Artificial Aquifer Recharge in the Colorado Portion of the Ogallala Aquifer

by

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OF THE OGALLALA AQUIFER

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PREFACE

The Colorado High Plains Technical Coordinating Committee serves as a forum for information exchange among interested agencies, organizations, and individuals concerned with the Colorado Ogallala region. As issues, concerns and needs in this region are identified, the committee works through task forces to develop solutions.

This report has been prepared to describe the potential for artificial recharge in the Colorado portion of the Ogallala Aquifer. This study is also in response to the recommendation made by the Colorado High Plains Advisory Committee in 1982 "THAT APPROPRIATE LOCAL, STATE AND FEDERAL AGENCIES DETERMINE THE SUITABILITY OF AQUIFER RECHARGE SITES AND CARRY OUT DEMONSTRATION PROJECTS." It is the hope of the Colorado High Plains Technical Coordinating Committee that this report will assist efforts to develop artificial recharge projects in the Colorado High Plains.

The report was prepared by: Bob Longenbaugh, Division of Water Resources; Don Miles, Colorado Cooperative Extension Service; Earl Hess, Soil Conservation Service; and Jim Rubingh, Colorado Department of Agriculture. The United States Geologic Survey provided several of the graphics.

EXECUTIVE SUMMARY

The overdraft of the Ogallala Aquifer in Colorado is approximately one million acre feet of water annually. This depletion of the aquifer is expected to result in the loss of approximately 240,000 acres of irrigated land by the year 2020--about 40 percent of the region's currently irrigated land. As the aquifer continues to decline, additional lands will be forced out of irrigation.

Artificial aquifer recharge is recharge of the aquifer using water not normally available for this purpose. It is one technique that can help to slow depletion of the aquifer. In the opinion of the authors artificial recharge--through the modification of playa lakes and the construction of spreading basins, recharge pits, and ponds--could add up to 20,000 acre feet annually to the Ogallala Aquifer in the Northern High Plains of Colorado. More studies are needed before such estimates can be made for the Southern High Plains of Colorado.

In the Northern High Plains of Colorado, five aquifer recharge demonstration projects have been constructed and their activity monitored and documented. These projects have shown that recharge from local stream flow is feasible and can salvage water which otherwise would flow out of the state.

Before an artificial recharge project is constructed, several factors should be considered: water availability, water rights, water quality, geology, soils, environmental impacts, cultural practices, the operation and maintenance of the facility, and the costs and benefits of its construction. The major constraint to the development of recharge projects in the High Plains is the availability of water. Natural precipitation in this region varies considerably in time and location. Introducing water from outside the region could greatly enhance recharge opportunities.

Cultivation practices and the location of precipitation runoff for recharge also must be considered before a recharge project is constructed. Cultivation practices such as minimum tillage affect the availability of water for recharge. Since minimum tillage reduces soil erosion and uses precipitation effectively, it should be encouraged. Its effect on runoff, however, needs to be considered when aquifer recharge sites are evaluated since much less runoff occurs because of this practice. Finally, recharge projects that simply change the location of naturally occurring recharge should be discouraged. Instead, projects should use water that would normally be lost due to evaporation or otherwise lost from the region.

TABLE OF CONTENTS

		Page
Preface		i
Executive Summary		ii
Chapter I:	Colorado High Plains Overview	1
Chapter II:	Artificial Recharge Methods	6
Chapter III:	Potential for Artifical Recharge in Colorado's Northern High Plains	9
Chapter IV:	Demonstration Projects in the Colorado High Plains	12
Chapter V:	Artificial Recharge Issues	15
Chapter VI:	Methodology to Evaluate Aquifer Recharge Sites	18
Bibliography		24

FIGURES

Figure 1:	The Ogallala Aquifer	1
Figure 2:	Colorado High Plains Region	2
Figure 3:	Recharge in the Northern High Plains of Colorado	4
Figure 4:	Potential for Recharge in the Northern High Plains of Colorado	10
Figure 5:	Recharge Demonstration Projects in the Northern High Plains of Colorado	12
Figure 6:	Effect of Tillage Methods on Runoff	16
Figure 7:	Procedures for Identifying Recharge Sites	19

CHAPTER I

COLORADO HIGH PLAINS OVERVIEW

Withdrawals for irrigation greatly exceed recharge rates from natural precipitation in many portions of the Ogallala Aquifer. Artificial means for increasing aquifer recharge include spreading basins, recharge ponds and pits, recharge wells, as well as playa lake and land surface modification.

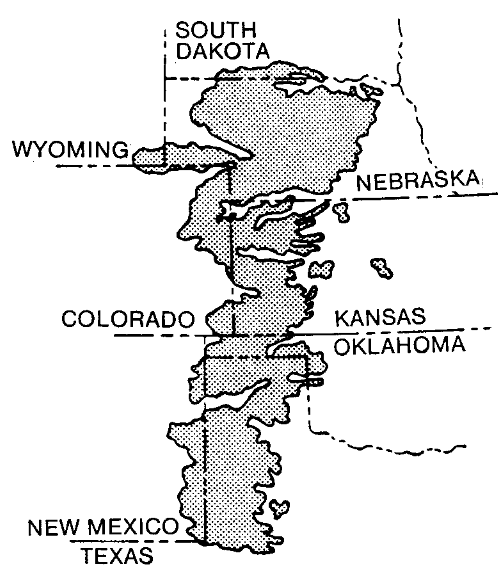
The purpose of this report is to discuss the potential contribution of such techniques to recharge portions of the Ogallala Aquifer in eastern Colorado. This chapter provides background information on the Ogallala in Colorado, and describes the origins of this report.

Numbers in parentheses refer to documents listed in the Bibliography.

Ogallala Aquifer

The Ogallala Aquifer is a huge underground water-bearing layer of sand, gravel, clay, and silt that lies beneath 156,000 square miles of land in eight High Plains states, including Colorado (Figure 1). The Ogallala contains more than three billion acre-feet of water--enough to cover the state of Colorado 45 feet deep. About 16 million acres--more than 20 percent of the nation's irrigated land--are watered from the Ogallala Aquifer (4).

Figure 1
The Ogallala Aquifer



The Ogallala Aquifer in Colorado lies beneath 12,000 square miles of land in parts of eleven counties in eastern Colorado (Figure 2). The Colorado portion of the aquifer contains over 90 million acre-feet of water--about three percent of the total Ogallala resource. About two-thirds of Colorado's Ogallala resource (60 million acre-feet) is considered to be economically recoverable (4).

