would be offset, in some cases, by elimination of land drainage costs associated with unlined canals and by other associated benefits.

The environmental impacts of implementing these alternatives will be mixed. Streamflows will be more variable in areas where extensive canal lining occurs. In some areas, such as the North Platte tributaries, canal lining may result in the loss of some significant fisheries (e.g., Nine Mile Creek), wetlands and wet meadows.

POLICY ALTERNATIVE #3C

AUTHORIZE NATURAL FLOW APPROPRIATORS TO EXPAND CROP ACRES SERVED BY AN APPROPRIATION.

DESCRIPTION

This alternative would allow an appropriator to expand irrigated acres served by the appropriation if it can be shown that the net amount of water in the stream is unchanged. This would provide an economic incentive for natural flow appropriators to install water use efficient techniques.

IMPLEMENTATION

Under existing law, the transfer of an appropriation can be approved if: (a) the requested change of location is in the same river basin as the original allocation and does not adversely affect any other water appropriator, and does not have any significant adverse effect on any riparian water user who files an objection; (b) the requested change will use water from the same source of supply as the current use; (c) the change of location will not diminish the supply of water otherwise available; (d) the water will be applied to a use in the same preference category as the current use; and (e) the requested change is in the public interest.

It is unclear whether the term "change of location" in the existing law is intended to allow a partial transfer thereby expanding the number of acres, or whether it is intended to allow only a complete transfer of the water right from one parcel of land to another. This alternative would involve legislative clarification to expressly allow partial transfers.

WATER USER RESPONSE TO ALTERNATIVE 3C.

This alternative would provide an incentive for improving water use efficiency if (a) additional irrigable land is available and (b) the benefits of increased productivity outweigh the costs of expansion.

Certain techniques are available to the natural flow irrigator to improve water use efficiency including ditch lining, surface barriers, pipelines, mulching and irrigation scheduling, and alternative cropping patterns. For a complete discussion of these techniques, the reader is referred to Chapters 6 and 7.

IMPACTS OF ALTERNATIVE 3C

The physical/hydrologic impacts of this alternative on streams would be minimal. The net effect of this alternative is measured on an instantaneous basis and by definition must be zero. Irrigators may adjust to this alternative by lengthening pumping periods, however. If water saved were obtained by reducing deep percolation, groundwater recharge and off-season streamflows could be reduced slightly. If water saved were obtained by reducing irrecoverable losses (ET), then this alternative would have no physical/hydrologic impacts.

A social/economic impact of implementing this alternative could be an increase in productivity by natural flow appropriators. There may, in some isolated cases, be a possible decrease in productivity by groundwater irrigators. It is anticipated that the decrease in productivity by groundwater irrigators will be minimal because much of the groundwater recharge takes place from application of water to fields, not from leaking on-farm distribution systems. Another impact would be the costs of installing water use efficient techniques. It is assumed that these techniques will not be installed if the benefits of installing such techniques do not outweigh the costs.

The environmental impacts of this alternative would be minimal with reference to streamflow. There would be some change in habitat types associated with converting land to irrigated crop land. The extent of this conversion is unknown.

There would be significant administrative impacts associated with modifying allocations. The difficulty in determining if water use patterns are, in fact, the same are hampered by insufficient streamflow data. The burden of proof will probably be on the irrigator to prove the net effect on the stream, however. Irrigators who choose to expand their operations by altering cropping patterns from one year to the next pose a unique problem. Because the allocation is tied to a certain number of acres, fluctuating the number of acres served from year to year would require modifying the conditions of the allocations annually. Administrative costs of monitoring this alternative would be high.

POLICY ALTERNATIVE 3D

REQUIRE WATER USERS TO PAY A WATER USE CHARGE, EXEMPTING SELF-SUPPLIED DOMESTIC AND LIVESTOCK WATERING USES.

DESCRIPTION

The purpose of this alternative is to reduce withdrawals by increasing the cost of water. Self-supplied domestic and livestock watering uses withdrawing less than 100 gallons per minute would be exempted.

Implementing this alternative would require water users to pay a water use fee based on the quantity of water used. Self-supplied irrigators and industrial users

would pay the fee directly. Those purchasing water from a municipal or rural water system or from an irrigation surface water supplier would pay indirectly, the fee being levied against the water supplier. This alternative would give water users a financial incentive to reduce water use.

The structure of the water use fee could be varied. The charge could be a flat rate or graduated (increasing with volume on a per-acre basis). Similarly, a certain amount of water could be used free with the charge beginning at a specified quantity. The water use fee could be implemented statewide, in problem areas (however defined), or in each NRD on a local option basis. The revenue from the water use fee could be used to fund research and education efforts related to improving water use efficiency or could be used to fund cost-sharing on improved water use efficiency methods or other water-related projects.

IMPLEMENTATION

Implementing this alternative would require enacting legislation establishing the water use fee. Collection could be administered by counties, NRD's, DWR, NRC or some combination of these. The fee could be adjustable over time to accomplish the desired water use efficiency levels. Administration of this alternative would require water metering and increased expenditures for monitoring and enforcement.

WATER USER RESPONSE TO ALTERNATIVE 3D

The effect of this alternative on the rate of adoption of efficiency techniques will depend on the type and level of charge that is levied. Both groundwater and surface water users would be affected.

A low water use charge will generate considerable revenues. There may be some reduction in water usage, but it is doubtful if the reduction would be significant. For most irrigators, water is cheap insurance against crop failure, even with a charge. Low cost-adjustment techniques, i.e., irrigation scheduling and minimum tillage, will be encouraged by this alternative.

The water use fee must be set very carefully. If the charge is high enough to make water an expensive insurance, the insurance may be no longer worth the perceived benefits. If the charge is too high, some irrigators will drop out of the irrigated agriculture business, some irrigators will drop those fields which are least profitable, and some will switch to less water consumptive crops. There is a possibility that irrigators may alter cropping patterns and irrigation techniques to create a more profitable operation. The point at which the charge would make irrigation unprofitable is impossible to assess at this time, because the breaking point is unique for each irrigator's situation and for each year depending on crop prices.

For industrial users the charge would be added to the cost of production. Once again, if the cost of production is greater than the return from the sale of the product, the industry will no longer produce. This charge may influence the decision of new industries with large water requirements, such as food processing plants, to locate in Nebraska. Power generation will also be affected by a water use charge, eventually passing the costs on to the consumer.

Essential domestic usage (drinking, cooking, sanitation and laundering) will not change significantly in light of a water use charge. Non-essential uses may be altered for a time. Over time, the extra-charge will probably be absorbed into the cost of having a nice yard, garden and clean car.

IMPACTS OF ALTERNATIVE 3D

The physical/hydrologic impacts of this alternative may depend on the level of the charge. If a low charge is instituted, there will be little, if any, physical/hydrologic impacts. However, if a high charge is implemented, the impact would be significantly reduced withdrawals from both surface and groundwater supplies.

The social/economic impacts of this alternative relate to possible increases in revenues for the state if the charge is set properly. However, the cost of monitoring and collection could outweigh the increased revenues. Although this charge would be politically unpalatable at first, it may be accepted as part of doing business. Also, it may be more acceptable if the funds generated were used for a water-related project.

An excessively high charge may result in irrigated crop lands reverting to dryland and rangeland production. This could be reflected in lower spendable income and lower tax revenues for the state. Operators working closer to the profit margin would revert to dryland and/or rangeland.

The environmental impacts are insignificant in the case of a low charge. In the case of a high charge, the impacts would be improved surface and groundwater quality as well as possible variations in streamflow. A change in habitat types will occur when irrigated lands revert to dryland or rangeland.

The administration of this alternative would require that staffing of the collection unit be increased in proportion to the number of irrigators in the area. The cost of data collection will be high. Administration would be eased if meters or some other form of measurement were installed.

POLICY ALTERNATIVE #4

ENCOURAGE THE INSTALLATION OF EFFICIENT WATER USE PRACTICES BY REGULATION

ALTERNATIVES 4A-1, 4A-2 AND 4A-3 CONCERN MODIFYING SURFACE WATER ADMINISTRATION.

Under state law, natural flow appropriations for irrigation are granted for an amount up to three acre-feet per acre per year. However, appropriations are not administered on the basis of the three acre-feet allocation because checking compliance would require all natural flow appropriators to install measuring devices. Instead, the Department of Water Resources generally administers natural flow appropriations on the basis of a rate of withdrawal of 1 cubic foot per second (cfs) for every 70 acres of land to be irrigated. This rate of withdrawal is also established by statute. It should be noted that the 1 cfs per 70 acres limitation is enforced only in times of shortage. If DWR is not administering rights on a stream, an appropriator may divert as much water as he is able.

DWR may issue appropriations at a lower rate of withdrawal, but the irrigator may obtain an additional appropriation to bring the total appropriation for a particular parcel up to the 1 cfs per 70 acres rate of withdrawal. (This rate of withdrawal is equivalent to applying approximately 0.3 inch of water per acre in a 24-hour pumping period.)

POLICY ALTERNATIVE #4A-1

AUTHORIZE DWR TO ADMINISTER NEW NATURAL FLOW APPROPRIATIONS AT A LOWER WITHDRAWAL RATE.

DESCRIPTION

The purpose of this alternative is to encourage new natural flow appropriators to adopt water use efficiency techniques by limiting the rate at which streamflow may be diverted to something less than the 1 cfs to 70 acres provided under existing law. The authorized rate of withdrawal could be established on a regional, local or individual basis reflecting the average rainfall for an area and the use of various water use efficiency techniques. If a field-by-field analysis were made, the topography and soils of a particular tract could also be taken into consideration.

IMPLEMENTATION

Legislative action to repeal Section 46-240-01, which allows appropriators to re-apply if their allocation is administered at some rate less than 1 cfs/70 acres and to authorize the Department of Water Resources to establish a rate of withdrawal that might force new surface water users to utilize more efficient techniques, would be needed.

POLICY ALTERNATIVE #4A-2

AUTHORIZE DWR TO ADMINISTER EXISTING NATURAL FLOW APPROPRIATIONS AT A LOWER WITHDRAWAL RATE

DESCRIPTION

The purpose of this alternative is to encourage existing natural flow appropriators to adopt water use efficiency techniques by reducing the rate at which water may be diverted from a stream to something less than the 1 cfs per 70 acres provided under existing law. The authorized rate of withdrawal could be established on a regional, local or individual basis at a rate reflecting the average rainfall for an area and the use of various techniques to improve water use efficiency. If a field-by-field analysis were made, factors such as topography and soils could also be taken into consideration.

Reducing the rate of withdrawal for existing appropriators would require the readjudication of those rights. This would be a time-consuming and expensive process requiring notice and hearing for contested cases.

IMPLEMENTATION

Legislative action would be necessary to implement this alternative. However, it should be noted that the constitutionality of this alternative is questionable. Chapter 3 contains a discussion of existing state law regarding water use efficiency. In the section of that chapter discussing the beneficial use concept as it relates to surface water, the Nebraska Supreme Court's 1939 decision in *Enterprise Irrigation District v. Willis* was discussed. In that case the court stated that irrigators are not required to use the latest and "most approved scientific method" in applying irrigation water. The court also stated that it was unconstitutional to reduce the quantity of water to which an appropriator is entitled if such action results in a "material injury" to the appropriator, i.e., a taking or damaging of a vested property right without compensation.

The constitutionality of this alternative would depend on whether its application was found to result in a material injury to existing appropriators. It is likely that if the application of this alternative required an existing appropriator to incur the expense of switching from an open ditch to a gated pipe or other more expensive application system, it would be found to be unconstitutional.

POLICY ALTERNATIVE #4A-3

AUTHORIZE DWR TO ESTABLISH EFFICIENCY STANDARDS FOR NEW CONVEYANCE SYSTEMS

DESCRIPTION

The purpose of this alternative is to improve the designed efficiency of new surface water conveyance systems. Under existing law, surface water conveyance systems are not subject to specific efficiency standards. In fact, LB 198, passed during the 1983 Legislative Session, provided legal recognition of the seepage of surface water from conveyance systems which recharge groundwater aquifers as a beneficial use. Permits to appropriate surface water for underground storage, through conveyance system seepage, and recovery of that water are provided for by LB 198. However, not all conveyance system losses contribute to recoverable underground water supplies. This alternative would authorize the Department of Water Resources to establish water use efficiency standards as conditions on the issuance of new permits for storage (if the water would be conveyed from a stream to off-stream storage), storage use, and natural flow appropriations. These standards could incorporate the recognition of conveyance system contribution to useable groundwater supplies.

IMPLEMENTATION

Legislation authorizing the Department of Water Resources to condition new permits in the manner described would be needed.

WATER USER RESPONSE TO ALTERNATIVES 4A-1, 4A-2, 4A-3

The response to Alternative 4A-1 could be to: (a) forego irrigating, (b) adopt water use efficiency techniques if economically feasible, (c) apply the appropriation to a lesser quantity of land than provided for in the permit, or (d) develop supplemental water storage. Failure to irrigate all of the lands described in the permit application would result in the cancellation of that portion of the appropriation which applied to the nonirrigated lands. Water use efficiency techniques available to surface water irrigators would be irrigation scheduling (when possible), the use of lined distribution ditches or pipelines, and conservation tillage. There will be no response to these alternatives by natural flow appropriators unless the stream is consistently being administered.

The first response to Alternative 4A-2 would be to sue the state. If the alternative were determined to be unconstitutional, there would be no further impacts. If the state won the suit, the next response of individual irrigators would be to implement the most economically and technically feasible irrigation practices that would allow them to operate under a lower withdrawal rate. This would include irrigation scheduling, lining on-farm distribution systems, and system conversion.

Generally, surface water deliveries do not approach the three acre-feet/acre allocation. The amount diverted varies considerably from basin to basin, depending upon numerous factors such as climate, soils, and age of the distribution system. For example, the North Loup River Public Power and Irrigation District delivers an average of one acre-foot of water per acre. The Sargent Irrigation District delivers 1.25 acre-feet of water per growing season, the Ainsworth Irrigation District delivers 1.38 acre-feet, the Mirage Flats Irrigation District delivers 0.8 of an acre-foot of water to its customers. In the Central Nebraska Public Power and Irrigation District, irrigators can contract for 1 or 1.5 acre-foot per acre to be delivered.[38] In the Cedar River and tributaries, the annual reported diversion averaged 0.24 acre-feet per acre per year from 1977 to 1982. This figure is a reflection of irrigating 50 percent of the land that is entitled to be irrigated.[37] Therefore, readjudication would require lowering the withdrawal rates on a field-by-field basis to effectively reduce water withdrawals and promote the adoption of efficiency techniques.

In response to Alternative 4A-3, new conveyance systems would be designed to meet efficiency standards unless project sponsors could demonstrate that conveyance system seepage contributes to groundwater recharge and will be utilized. If the water leaking from the canals were not recoverable, then lining or re-routing of the canal might be required. The costs of doing so might alter the benefit/cost ratio such that the project may no longer be feasible.

IMPACTS OF ALTERNATIVES 4A-1, 4A-2, 4A-3

The physical/hydrologic impacts of these alternatives will depend on the response to the alternatives. Alternatives 4A-1 and 4A-3 would have very little, if any, impact because there are few new natural flow appropriations issued each year compared to existing appropriations. During times of drought, new appropriations are junior and will be the first to be administered by DWR. If new diversion projects are proposed, an impact of this alternative would be to force project sponsors to consider water use efficiency techniques in the design of these projects (see Water User Response for 4A-3).

Alternative 4A-2 may have considerable impact if the rate of withdrawal is reduced during times of administration. There will be no impact on streams which are not administered. This would leave more water in the source of diversion and thus increase streamflows between the source of diversion and the point of return. If extensive canal lining takes place because of this alternative, then wetlands and seepage lands, such as around the Farwell project, would be reduced. A more detailed discussion of the impacts of canal lining and pipeline conversion is found in Chapter 6.

In the absence of storage, reducing surface water withdrawals one year has no effect on the next year's surface water supply. However, a reduced withdrawal rate for senior appropriators may make junior appropriations more secure. It is then possible that total consumption may increase.

The social/economic impacts of Alternative 4A-2 would be in the form of costs to the state. The administrative costs of readjudication would be very high. Also, the probability of a large number of law suits stemming from readjudication would be quite high. As mentioned in the impacts to Alternative 3B, the costs of lining canals could represent a real burden to whoever would need to line the canal.

The environmental impacts would result primarily from reduced diversions and reduced return flows. This will result in improved fisheries habitat between the point of diversion and the point of return, loss of some wetland habitat associated with leaky canals, and variable effects on water quality. A more detailed discussion of the environmental impacts of canal lining and conversion to pipelines is found in Chapter 6; a discussion of on-farm techniques is found in Chapter 7.