Figure 2
COLORADO HIGH PLAINS REGION

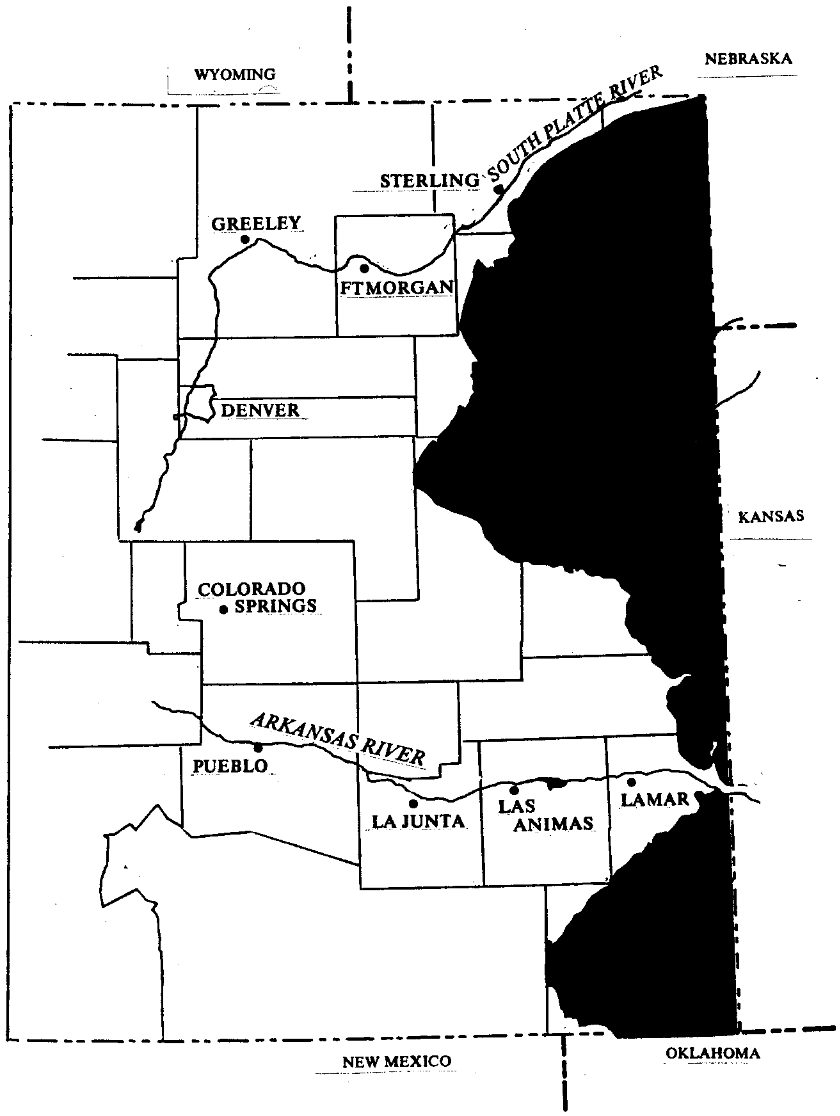


Table 2.1
LAND USE
(Colorado High Plains, 1979)

	Area (1000 acres)	Percent of Region	Percent of Colorado's Land in that Use
Irrigated Land	600	8	17
Dry Cropland	3,358	44	45
Rangeland	3,172	42	14
Other Land	409	5	1
All Land	7,539	100	11

In Colorado, the Ogallala Aquifer consists of two regions. In the Northern High Plains region, about 3800 wells irrigate approximately 500,000 acres. In the Southern High Plains region, about 1000 wells irrigate approximately 100,000 acres of land. Together, these two regions represent 600,000 acres of irrigated farmland in the state--about 20 percent of Colorado's total irrigated land (4).

Colorado's Ogallala region accounts for a significant portion of the state's agricultural production. In 1979, this region accounted for 44 percent of the state's corn production, and 32 percent of the value of all crops grown in the state. In 1978, crop and livestock sales in the 11-county area above the Ogallala region in Colorado exceeded $900 million. Sales in farm services and food processing in the region generated nearly $600 million more that year (4).

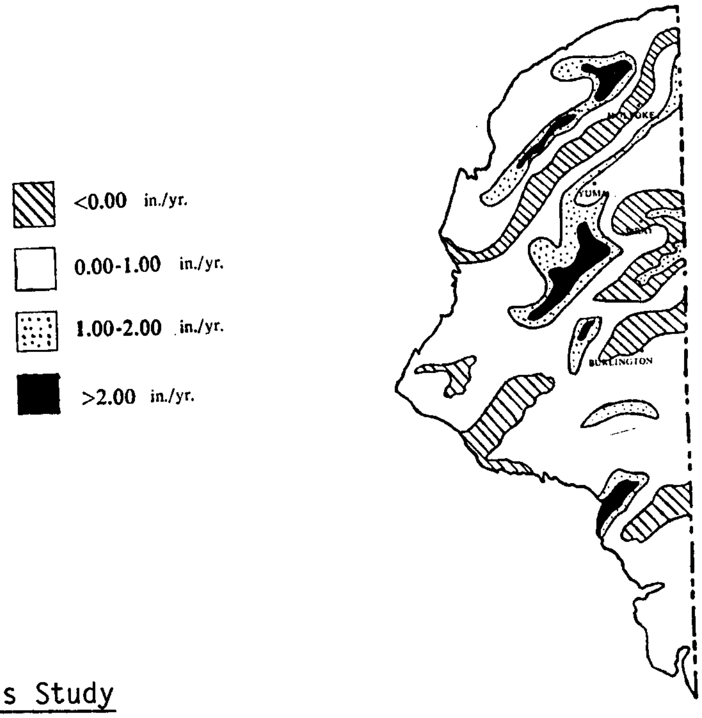
Unlike rivers and streams, which are replenished annually from rain and snowmelt, the Ogallala Aquifer is essentially nonrenewable. No streams or rivers significantly recharge the Ogallala. Although natural precipitation adds approximately 430,000 acre feet of water annually to the Northern High Plains region in Colorado, underground outflows to Kansas and Nebraska almost equal this amount.

Withdrawals for irrigation in the Colorado portion of the Ogallala Aquifer currently exceed recharge from natural precipitation by about one million acre feet per year. If this rate continues, the recoverable water in the Ogallala Aquifer in Colorado will be largely depleted within 60 years.

Saturated thickness and the distance from the land surface to ground water in the aquifer vary widely throughout the region. Saturated thickness is the thickness of the part of the geologic layer from which water can be extracted by pumping. The saturated thickness along the aquifer's western edge in Colorado ranges from 5 to 50 feet, while along the Kansas and Nebraska state lines it ranges from 50 to 350 feet. Irrigation is generally considered economically and technically feasible only in areas where the saturated thickness is at least 35 feet. Depths to water range from 20 feet to more than 400 feet. During the past 25 years, the water table has dropped by as much as 40 feet in some places as a result of irrigation withdrawls.

Although the Ogallala Formation slopes slightly from west to east, there is little movement of water in that direction. Most of the change in water level is caused by withdrawal through the large-capacity wells used for pumping irrigation water. Natural recharge of the aquifer from precipitation is estimated to be one-half to two inches per year--very small compared to irrigation withdrawals (Figure 3).

Figure 3
Recharge in the Northern High Plains of Colorado



High Plains Study

A major six-state study of the future of the Ogallala Aquifer, known as the High Plains Study, was completed in January 1983. A complete bibliography on this massive study is given in reference (4), listed in the back of this report. This reference also summarizes the Colorado research results, and lists recommendations for action. Reference (22) is the basic source document for agricultural production and aquifer depletion projections in the Colorado Ogallala region.

One of the principal conclusions of the study is the following:

> Under "business as usual" conditions, 40 percent of the land currently irrigated by the Ogallala Aquifer in Colorado is projected to go out of production by the year 2020. This represents a decrease from 600,000 acres currently irrigated to 360,000 acres within 40 years.

The projected loss of irrigated acreage in eastern Colorado is not uniform. In particular, irrigation in the northern portion of the region near Yuma and Wray is projected to continue well past 2020. These variations are chiefly due to differences in the thickness of the geologic layers containing Ogallala water, and the depth from the land surface to these layers.

Recommendation to Study Aquifer Recharge Potential

During 1981-82, research results were reviewed by eastern Colorado citizens in six public meetings under the guidance of the Colorado High Plains Advisory Committee, a group of 22 eastern Colorado residents. Strategies for action were also discussed, under four categories:

1. Improve irrigation efficiency to produce more food and fiber per unit of water and energy.

2. Restrict ground water use to extend the life of the aquifer.

3. Increase water supply in the region to offset aquifer decline.

4. Expand economic development opportunities to broaden the base of the High Plains economy.

Early in 1982, this committee developed 20 specific recommendations for action, including the establishment of a technical coordinating committee:

> THAT A COLORADO HIGH PLAINS TECHNICAL COMMITTEE BE FORMED TO COORDINATE IRRIGATION RESEARCH, DEMONSTRATION, EDUCATION, AND TECHNICAL ASSISTANCE IN THE REGION.

In June 1982 the Colorado High Plains Technical Coordinating Committee was formed in response to this recommendation. The group consists of representatives from local, state, and federal agencies and private organizations with responsibilities and interests in the High Plains.

Out of its study of options to increase the region's water supply, the Advisory Committee also recommended:

> THAT APPROPRIATE LOCAL, STATE, AND FEDERAL AGENCIES DETERMINE SUITABLE AQUIFER RECHARGE SITES AND CARRY OUT DEMONSTRATION PROJECTS.

This report on aquifer recharge potential was prepared by the Colorado High Plains Technical Coordinating Committee in response to this recommendation.

CHAPTER II

ARTIFICIAL RECHARGE METHODS

Natural recharge is the replenishment of an aquifer by deep percolation of water from rain and snowmelt. Artificial recharge is the incremental increase in recharge to the groundwater aquifer due to man-made activities. Man either modifies the land surface to increase the rate of recharge, or else introduces additional water into the aquifer from other sources.

This chapter describes five methods of artificial recharge: spreading basins, recharge ponds or pits, recharge wells, playa lake modification, and land form modification.

Spreading Basins

Spreading basins are tracts of land to which excess moisture is diverted. They are best suited for areas with inexpensive land, soils with high infiltration rates, and no impervious layers between the land surface and water table. This technique was successfully demonstrated in the 1960's on the Arikaree River west of Cope in northeast Colorado. (See Chapter IV.)

Recharge Ponds and Pits

Ponds and pits are more suitable than spreading basins if land is expensive and if construction of the pond or pit would remove impervious layers between the land surface and water table. Recharge from pits and ponds may be greater through the sides of the pit than through the bottom where sediment may collect.

Abandoned gravel pits near existing stream channels often make excellent recharge pits. Recharge rates in abandoned gravel pits are usually very high because gravel is coarse and highly permeable. Gravel sales may partially offset land and operating costs of the recharge facility. This technique has been successfully demonstrated in the eastern High Plains of Colorado during the 1970s. (See Chapter III.)

The potential for spreading basins or recharge pits and ponds is good throughout most of the Northern High Plains of Colorado and for the Ogallala Formation in the Southern High Plains of the state. (See Chapter III.)

Recharge Wells

Recharge wells are normally used where one or more impervious layers separate the land surface and the water table. These wells conduct excess surface water directly to the aquifer. Recharge wells could be used to recharge confined aquifers in the Southern High Plains region of Colorado.

Aquifer recharge from wells can pose problems, however. First, runoff from rainfall or snowmelt usually contains significant sediment. Injecting water with sediment often plugs the recharge well by plugging the well screen or plugging the pore spaces in the aquifer. Injection water containing entrained air can also cause trouble by plugging the pore spaces with air. Once air is released it is very difficult to dislodge because of the force of capillar pressure. It will effectively plug the pores and impede recharge. Bacterial organisms in the recharge water may grow and multiply within the well screen and surrounding aquifer. A demonstration project in Texas (16) partially met these problems through alternate cycles of pumping and recharge, coupled with a supply of good quality water treated to eliminate bacterial growth.

Playa Lakes

Playa, or wet weather, lakes are depressions that collect water after rainfall or periods of snowmelt. Water from playa lakes can be pumped directly to fields for irrigation or used to artificially recharge an aquifer. Heavy clay soils can be broken up and the lake bottom regraded for maximum recharge.

There are several playa lakes in the Northern High Plains of Colorado and a few in the Southern High Plains, ranging in size from one to 20 acres each. The U.S. Geological Survey estimates there are over 3,000 of them in Kit Carson County, where they are most common.

Because of the variability of runoff, the number of playa lakes and the amount of available water changes annually. Some lakes may remain dry for several years. Many playa lakes have tight clay and silt deposits that restrict or even prevent leakage of water from the lake. Nearly all the water is lost to evaporation or to non-beneficial use through vegetation growing in the lake. Many of the lakes are very shallow, so using a centrifugal pump to pump the water directly into a pipeline for irrigation purposes is often not possible.