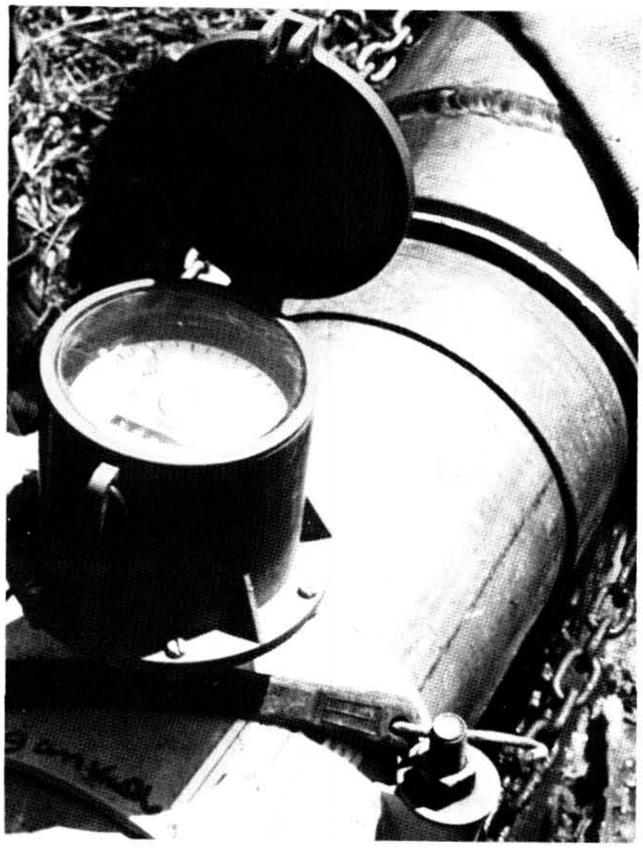
Alternatives 4A-1 and 4A-3 would have little, if any, administrative impacts. Alternative 4A-2 would result in considerable activity by DWR. Readjudication hearings are expensive and time consuming. It has been estimated that such hearings cost between $300 and $500 a day, and the time required to readjudicate a basin will range from four to ten days. The costs of readjudicating all basins in the state could range from $30,000 to $120,000, excluding salaries.

POLICY ALTERNATIVE # 4B

EXPAND THE TYPES OF CONTROLS THAT CAN BE REQUIRED BY NRDS IN A CONTROL OR MANAGEMENT AREA.

DESCRIPTION

Under existing law, a natural resources district in which a groundwater control area has been designated can adopt a variety of controls on groundwater use. It can require groundwater users to install measuring devices. The NRD can also set up a system of allocation or rotation of use, adopt well spacing requirements greater than those applying generally throughout the state, or adopt any other reasonable regulations. If the control area has been designated because of water quality concerns, irrigation scheduling may also be required. If the NRD determines that imposition of the controls listed above are not adequate to protect the public interest, the NRD may, with the approval of DWR, impose a one-year moratorium on the issuance of new well construction permits. The moratorium can be extended for additional one-year periods with the approval of DWR. NRDs with management areas can require meters, institute an allocation or rotation



system, or adopt stricter well spacing requirements.

This alternative would expand the list of authorized controls to include the water use efficiency techniques described in Chapter 7 that relate to groundwater use. These could include irrigation scheduling, reuse systems, system modifications, residue management, alternative cropping and hybrid selection, and/or windbreaks.

IMPLEMENTATION

Legislative action to amend the Ground Water Management and Protection Act would be necessary to implement this alternative.

WATER USER RESPONSE TO ALTERNATIVE 4B

The response to this alternative will vary with the type of practices required. In those areas where soil and water conservation are now widely accepted and practiced, little if any change would be expected.

The response of the water users will be to install the designated practices. All of the techniques described in Chapter 7 could be applicable in different situations. Agricultural techniques include land shaping and leveling, reuse pits, terrace construction, cropping patterns, system conversion, conservation tillage, irrigation scheduling, and mulching (if possible).

IMPACTS OF ALTERNATIVE 4B

The physical/hydrologic impacts of this alternative relate directly to the water use efficiency techniques required by the NRD. These impacts will relate primarily to runoff water and a reduction in groundwater withdrawals. Groundwater recharge will be increased by catching precipitation and keeping it where it falls, if there is an underlying aquifer to recharge. The average amount of water in soil moisture storage will increase. This quantity will vary with seasonal and climatic conditions. As the quantity of water in soil storage increases, the demand for irrigation may decrease. If the quantity of water in soil moisture storage is increased significantly, withdrawals would be reduced accordingly.

The social/economic impacts of this alternative would relate primarily to capital investment of any of the techniques, the administrative costs of developing and enforcing the control or management area requirements, and possible long-term economic returns from reduced pumpage and soil conservation. A reduction in current economic well-being may be necessary in order to prolong the economic base, however.

The primary environmental impacts relate to: (a) possible increase in surface and groundwater quality; (b) variable effects on streamflows; and (c) variable effects on wetlands, i.e., existing wetlands could be maintained if they result from high groundwater levels; however, if they result from surface water runoff these wetlands may disappear.

GLOSSARY OF WATER-RELATED TERMS

ACRE-FOOT — A volume measurement of water which would cover 1 acre to a depth of 1 foot; consists of 325,851 gallons.

AQUIFER — A water-bearing stratum of rock or sediment capable of yielding supplies of water.

AQUIFER, CONFINED (OR ARTESIAN) — Artesian refers to groundwater which is under sufficient pressure (hydrostatic head) to rise above the aquifer in which it is contained.

AQUIFER, UNCONFINED — Refers to groundwater which is NOT under sufficient pressure to rise above the aquifer in which it is contained.

AVAILABLE WATER — The portion of water in a soil that can be readily absorbed by plant roots.

CAPILLARY RISE — The rise of water in the soil from a free-water surface (i.e., a water table). The term derives from the "capillary model," which regards the soil as analogous to a bundle of capillary tubes.

CONSUMPTIVE USE — Any water that is stored, withdrawn, or diverted from its source and is evaporated, incorporated into a product, or reduced in quality to the point where the water is unfit for future use.

CONVEYANCE SYSTEM — Any means of carrying water from the point of diversion or withdrawal to the on-site use.

CUBIC FEET PER SECOND (CFS) — A measure of rate of flow, expressed as number of cubic feet of water passing by a given point in each second.

DISCHARGE — The flow of a stream, canal, or well measured in appropriate units.

EROSION — (1) The wearing away of the land surface by running water, wind, ice, or other geological agents, including such processes as gravitational creep. (2) Detachment and movement of soil or rock by water, wind, ice, or gravity.

EVAPORATION — The process by which water is changed from a liquid to a vapor.

EVAPOTRANSPIRATION — The process by which water is transmitted to the atmosphere as a vapor as the result of evaporation from any surface and transpiration from plants (commonly referred to as ET).

FIELD MOISTURE CAPACITY — The percentage of water remaining in a soil two or three days after having been saturated and after gravity drainage has practically ceased.

GROUNDWATER — Water within the earth that may supply wells and springs; water in the zone of saturation where all openings in rocks and soil are filled.

HYDROLOGIC CYCLE — The "circular" movement of water from the oceans to the air (clouds), to the earth in the form of rain and snow, and finally back to the ocean reservoir via streams and groundwater discharge.

HYDROLOGY — The science of the study of water movement in the hydrologic cycle.

INFILTRATION — The process whereby water soaks into, or is absorbed by, the surface soil layers.

IRRECOVERABLE WATER LOSS — That water which is lost to the current user, and which cannot be recovered and used at a later time or by another user in the state.

IRRIGATION EFFICIENCY — The ratio of the water retained in the root zone after irrigation which is available for crop use to the total water applied in the irrigation.

LEACHING — The removal in solution of the more soluble minerals by percolating waters.

MULCH — Any material such as straw, sawdust, leaves, plastic film, and loose soil that is spread upon the surface of the soil to protect the soil and plant roots from the effects of raindrops, soil crusting, freezing, evaporation, etc.

MULCH FARMING — A system of farming in which the organic residues are not plowed into or otherwise mixed with the soil, but are left on the surface as a mulch.

NATURAL FLOW — Water in a stream which originates from natural sources such as snow or rainfall; it is not water that is intentionally released from reservoirs.

NONCONSUMPTIVE USE — The amount of water that is used in a stream or lake, or withdrawn or diverted and returned to the source, without substantially reducing the supply of water or degrading the quality of the water to the point it cannot be reused.

PERCOLATION — The downward flow of water through soil and permeable rock formations to the water table.

PERMEABILITY — The permeability of rock or unconsolidated material is its capacity for transmitting a fluid. Depends on the volume of the openings and pores and on how these openings are connected one to another.

POLLUTION — The process of contaminating air, water, and land with impurities to a level that is undesirable.

POROSITY — The proportion, usually stated as a percentage, of the total volume of a rock material that consists of pore space or voids.

PRECIPITATION — Water added to the surface of the earth from the atmosphere. It may be either liquid (e.g., rain and dew) or solid (e.g., snow, frost and hail).

RECOVERABLE WATER LOSS — That water which is lost to the current user, but which can be recovered and used at a later time or by another user in the state.

RETURN FLOW — Water in excess of a water user's needs or water that has served a use and is returned to some natural watercourse.

RUNOFF — The portion of precipitation that moves along the land surface by gravity in sheet flow or in surface channels.

SELF-SUPPLIED INDUSTRIAL USE — Water supply developed by an individual industry or factory for its own use.

SOIL — The upper layer of earth which can be cultivated and in which plants grow.

SOIL DRAINAGE — Refers to the frequency and duration of periods when the soil is free of saturation; for example, in well drained soils the water is removed readily but not rapidly; in poorly drained soils the root zone is water-logged for long periods unless artificially drained and the roots of ordinary crop plants cannot get enough oxygen; in excessively drained soils the water is removed so completely that most crop plants suffer from lack of water.

SOIL MOISTURE STORAGE — Water stored in the root zone.

STORAGE WATER — The opposite of natural flow; water that is intentionally released from reservoirs.

STUBBLE MULCH — The stubble of crops or crop residues left essentially in place on the land as a surface cover before and during the preparation of the seedbed and at least partly during the growing of a succeeding crop.

SURFACE WATER — Water on the surface of the earth, including snow and ice.

TENSIOMETER — A device for measuring the force by which water is held in porous material. This measurement can be converted to soil moisture content.

TERRACING — A soil conservation technique in which land slopes are converted into a series of broad-based "steps;" the velocity of runoff water is thus retarded and soil erosion is reduced.

TRANSMISSIVITY — A measure of the capability of an aquifer or the groundwater reservoir to transmit water.

TRANSPIRATION — The process by which water vapor passes through a living plant and enters the atmosphere.

UNSATURATED FLOW — The movement of water in porous materials having some air-filled pores.

UNSATURATED ZONE — Porous material having some air-filled pores. Sometimes called the vadose zone.

WATERSHED — In a natural basin, the area contributing flow to a given place or a given point on a stream. The total area drained by a particular stream; may range from a few square miles in the case of a small stream to thousands of square miles in the case of the Missouri River.

WATER TABLE — The upper surface of groundwater or that level below which the rocks are saturated with water; measured as the static water level or potentiometric surface in a well.

WATER TABLE, PERCHED — The surface of a local zone of saturation held above the main body of groundwater by a layer with low permeability.

ZONE OF SATURATION — Earth materials in which every available pore and/or void space is filled with water.

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POLICY ISSUE STUDY
ON
WATER USE EFFICIENCY

STATE WATER PLANNING AND REVIEW PROCESS

AN APPENDIX TO
THE WATER USE EFFICIENCY
POLICY ISSUE STUDY
APPENDIX A THROUGH F

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APPENDIX A

WATER USE EFFICIENCY POLICY ALTERNATIVES: THE RESPONSE BY PUBLIC OFFICIALS

On June 16, 1982, the Nebraska Water Resources Center convened a meeting of public officials — members of the Legislature's Public Work Committee, the Natural Resources Commission, and the NRC's Public Advisory Board — to discuss pertinent water use efficiency issues in Nebraska. Specifically, these officials were asked to consider the feasibility of an initial set of policy alternatives developed by J. David Aiken, UNL Water Law Specialist. These alternatives were developed in cooperation with the task force for the Water Use Efficiency Policy Issue Study, Nebraska State Water Planning and Review Process.

This report is a summary transcript of the proceedings of this meeting. Each alternative is described below and is followed by a synopsis of comments provided by the public officials, task force members and agency representatives who attended the meeting. This transcript, and subsequent comments provided by public officials, were used by the task force to refine the alternatives for further analysis.

The alternatives presented in this appendix have been reduced and modified in the final Task Force report.

ALTERNATIVE WHICH PROVIDES FOR NO CHANGE IN CURRENT POLICIES

ALTERNATIVE 1: MAKE NO CHANGES IN CURRENT ADMINISTRATIVE AND STATUTORY POLICIES RELATED TO WATER USE EFFICIENCY

DESCRIPTION

While features of Nebraska surface and groundwater law support requiring a high degree of irrigation water use efficiency, these laws have not been so implemented. Although Nebraska surface water law is based on the concept of "beneficial use", current implementation of Nebraska surface water appropriation law does not require irrigators to use a high degree of water use efficiency.

One provision of Nebraska surface water law — the "appurtenancy doctrine" — has acted to discourage water use efficiency. Since a water right attaches to a specified unit of land, the appurtenancy doctrine does not permit use of that water on additional land. Thus, if practices were improved such that an irrigator does not need the entire amount of water appropriated for a unit of land, the irrigator could not irrigate more land under the original appropriation. Permitting such action, however, may reduce return flows to be used by downstream irrigators.

Groundwater irrigation runoff controls have excellent potential for improving groundwater irrigation practices statewide. Under the Ground Water Management and Protection Act, irrigation runoff controls comprise the major provision encouraging water use efficiency. Runoff problems are handled by NRDs on a complaint basis. The NRDs react by encouraging landowners causing the problems to reduce runoff. If the problems persist, the NRDs may initiate court action.

Implementation of these requirements varies widely, however, and this program has not reached its full potential. Irrigation scheduling can be required in groundwater control areas or management areas through groundwater allocations (i.e., restricting withdrawals). Allocations have been implemented in one control area only, however. Educational and cost sharing programs have encouraged irrigators to voluntarily adopt improved irrigation practices. These programs, plus the groundwater runoff control requirements, have probably had the greatest effect on improved irrigation practices in Nebraska (in addition to rising energy costs).

OFFICIALS' REACTION

A question was asked regarding the method used by the Department of Water Resources to enforce the current three acre-feet allotment for irrigation. DWR answered that it regulates on the basis of rate (i.e., cubic foot per second per 70 acres), not on the basis of three acre-feet.

ALTERNATIVES WHICH PROMOTE RESEARCH AND EDUCATION

ALTERNATIVE 2: INCREASE STATE APPROPRIATIONS FOR RESEARCH AND EDUCATIONAL ACTIVITIES TO IMPROVE IRRIGATION WATER USE EFFICIENCY.

DESCRIPTION

UNL research and extension activities regarding irrigation scheduling, conservation tillage, and related agricultural practices could be increased if state appropriations for such purposes were increased. This could lead to voluntary adoption of these improved agricultural practices if landowners believed such practices were profitable.

OFFICIALS' REACTION

Official's Comment: This alternative should be expanded to include municipal, industrial, and domestic water use efficiency.
Question: What research is being done now for improving water use efficiency?
Response: Several projects are underway which involve efficiency aspects, including: (1) research on the use of low-pressure nozzles in the rolling hills of northeastern Nebraska, to reduce both soil erosion and water runoff; (2) the Hall County project, which, among other aspects, is examining the premise that if the amount of irrigation water applied is reduced, the amount of nitrates applied can likewise be reduced; and (3) research at the University's Rogers Farm, which is looking at crop water requirements, i.e., the effect on crop yields if water application is reduced below optimum..The research will attempt to determine the best time to apply water when the available supply is below optimum.

In addition, the Burlington-Northern Railroad has donated funds to the University Foundation which will be used to disseminate information on irrigation scheduling. Field technicians will be hired to provide technical assistance to irrigators and to encourage irrigators to adopt irrigation scheduling practices. The B-N donation is appreciated and will be helpful. No portion of these funds will be given directly to farmers as an incentive to adopt water use efficiency practices.
Task Force Comment: There is a problem of getting from the stage of research findings to that stage where those findings are applied by the water user. With what is known, we could do a lot more water-saving without doing more research. But, there's that one step — getting the technology to the water user. Maybe this alternative needs to be expanded to discuss ways and means of getting these things moved from the research results and findings to on-farm use.
Task Force Comment: Yes. We need to get this research off the drawing board and onto the fields. However, some studies indicate that we do not have enough research and techniques to get some of these findings out. But, there is other research that is ready to go, e.g., irrigation scheduling: We've made great strides in getting this to the farmer.
Task Force Comment: Maybe we should examine some imaginative alternatives that could be developed to get such information and technical assistance to the people.