Playa lakes have become a nuisance since extensive irrigation development began in the early 1960s. Some farmers have changed the land surface to eliminate the lakes, decrease their area, or convert them to tailwater sumps. In some instances, agricultural practices such as deep chiseling have improved the infiltration capacity so that lakes do not form for extended periods.

One disadvantage of draining playa lakes is that the production of water fowl may be reduced. The Colorado Division of Wildlife has expressed concern about the impact of drying up playa lakes on ducks in Colorado.

In a demonstration project near Lubbock, Texas, playa lakes were modified by excavating concentration pits and using the excavated soil to raise the elevation of some of the previously flooded lands. The benefits from such a modification include: (1) a reduced water surface area and corresponding reductions in evaporation; (2) increased area for farming, thus more revenues to pay the cost of lake modification; (3) an increase in recharge, because the excavation of the pit was deep enough to expose more permeable soils and increase infiltration from the bottom and sides of the pit; and (4) fewer mosquito problems, because the shallow pond--ideal for mosquito propagation--was destroyed.

Landform Modification

Researchers at the Central Great Plains Field Station near Akron, Colorado are evaluating the feasibility of harvesting rainfall from one land area and using it on adjacent areas to increase the annual available moisture . By making one area less permeable, researchers expect that the rainfall falling on the first area will run off and be available for recharge or for direct crop use on the second area.

CHAPTER III

POTENTIAL FOR ARTIFICIAL RECHARGE IN COLORADO'S NORTHERN HIGH PLAINS

This chapter gives necessary criteria for artificial recharge projects, estimates the potential maximum for artificial recharge in the Northern High Plains of Colorado, and displays subareas where such recharge is most feasible.

Artificial Recharge Criteria

Increasing aquifer recharge from natural precipitation through spreading basins, recharge ponds and pits, recharge wells, playa lake modification, and other man-made activities requires a favorable combination of several conditions. These conditions include:

- distribution and intensity of precipitation
- topography, as it permits or retards runoff
- permeability and moisture-holding capacity of the soils
- evapotranspiration rates of vegetation that must first be satisfied by available moisture
- farming practices used in the area
- unsaturated materials for injection
- geology which allows downward movement of water so that a perched water table does not occur.

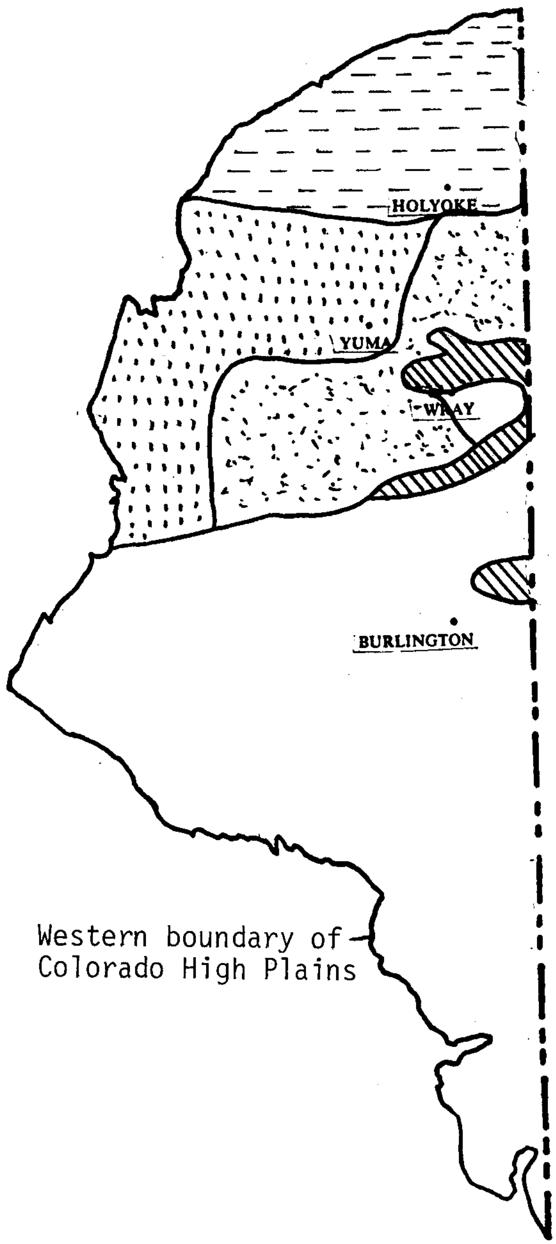
The U. S. Geological Survey estimates that natural recharge adds 430,000 acre-feet of water annually to the Ogallala Aquifer in the Northern High Plains region of Colorado. However, almost as much water from the Ogallala leaves the state by underground flow each year because the aquifer slopes from west to east. (See Chapter III of reference (4) for a brief discussion on this point.)

Compared to natural recharge, the potential for artificial recharge in the High Plains region is not as great as many people have assumed. The authors estimate that artificial recharge, including the modification of playa lakes and landforms, could add up to 20,000 additional acre-feet annually. In the Southern High Plains of the state, more study is needed on aquifer characteristics and water availability before the benefits of aquifer recharge can be estimated. In some areas, artificial recharge would only change the location of the recharge, as the water is now being naturally recharged downstream. Changes in cultivation practices, such as minimum tillage, are significantly reducing the amount of water potentially available for recharge purposes. (See Chapter V for more discussion.)

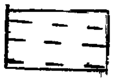
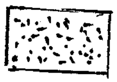
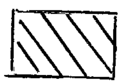
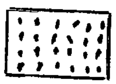
Artificial recharge is technically feasible at many sites, but the chief limiting factor is usually the availability of water. Natural runoff that could be used for recharge varies in time and space. Due to rainfall variability, water may only be available once or twice in any ten-year period at a specific site. Even in places where water is always available, the geology may restrict recharge: the lower Arikaree and the South and North Forks of the Republican rivers are examples.

Figure 4 displays five different recharge regions in the Ogallala Formation. The accompanying table explains the recharge characteristics of each region.

Figure 4
Potential for Recharge in the Northern High Plains of Colorado



RECHARGE AREA CHARACTERISTICS

MAP CODE	WATER AVAILABILITY	SOILS	GEOLOGY	WATER RIGHTS c/	TYPES OF AQUIFER RECHARGE TECH. FEASIBLE
	Limited to rainfall and snowmelt run-off. Some surface runoff and playa lake storage.	Low to moderate in-filtration rates. Considerable local variation.	Localized variation in unsaturated zones. Generally contains rechargeable soils. Localized clay, caliche lenses could cause perched water levels.	Surface runoff may be required to meet downstream water rights.	Playa modification Spreading Terraces Ponds Pits d/
	Limited to rainfall and snowmelt run-off. Some surface runoff.	Same as above.	Same as above.	No problems anticipa-ted but could be subject to Frenchman Creek Compact Admin-istration.	Spreading Terraces Ponds Pits
	Limited to rainfall and snowmelt run-off. Some surface runoff and playa lake storage. a/	Same as above.	Same as above.	No problems antici-pated.	Spreading Terraces Ponds Pits
	Little or no water available due to high natural re-charge.	High infiltration rate.	Same as above.	No surface water rights in area.	Playa modification
	There is flow in the streams and rainfall runoff	Most alluvial mater-ials have high in-filtration rates. Sloping lands adja-cent to alluvium have low infiltra-tion rates.	Where bedrock high and high water tables in the allu-vium exist, there is no unsaturated materials to be recharged. b/	Surface water rights in each area. Diver-sion may be higher. version of water for artificial recharge subject to current decrees.	Spreading

NOTES FOR CHART

a/ Some surface runoff from this area is now naturally recharged into the sandhills area.

b/ Limited areas could be used for recharge where the water artificially recharged would later return as surface stream flow

c/ Impacts to both surface water and groundwater users must be determined.

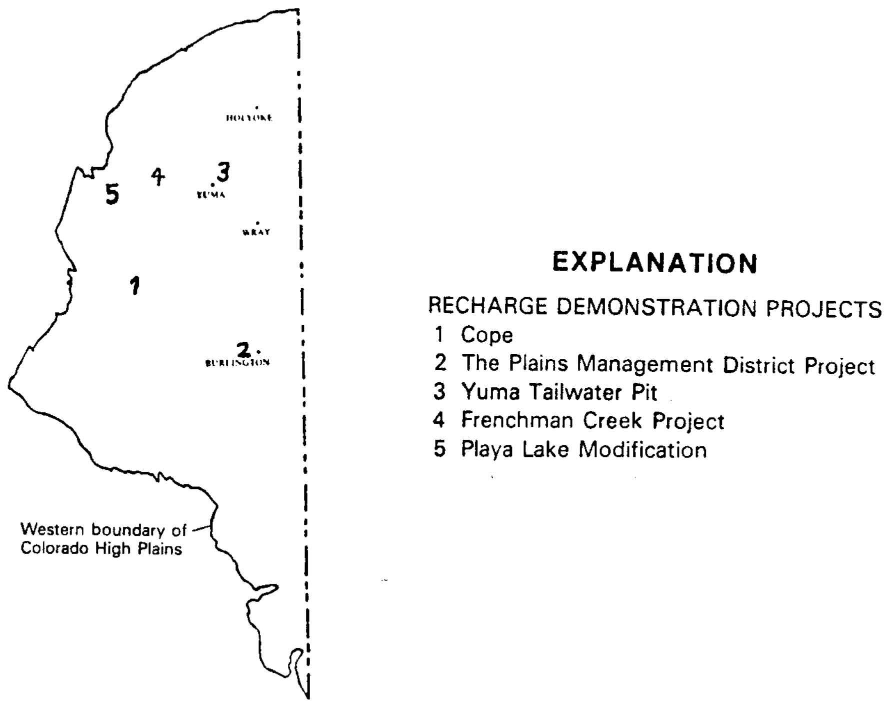
d/ For Southern High Plains to recharge, the sandstone aquifers would require recharge wells.

CHAPTER IV

DEMONSTRATION PROJECTS IN THE COLORADO HIGH PLAINS

Demonstration projects have shown that artificial recharge is feasible if water exists and soil and geologic conditions are favorable. Since the early 1960s, at least five artificial recharge demonstration projects have been constructed in the Northern High Plains of Colorado. This chapter briefly describes each of them. Figure 5 indicates their location and type of recharge method evaluated.

Figure 5
Recharge Demonstration Projects



Cope Project

In 1962 the Colorado Ground Water Commission funded a five-year study on the Arikaree River west of Cope, Colorado. The purpose of the project was to capture the natural stream flows of the Arikaree River and spread them over nearby lands. Natural recharge occurs in the stream channel, but the spreading and impounding of the water increases recharge and decreases or completely eliminates downstream flows.

The Ground Water Commission contracted with the Civil Engineering Department at Colorado State University to select recharge sites, oversee the study, and evaluate the study results. The Commission also contracted with the Cope Soil Conservation District for construction costs. A local contractor was assigned to carry out the construction of the recharge structures. These structures consisted of earth fill dams and dikes to divert the flow and spread it over a large area for infiltration.

The Arikaree River flows after heavy thunderstorm activity in the watershed upstream. During 1963 and 1964, there were no flow events. In 1965 there were several small flow events in early June, which clearly demonstrated the benefits of this project. In late June 1965, a large storm system over the entire watershed caused entensive flooding and destroyed much of the demonstration project. It was later rebuilt, and several successful recharge periods occurred before the project ended in 1968. Unfortunately, no organizational sponsor was found to continue operating the project. The structures were left to erode and have since been destroyed.

Artificial recharge at these sites contributed 1810 acre-feet of water from 1964-1968. The total construction and maintenance cost was $13,140 or a cost of $7.26 per acre-foot.

Several important conclusions can be drawn from the Cope study:

1. Recharge with local streamflow is feasible and can salvage water which might flow out of the state.

2. Flows for recharge are available on an irregular basis.

3. Maintaining recharge structures is essential to repair erosion damage and to remove sediment deposits that impede infiltration capacity.

4. A total watershed program would need sufficient structures to minimize flood damages due to large rainfall events and to capture all of the extra runoff.

5. A local or regional organization is needed to take responsibility for design, construction, operation, and maintenance of artificial recharge projects.

The results of the study are illustrated and described in references (2,11).

The Plains Ground Water Management District Project

The Plains Ground Water Management District in Kit Carson County constructed two recharge facilities to demonstrate how surface stream flows could be captured in an adjacent gravel pit. They were able to estimate the volumes of water captured in the pit and to document in nearby wells the rise in the water table coinciding with each recharge period.

Yuma Tailwater Return/Recharge Pit

In 1970-72, researchers from Colorado State University cooperated with a local farmer near Yuma, Colorado to construct a recharge pit that also served as a tailwater return pit (13, 14). Sufficient data were collected to show that artificial recharge was occurring, but the farmer desired to pump the water directly from the pit back to the head of the field, rather than recharge the water from the pit and then pump a larger amount from the aquifer with his production well.

Waters captured in the pit were recharged during the nonirrigation season or during heavy rainfall periods when irrigation was not required. Construction of similar pits at other localities could capture water that now flows into roadside borrow pits and evaporates.