ALTERNATIVES WHICH PROVIDE FOR FINANCIAL INCENTIVES AND DISINCENTIVES

ALTERNATIVE 3: INCREASE STATE APPROPRIATIONS TO THE NEBRASKA WATER CONSERVATION FUND TO BE USED FOR COST-SHARING ON REUSE PIT INSTALLATION, CONSERVATION TILLAGE AND IRRIGATION SCHEDULING AND TIE COST-SHARING AVAILABILITY TO NRD ENFORCEMENT OF RUNOFF CONTROL REGULATIONS

DESCRIPTION

A good first step in improving irrigation water use efficiency is to prevent waste. Irrigation runoff controls are an effective way to do this. Because over 80 percent of the irrigation land in Nebraska is irrigation with groundwater, vigorous enforcement of NRD runoff regulations and increased cost sharing for reuse pit installation and conservation tillage would be a good first step to improving irrigation water use efficiency in Nebraska.

OFFICIALS' REACTION

Official's Comment: This alternative should be broadened to apply to all water users (i.e., not just irrigators). This would make the alternative flexible enough to apply in problem areas.
Official's Comment: The cost of energy has made a lot of farmers more efficient than anything else.
Question: Where is the money going to come from, and how popular is this alternative?
Response: We may get an indication of public acceptance this Fall when LB 577 (Constitutional Amendment to allow issuance of revenue bonds for water management) is submitted to the voters, even though LB 577 is somewhat different from this alternative. In addition, a public survey will be conducted about a year from now to measure public acceptance of this and other alternatives formulated by this task force.
Official's Comment: In light of the current tight state funding, public acceptance will be necessary to justify investment in this regard.
Task Force Comment: Perhaps we should look at innovative techniques to raise necessary funds.

Task Force Comment: Financing considerations is the subject of another policy issue study.

Official's Comment: I think the public attitude toward spending money for conservation is good. However, an improvement in economic conditions may be necessary to get good public support for taxes earmarked for this alternative. USDA's Resource Conservation Act program indicated "broad public support" for public moneys for conservation programs.

Task Force Comment: In the summary report on water use efficiency in agriculture, there is a statement that there could be considerable savings as well as reductions in water use through the use of reuse pits, for surface water in particular.

Official's Comment: Small towns in Nebraska have no meters on their water system. They pay a minimum monthly fee, but that fee does not encourage (greater) efficiency.

Task Force Comment: The Nebraska Department of Health is concerned with water use efficiency in municipal supplies, realizing that municipal use is a fairly small percentage of total use in Nebraska, and realizing that with increased water use efficiency, the total resulting amount available or otherwise saved by the state would be reasonably small. But, at the same time, there is considerable public investment in municipal water systems.

If we took the water which we would expect to use in one center pivot and built a municipal water system to utilize that same amount of water, the capital investment required would be at least $750,000.

The Department of Health's concerns with respect to municipal needs are also that municipal systems have the capability to provide adequate amounts of water at all times. If the supply is inadequate or ceases, there is an immediate impact on the public health and safety.

For municipal systems, the benefits of water use efficiency are: (1) that it helps ensure the continued capability of the systems to provide water; and (2) that it is possible to delay the cost of and need for capital inprovements.

In general, smaller communities are doing a much poorer job of water use efficiency than larger communities. In larger communities (population larger than 15,000), the average use is 184 gallons per capita per day; in smaller communities (in particular, those with a population of around 2,500) the average use is 218-220 gallons per capita per day.

One alternative to provide an incentive to use techniques which improve efficiency would be the use of **pricing** schemes. People must need some sort of incentive to conserve — pricing may accomplish this. Most towns do not have meters; customers are priced on a flat rate.

Task Force Comment: Statewide, if everybody put a brick in their toilet to save water, the savings may be 7,000 acre-feet per year — a conservation estimate based on the normal pricing structure.

Reductions in domestic use through conservation would not be significant — for example, it may be less than 100 acre-feet per year in Lincoln. However, this is hard to justify due to lack of data.

One way in which domestic users may benefit is to reduce losses in the distribution system. Metering may help in detecting such losses. This may result in overall savings in pumping costs.

Task Force Comment: From the preceding discussion, two new alternatives could be developed: (1) Require metering on all new installations in communities and/or metering on wells. (2) Develop a pricing structure to encourage efficiency.

Task Force Comment: Although data are limited, the Department of Health has found that in some communities where metering is installed, the initial decrease in water consumption is in the vicinity of 40 percent.

Official's Comment: (referring to cost-sharing for reuse pit installation): I am apprehensive. I see the possibility that we're "trying to re-invent the wheel." We've used reuse pits for a considerable length of time. The incentive is the $35 pumping cost on the deep well, compared to $10 or less from that water which comes from the reuse pit.

Let the research help me devise a way (e.g., equipment) to farm and irrigate "tight" ground.

Regarding irrigation scheduling: For each well, it costs me $150 per day to use water when I don't need to. We've hired technicians to schedule irrigations, at $5 per acre. (Implies that incentive is inherent — no public assistance needed.)

Official's Comment: Conservation tillage would not be affordable unless it were cost-shared, but this would require a great deal of money. I don't know if there is enough money available to make it worthwhile as an incentive.

Official's Comment: How would you cost-share on scheduling?

Official's Comment: I don't think either one (cost-sharing for conservation tillage or irrigation scheduling) is affordable.

Official's Comment: Reuse pits have proved their worth. They are good and are being used. They are in the conservation program right now.

Official's Comment: The conservation fund now only applies to reuse pits, not the others (conservation tillage and irrigation scheduling).

Task Force Comment: Administration of this alternative would be a horrendous task — in terms of what constitutes conservation tillage and what constitutes irrigation scheduling.

Official's Comment: I don't think I ought to be paid for conservation tillage - I think I'm **getting paid** by using common sense. I don't think we ought to pay people for things they ought to be doing. Most people are doing a pretty good job now (scheduling) due to the cost of energy.

ALTERNATIVE 4: REQUIRE WATER USERS TO PAY A WATER USE CHARGE.

DESCRIPTION

Implementing this alternative would require water users to pay a water use fee based on the quantity of water used. This would give water users a private financial incentive to reduce water use: If water use were reduced so would the water use fee. The structure of the water use fee could be varied: The charge could be a flat rate or graduated, and a certain amount could be used free with the charge beginning at a specified quantity. The revenue from the water use fee could be used to fund research and education efforts related to improving water use efficiency (alternative 2), or could be used to fund cost sharing on agricultural methods and structural measures to improve water use efficiency (alternatives 3 and 5). The idea behind the alternative is that if irrigators had to pay for their water in addition to, e.g., energy costs and other fees, the increased costs would make them more careful — they would want to reduce costs as best they could.

OFFICIALS' REACTION

Question: Where's the money from the charge going?
Response: It could be used for research, education, cost-sharing programs, for example.
Official's Comment: This would be difficult to police.
Task Force Comment: This would have to apply to all water users. Singling out specific groups (e.g., irrigators) would be unconstitutional.
Official's Comment: This alternative has been tried before, in the Legislature. It was in the form of a water tax, with a provision requiring metering. The bill didn't get very far. We are going to have to figure out how to implement something of this sort (realizing the problems identified previously). We are going to have to have meters — we can't implement it (user charge or tax) without meters — that's the trouble — it's been shot down before.

Politically speaking, a tax is a tough one. But, projects need financing. We need something reasonable to do these projects. A water use charge may be a viable alternative. Show us what the economic and conservation effect would be.
Task Force Comment: The tax would not necessarily have to be levied on volume. It could be levied, for example, on the basis of irrigated acres, or on the basis of a surcharge. But, if the object is to achieve a water conservation "effect", we might get more of an effect with meters than without.
Official's Comment: Why not implement a **demand charge**? Use of a demand charge is the "trend" in rates. Instead of having a "flat rate" or a "step-down" rate (where one pays less the more water is used), use the demand charge, where the rate increases the more water is used.
Task Force Response: Demand charge provisions are included in the alternative.
Question: What are other states doing?
Response: California legislation has given authority to various levels of government to ration water in times of shortage. The task force report will examine programs implemented in other states.
Official's Response: Some believe irrigated land is taxed too much already (when compared with dryland). If it can be shown that an additional tax will help extend water supplies, then such a tax may be justified.
Official's Comment: The "urban response" to implementation of a sales tax for water projects may be based on the perception that urban residents will not receive benefits from these projects, since they are, for the most part, rural in nature. If there was a "self-charge" (i.e., a person using water would pay to help himself), this may be more palatable (to urban residents).
Question: How much are you going to charge the farmer for the water?
Response: This would be difficult to determine.
Official's Comment: This may be one of the most unpopular alternatives, but may be the most practical. Meter systems will cause headaches, but water use charges will have to be talked about.

ALTERNATIVE 5: AUTHORIZE IMPROVEMENTS IN WATER CONVEYANCE SYSTEMS AS A PRACTICE ELIGIBLE FOR STATE GRANTS UNDER THE NEBRASKA RESOURCES DEVELOPMENT FUND, AUTHORIZE GRANTS AND LOANS TO PRIVATE WATER USERS FROM THE FUND TO IMPROVE WATER CONVEYANCE SYSTEMS, AND INCREASE STATE APPROPRIATIONS TO THE FUND FOR THESE PURPOSES.

DESCRIPTION

Under existing policies, state loans are available to public irrigation districts, NRDs, etc., from the Resources Development Fund (RDF) to improve public water conveyance systems. This alternative (1) would allow state grants to be made in addition to loans to improve public water conveyance systems, and (2) would authorize private water users to qualify for state financial assistance under the RDF. This would aid, e.g., surface water irrigation system improvement by making money available to ditch companies for lining ditches, for example.

OFFICIALS' REACTION

Official's Comment: Delete the provision regarding state grants for water conveyance systems, since they already are authorized.

ALTERNATIVE 6: AUTHORIZE STATE INCOME TAX CREDITS FOR INSTALLING PRACTICES OR MEASURES IMPROVING WATER USE EFFICIENCY.

DESCRIPTION

State, NRD and federal cost sharing are usually available to landowners to install practices or measures improving water use efficiency, such as irrigation reuse pits. Reducing the cost of these measures through a state income tax credit would increase private economic incentives to install such practices or measures.

OFFICIALS' REACTION

Official's Comment: This alternative should be deleted. Why should you have a tax credit for doing something to help yourself?
Official's Comment: For the most part, the income tax credit concept has been one that has been shunned by the Legislature. However, the solar tax credit was passed this year. I would suggest that you monitor the success of the solar tax credit and, assuming it works, use it as a model for developing this alternative. I would also suggest that any sort of tax incentive should be short-term, if possible, that redirects investment.
Official's Comment: Change the title of the alternative: strike "for installing", and insert "for the continued use of", since it is conceivable that someone might install practices and not use them.

ALTERNATIVE 7: AUTHORIZE APPROPRIATORS TO SHIFT THEIR ALLOCATION TO ANOTHER TRACT OF LAND, SUBJECT TO DEPT. OF WATER RESOURCES APPROVAL AND TO THE PROTECTION OF DOWNSTREAM APPROPRIATORS.

DESCRIPTION

Some appropriators have surface water appropriations for land not well suited for irrigation. In these cases irrigation water use efficiency could be improved if the appropriator could shift the appropriation to land better suited for irrigation. If an appropriator wished to transfer his appropriation to another tract of land, he would apply to the DWR for an appropriation transfer. If other appropriators objected the DWR would hold a public hearing on the proposed transfer. After the hearing the DWR would be authorized to grant or deny the appropriation transfer. The DWR would be required to condition the appropriation if necessary to insure that the amount of water available to downstream appropriators is not reduced.

The general topic of surface water appropriation transfers is the subject of a separate state water planning study, **Transferability of Surface Water Rights.**

OFFICIALS' REACTION

Official's Comment: Wouldn't this cause a lot of legal problems? Isn't this alternative a bit premature? I don't think the people of Nebraska are ready for it. It may be politically unacceptable.
Task Force Response: There would be legal problems. The impact analysis would identify them.

ALTERNATIVE 8: AUTHORIZE APPROPRIATORS TO USE WATER SAVED BY IMPROVING WATER USE EFFICIENCY TO ADDITIONAL LAND, SUBJECT TO DWR APPROVAL AND TO THE PROTECTION OF DOWNSTREAM APPROPRIATORS.

DESCRIPTION

This alternative would give appropriators some private economic incentive to improve water use efficiency by allowing appropriators to use any water saved on additional land with DWR approval. If an appropriator wished to use saved water on additional land, he would apply to the DWR for a modification of his appropriation to allow the use of water on additional land. If other appropriators objected, the DWR would be authorized to grant or deny the appropriation modification. The DWR would be required to condition the modification if necessary to insure that the use of saved water on additional land did not reduce the amount of water available to downstream appropriators.

A major issue, then, would be to consider the balance between allowing people to save water and apply savings to more land versus harming people downstream if upstream users increased consumption.

The general topic of surface water appropriation transfers is the subject of a separate state water planning study, *Transferability of Surface Water Rights*.

OFFICIALS' REACTION

Official's Comment: "Another tract of land" might be marginal land and might be poor to irrigate. Additional water might be put to poor use. There should be some requirement that this land be suited for irrigation, and also that this land should be continguous to the present allocation.
Official's Comment: I could see where this could work, subject to the protection of downstream appropriators.

REGULATORY ALTERNATIVES

ALTERNATIVE 9: EXTEND IRRIGATION RUNOFF CONTROL REQUIREMENTS TO IRRIGATORS USING SURFACE WATER.

DESCRIPTION

Under existing law the DWR can require appropriators to restrict their withdrawals if they are wasting water (i.e., if they are not using water beneficially). Implementing this alternative would formalize this authority into a program which could be implemented by the DWR, by NRDs, or jointly by the DWR and NRDs. Implementing this alternative could alter return flow patterns for some surface water irrigation projects, and thus could affect project operations. It could also affect groundwater recharge patterns.

OFFICIALS' REACTION

Official's Comment: This provision was included in a previous legislative bill and was challenged by irrigation districts. The districts have contracts with landowners to deliver specified amounts of water. The restriction of amounts through this alternative would violate that contract.
Task Force Response: This alternative should be tied with alternative #3: Where there is more efficient use of water, there should be some cost-sharing to make up the deficit which the irrigation district would incur.
Question: How well are the NRDs handling the runoff-control program? How effective has it been, before we start talking about expansion?
Response (by official): I know of one instance where a complaint was filed. It (the complaint system) is not necessary, simply because for me to stay in business, I can't wait around until that (excessive irrigation runoff) happens, nor can my neighbors.
Response (by agency representative): I think statewide there have been very few complaints. I don't know of any major problems once they have been filed; I think they have been handled in a very forthright manner.
Official's Comment: The reason groundwater runoff control requirements don't work is the lack of uniform, thorough enforcement (used analogy of 55 mph speed limit). Leeway has been the problem. Fines don't make much difference. The NRD has the enforcement responsibility, but problems arise since the NRD has to live with you (i.e., difficult to administer on one with whom you rub elbows).

Public relations may be the most effective means to eliminate (or reduce) erosion.
Response (by agency representative): Let's not sell a lot of these people short. Let's not give up on what we've got, because I've seen a lot less water in road ditches than 25 years ago. I don't know what has caused that change, but I can't help but think that the kinds of controls that have been put on have had an impact.
Official's Comment: I will agree; we don't have to "buy" many farmers to put on good management practices. I don't think we can continue to support people who don't care, by giving them contributions. Somewhere along the line we've got to shut them off....

ALTERNATIVE 10: ESTABLISH SOIL EROSION CONTROL REQUIREMENTS.

DESCRIPTION

If it wished landowners to use better soil conservation measures to insure that water runoff and soil erosion were reduced, the Legislature could establish soil erosion control requirements similar to existing groundwater irrigation runoff control requirements. The erosion control requirements could be implemented by NRDs with technical assistance from the U.S. Soil Conservation Service. The regulations could require that state cost-sharing assistance be available before landowners are required to install soil conservation practices or measures. If this were required, increasing state appropriations to the Nebraska Water Conservation Fund would be appropriate (Alternative 3).

OFFICIALS' REACTION

Official's Comment: I think we need to establish soil erosion requirements — not only on irrigated land, but on all land.
Official's Comment: I think your emphasis on tying water use efficiency with soil conservation practices is good.