Frenchman Creek Project

This project in the Frenchman Creek Basin near Haxtun, Colorado sought to evaluate the artificial recharge benefits from the Great Plains Soil Conservation Program that provides funds for constructing ponds, pits, and broad-based terraces (5,6,7). The 1975-77 study by Colorado State University documented benefits near ponds and pits with an unsaturated zone beneath to store recharged water.

Several pits were dug that intercepted the regional ground water table or localized perched water tables. Benefits from these pits were questioned because of the increased evaporation loss during non-recharge periods. Neutron probes near broad-based terraces and in the non-terraced adjacent areas indicated that more water was recharged to the aquifer in the terraced areas.

The Great Plains Conservation Program appeared to reduce soil erosion in the upper Frenchman Creek watershed, and probably recharged more water to the underlying aquifer. There is reason to believe, however, that the recharge in western Phillips County used water which would have naturally recharged to the water table through Frenchman Creek flows. Some eastern Phillips County farmers claim they had been damaged. However, waters recharged in the western part of the county move down gradient to the east and are available for later withdrawals by eastern Phillips County farmers.

Central Great Plains Research Center Playa Lake Modification

In 1964 researchers from the Central Great Plains Experiment Station leveled a playa lake east of Akron to improve the farming potential of the area. This was done by cutting into the soil along the perimeter of the lake and using that soil as fill material on the lake bottom. Through this technique, the entire leveled surface became available for crop production. The water in excess of that required by the crop became recharged through the permeable soils uncovered by excavating the sides of the lake.

This project demonstrated the capability of increasing the amount of available land and recharging water previously lost through evaporation.

Southern High Plains

It is unknown whether or not aquifer recharge demonstration projects have been constructed in the Southern High Plains. Recharge to the Ogallala in this area could be achieved with practices demonstrated in the Northern High Plains. Recharging the confined Dakota and Cheyenne Sandstone aquifers could be done by using spreading basins or pits where the outcrops surface in western Baca or Las Animas counties. Otherwise, recharge wells would have to be used. Because of lower rainfalls in Baca County, there is limited water for recharge.

CHAPTER V

ARTIFICIAL RECHARGE ISSUES

Thousands of acre-feet of water are lost each year through evaporation and runoff that leave the state. Artificial recharge is one technique which can be used to capture this water and make it available for use in eastern Colorado.

Artificial recharge, however, should not be considered as a goal in itself. Rather, it is a tool that may be of value in achieving public goals. We need to ask not only: Can it be done?, but also: Is artificial recharge the best tool for each situation? Artificial recharge may save water that would otherwise be lost, but it may only change the location of recharge, or it may depend upon water that could be more effectively used for crop production directly through the use of conservation practices. We must also ask: Who benefits? Do the benefits justify the costs? Who should pay for recharge projects? These questions should be considered in developing a policy on artificial recharge. Two important issues, recharge vs. conservation and changing the location of recharge, are discussed below in more detail.

Recharge vs. Conservation

When the sod was broken in the High Plains, it was done with moldboard plows and one-way disc plows. As the sod decayed, infiltration rates declined and runoff and soil erosion increased. The one-way remained as the primary tillage tool for many years. As stubble mulch tillage systems came into widespread use, more of the precipitation infiltrated into the soil and less ran off. Now, the use of chemical fallow with little or no accompanying tillage is becoming a common practice. Conservation bench terraces almost eliminate runoff from some land. It appears that furrow damming, now a widely-used practice in the Texas High Plains, has considerable potential for water conservation in the grain sorghum growing areas of eastern Colorado.

Contour chiseling is being used on some rangeland to increase infiltration. Preliminary research results from non-irrigated cropland indicate that widely-spaced chiseling conserves water and increases yields when used with chemical fallow. Runoff has decreased as these practices have been put into use, and it can be expected to continue to decrease in the future. Therefore, whenever artificial recharge is considered, it should be determined that adequate water will be available for long enough to make it feasible.

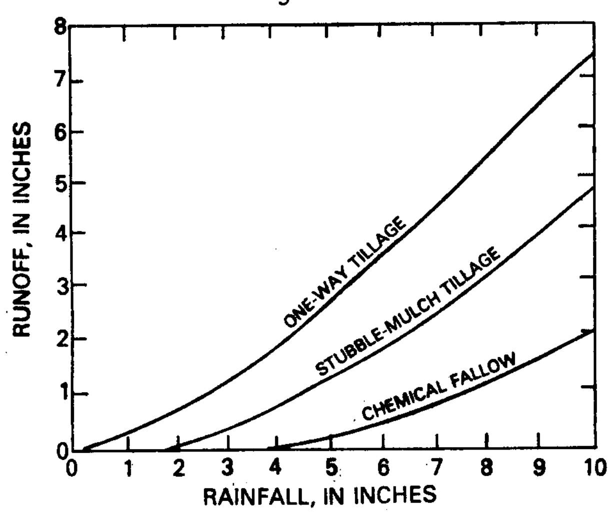
Figure 6 illustrates the effect of tillage methods on runoff. This figure provides some general relationships for a hypothetical, moderate-textured soil, assuming other conditions are similar to those encountered in the Northern High Plains. The graph shows that as more water conservation cultivation techniques are employed, increasing amounts of rainfall need to fall in order for runoff to occur.

If small recharge facilities were located very close to the source of run-off, recharge could start after only 0.1 inches of run-off has occurred. This graph shows that this would require only 0.6 inches of precipitation. This would be an average for the fallow and the crop years together. However, under stubble mulch tillage, two inches of rain would be required before 0.1 inches of run-off would occur. The bottom curve assumes farming systems in the future which might include the use of more terraces, chemical fallow and chiseling on the contour in chemical fallow. A four-inch rain would be required before any water would be available for recharge.

If recharge facilities were located farther from the water source--generally the case in Colorado's demonstration projects--about 0.75 inches of run-off would be needed before any water could be available for recharge. In this case, more than two inches of rain would be necessary to result in recharge under one-way tillage. It would take more than four inches of rain to produce recharge under stubble mulch tillage, and more than seven inches of rain to produce recharge under conditions that are likely to exist in the future.

Future farming practices are likely to make it uneconomical to construct some recharge facilities that could have been effective in the past. These cultivation changes, however, are desirable because they stabilize agriculture in the area and are likely to produce much more net income from the production of non-irrigated crops than would have resulted from the use of recharged water on irrigated crops. Therefore, rather than discouraging conservation tillage practices, it appears to be desirable to encourage such practices while making allowance for them in any economic analysis of potential artificial recharge. Artificial recharge facilities should be considered only for those areas where adequate water is likely to remain available.

Figure 6
Effect of Tillage Methods on Runoff



Changing Location of Recharge

Runoff from an upstream area is often recharged naturally at a downstream location. The most obvious examples of this process are found in Yuma and Washington counties, where streams originating in upstream hardlands end in downstream sandhill areas. Less obvious examples are found in locations where surface drainages cross permeable soils which recharge some or all of the stream flow. If upstream artificial recharge facilities were installed, the primary effect would be to change the location of recharge, thereby taking the water from a downstream user and giving it to an upstream user. This type of artificial recharge should be avoided, and projects should only be constructed where the water would otherwise be lost to the region.

CHAPTER VI

METHODOLOGY TO EVALUATE AQUIFER RECHARGE SITES

The selection of a successful site for artificial recharge depends upon a wide range of factors. The purpose of this chapter is to describe these factors and to list state and federal agencies that have information to help determine the suitability of each factor.

Ten criteria have been identified for evaluating potential recharge sites. Although the order in which the first five criteria are analyzed does not matter, each is essential for a successful recharge project (Figure 7). It is usually most efficient to begin with the factor that is most likely to be limiting. The following discussion describes each of the factors.

1. Physical Availability of Water. Water must be available in sufficient quantities if a recharge project is to be constructed. Neither the Northern nor Southern High Plains of Colorado has any continuously flowing streams that bring additional surface water into the basins. Both of these areas are topographic highs where streams flow out of the state across the eastern boundary. No streams flow into these regions.

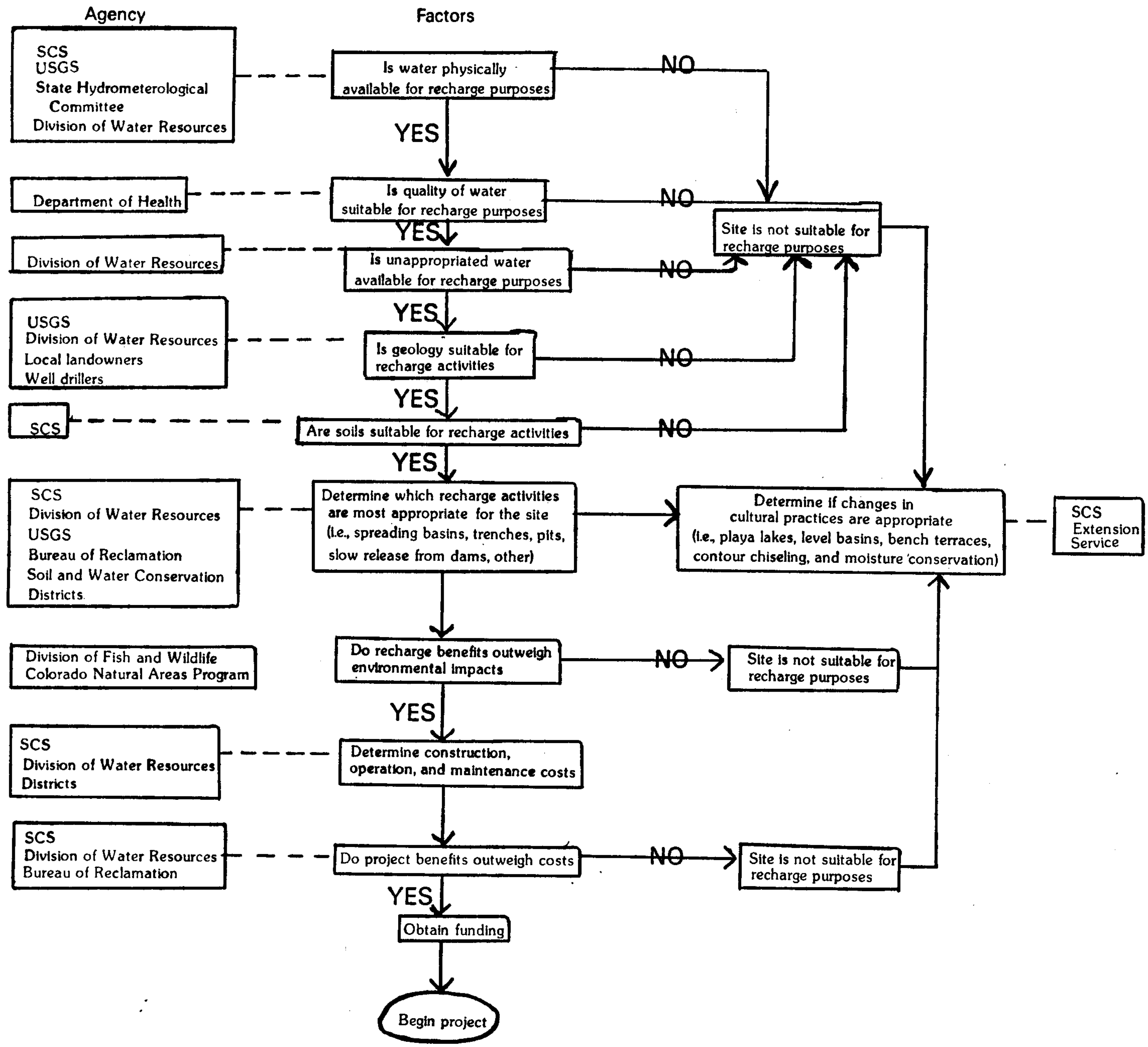
Because water flows out of the region, water rights must be considered before any projects are constructed. This is true for both ground water and surface water rights.

Precipitation varies greatly over Colorado's Ogallala region: the annual rate ranges from a low of 12 inches near Two Buttes to 18 inches near Fleming. A study by Reddell (13) indicates that the annual recharge may exceed two inches in the sandhill areas; but it may be near zero in some of the hardlands areas.

Precipitation in both the Northern and Southern High Plains is dominated by generalized rains between April and June or occurs as localized high-intensity summer thunderstorms. There may be some surface runoff from either type of rainfall. The surface runoff may accumulate and flow in the normally dry streams, or some of it may flow to small-to-medium sized playa lakes. Snowmelt on top of a frozen soil surface can result in significant flows in one year out of ten.

Runoff from thunderstorms generally will not occur unless the rainfall exceeds two inches in a single storm. Some storms have been known to drop three to six inches, and there are records of over 12 inches in a single 24-hour period. These high intensity storms usually result in severe erosion, localized runoff, and sediment-laden water. For localized storms, pits and terraces could recharge significant quantities of water.