ALTERNATIVE 11: REDUCE SURFACE WATER ALLOCATIONS FOR NEW APPROPRIATORS SUCH THAT THEY ARE REQUIRED TO USE IRRIGATION SCHEDULING TECHNIQUES.

DESCRIPTION

This alternative is currently authorized regarding new natural flow appropriations under the good husbandry provision of Neb. Rev. Stat. SS 46-231, and could be implemented immediately by the DWR without legislative action. To extend this to new storage appropriations would require additional legislation.

Under present Nebraska law, direct flow surface irrigators automatically receive three acre-feet of water per acre of land to be irrigated. Research suggests that three acre-feet allocations may exceed the needs of many Nebraska farmers.

The Department of Water Resources has legal authority under existing Nebraska law to limit the amount of water that new surface irrigators are entitled to receive, based upon the premise that an irrigator should not receive any more water than "good husbandry" indicates that he needs. The definition of "good husbandry" is open to interpretation. Some may argue that it can be practiced with "normal" irrigation practices, e.g., irrigation scheduling. Water requirements may be substantially different when comparing these two interpretations.

It is believed by some that the DWR may implement this alternative administratively, however, others might argue that such authority must be granted by statue.

OFFICIALS' REACTION

General Consensus: A degree of reduction would not cause harm.
Task Force Comment: According to Neb. Rev. Stat. SS 46-240.01, if the Department of Water Resources reduces the allocation to appropriators, the latter have the right to apply for an additional appropriation rate up to the statutory limit. What, then, would alternative #11 accomplish?
Agency Head Response: Wouldn't DWR have the option to disapprove the request for additional appropriation?
Task Force Comment: Does DWR have the right to restrict to less than the statutory limit?
Task Force Response: Isn't it implied that the alternative would accomplish this?
Task Force Response: DWR may not be able to impose the restriction administratively, thus requiring a change in law to authorize such action. The alternative will be expanded to cover these aspects.
Official's Question: Are all appropriations referred to in this alternative, or just irrigation?
Task Force Response: There is nothing specific in the statutes that refers to limits for non-irrigation appropriations, other than a general statement that people can appropriate water for a beneficial use. The DWR would assign the appropriator a specific amount when he applies for an appropriation, but the department does not have the three-acre statutory criterion to go by (e.g., there is no specified quantity for municipal withdrawals).
Official's Question: Would non-irrigation appropriations be readjudicated, too?
Task Force Response: The alternative could be amended to include that provision.

ALTERNATIVE 12: REQUIRE ALL EXISTING APPROPRIATIONS TO BE READJUDICATED TO REQUIRE APPROPRIATORS TO INSTITUTE IRRIGATION SCHEDULING PRACTICES TO MAINTAIN THEIR CURRENT LEVEL OF IRRIGATION.

DESCRIPTION

Implementing this alternative would require the DWR to readjudicate the quantities of water appropriators are entitled to, limiting them to the amount they would need if they used current irrigation scheduling techniques. In effect, this would change all existing surface water rights to something less than three acre-feet of water per acre of land (would vary depending upon individual conditions). Implementing this alternative statewide would have a major impact on surface water withdrawals, return flow patterns, and groundwater recharge patterns. Irrigators would have the option of (1) instituting irrigation scheduling techniques, (2) irrigating fewer acres using existing irrigation practices, or (3) irrigating crops requiring less water. These changes could raise or lower the irrigator's profits, depending on crop prices and operating costs.

Implementing this alternative raises significant legal issues. Irrigators could argue that they have a constitutional right to use the quantity of water originally appropriated in perpetuity, regardless of changes in irrigation practices. Whether this argument would prevail depends on whether the Nebraska Supreme Court would rule that the beneficial use concept is static or dynamic. The traditional view is that an appropriator must meet only the standard irrigation practices at the time he initiates his appropriation. See I Hutchins, *Water Rights Law* at 644-50. This static view of the the beneficial use doctrine ignores (1) that water generally is in short supply and (2) that improvements in water use efficiency do occur over time. A dynamic view of the beneficial use concept would give an appropriator a reasonable period of time in which to amortize his original investment in irrigation equipment, but would require him to adopt more current irrigation practices as a condition of maintaining his appropriation. If the courts would adopt this approach to the beneficial use concept, legislative and administrative attempts to retroactively impose water use efficiency requirements on existing appropriators would be constitutional.

OFFICIALS' REACTION

Official's Comment: I sure agree with this alternative.
Official's Comment: Expand this alternative to non-irrigation uses as well.

ALTERNATIVE 13: REQUIRE ALL NRDs (1) TO ESTABLISH GROUND WATER MANAGEMENT AREAS, AND (2) TO ESTABLISH GROUND WATER ALLOCATIONS REQUIRING IRRIGATORS TO IMPLEMENT IRRIGATION SCHEDULING.

DESCRIPTION

Implementing this alternative would do the most to slow groundwater depletion and minimize water pollution related to irrigation. Again, irrigators would have the option of (1) instituting irrigation scheduling techniques, (2) irrigating fewer acres using existing irrigation practices, or (3) irrigating crops requiring less water. These changes could raise or lower the irrigators' profits, depending on crop prices and operating costs. There are no serious legal barriers to implementing this alternative, although implementation could pose a substantial managerial challenge to many NRDs.

In effect, this alternative would force groundwater irrigators to use more efficient irrigation practices. However, the resultant increased efficiency could mean reduced streamflow in some parts of the state.

OFFICIALS' REACTION

Official's Comment: This is a viable alternative.
Official's Comment: How do you establish a management area when there is no definable aquifer in an NRD? Likewise, it may be difficult to set up a management plan without a definable aquifer.
Official's Reaction: Even with no definable aquifer, it would be viable to require scheduling for irrigators.

GENERAL COMMENTS BY OFFICIALS

Official's Comment: You will enhance irrigation scheduling if we can come up with some type of a method that gives us an instantaneous reading of soil moisture, thus allowing us to get on with the show...
Task Force Response: There are lots of measuring techniques, but they all have problems.
Official's Comment: Energy conservation seems to relate to water conservation — they tie in very close together. I would like to see the water use efficiency study tie into the energy question — how much energy savings would result from improved water use efficiency. A study by Paul Fischbach found that proper scheduling could result in 35 percent savings in the amount of energy used. Thus, energy considerations should be tied into the analysis.

Investment put into energy conservation is going to save so much more energy per dollar than investment in new power plan construction. I feel the same concept might apply to water use efficiency.

If you can show that an alternative can (1) take care of a water problem (2) take care of an energy problem, and (3) have a cost-benefit ratio better than some of the other alternatives, then you're going to get a lot further with the Legislature.
Task Force Response: The *Water/Energy Policy Issue Study* will examine "water for energy" and "energy for water". Your concerns probably would be appropriate for that study.
Official's Response: Make sure that the issues are covered...

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APPENDIX B

COMPONENTS OF IRRIGATION WATER LOSS: A LITERATURE REVIEW

Water loss in irrigation can be placed in three categories: (a) evaporation losses, (b) runoff losses and (c) deep percolation losses,[20]. Each of these categories is discussed below.

EVAPORATION LOSSES

Evaporation occurs when there is a direct loss of water to the atmosphere, both during and following each irrigation application. This category of losses can be divided among the following sub-categories:[20]

(a) direct evaporation of spray droplets
(b) drift losses
(c) plant interception losses
(d) post-irrigation evaporation from wet soil.

Categories (a) and (b) usually are combined and referred to as "spray losses". In performing practical measurements, it is very difficult to separate these two categories and, for that reason, they are usually grouped together.[9]

SPRAY LOSSES

Spray losses are those occurring by direct evaporation from water droplets in the jet spray. Very fine-sized droplets may be entirely evaporated while others may be partially evaporated and thus be reduced in size.

Spray losses have commonly been measured by the catch can method in which catchment devices (placed within the sprinkler irrigation area) intercept water at the top of the crop canopy. As reported by Christiansen,[3] spray losses measured by this method ranged from 10 to 42 percent in several hundred afternoon tests conducted in an arid California climate. These loss values are acknowledged to over-estimate the actual losses because of the evaporation of water from cath cans before the catch volume could be recorded.

Under an approximate thermodynamic expression for evaporation spray loss and addition tests to estimate temperature drop of water after discharge from sprinklers, it was concluded that the spray loss was probably very small, not likely to exceed two percent of the gross amount applied. It was also reported that a study of the distribution of droplet sizes in a spray jet indicated that a very small part of the discharge water could be completely evaporated or blown away by the wind.[3]

Arizona researchers Frost and Schwalen[5] conducted 700 tests under various weather conditions to evaluate spray losses. The following operational and climatic factors were identified as influencing losses during sprinkling: droplet size, application rate, crop type, crop height, water temperature, vapor pressure deficit, humidity, wind velocity and cloud cover. They found spray losses to increase with increases in the factors of temperature, wind speed and nozzle pressure and to decrease with increases in humidity and nozzle diameter.

Frost and Schwalen[5] developed a nomograph from the results obtained when using a single sprinkler in the test plot. The nomograph showed the relationship of relative humidity, air temperature, nozzle diameter, nozzle pressure and wind velocity on evaporation losses. They considered the fine spray which was carried out of the collection area at high wind velocities to be a complete loss. Under extreme conditions, this nomograph showed evaporation losses as high as 20 percent. They suggested that a value of approximately 25 percent of the loss value computed from the nomograph could be used for a solid set system for the following reasons: (1) the nomograph was computed for a single sprinkler; and (2) wind drift losses may not be actual net losses in a large area. The conditions in which the tests were conducted were not very windy; wind velocity was as high as 4.5 m/sec. (10 mph) but for most of the tests, was less than 2.2 m/sec. (5 mph).

Lysimeter studies on rye grass plots in California were conducted by Sternberg[21] to evaluate spray losses (spray evaporation and drift) and the amount of ET which would occur during and following sprinkling. In daytime conditions with wind velocities under 3 mph and temperatures between 82 and 92 degress F., spray losses ranged from 17 to 25 percent. In night conditions, losses were between 11 and 16 percent. By comparing results from day and night conditions, he estimated that 60 percent of the daytime loss was due to wind drift and 40 percent was due to spray evaporation.

Work to evaluate various water losses in sprinkler irrigation was done by Kraus[13] using lysimeters on rye grass plots in Davis, California. In 31 tests, total losses ranged from 3.4 to 17 percent, with drift losses representing an average of 36 percent of these total losses. Although the depth of drift was negligible, the change in micro-climate in the drift zone as compared to the region unaffected by the drift caused a signficant change in ET rates within and outside the drift zone. In wind speeds less than 8 mph, the ET rate in the drift zone was consistently less than that observed outside the drift zone, for one to three hours after irrigation. The opposite effect occurred when wind speed exceeded eight miles per hour. The explanation given for this phenomenon was that partial stomatal closing (and thus ET reduction) was induced in the region unaffected by wind drift, whereas no noticeable stress occurred in the drift affected zone because of the prevailing wetter micro-climate.

Hermsmeier[7] investigated spray losses in the Imperial Valley of California. He found that evaporation losses tend to increase as application rates decrease. With low application rates water must be applied for a longer time in order to satisfy a particular irrigation requirement. Low application rates also require smaller nozzles, which produce smaller drops. The small drops have a higher evaporative potential. Evaporation losses measured in these tests ranged widely, from 0-50 percent. Statistical analysis of data from 55 tests conducted in a wide range of climatic conditions indicated that evaporation losses increased as wind speed and temperature increased, and decreased as relative humidity and application rate increased. Air temperature and application rate had a greater effect than did wind speed and relative humidity. Part of the investigation was to look at the effect of time of day on evaporation losses. Hermsmeier concluded that for July and August conditions in the Imperial Valley, evaporation during daytime hours is 3-4 times greater than during night-time hours.

Texas researchers Clark and Finley[4] noted that climatic conditions in the southern plains are quite different than areas where previous research examining sprinkler evaporation losses had been conducted. The conducted research to evaluate evaporation losses in this climatic region which has low rainfall, low humidity, high winds and frequent hot temperatures during the summer. Evaporation losses ranging from 0-27 percent were measured in tests conducted under various conditions in which air temperature ranged from 15-38 degress C (60-100 degrees F), vapor pressure deficit ranged from 9-56 mb, and wind velocities ranged from 1.3 to 8.1 m/sec (2.8 to 18.9 mph). Their results indicated that spray losses mainly depend on wind velocity and vapor pressure deficits. Above a critical value of 4.5 m/sec (10 mph), the wind velocity variable with its transport mechanisms, overshadowed the other variables. Below this critical velocity, evaporation losses depend mainly on vapor pressure deficit, as shown by other researchers. No attempt was made to estimate net evaporation losses by considering the degree to which spray losses reduced plant transpiration. Considering the average annual wind velocity, they concluded that average spray losses of about 15 percent can be expected from sprinkler irrigation in much of the southern plains.

Some reported research addressed the difference between gross and net spray losses. In 1969, Hotes[8] reviewed the work of previous investigators and tentatively concluded that spray losses would constitute only two to four percent of the total application. He indicated that portions of the wind drift losses not evaporated may eventually reach the soil or plant. He concluded that the only significant water loss may be that part of the water applied to the soil and subsequently lost by evaporation.

An energy balance model developed by Seginor[19] predicted that for normal climatic and operational conditions spray losses may amount to only a negligible proportion of the applied depth. The spray loss can be expected to replace some of the crop transpiration in supplying the atmospheric evaporative demand.

Kruse and Heerman[14] indicated that since evaporation losses during sprinkling absorb energy which otherwise would be absorbed by transpiration, the net loss from spray losses is quite small except under high advective (dry and windy) conditions. Highly advective conditions may alter this energy exchange situation and would definitely increase above normal ET and evaporative losses.

A field study to evaluate evaporation water losses under sprinkler irrigation was conducted at South Dakota State University during 1966-67 and reported by Wiersma.[23] In this study, both evaporative water losses within the wetted area of a sprinkler system and the change in evapotranspiration downwind from the wetted area were analyzed under a range of climatic and operating conditions. The study site was a flat field of well-irrigated brome grass in which the necessary instrumentation had been installed. The sprinkler system was described as a low application rate system. Sprinkler spacing along the lateral was 30 feet. A range of nozzle sized (7/64"-3/16") and discharge pressures (25-60 psi) were combined to provide a range in individual sprinkler discharge rates (2.15-7.55 gpm). Other limitations on the data collection used in the analysis were as follows:

1. Because of the location of field instrumentation, data were gathered only when wind direction was within a 12 degree deviation from south. Such southerly winds represented a wind direction perpendicular to the operating sprinkler lateral and the condition under which the necessary profiles of atmospheric parameters could be obtained.

2. The time period in which test data was gathered was limited to between 10:00 a.m. and 2:00 p.m., the time of peak daily radiation. In analyzing field data, measured profiles of humidity, temperature, and wind speed were used to determine the quantity of evaporation loss from the sprinkler area. The evaporation loss determinations, obtained by a described methodology, consisted of all sources of water evaporation, including spray evaporation, evaporation from the plant surface and plant transpiration within the wetted area. It is reasonable to assume that plant transpiration is essentially zero during sprinkling.[23]

In the 70 separate tests on which analyses were made, these evaporation losses ranged from 20-50 percent of the water delivered by the sprinklers, with the mean value being about 33 percent. The analyses indicated that the quantity of evaporation losses was primarily affected by factors of wind speed, vapor pressure deficit and radiant energy and that the factors of sprinkler discharge rate and operating pressure had minimal effect on the quantity of loss. The range in air temperature covered in these 70 tests was 16.5-31.8 degrees C (62-88 F) and wind speeds ranged from 2.4-7.8 m/sec. (5-17 mph) at 1.8 m (approximately 6 ft.) above ground-level.[23]

These loss volumes represent nearly peak loss rates, as observations were made only during the time of day when energy available for evaporation was at its maximum. An overall figure for evaporation losses also must consider losses at other times of the day but no suggestions were made regarding how this could be accomplished.[23]

Another part of this study was to estimate the change in the ET regime downwind from the sprinkler wetter area. The advective cooling and increased humidity of the air, induced by the evaporation from the wetted area, reduces the crop ET in the downwind area, thereby off-setting some of the evaporation losses from the wetted area. The effect of this decrease in ET is greater adjacent to the wetted area and diminishes with increasing distance from the sprinkler line. At a distance of 70 meters (230 feet) downwind from the sprinkler line, the ET regime was unaffected by the sprinkler operation in all the conditions observed in this study. The distance over which micro-climate effects decreased the ET regime downwind of the sprinkler line was decreased with increased wind speed and increased vapor pressure deficit (increased dryness of the air). For the conditions encountered in this study, the amount by which downwind ET reductions (in the first 70 meters downwind of the sprinkler line) off-set evaporation within the sprinkled area ranged from 7 to 21 percent, with an average of about 12 percent.

In Nebraska, Yazar[24] conducted a field study to measure the spray losses under sprinkler irrigation systems. The following conclusions were drawn as a result of his experiment:

1. Average evaporation losses from the sprinkler sprays ranged from 1.5 to 16.8 percent of the total volume of water discharged by the sprinklers under various operating and climatic conditions encountered during the study. Thus, an average evaporation loss of about 10 percent can be expected in southeastern Nebraska during the summer months.
2. Vapor pressure deficit and wind velocity are the most significant factors affecting the evaporation loss from a spray.
3. Evaporation losses increase exponentially with both the wind velocity and vapor pressure deficit.
4. For the pressure level of 50 psi at pivot and 40 psi at end gun, the operating pressure factor did not have a significant effect on evaporation.
5. Drift losses varied from 2.0 to 15.1 percent of the total volume of water discharged by the sprinklers when the losses due to drift were measured at 21 meters (69 ft.) downwind from the lateral under the different wind speed conditions; and when the drift measurements were made at 26 meters (85 ft.) downwind from the lateral, the drift losses ranged from 1.5 to 10.4 percent.
6. Drift losses from sprinkler sprays decreased with the increasing distance downwind from the lateral.
7. Drift losses increased in proportion to approximately the second power of the average wind speed, which is the most significant factor determining the magnitude of drift losses from a given sprinkler system.
8. Combined spray losses ranged from 1.8 to 29 percent when the drift losses estimated at 21 meters (69 ft.) were considered in calculating the total spray losses. When the losses due to drift at 26 meters (85 ft.) were added to the evaporation losses, then the combined spray losses ranged from 1.7 to 22.9 percent of the total volume discharged.
9. On the average, 47 percent of the combined losses was due to the drift for wind velocities greater than 4.0 m/sec. (9 mgp) and for wind velocities less than 4.0 m/sec. (9 mph) the average drift losses consist of 25 percent of the total losses.
10. Evaporation losses from a standard center-pivot sprinkler system decreased with the radial distance from the pivot point. Drift losses from a center-pivot system would be considered negligible except in cases of very high wind speeds, for example, wind speeds greater than 10 m/sec. (22 mph).

Application of these research findings to actual field sprinkler irrigation practice is not very straightforward, considering the limitations of the underlying field-study data. However, some important observations can be made, each helping to show the complexity involved in attempting to precisely define water losses, and thus irrigation efficiency values for a sprinkler irrigation system:

1. Water losses are affected by various atmospheric factors and because these factors change with time, the actual irrigation efficiency measures for an operating sprinkler system also vary temporally.
2. Evaporation losses in sprinkler irrigation also vary spatially within a field due to changing sprinkler positions and changing wind direction along with the effect of the other temporally-varying atmospheric factors.
3. Evaporation losses during sprinkling are affected little by the rate of water application, that is, the amount of evaporation loss during sprinkling is about the same for any given atmospheric condition whether the water application rate is relatively high or low. However, when these losses are expressed as a percent of the total depth of water application, the duration of the sprinkling period is important. Under conditions in which the rate of evaporation loss during sprinkling is greater than the normal ET rate of the crop (while not being sprinkled), it would be desirable, from the standpoint of minimizing evaporation losses, to use a high application rate because the duration of sprinkling would be reduced. Of course, other factors including soil intake rate, pipeline and pumping plant economics and time schedules must be considered in an overall design.

Because there are so many factors influencing sprinkler irrigation evaporation losses, it is not possible to make an all-encompassing statement on this matter. Generally speaking, net evaporation losses from sprinkler irrigation probably range from 2 to 10 percent. When advective evaporating conditions are high (hot, dry and windy), higher net losses may be expected, as indicated by the research work in Texas and South Dakota. This observation demonstrates the major effect of the climatic conditions in which sprinkling is done and the merit of avoiding irrigation during hot, windy conditions, especially when the wind drift losses are transported (blown) outside the irrigated field. Utilizing the newly developed low angle and low pressure sprinklers tends to reduce evaporation losses since these discharge the water with smaller angles and have large droplet size[9].

PLANT INTERCEPTION LOSSES

Part of the water delivered from a sprinkler to the top of the crop canopy is intercepted by the plant foliage before it reaches the ground surface and infiltrates the soil. The amount of foliage interception depends on such factors as plant height, plant type, foliage density and plant spacing. The intercepted water first wets the plant foliage to the point that additional water will flow down or drop from the plant to the ground. Additional intercepted water either keeps the foliage wet or runs off the plant to the soil.

Christiansen[3] concluded that the evaporation of foliage intercepted water was probably much more significant than spray losses. He also concluded that the intercepted water would not constitute a total loss since the wet foliage would also serve to temporarily reduce the crop ET (more precisely the E rate from the soil and T rate from the plant).

After investigating the evaporation loss of water intercepted by plant foliage, Frost and Schwalen[5] indicated that the magnitude of actual spray loss was probably much smaller than they had reported previously. They concluded that ET during sprinkling is less than or equal to normal ET and that under similar atmospheric conditions, dry-leaf ET equals or exceeds wet-leaf ET for low growing crops fully covering the ground and at low wind velocities. They said that in effect, the actual evaporation losses are nearly zero because spray losses are small (except under windy conditions) and essentially serve to reduce crop ET by an equal amount.

In his lysimeter studies previously mentioned, Sternberg[21] observed that virtually no ET occurred during sprinkler irrigation and that ET immediately following an irrigation was suppressed (to about two-thirds of the ET rate in non-irrigated lysimeter for about an hour in the afternoon conditions in which sprinkling was done) due to the rather rapid evaporation of intercepted water after sprinkling ceased. However, his data showed that the ET rate from the irrigated lysimeter was increasing while that from the non-irrigated lysimeter was decreasing during this hour after sprinkling. The low ET rates were nearly equal at the end of this hour and then decreased similarly. Recognizing that sprinkling was done in mid-afternoon (3:00 to 5:00 p.m.) in these studies, it was surmised that if the irrigation had ended at midday, when evaporative conditions were higher, the ET rate from the irrigated plat may have increased to or exceeded that of the non-irrigated plot in less time. This suggests that the effect of foliage-interception losses in reducing normal ET (which would otherwide occur) actually depends on the atmospheric evaporative demand in the post-sprinkling period.

Seginor[19] indicated that gross interception is on the order of 2-4 mm (0.08-0.16 inches) per irrigation for many crops, and also indicated that net interception losses may be much less because evaporation from the wet leaf surface basically replaces transpiration which otherwise would have occurred.

Lysimeter results reported by Heermann and Shull[6] indicate agreement with other investigators in showing how evaporation of the foliage interception losses decrease plant transpiration so that short term ET is not significantly changed.

In summary, it appears very reasonable to consider that net loss of water due to foliage interception is very insignificant and can generally be ignored as a loss. This conclusion is reached because: (1) foliage interception represents a very small depth of water, and

(2) direct evaporation from wet foliage serves to reduce transpiration from the leaves by roughly an equivalent amount.[9]

EVAPORATION FROM WET SOIL

Traditionally, crop water use has been measured by accounting for both plant transpiration and soil evaporation which together make up total evaporation (ET). Transpiration of water through and out of the plant is necessary to maintain a healthy, turgid plant which develops normally and produces an optimum yield. Soil evaporation, however, is water that is lost directly from the soil to the environment and produces only very minimal cooling to the plant canopy.

Ritchie and Burnett[17] reported on the first attempt to separate the components of plant transpiration and soil evaporation. In a two-year study of dryland sorghum and cotton in the sub-humid climate of Temple, Texas, they found that soil evaporation accounted for 20 to 29 percent of the total growing season crop water use for sorghum and cotton, with an overall average of 10.4 inches. Average measured runoff was 2.0 inches or 20 percent of the applied water.

Tanner and Jury,[22] who worked with potatoes in Wisconsin over two years, found that soil evaporation accounted for 47 percent of the total crop water use during the period of the season when there was only "partial cover" of the soil surface by the crop. Phillips, et.al.[16] studied the contribution of soil evaporation in corn grown with conventional tillage and no-tillage conditions in Kentucky. In a four-year study, they found that soil evaporation accounted for 6 to 35 percent of the total evapotranspiration for the no-till and conventionally tilled corn, respectively. The attributed this dramatic difference to the surface mulch present in the no-till plots. The mulch reduced the soil evaporation during the growing season from 12.8 cm (4.3 inches) to 2.0 cm (92 inches). The water not consumed for evaporation would be available for plant transpiration if there were insufficient rainfall or soil moisture.

In Nebraska, during the 1980 and 1981 growing seasons, a field study was conducted at the Sandhills Agricultural Laboratory by Klocke[11] to evaluate field research techniques of measuring the components of plant transpiration and soil evaporation. Hydraulically weighed lysimeters with a surface area of 76 cm (26 inches) by 152 cm (52 inches) were the main research tools for the experiment. There was no crop residue or surface mulch in the immediate area of the lysimeters.

Due to the physical limitations of the treatments, the primary data collection period was after the corn reached a height of 46 cm (16 inches). The relative portion of soil evaporation should be lower during this portion of the growing season than during the early part. Nevertheless, it was found that 33 percent of the total crop water use (ET) was due to soil evaporation. This may be slightly conservative figure in relation to the typical sprinkler irrigation practices in Nebraska. During the study, irrigation was carried out on a once per week frequency. Application depths (net) were in the range of 2.5 cm (0.85 inche) to 3.8 cm (1.3 inches). Since soil evaporation rates are highest immediately after irrigated or rainfall, higher frequency irrigations with smaller application depths have a higher potential for soil evaporation throughout the season.[11]

An investigation of the effect of a light (1 inch) rainfall and irrigation amounts on hourly, daily and seasonal crop ET losses was reported by Heermann and Shull.[6] Their field results (obtained from a precision weighing lysimeter in which alfalfa was growing) verify the need for a technique to account for the extra evaporation which occurs for a time period (1-3 days) following irrigation or rainfall to a crop which has not yet reached full cover. This extra evaporation occurs because of the wetter conditions of the surface soil following water applications. The number of days for which this extra evaporation continues depends on the soil type. For example, the surface of sandy soils dry more quickly and extra evaporation continues for fewer days than would be the case on silty or clay soils. This extra evaporation occurs only until the crop has reached full cover because after the crop has reached this size and is adequately watered (crop coefficient 1.0), ET is a function of the available atmospheric energy. This increase in the seasonal ET arising from lighter, more frequent irrigations was illustrated by Heermann and Shull[6] by simulating irrigation of corn using weather data for Akron, Colorado.

Accounting for the increased evaporation from moist soil surfaces following irrigation or rain before full crop cover development is a feature incorporated into some computer-based irrigation scheduling programs.

RUNOFF LOSSES

Runoff occurs when the water application rate to the soil exceeds the water intake rate capability of the soil. The water accumulating on the soil surface then moves by overland flow and is carried away from the place at which it is applied. If this water flows off the field being irrigated, it is obviously a field runoff loss. If, instead, this water is contained within the field and flows to the lowest lying areas, it only serves as a redistribution of water from the original application pattern and causes a variation in the application depth. Depending on the soil and other conditions, this water may or may not be lost from the field by other means such as evaporation or percolation. The water intake rate capability of a soil is an important factor in irrigation system design.

Numerous factors such as field slope, soil texture and structure, soil variability, water application or flow rate, vegetation cover, crop residue, etc., affect the water intake rate characteristics of a soil. Sprinkler systems, if possible, should be designed and operated to apply water at a rate which will not exceed the intake rate capability of the soil.[2]

Kincaid, et.al.,[10] in a study related to application rates and runoff under center pivot sprinklers, presented experimental runoff estimates up to 21.4 percent under a center-pivot with conventional sprinklers. Addink[2] conducted a study to measure the runoff potential of spray nozzles and center-pivot sprinklers in western Nebraska. He concluded that spray nozzles on center-pivots can result in considerable water runoff because of high application rates. In his study, there was a strong correlation between the use of spray nozzles and runoff on a very fine sandy loam, but no runoff on sand.

He also indicated that low pressure spray nozzles could have high variations in applied depths on hilly ground because of runoff, and also spraying in only one direction increased runoff. Runoff measured in six different tests on fine sandy-loam soil was in the range of 13 to 65 percent of applied water under spray nozzles compared to 0 to 22 percent under the conventional sprinklers.

Kranz, et.al.,[12] in an on-farm irrigation management study, measured the runoff on eight different irrigated fields at Farwell, Nebraska. The average field size was 32 acres. Irrigation application ranged from 7.7 to 14.8 inches, accounting for both plant transpiration and soil evaporation which together make up total evapotranspiration (ET). Transpiration of water from the plant is necessary to maintain a healthy, turgid plant which develops normally and produces an optimum yield. Soil evaporation, however, is water that is lost directly from the soil to the environmental and produces only very minimal cooling to the plant canopy. Quantifying the individual contributions of plant transpiration and soil evaporation has been the initial thrust of the field work discussed below. Further work dealing with techniques to reduce the soil evaporation component also are discussed.

Under center pivot sprinklers, the potential runoff problem is greatest at the outer part of the circle because there the application rate is highest and the likelihood of a reduced soil intake rate is greater because of the effect of larger sized droplets associated with lower discharge pressure. Residue management practices and/or surface shaping and furrow diking practices can be performed to minimize the runoff hazard at the outer part of a center pivot sprinkler. The soil erosion hazard and traction problems associated with water runoff in the wheel tracks of the center-pivot machine is a significant problem in certain situations, especially on slopes or soils which are easily eroded.[18]

In an investigation of runoff control methods under center pivot irrigation, Aarstad[1] reported that the use of small basins between crop rows (furrow diking) enabled runoff to be reduced from about 40 percent to less than 1 percent. Associated with this runoff control method, increased sugar beet and potato yields were also reported.

DEEP PERCOLATION

Deep percolation is a water loss which results from movement of water downward below the root zone and thus out of the storage reservoir from which the crop draws moisture to meet its water need. The magnitude of this loss is directly affected by the water application rate and distribution pattern from the sprinkler system and the manner in which the system is operated.

In the literature reviewed, little work was found regarding the measurements of this loss component under sprinkler systems. Miriovsky[15] in a study with the primary objective of developing a crop production function for corn, estimated, from his experimental data, deep percolation losses from 3 to 30 percent (depending on the amount of water applied by the sprinkler system).

In Nebraska, Kranz, et.al.[12] also estimated deep percolation in their on-farm irrigation management study on eight irrigated fields as mentioned before. The average total rainfall during the period of study was 15.0 inches. Average irrigation application was 10.4 inches. The estimated deep percolation was 6.1 inches or 24 percent of the total water received.

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APPENDIX C

AN ECONOMIC COMPARISON OF CONSERVATION TILLAGE SYSTEMS

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There are a number of potential economic advantages for reducing the number of tillage operations for row crop production. These include: (1) reduced fuel costs due to fewer operations; (2) reduced number of tillage machines required which results in lower machinery ownership costs in the long run; (3) reduced labor requirements which reduces direct labor costs and/or releases labor to perform other critical spring tillage and planting tasks; (4) reduced wind and water soil erosion; and (5) soil moisture conservation. While rising energy costs have precipitated much of the interest in conservation tillage, the other factors are important considerations.

It is difficult to define conservation tillage in terms of the amount of fuel, soil or moisture conserved, but we can compare the ground cover left after planting by different tillage systems. A reduced number of passes over the field reduces costs but also leaves more trash on the surface reducing the potential soil erosion losses. Conservation tillage can then be defined as a tillage system which leaves 20 to 30 percent ground cover after planting.

Two important economic questions are raised when comparing tillage systems. First, does it really pay to use a tillage system other than the traditional moldboard plow system? And second, if so, which of the alternative systems are the most economical and how do they compare with the moldboard plow system? There are a number of different tillage and planting machines available and a selection must be made. Four conservation tillage systems are defined in this paper. Labor, fuel, chemical and equipment costs are analyzed to determine the costs of the alternative systems. The effect of farm size on the comparative costs is also presented.

THE TILLAGE SYSTEMS ANALYZED

The systems analyzed and the operation of each system are summarized below. The original investment cost of each system is given in parentheses. New machinery costs were used to determine the initial investment cost of each system.