Figure 7
Procedures for Identifying Recharge Sites



In order to evaluate the availability of water for recharge, it is necessary to:

a. Determine the availability (quantity, timing, location) of surface runoff. (Such information is necessary for the construction of basins, trenches, pits, and slow release from dams.)
b. Determine location of headwaters on lands of origin. (This water can be used for concentration basins, level pans, or borders.)
c. Determine location of playa lakes.
d. Determine location of sheet runoff that can be used in cultural practices.

The U.S. Soil Conservation Service is the best source of information for these four factors. The U.S. Geological Survey and the Colorado Division of Water Resources help determine the amount of water that would be available through existing water courses. A report is also available on the probability of various-sized rain storms for each week of the year (8).

2. Water Rights. It is necessary to determine if the proposed project will impair vested water rights. In order to avoid conflicts with other water recharge efforts and other water users, it is often best for the project to be carried out in the name of the local water district. The Colorado Division of Water Resources maintains records on water rights and can supply information.

3. Water Quality. It is necessary to determine that available water is free of toxic substances and that its quality is compatible with the water in the aquifer. It is often possible to design and operate recharge facilities that would remove bacteria from the water. The Water Quality Division in the Colorado Department of Health can help determine water quality.

4. Geology. Existing data from the U.S. Geological Survey should be used to determine the general geology of the region and to locate any restrictive clay lenses in the area. Well logs are important sources of geological information. Check with the Colorado Division of Water Resources, as well as local residents and well drillers with well logs of domestic or test holes. If adequate information does not exist, test holes must be drilled.

5. Soils Data. It must be determined if soils at proposed recharge sites have any characteristics that would restrict infiltration and percolation of recharge water. Soils characteristics are important in determining how much land a project may require for adequate recharge. For example, a recharge pond with tight soils would have to be so large that a project would not be feasible.

The U.S. Soil Conservation Service is the prime source of soils data.

6. Environmental Impacts. The use of water for recharge may adversely affect water fowl, or endangered plants and animals at that site. The Colorado Division of Fish and Wildlife and the Colorado Natural Areas Program of the Department of Natural Resources could assist in determining possible environmental impacts.

7. Types and Size of Recharge Activities. If the above factors all prove to be compatible with recharge activities, the type and size of recharge project to be constructed can then be determined. The sizing of artificial recharge structures depends upon watershed area, rainfall intensities, and recharge rates. In designing such structures, it is usually assumed that the water stored for recharge due to one rainfall event would be recharged before the next event. A particular location could go for several years without a recharge event as happened on the Arikaree River near Cope in 1963 and 1964.

Recharge due to snowmelt upon frozen ground is often regional in nature, and would require larger recharge facilities to capture all of the water. The frequency of runoff would be less, however.

The type and size of structure constructed will depend upon what is found when each of the previous factors are investigated. The following are examples of possible recharge structures:

a. Basins. Application primarily to larger water courses where high flows would likely make it impractical to construct permanent diversions. Low dams would be constructed across a water course to form a series of recharge basins. Sediment will settle out in upper basins and clearer water infiltrate in lower basins.

b. Trenches. Used where some or all of the water can be diverted from a water source. Trenches tend to be self-cleaning if properly designed.

c. Pits. Can be used without danger of washing out in floods.

d. Injection Wells. This technique can be very effective in areas where clay lenses may prohibit other types of recharge structures.

e. Slow Release from Dams. Dams with outlet tubes are constructed immediately upstream from permeable reaches of streambed. Slow release allows increased time for infiltration. This will often be more effective if water is released into trenches which have been dug into highly permeable material.

The U.S. Soil Conservation Service, U.S. Geological Survey, the Cooperative Extension Service, Colorado Division of Water Resources, and local water conservation districts all have information on the different types of recharge structures.

8. Cultural Practices. In some cases, physical or environmental parameters may prohibit the construction of recharge facilities. In such cases, changes in cultural practices should be investigated. These practices serve a dual purpose of storing water closer to the surface for use by plants, plus allowing excess water to recharge the aquifer. Some possible changes in cultural practices:

a. Playa Lakes. These depressions that collect water during periods of high precipitation can be pumped directly to supply crop needs or can be modified to allow recharge to the aquifer. In some cases it will be necessary to construct a recharge pit on one edge. After the basin is irrigated, the surplus water is released into the pit.

b. Level Basins or Borders. These areas can be flooded with the runoff from areas ranging up to several hundred acres. All surplus water can be used for recharge.

c. Bench Terraces. These structures collect runoff from sloping land above them. Recharge can occur during wet periods when runoff exceeds the soil moisture storage capacity. Deep tillage may be necessary to increase infiltration and percolation.

d. Contour Chiseling. Helps to intercept and infiltrate runoff.

e. Minimum Tillage. Conservation practices that involve mulch tillage and chemical fallow systems will increase the amount of recharge as well as the amount of water available for crop use.

f. Furrow Dikes. These have proven effective on cultivated cropland in significantly reducing runoff.

The U.S. Soil Conservation Service and the Cooperative Extension Service can provide useful information on appropriate cultural practices for water conservation purposes.

9. Operation and Maintenance. If structures are built for recharge, they should be maintained. Special operation and maintenance agreements should be prepared, indicating who will be responsible and who will pay. The U.S. Soil Conservation Service, Cooperative Extension Service, and local water conservation districts can help to determine the costs associated with operation and maintenance.

10. Benefits and Costs. A basic question to be asked is whether or not the value of recharged water in the aquifer is greater than the costs of planning, land acquisition, construction, operation, and maintenance of the recharge facilities.

Experience from recharge demonstrations indicates that the benefits are likely to exceed costs for favorable sites, but that estimates of benefits are subject to large errors. The reason is that estimates of available runoff have to be made on a probability basis with no way of predicting the timing of runoff events. When the level of uncertainty is high, both public and private investors are likely to require more favorable benefit-cost ratios than when benefits are more certain and continuous.

Because someone has to finance artificial recharge projects, another basic question is: Who benefits and who pays? The primary effects of any one recharge project are usually to a small area. One landowner or a small group of landowners may be willing to construct facilities from which they will receive most of the benefits. If several projects are to be built in an area, a larger group of landowners may be willing to finance the effort.

This private approach to recharge appears to have merit, but there are also good arguments in favor of public participation. If a groundwater management district or some other entity were involved, it could develop a coordinated plan that could make the best use of all of the runoff in the area. Also, public benefits justify county, state and federal involvement.

The extent of public involvement is a policy decision that should be made before artificial recharge activities begin. Otherwise, the options will be greatly limited by the construction of the first facilities.

It appears that policy should be established to encourage conservation in preference to artificial recharge and not encourage projects that would only change the location of recharge. Artificial recharge would then be considered only for those situations where the water would otherwise be lost. No opportunity costs would be associated with the water.

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