Moldboard Plow System ($69,150)
- Spring or fall plow
- Two diskings
- Conventional planting
- Postemergent cultivation

Chisel Plow System ($66,350)
- Fall or spring chiseling
- Two diskings
- Conventional planting
- Postemergent cultivation

Disk System ($61,750)
- Two diskings
- Conventional planting
- Postemergent cultivation

Till Plant System ($51,650)
- Stalk shredding
- Till planting
- Two postemergent cultivations

No Till System ($43,000)
- Slot planting
- Two custom spraying operations

METHOD OF ANALYSIS

Farm machinery system investments produce costs and returns over a number of years. This stream of costs and returns will be different for each system. One system might have higher machinery system acquisition costs but lower annual crop input costs than another system. For example, let's say the tillage and planting equipment in one system cost $70,000 and the annual operating costs are $40.00 per acre. The machines in an alternative system cost $50,000, but the annual costs are $50.00 per acre. The problem is to determine which system to select. The stream of costs for each system vary with time, and it is not simply a matter of adding up the costs for each system for a specific time period. The problem can be overcome by putting all costs and returns on a present value basis.

What we need to do is discount or reduce all the future costs and returns back to their present value.

The procedure of discounting is simply the opposite of compounding where the interest rate used for the discounting is equal to the interest rate that could be earned on equity capital or the interest rate paid if capital is borrowed to make the machinery investment.

In looking at a 10 year investment, it is important to recognize the effects of inflation over the budgeted life of the machinery. Inflation will affect both the annual operating costs and the terminal value of the machinery at the end of the 10 year period. Therefore, the annual costs were inflated before being discounted to the present value.

The discount rate in an investment analysis is the nominal or actual rate of return expected on your next best alternative investment. It represents the sum of the expected change in prices (inflation) plus the real rate of return. In this analysis, an inflation rate of 9 percent was used and the nominal discount rate used was 13 percent. This means the real interest rate was 4 percent. With the 13 percent discount rate, $1.00 in 10 years is worth only $0.29 today.

A cash flow analysis was utilized to compare the different tillage systems over a 10 year period. All the costs associated with owning and operating the machinery systems were allocated on a cash flow basis. That is, depreciation was not charged as a direct cost. Costs were allocated on a cash basis in the year they will actually occur during the 10 year period. The benefit of depreciation for tax purposes was included in the analysis. To reduce the analysis to a manageable time period it was assumed the machines were sold at the end of the 10 year period.

The direct cash outflows are:

(1) the initial investment at the beginning of the 10 year period

(2) operating costs which include fuel, oil, repairs, labor, chemicals, insurance and interest on operating capital; and

(3) tax at the end of the 10th year on any depreciation recapture when machines are sold.

There are a number of items which reduce the cash outflow and act as a cash inflow. These include:

(1) tax savings for depreciation charges;

(2) tax savings for deductible operating expenses;

(3) investment credit at the end of the first year; and

(4) the value of the used machinery at the end of the tenth year.

The outflows were subtracted from the cash inflows for each system for each of the 10 years to get the annual net cash flows. These annual cash flows were then discounted to the present value to get the total present value for each system. The system with the lowest present value of net cash outflows is the least cost system to own and operate for the 10 year period.

EXAMPLE OF COST ANALYSIS

Only the costs that are different between systems need to be considered to compare the five systems. Costs, such as seed costs, that are the same for all systems need not be included in the analysis. An example set of calculations is given for the moldboard plow system for 480 acres off row crop productions.

Cash Inflows:

Annual tax savings for depreciation in each year
= annual straight line depreciation x 25% tax bracket
= $5,186 x .25 = $1,297 = $2.70 per acre

·Tax savings for operating costs in year 1
= annual operating costs x 25% tax bracket
= $30.29 x .25 = $7.57 per acre

Tax savings for other years is calculated the same way. The actual operating costs increase each year due to inflation. For example:

Tax savings for operating costs in year 10
= $65.77 x .25 = $16.44 per acre Investment credit in year 1
= $69,150 x 10% = $6,915 = $14.41 per acre Value of used machinery at the end of year 10
= $69,150 x 75% = $51,861 = $108.05 per acre

Cash Outflows:

Initial investment year 0 (now)
= $69,150 = $144.00 per acre

Operating costs in year 1 = $30.20 per acre

Operating costs in year 10 = $65.77 per acre

Tax on recaptured depreciation at end of year 10
= recaptured depreciation x 25% tax bracket
= ($108.05 — $36.02) x .25 = $18.01 per acre

A summary of the cash flows for the moldboard plow system example is presented in Table C-1. The calculations for the intervening years are done in a similar manner. The investment credit occurs only at the end of the first year and the value of the used machinery and associated tax liability is credited at the end of the tenth year.

TABLE C-1

EXAMPLE CASH FLOWS FOR MOLDBOARD PLOW SYSTEM, PER ACRE

		Year 0	Year 1(a)	Year 10
1.	**Cash Inflows:**			
	Annual tax savings - depreciation		$ 2.70	$ 2.70
	Tax savings - operating costs		7.57	16.44
	Investment credit		14.41	
	Value, used machinery			108.05
		Totals	**$24.69**	**$127.19**
2.	**Cash Outflows:**			
	Initial investment	$144.00		
	Operating costs		$30.29	$ 65.77
	Tax on recaptured depreciation	——	——	——
		$144.00	$30.19	$ 83.78
3.	**Net Cash Flow**	-$144.00	-$5.61	+$43.41(b)
4.	**Present Value of Cash Flow**	-$144.00	-$4.96	+$12.79

(a) The calculations for years 2 to 9 are similar to those for year 1.
(b) The "-" sign denotes a net cash outflow and the "+" sign denotes a net cash inflow.

COMPARISON OF SYSTEMS

The ranking of the systems from the least cost to the highest cost for the 480 acre situation is as follows:

Rank	System	Net Present Value of Cash Outflow for 10 years
1	Till Plant	$204.50 per acre
2	Disk	$219.96 per acre
3	Chisel Plow	$244.15 per acre
4	No Till	$252.71 per acre
5	Moldboard	$262.18 per acre

The till plant system is the least cost system and the disk system is ranked second. The chisel plow system is ranked third and the no till system is ranked fourth.

The no till system is more expensive than the till plant system, but lower in cost than the moldboard system. The present value of the cash outflow for the till plant system is $204.50 per acre compared to $252.71 per acre for the no till system. This represents a difference of 24 percent over the 10 year period. The disk system is 8 percent higher, the chisel plow system 19 percent higher, and the moldboard system 29 percent higher than the till plant system.

Although the disk system has the same number of passes over the field as the spring chisel operation, the disk system does not include a chisel plow, hence one less piece of machinery to increase ownership costs. As a result, the costs of the disk system are 6 percent less than the costs of the spring chisel system.

The till plant system as defined, does not include any chemical application operations. It is a one-pass tillage planting operation with the seed being planted in ridges formed during the cultivation for the previous crop. The system combines the economic advantages of fewer owned machines and no expensive chemicals to purchase and apply. The stalk shredding operation is included in this system to reduce equipment malfunctions caused by excessive crop residues.

EFFECTS OF FARM SIZE

The present value of the net cash outflow for the 10 year period, as a function of the crop acreage, for the five tillage systems is shown in Figure 5 (Chapter 7 of this report). The computations used to prepare Figure 5 were the same as those given in detail in previous sections. The machines sizes were increased consistent with the increase in farm size. The till plant system is the least cost per acre for all sizes in the considered range of 320 acres to 960 acres. The no till system is the third lowest cost system at the low acreages. At 320 acres it is lower cost than the moldboard plow system and the chisel system. As the acreage is increased and machinery ownership costs are spread over a larger acreage, the herbicide costs for the no till system remain constant on a per acre basis regardless of the acres planted. The machinery investment per acre is the lowest for the no till system. But, at larger acreages, the herbicide costs outweigh the lower per acre machinery costs and the no till system loses its initial economic advantage. The constant herbicide costs have an increased impact on the relative costs of the "tillage" systems versus the no till or "chemical" systems as the acres planted increases.

A constant wage rate was used in this size comparison. That is, $5 per hour was used as the wage rate for all sizes of farms studied. On large farms where labor is a limiting or constraining factor, labor would be more valuable than on smaller farms where ample labor is available. This would be particularly true during the spring planting period and for operators who did not wish to hire additional labor.

EFFECT OF LABOR REQUIREMENTS

There are really two ways to view the labor question. First, the completion of spring field work is often very time critical. If operations are not completed at the appropriate time, yields can be reduced. Hence, practices which reduce the field time required, such as the no till system, can increase potential yields compared to the more labor intensive systems such as the moldboard plow system or the chisel system.

The second consideration is the total number of acres that can be farmed with the available labor. A reduced tillage system would enable a farmer to farm more acres with the same labor and thereby increase the total labor and management return. If more acres can be farmed with the no till system, the labor and management return to the operator can be increased which again negates some of the cost disadvantages of the no till system. It must be pointed out, however, that labor that is freed up because of reduced tillage operations must be productively employed to achieve these economic benefits.

The spring tillage and planting operations are more time critical and restrictive in terms of the number of acres that can be covered than the post emergent cultivations. Some tillage operations might be completed in the fall, but in this analysis it is assumed all are completed in the spring. This assumption is consistent with the objective of conservation tillage of reducing soil erosion.

The labor time requirements for tillage and planting operations for each of the systems is given below:

Moldboard Plow	.75 hrs. per acre
Chisel Plow	.63 hrs. per acre
Disk	.48 hrs. per acre
Till Plant	.43 hrs. per acre
No Till	.32 hrs. per acre

The number of acres that can be covered for different labor constraints is presented in Table C-2.

TABLE C-2

NUMBER OF ACRES THAT CAN BE PRODUCED BY FIVE TILLAGE SYSTEMS

System	Number of Hours Available in Spring Period 240	400
Moldboard Plow	333	533
Chisel Plow	381	635
Disk	500	833
Till Plant	558	930
No Till	750	1250

The question is: will the larger acreage allowed by the reduced tillage systems overcome any per acre cost disadvantage they may have? For this to occur it must first be assumed that labor is available for expansion. If operator and/or family labor is not available, it is assumed that hired labor is available. Remember the previous analysis assumed all labor received compensation at the rate of $5.00 per hour.

To make this analysis, let's look at one situation. Let's use the 400 hours of available labor and the disk system. The above table shows we could handle 833 acres with the disk system. If we switch to the no till system, we could increase the acreage to 1250 with the same amount of labor. Is this an economically sound decision? The calculations are as follows, again using the 10 year analysis period and a present value approach:

Net Present Value of Costs for:

No Till System	\$206 per acre
Disk	158 per acre
Difference	\$ 48 per acre

Net Loss for first 833 acres by switching to No Till System = 48 x 833 = \$39,984

Net Return that must be achieved on next 417 acres (1250 - 833) to break even = $\frac{39,984}{417}$ = \$95.88 per acres for 10 year period

= \$17.67 per year (\$95.88 = P.V. of 17.67 per year for 10 years)

If the operator can cover any loan payments incurred by expanding from 833 to 1250 and achieve an average return to management of \$17.67 per acre per year, it would be advantageous to switch to the no till system.

ECONOMIC BENEFITS OF EROSION CONTROL

In the introduction, reduced wind and water soil erosion was stated as one of the economic benefits of conservation tillage systems. Saving the land for future production is a real benefit, but it is difficult to evaluate the economic magnitude of that benefit. Erosion control may be a long-term benefit without any economic impact in the next few years. Soil erosion will eventually affect the ability of some land to produce crops and will affect the cost of crops produced on eroded land. Crop yields can be maintained with lower input costs on land that has not been eroded than on land that has been eroded. In addition, if all land increases in value in the future, property that has been subject to good tillage practices and has not eroded will be more valuable than a similar property that has been subject to erosion because of poor tillage practices.

The economics benefits of erosion control are future benefits and are very difficult to assess today. Suffice it to point out here that there are economic benefits to erosion control. The difficulty lies in being able to measure the exact size of those economic benefits.

SUMMARY

The major points can be summarized as follows:

(1) The till plant system was the least costly system for all acreages studied followed closely by the disk system.

(2) The cost curves in Figure 5 show the till plant and disk systems would continue to be the least cost systems regardless of the number of acres of row crop production.

(3) The no till system saves fuel, machinery investment costs and labor. The higher chemical costs outweigh these cost savings making the no till system the highest cost system at higher acreages.

(4) If the labor freed up by the no till system is used for other economic pursuits, such as expanding farm size, the operators return to labor and management could be increased and thereby overcome the higher costs of the no till system.

(5) Erosion control is a real economic benefit of conservation tillage systems, but it is difficult to measure the exact size of this benefit.

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APPENDIX D

CALCULATIONS FOR DETERMINING EFFICIENCY OF AGRICULTURAL TECHNIQUES

The procedures listed here are based on a series of tables that serve as background for the comparative analysis of the techniques suggested for improving water use efficiency in irrigated agriculture.

TABLE D-1
1981 IRRIGATED CROP ACREAGE IN NEBRASKA.

Crop	Irrigated Acreage
Corn	5,250,000
Soybeans	800,000
Pasture, hay	730,000
Sorghum	570,000
Wheat	300,000
Beans	160,000
Sugar Beets	85,000
Potatoes	6,500
Barley	5,500
Total	7,907,000

Source: *Irrigation Journal* (1981). "Irrigation Survey."

The water supply for the Nebraska acreage has been developed primarily from groundwater sources, accounting for 72 percent of the irrigation water used. The remaining 28 percent of the water is delivered from surface supplies. Approximately 57 percent of the irrigated acreage of Nebraska uses surface (gravity) flow on-farm systems. Gated pipe is used on about 83 percent of the surface flow method acreage and the remaining 17 percent is irrigated by open ditch on-farm systems. About 50 percent of the gated pipe systems also have a runoff water reuse system installed. Of the open ditch systems an estimated 25 percent employ reuse system (1981 "Irrigation Survey").

Application efficiency with properly managed sprinklers is often good if it is designed to apply water with high uniformity and at rates less than the soil water intake capacity, thus preventing runoff. Many people expect evaporation from sprinkler water droplets to be extremely high; however, under many conditions, total water consumption is not significantly greater for sprinkler irrigation than for surface methods. Wind drift and evaporation can reach about 25 percent of water applied under conditions of high wind, high temperature, and low humidity. (This estimate is based on the literature review presented in Appendix B.)

Irrigation systems are designed and operated to supply water to meet the crop water needs so that yields are not limited by water shortages. The crop root zone, or the depth of soil in which roots are actively growing, provides a reservoir to store water from irrigation and precipitation until used by the crop. Precipitation and/or irrigation water which infiltrates into this reservoir but exceeds its water holding capacity will percolate below reach of the roots and is a loss to the irrigator. However, considering an entire hydrologic unit (drainage basin) deep percolation is not a water loss to the community because most of the water returns to the groundwater reservoir and can be reused.

Water is used consumptively by irrigated crops through the processes of transpiration from leaf surfaces and evaporation from the soil. The combination of these processes is termed evapotranspiration (ET). This consumptive use cannot be significantly changed by improving irrigation practices. For close growing crops, whose canopy essentially covers the field surface, the evapotranspiration is controlled by the availability of solar energy for evaporation and availability of water to be evaporated. Adequate amounts of water must be made available throughout the season to meet the crop evapotranspiration demand and to prevent reduced crop yields. Therefore, climatic conditions and type of crop generally govern water consumption in irrigated agriculture. Table D-2 presents the average annual amount of potential evapotranspiration (ET) for each of the various crops grown in Nebraska.

TABLE D-2

EVAPOTRANSPIRATION (ET) OF VARIOUS CROPS GROWN IN NEBRASKA.*

Crop	ET (in inches)
Corn	26.5
Soybeans	23.0
Sorghum	23.0
Alfalfa	33.0
Wheat	17.0
Beans	19.0
Sugarbeets	30.0
Potatoes	21.0
Barley	17.0

*Developed using a modified form of the Blaney-Criddle method and adjusted in consultation with Nebraska Irrigation specialists.

Potential irrigation application efficiency gives a reasonable measure of performance attainable under good management when applying full irrigation. A low value of potential application efficiency is usually associated with poor system design (unless intentional for economic reasons). The difference between potential and actual application efficiency is a measure of management problems. Potential irrigation efficiencies are given in Table D-3. These efficiencies were estimated in consultation with Nebraska irrigation specialists.

TABLE D-3

IRRIGATION APPLICATION EFFICIENCY OF VARIOUS IRRIGATION METHODS PRACTICED IN NEBRASKA.

Irrigation Method	Efficiency Range (%)	Efficiency Average (%)
Sprinkler	70-80%	75%
Gated pipe:		
with reuse	70-80	75
no reuse	50-60	55
Open ditch:		
with reuse	60-70	65
no reuse	40-50	45

Based on the results of the studies mentioned in Appendix B, Table D-4 was developed to present the water loss as a fraction of total water applied for each along with the percent of water which could be saved from both irrecoverable losses and recoverable losses.

The acreage devoted to the various crops and the irrigation methods are presented in Table D-5. Data from this table and Table D-2 are used in the compilation of irrigation water requirements. The net irrigation water requirement for each crop is simply the difference between crop ET and the average rainfall during the crop growth season. The gross water requirement is based on the average irrigation efficiencies as presented in Table D-3. The potential reduction and savings are based on data given in Table D-4.

The following discussion outlines the procedure for determining irrigation system efficiencies. This process was used to produce Table 4: Sprinkler Irrigation Systems — Present Irrigation Water Use and Potential Reduction Of Gross Withdrawals Using Various

TABLE D-4

COMPONENTS OF WATER LOSS AND POTENTIAL SAVINGS BY VARIOUS WATER USE EFFICIENCY (WUE) TECHNIQUES.

Component	Present Percent Loss	Potential Percent Saved	Water WUE Techniques
Drift and spray evaporation	15-25	5	Low angle and low pressure sprinkler; not irrigating in windy and dry conditions
Evaporation from wet soil (i.e., the E of ET)	20-30 of ET	10-15 of ET	Crop residue and no tillage, mulching and less frequent irrigation
Runoff and deep percolation	15-50	5-30	System improvement, irrigation scheduling and management

Water Use Efficiency Techniques For Crops Grown In Nebraska, and to produce Table 5: Surface (Gravity) Flow Irrigation Systems — Present Water Use and Potential Reduction Of Gross Withdrawals Using Irrigation Scheduling And Management Programs For Various Crops Grown In Nebraska. These tables are found in Chapter 7.

GRAVITY FLOW SYSTEMS

ET rainfall = net irrigation required.

Net irrigation required	/	Irrigation system efficiency (%)	=	gross application required
present gross application required for a specific system	x	(100 effectiveness of irrigation scheduling (%))	=	new gross application requirement

Computations:

(Crop acreage x net irrigation required)	/	system efficiency	=	gross inches of water application
Gross inches of water application	/	12	=	gross acre feet of water application

Continued

Computation for reduction of water use if open ditch systems were to be converted to gated pipe systems and, also, for gated pipe with reuse systems:

Gross acre feet of water applied	x	Efficiency of open ditch system with reuse	=	Net water requirement

(The net requirement for the acreage of open ditch systems with reuse systems is needed in order to apply the efficiency factor of the new type of technique to be used; i.e., gated pipe with reuse systems.)

Net water requirement	/	WUE technique efficiency	=	gross water application
Gross acre feet of water applied	-	new gross water application	=	application required

(Reduction in water application that, potentially, could be expected from changing the system; i.e., to gated pipe with reuse system). This reduction is expressed as a percent.

Where open ditch systems have no reuse system, the computation is identical, except the WUE technique efficiency for gated pipe alone is used.

If all systems listed were to add a reuse system as the only change, the computation again follows the formula above, using the proper system efficiencies.

Reduction in water application experienced through irrigation scheduling is 10% of the total water applied.

The remainder of the table, in general, is constructed by finding the efficiency factors of the WUE techniques and multiplying (100 — WUE technique efficiency) to the water use figure desired.

The following computations were used to calculate sprinkler system efficiencies.

Net irrigation required (acre inches/ acre)	/	System efficiency (.75)	=	gross irrigation required (acre inches/acre)
Gross irrigation required (acre inches/acre)	/	12	=	gross irrigation required (acre feet/acre)
Gross water required (acre feet)	x	WUE 100 - technique reduction (%)	=	potential reduction (acre feet)

Residue management (mulch) effectiveness is estimated at 10 percent of the crop ET. This reduces evaporation, which, in turn, reduces the ET requirement. Therefore:

Average ET	-	(average ET x .10)	=	new average ET.
New average ET	-	average rainfall	=	net irrigation required (inches)

The computation then follows the above procedure to determine the new gross water requirement (with residue management for that acreage).

Gross water required — new gross water requirement, with residue management = potential savings by using residue management.

Gross water required	-	new gross water requirement	=	potential savings by using residue management

Continued

Since residue management is involved, begin with the new gross water requirement for that acreage.

New gross water requirement	x	(100 — effectiveness of the WUE technique (%))	=	potential reduction
Gross water requirement	-	gross water requirement with 2 conservation techniques	=	potential reduction of a combination

This calculation must be accomplished in a specific order:

1. Residue management is accomplished before the crop uses water and, therefore, reduces the ET requirement by 10 percent.
2. Irrigation scheduling reduces the amount of gross water needed by better irrigation, which reduces the amount of water pumped.
3. That, in turn, means that water reduction by sprinkler modification, renozzling, applies only to the gross water application after scheduling.

Therefore, first determine total gross water requirement with residue management in place for the crop acreage involved. Then, in succession, calculate the WUE technique percent of reduction by using the gross water requirement with residue management in place. To find the potential reduction figure, subtract the gross water requirement with all three techniques in place, from the gross water required. The computation method follows:

Gross water requirement for a given acreage (with mulching)	x	(100 — WUE technique improvement)	=	gross water reduction with both techniques
Gross water requirement with mulching	-	gross water reduction with scheduling	=	gross water requirement using both techniques
Gross water requirement with mulching and scheduling	x	(100 — renozzeling effectiveness (.05))	=	gross water requirement of 3 techniques
Initial Gross water requirement with no efficiency techniques	-	gross water requirement of 3 techniques	=	potential reduction of withdrawals

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APPENDIX E

CALCULATIONS FOR DETERMINING EFFI CIENCY OF MUNICIPAL, INDUSTRIAL AND POWER TECHNIQUES

MUNICIPAL

The UNL Conservation and Survey Division[3] reports that in 1979, 99,030 million gallons of water were pumped by municipal and public water supply systems to serve 1,313,307 persons in Nebraska.

It is necessary to estimate how that water was used in order to determine the potential effectiveness of the various conservation techniques which are found in the literature and discussed in this report.

The following assumptions were used to estimate water use for the various activities:

(1) Fifteen percent of the water pumped is lost in the conveyance system.[2] Under this assumption, 84,176 million gallons of water were delivered to customers in 1979.

(2) Further loss occurs due to leaks at the point of connection and plumbing within buildings. A conservative estimate of 10 percent was chosen to represent this loss. The remaining 75,758 million gallons are available for use in residences, landscape irrigation, swimming pools, institutions, business and municipally supplied industries.

(3) Estimates of in-house residential uses are discussed in various reports. The Federal Housing Administration[7] suggested in the 1965 Minimum Property Standards to allow 100 gpcd. James and Lee[9] report that 70 to 90 gpcd is a typical range. Linaweaver, et. [11] report that while total residential use varies considerably, household domestic use was remarkably similar at 80 gpcd regardless of geographic or economic differences. Milne[12] chose 70 gpcd as a representative estimate. Data available from the Conservation and Survey Division[3] shows actual meter readings for eight small communities (where industrial use is not an important factor) averaged 72 gpcd in 1979. Estimates based on data from the Metropolitan Utilities District (Omaha area) indicate an average of 88 gpcd for residential use in 1980. A rather conservative 70 gpcd was chosen for this report. Multiplying the assumed 70 gpcd by the number of users reported in 1979 (1,313,307), gives 33,555 million gallons used for domestic purposes in 1979 (Tables E-1 and E-2).

(4) A further breakdown of the domestic uses is displayed in column 1 of Table E-4, and the range of potential reduction is displayed in Table E-5.

(5) Residential outdoor usage was estimated by comparing the average winter usage (November-April) to the average summer usage (May-October) for six Nebraska municipalities. In these cities, a range of 30 percent to 47 percent of the total municipal demand was pumped for summertime activities. Based on these calculations, 40 percent was assumed as the portion of total municipal water use supplied for summertime activities as a state-wide average. It was further assumed that this use was primarily landscape irrigation. A small percentage (1 percent) was assigned to other uses such as swimming pools, car washing and water-cooled air conditioners. Using these assumptions, the landscape irrigation is estimated at 30,003 million gallons per year, or 63 gpcd (see Table E-3).

No studies are available to determine the lawn watering rate used by homeowners in Nebraska. Studies available from other states show that a 50 percent reduction in water usage may be reasonable and as the percent reduction assumed for this report.[5]

The estimates used for this report are total residential use 133 gpcd, with 70 gpcd for domestic uses and 63 gpcd for landscape and garden irrigation. This represents 84 percent of the municipal water demand. The remaining 16 percent (approximately 12 million gallons) is available for commercial, industrial, and other public uses. The numbers calculated for this report are strictly for the purpose of comparing alternative techniques. The various techniques and potential reductions of household use are displayed in Table E-3.

TABLE E-1

WATER USE ESTIMATES FOR MUNICIPAL USES.

(1)	Amount of water pumped (1979)	99,030 MG
(2)	Leakage of distribution system (15% of line 1)	14,854 MG
(3)	Water delivered to service connections	84,176 MG
(4)	Leakage from connections and plumbing (10% of line 3)	8,418 MG
(5)	Water available for use	75,758 MG

TABLE E-2

ESTIMATES OF 1979 RESIDENTIAL WATER USE FOR NEBRASKA.

Domestic household use (70 gpcd x 1,313,307 users)	33,555 MG
Landscape and garden irrigation*	30,003 MG
Total residential use	63,558 MG
Other uses	12,200 MG

**NOTE:* The summer usage minus the winter base use was found to be 40% of the total use. 75,758 x 40% is 30,303 MG. 1.0% is allowed for summer uses other than landscape irrigation, so the landscape irrigation use is estimated to be 30,003 MG.

TABLE E-3

SUMMER AND WINTER RESIDENTIAL WATER USE IN REPRESENTATIVE NEBRASKA COMMUNITIES.

Municipality	Total Use (MG)	Summer Use (MG)	Winter Use (MG)	Increase Summer Use (MG)	Average Outdoor Use (per annum) gpcd	Average Outdoor Use (summer only) gpcd
Scottsbluff	1436.5	1054.3	382.2	672.1	130.3	259
Alliance	994.6	705.0	289.6	415.4	114.4	229
Ainsworth	134.8	92.8	42.0	50.8	62.2	123
North Platte	2299.9	1652.8	647.1	1005.7	112.6	223
Hastings	2564.7	1748.2	816.5	931.7	110.9	220
Lincoln	13272.5	8602.2	4670.3	3931.9	62.7	124

TABLE E-4

RESIDENTIAL DOMESTIC USE AND POTENTIAL REDUCTION.

Activity	% of Total Domestic Use*	Estimated 1970 Use (MG)	% Potential Reduction	Potential Reduction (MG)
Toilet Flusing	45%	15,100	15%	2,265
Shower & Bathing	30	10,066	20	2,013
Laundry & Dishes	20	6,711	10	671
Cooking & Drinking	5	1,678	—	—
TOTAL		33,555		4,949

*Based on calculations by Milne (12).

TABLE E-5

COMPARISON OF ESTIMATED POTENTIAL REDUCTION OF WATER USAGE IN VARIOUS HOUSEHOLD ACTIVITIES.

Activity	Percent Reduction		
	Howe (8)	Sharp (13)	Stone (14)
Toilet	41 to 56%	up to 30%	12 to 27%
Shower	20 to 34	50 to 70	0 to 32
Laundry	20 to 27	——	0 to 2
Faucet	——	50	0 to 2

INDUSTRIAL WATER USE DATA

Table E-6 shows the 1979 water use of the five major water using industries in Nebraska which supply their own water [4]. Table E-7 shows the water requirements of various industries as estimated by Kollar and MacAuley [10]. These estimates were used to determine the water used by the major water consuming industries in Nebraska. The five major water consuming industries in Nebraska are noted with an asterisk (*).

These tables are included for informational purposes only. No comparisons can be made without more detailed information on units of productions in the Nebraska industries.

TABLE E-6

INDUSTRIAL WATER USE OF NEBRASKA'S FIVE MAJOR SELF-SUPPLIED INDUSTRIES.

Industry	1979 Water Use (millions of gallons)
Industrial Inorganic Chemicals	6967.12
Meat Packing	4228.89
Beet Sugar	2743.70
Hydraulic Cement	1118.72
Petroleum Refining	1051.20

Source: Adapted from *An Inventory of Public, Industrial, and Power-generating Water Use in Nebraska, 1979 and 1980.*

TABLE E-7

WATER USE OF VARIOUS INDUSTRIES IN STANDARDIZED UNITS OF PRODUCTION.

Industry	Parameters of water use	Gross Water Used by Unit of Production	Intake by Unit of Production	Consumption by Unit of Production	Discharge by Unit of Production
Industrial inorganic chemicals*	gal/ton chemical products	14,500.gal/ton	4,700.gal/ton	470.gal/ton	4,300.gal/ton
Meat Packing*	gal/ton carcass weight	7,194.gal/ton	4,331.gal/ton	78.gal/ton	4,253.gal/ton
Beet sugar*	gal/ton beet sugar	33,145.gal/ton	11,118.gal/ton	386.gal/ton	10,731.gal/ton
Hydraulic cement*	gal/ton cement	1,355.gal/ton	831.gal/ton	146.gal/ton	685.gal/ton
Petroleum refining*	gal/gal crude petroleum	44.gal/gal	6.9.gal/gal	0.7.gal/gal	6.2.gal/gal
Poultry dressing	gal/ton ready-to-cook wt.	7,389.gal/ton	6,542.gal/ton	296.gal/ton	6,246.gal/ton
Dairy products	gal/ton milk processed	1,692.gal/ton	1,035.gal/ton	63.gal/ton	964.gal/ton
Canned fruits and vegetables	gal/ton vegetables canned	19,700.gal/ton	9,400.gal/ton	850.gal/ton	8,550.gal/ton
Frozen fruits and vegetables	gal/ton vegetables frozen	22,500.gal/ton	14,100.gal/ton	300.gal/ton	13,800.gal/ton
Wet corn milling	gal/ton corn ground	14,869.gal/ton	7,988.gal/ton	643.gal/ton	7,345.gal/ton
Cane sugar	gal/ton cane sugar	28,102.gal/ton	18,256.gal/ton	944.gal/ton	17,312.gal/ton
Malt beverages	gal/gal beer & malt liquor	49.gal/gal	14.gal/gal	3.gal/gal	1.gal/gal
Textile mills	gal/ton fiber input	69,808.gal/ton	30,016.gal/ton	3,008.gal/ton	27,008.gal/ton
Sawmills	gal/board ft. lumber	5.4.gal/bd.ft	3.3.gal/bd.ft	.63.gal/bd.ft	2.7.gal/bd.ft
Pulp and paper mills	gal/ton paper	130,047.gal/ton	37,971.gal/ton	1,178.gal/ton	36,193.gal/ton
Alkalis and chlorine	gal/ton chlorine	29,840.gal/ton	22,302.gal/ton	676.gal/ton	21,626.gal/ton
Industrial gases	gal/ton wt. of gas	16,080.gal/ton	5,700.gal/ton	780.gal/ton	4,900.gal/ton
Inorganic pigments	gal/ton pigments	97,800.gal/ton	49,400.gal/ton	1,600.gal/ton	47,800.gal/ton
Paper converting	gal/ton paper converted	6,584.gal/ton	3,861.gal/ton	273.gal/ton	3,588.gal/ton
Plastic materials and resins	gal/ton plastics	47,061.gal/ton	13,338.gal/ton	1,078.gal/ton	12,278.gal/ton
Synthetic rubber	gal/ton synthetic rubber	110,600.gal/ton	13,200.gal/ton	2,800.gal/ton	10,373.gal/ton
Cellulosic man-made fibers	gal/ton fibers	462,230.gal/ton	135,100.gal/ton	9,200.gal/ton	125,846.gal/ton
Organic fibers, noncellulosic	gal/ton fibers	202,123.gal/ton	76,523.gal/ton	2,153.gal/ton	74,369.gal/ton
Paints and pigments	gal/gal paint	13.2.gal/gal	7.8.gal/gal	0.4.gal/gal	7.4.gal/gal
Industrial organic chemicals	gal/ton chem.bldg.blks.	124,700.gal/ton	54,500.gal/ton	2,800.gal/ton	51,700.gal/ton
Nitrogenous fertilizers	gal/ton fertilizer	28,506.gal/ton	4,001.gal/ton	701.gal/ton	3,299.gal/ton
Phosphatic fertilizers	gal/ton fertilizer	35,602.gal/ton	8,461.gal/ton	1,277.gal/ton	7,184.gal/ton
Carbon black	gal/ton carbon black	9,200.gal/ton	7,885.gal/ton	1,771.gal/ton	6,114.gal/ton
Tires and inner tubes	gal/tire car & truck tires	518.gal/tire	153.gal/tire	14.gal/tire	139.gal/tire
Steel	gal/ton steel net tons	62,601.gal/ton	38,200.gal/ton	1,400.gal/ton	36,800.gal/ton
Iron and steel foundries	gal/ton ferrous castings	12,407.gal/ton	3,024.gal/ton	260.gal/ton	2,764.gal/ton
Primary copper	gal/ton copper	106,000.gal/ton	34,000.gal/ton	8,200.gal/ton	26,000.gal/ton
Primary aluminum	gal/ton aluminum	96,300.gal/ton	23,900.gal/ton	381.gal/ton	23,500.gal/ton
Automobiles	gal/car automobiles	36,500.gal/car	11,464.gal/car	649.gal/car	10,814.gal/car

Source: *"Water Requirements for Industrial Development"* Kollar and MacAuley.[10]

WATER USE FOR POWER PRODUCTION[6]

Of the technologies described, water is now consumed in the production of oil, natural gas, electricity, and ethanol in Nebraska. If Nebraska's geothermal or uranium resources are developed, water will also be required for their production. Typical water consumption rates for each of these technologies are summarized first; then total water use for energy production in Nebraska is discussed.

OIL AND NATURAL GAS

Table E-8 summarizes water use rates for production of oil and natural gas. As indicated, during exploration small quantities of water are consumed as drilling fluid make-up water. "Primary" recovery of oil and gas requires no water since water is produced along with the oil and gas extraction. That water is usually in excess of what is needed at the well. However, secondary and tertiary recovery techniques for oil do require water. Typical national average values are 10 barrels water per barrel of oil for a water flood, 1 to 6 barrels for a steam flood, and 7 to 15 barrels per barrel of oil for a carbon dioxide flood. Using data from Ballard (1), about 1 barrel of water is consumed for each barrel of oil produced in Nebraska now. This is an average value reflecting oil fields where no water is consumed and those where water is used for water flooding. Finally, natural gas processing also requires small amounts of water.

ELECTRIC POWER GENERATION

Electric power is generated in Nebraska at hydroelectric facilities and nuclear and fossil-fueled thermoelectric plants. At hydroelectric plants, water is the source of energy being converted to electricity. At thermoelectric plants, water is used primarily for cooling of steam condensers.

Hydroelectric facilities include both on-stream and off-steam plants. At on-stream plants, all or a portion of the natural streamflow flows through the turbines and returns to the river, with essentially no consumptive loss of water. The amount of power generated at on-stream plants is limited by the available streamflow, the amount of head drop, and the capacity of the turbines to utilize the available flow.

At thermoelectric plants in Nebraska, two condenser cooling methods predominate. Using the once-through cooling method, the water requirements for cooling are large but most of the water withdrawn from the stream is returned to the original source with little consumptive loss. In contrast, for plants using wet cooling towers, the water requirements for cooling are less but most of the water withdrawn is consumed (evaporated). Groundwater is sometimes the source of cooling water for cooling towers. Thermoelectric power plants also use smaller amounts of water for boiler make-up, potable, screen backwash, warm water recirculation in the winter to prevent ice build-up, and surface slicing to keep debris away from the intake structures.

TABLE E-8
WATER USE FOR THE PRODUCTION OF OIL AND GAS

Activity	Water Use	Purpose of Water Use
Oil and Gas Exploration	200-500 barrels of water per day per drilling rig	Primarily for drilling fluid make-up
Primary Recovery: Oil and Gas	0	Water is normally produced along with the oil and gas in excess of the requirements
Secondary Recovery: Oil Water Flooding	10 barrels water per barrel oil	The amount of water needed for a waterflood is a function of the amount of water produced with the oil. This 10 barrels will be reduced by the amount of water recovered.
Tertiary Recovery:	1 to 6 barrels water per Oil Steam Flooding	Water is used for steam generation. barrel oil
Carbon Dioxide Miscible Flooding	7 to 15 barrels water per barrel oil	Water acts as a drive to push the carbon dioxide throughout the reservoir.
Natural Gas Processing	0.5 gallons water per cubic foot of	Water is used to cool the compressed gases and process streams; it is evaporated in cooling towers.

Source: *Energy From the West, Energy Resources Development Systems Report,* Vol. V; EPA-600/7-79-060-C, pages 24, 86, 112, 127.

Water use for hydroelectric power generation in Nebraska in 1980 is summarized in Table E-9. For off-stream hydroelectric plants, the amount discharged through the turbines is greater than the amount diverted. This unusual situation is created because water diverted by irrigation canals is used to generate power at more than one hydroelectric plant. About 3,500 gallons of water are discharged through turbines for each 1,000 kilowatt-hours generated at off-stream plants. The corresponding value for on-stream plants is about 24,300 gallons. Again, the smaller value for off-stream plants reflects the fact that the same water generates power at more than one plant. The Gavins Point plant on the Missouri River generates 1.4 times as much power as all other hydroelectric plants in the State. Compared to the on-stream plants within State boundaries, its lower water use rate of 8,180 gallons discharged per 1,000 kWh generated reflects the better hydrologic conditions that exist there. In no case is water actually consumed at hydroelectric power plants.

TABLE E-9

WATER USE RATES FOR HYDROELECTRIC POWER PRODUCTION IN NEBRASKA IN 1980

	Off-stream	On-stream	State Total	Gavins Point, Missouri River
Power Generated (million kWh)	541	11.7	553	729.9
Water Diverted (acre-feet/yr)	3,449	NA	3,449	NA
Water Discharged Through Turbine (acre-feet/yr)	5,810	871	6,682	19,904
Discharged Per kWh (gallons/thousand kWh)	3,496	24,273	3,936	8,181

Source: *"Water Use by Public Supplies, Self-Supplied Industries, and Power Generating Facilities 1979 and 1980,"* Conservation and Survey Division, University of Nebraska-Lincoln, 1982.

TABLE E-10

WATER USE RATES FOR THERMOELECTRIC POWER PLANTS

	Water Withdrawn (Gallons/Thousand kWh)	Water Consumed (Gallons/Thousand kWh)
Once-Through Cooling		
From **Energy Alternatives**[a]		
Nuclear	53,283	0
Coal	31,666	0
From **Platte Level B**[c]	50,000 to 130,000	300 to 700
From **NE Water Survey Paper**[d]	66,900	NC
From **Memo to NNRC**[e]	29,350	0
Wet Cooling		
From **Energy Alternatives**[a]		
Nuclear	1,060	663
Coal	631	394
From **Energy From the West**[b]	187 to 427	187 to 427
From **Platte Level B**[c]	50,000 to 180,000	500 to 1,100
From **NE Water Survey Paper**	2,832	NC
From **Memo to NNRC** [d]	580	580

NC = Not considered.

a *Energy Alternatives* by the Science and Public Policy Program, University of Oklahoma, U.S. Government Printing Office, Washington, D.C.

b *Energy From The West* by M.D. Devine, S.C. Ballard, and others, University of Oklahoma Press, Norman, 1981, page 61. Range represents variations among different sites in the West.

c *Platte Level B Study*; includes thermoelectric power plants in the Platte Valley only.

d Memo to Jerry Wallin from Don Adelman for the *High Plains Study*, dated October 10, 1980.

In contrast, water consumption does occur at thermoelectric power plants. Table E-10 summarizes data from national and state sources on water use rates at thermoelectric power plants. As indicated, if once-through cooling is used, water withdrawals are large, but according to four of the five studies, water consumption is negligible. If wet cooling is used, water withdrawals are smaller by more than an order of magnitude but water consumption is significant. About 600 gallons per 1,000 kWh is considered to be the best estimate for Nebraska. It represents consumptive water use at a power plant that employs wet cooling.

ETHANOL PRODUCTION

Ethanol plants require water for the mixing, fermentation and distillation process as well as for sanitary purposes. In the first year of operation, a commercial-size ethanol facility (producing on the order of 10 million gallons of ethanol per year) will consume about 7.2 gallons of water for each gallon of ethanol produced. Because about half of this water can be recycled, water requirements decrease to 3.4 gallons water per gallon of ethanol in the second year and thereafter. (These data are from the Nebraska Gasohol Committee, personal communication.)

IN-SITU URANIUM MINING

The water requirements for an in-situ solution uranium mine producing 500,000 pounds of uranium oxide per year are given in Table E-11. Water is required for the drilling operations, for the leaching process, for aquifer restoration, and for sanitary use. The total, about 183,000 gallons per day or 205 acre-feet per year, is relatively small.

GEOTHERMAL ENERGY

As with oil wells, water requirements during geothermal drilling are 200 to 500 barrels per drilling rig per day, primarily for use as drilling fluid. At the average consumption of 375 barrels per rig-day and assuming that sixty days are required to drill each well, the average water requirement is 22,500 barrels per well in a geothermal field. No water is required to produce the geothermal energy after the wells are drilled.

TABLE E-11

WATER REQUIREMENTS FOR AN IN-SITU URANIUM MINE PRODUCING 500,000 POUNDS URANIUM OXIDE PER YEAR

Activity	Water Requirements (gallons/day)
Drilling	9,000
Process Water	51,000
Aquifer Restoration	121,000
Sanitary Water	2,000
TOTAL	183,000 (205 acre-feet/year)

Source: *Energy From The West, Energy Resource Development Systems Report,* Vol. IV, EPA-600-7-79-060d. p. 150.

TOTAL WATER USE

Using the data provided for each technology, total water use for energy production in Nebraska in 1980 was analyzed. The results are summarized in Table E-12. While about 2,900,000 acre-feet were needed to produce power, nearly all of this was non-consumptive use. Only 2,900 acre-feet were consumed and most of this consumption occurred in wet cooling towers.

TABLE E-12
TOTAL WATER USE FOR ENERGY PRODUCTION IN NEBRASKA: 1980 (THOUSANDS OF ACRE-FEET)

	Water "Withdrawn"	Water Consumed
Oil and Gas Production[a]	0.9	0.9
Electric Power Generation		
Hydroelectric[b]	3.5	0
Thermoelectric		
Once-Through	2,860.8[c]	0
Wet Cooling Towers	9.5	2.0[d]
Alcohol Production[e]	0.03	0.03
TOTAL	2,874.73	2.93

a From Ballard, **op.cit.**

b See Table 4, Gavins Point is excluded.

c From "Water Use by Public Supplies, Self-Supplied Industries, and Power Generating Facilities," Conservation and Survey Division, **op.cit.**

d Based on 600 gallons per thousand kWh and 1,094.1 million kWh generated in 1980 at plants with wet cooling towers.

e Based on 3.4 gallons water per gallon alcohol and 3.35 million gallons alcohol produced in the State in 1981.

REFERENCES FOR APPENDIX E

(1) Ballard, J.L., "Nebraska A-2 Element of the High Plains Ogallala Aquifer Study," 1980, University of Nebraska. Data on page 24 indicates that 900 acre-feet of water were consumed to produce the 7.4 million barrels of oil produced in Nebraska in 1981.

(2) Brainard, Frank S., Jr. 1979. "Leakage Problems and the Benefits of Leak Detection Programs." Journal of the American Water Works Association 71(2): 64-65.

(3) Conservation and Survey Division. Preliminary Results of Inventories of 1979 Water Use for Power Generating Facilities. UN-L. Unpublished report.

(4) Conservation and Survey Division. Water Data Collection Project. UN-L, 1979-1980. Unpublished report.

(5) Cotter, Donald J. and D.B. Croft. 1974. "Water Application Practices and Landscape Attributes Associated with Residential Water Consumption." Technical Completion Report C-4060-NMEX. New Mexico WRRI Report #049. New Mexico State University, Las Cruces, New Mexico 88003. 64p.

(6) Gilliland, Martha W., Department of Civil Engineering, UNL. November 1982. "Nebraska Energy Imports, Production and Exports," prepared for the Water/Energy Policy Issue Study, Nebraska Natural Resources Commission.

(7) Hancock, John. 1979. "Water Conservation in Housing." In: *Water Conservation, Needs and Implementation Strategies*. Proceedings of 1979 Conference co-sponsored by ASCE, USEPA, OWRT, and USWRC. Published by ASCE, 345 East 47th Street, New York, N.Y. 10017. pp. 69-73.

(8) Howe, Charles, and F.P. Linaweaver. 1967. "The Impact of Price on Residential Water Demand and Its Relation to System Demand and Price Structure." *Water Resources Research*, #3, pp. 15-33.

(9) James, L.D. and R.R. Lee. 1971. *Economics of Water Resources Planning*. McGraw-Hill Book Company, Inc. New York, N.Y.

(10) Kollar, K.L., and P. MacAuley. 1980. "Water Requirements for Industrial Development." *Journal of the American Water Works Association* 72(1): 2-9.

(11) Linaweaver, F.P., J.C. Geyer, and G.B Wolff. 1967. "A Study of Residential Water Use." Department of Environmental Engineering, Johns Hopkins University, Baltimore, MD.

(12) Milne, Murray. 1979. *Residential Water Re-Use*. California Water Resources Center. Report #46. University of California, Davis, CA.

(13) Sharpe, William E. 1981. "Water Conservation Devices for New and Existing Dwellings." *Journal of the American Water Works Association* 73(3): 144-149.

(14) Stone, Brian. 1978. "Suppression of Water Use by Physical Methods." *Journal of the American Water Works Association* 79(9): 483-486.

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APPENDIX F

SURVEY INSTRUMENT FOR THE WATER RESOURCES CENTER SURVEY OF NEBRASKA WATER MANAGERS

Cover Letter

Dear

The Nebraska Water Resources Center is currently studying water use efficiency issues as part of the State Water Planning and Review Process. A segment of this study involves surveying those involved in water management about factors which may limit attainment of efficient water use. The responses to this survey will assist us in developing a variety of alternative water policies for the improvement of water use efficiency. These alternatives will then be submitted to the Natural Resources Commission for consideration.

You were chosen for this survey because you are a representative of energy interests. The selection process involved examining various public documents from state agencies and choosing representatives from industrial, agricultural, and energy interests from each natural resources district.

We would appreciate your help by completing and returning the enclosed questionnaire. Your response is important so that we may obtain a statewide perspective. Please contact me if you have any questions.

Sincerely,

Donn Rodekohr
Water Resources Technologist

DR:db

Enclosure

SURVEY OF WATER MANAGERS

The purpose of the following questions is to determine what **factors influence the ways in which you allocate the water within your operation to achieve efficiency**. For the purposes of our study, water use efficiency is defined as "minimizing the amount of water used while optimizing the benefits received." If you need more room to answer any of the questions, please feel free to attach another sheet of paper.

1. In which NRD(s) is your operation(s) located?____________________________

2. In what way(s) is water used in your operations?

3. How important do you consider water as a factor in the success of your operation?

______	unimportant	______	somewhat important
______	somewhat unimportant	______	very important

4. The following is a list of some possible restrictions on water use. Please indicate the degree to which these factors restrict your water use.

   Severely restricts = 1
   Somewhat restricts = 2
   Does not restrict = 3
   Does not apply = 4

______	Availability of water	______	Water Quality
______	Federal regulations	______	Technical limitations**
______	State regulations	______	________________
______	Local regulations*	______	________________
______	Energy costs	______	________________

For any of of the factors that you rated as 1 or 2, please explain how they restrict your water use.

* NRD, county, municipality, irrigation district, etc.
** Machinery, pumps, irrigation systems or other man-made devices.

5. Have you or your company made any recent changes to improve water use efficiency?

   ______ yes ______ no

   If you answered "yes" to #5, were these changes brought about by:
   ______ Federal governmental incentives (i.e., cost sharing)
   ______ State governmental incentives
   ______ Local governmental incentives
   ______ Federal governmental discouragement (i.e., taxes or fines)
   ______ State governmental discouragement
   ______ Local governmental discouragement
   ______ Non-governmental factors

If you indicated any of the above, please identify and explain.

6. Are there any water use efficiency improvements that you could make but have not made?

   ______ yes ______ no

Continued

If you answered "yes" to #6, were these improvements precluded by:

_______ Lack of Federal governmental incentives (i.e., cost sharing)
_______ Lack of State governmental incentives
_______ Lack of Local governmental incentives
_______ Federal governmental discouragement (i.e., taxes or fines)
_______ State governmental discouragement
_______ Local governmental discouragement
_______ Non-governmental factors

If you indicated any of the above, please identify and explain.

7. Additional comments or observations:

Please indicate your name and the company which you are representing. This will aid us by minimizing duplicate follow-up letters and phone calls. All responses will be kep separate from this sheet so that the privacy and integrity of your answers will be maintained.

Prepared by:

____

Name of Company:

____

Please return the completed questionnaire in the enclosed stamped return envelope by **FEBRUARY 4**. Thank you for your cooperation and help.