CONCEPTUAL STUDY OF POTENTIAL LARGE UNDERGROUND RESERVOIRS IN SOUTHERN IDAHO

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ABSTRACT

The purpose of the project was to study the concept of large underground reservoirs for use in Idaho. Four general categories of underground reservoirs were examined: 1) natural basins with artificial recharge, 2) natural underground caverns, 3) man-made underground reservoirs, and 4) reservoirs formed behind underground barriers. Man-made underground caverns have potential usage for special purpose storage reservoirs. Underground barriers could be used to control the ground water flow and to form large underground reservoirs in Idaho. The generalized benefits and environmental effects of an underground reservoir system were discussed.

The man-made underground barrier concept was examined further as to techniques of construction and analysis of the hydrologic effects. The effects of the barrier concept were computer modeled and presented. A finite difference program was used to examine the effects of various barrier configurations and parameters in idealized basins. A finite element steady state program was also used to examine the effects of and flow through a barrier cross-section for various parameters and configurations.

A site evaluation process was given with the basic siting considerations defined for an underground reservoir system with an underground barrier. The initial steps of the siting process were applied in a preliminary form to determine potential sites in Southern Idaho.

INTRODUCTION

This thesis is based on a project concerned with providing storage of unused flows of the Snake River in Southern Idaho. The present opposition to building surface reservoirs has made it imperative that alternatives for storage of water be studied. Developing large underground reservoirs offers a possibility that will aid in recharge of underground aquifers, aid in reduction of evaporation losses, raise water table elevations to reduce pumping lifts, reduce environmental impact on vegetation and wildlife, and offer less disturbance to the visual corridors along stream drainages.

The project was originally intended to be a three year study with the specific objectives:

1. To study the hydrology and water supply situation of the Snake River Basin which would be favorable to developing an underground reservoir.
2. To search for a favorable geological situation which would offer opportunity for building a dam or barrier within the earth to confine water in a known or defined zone of the upper portion of the earth's crust.
3. To study techniques necessary to construct an underground barrier or dam.
4. To study the impact of the development of an underground reservoir system on the environment.
5. To accumulate economic data that could be used in the decision of whether such an idea is feasible.

The research work completed and reported herein is based on one year of funding by an initiation grant from the Short Term Applied Research (STAR) program at the University of Idaho.

This study includes only the initial phase of the research on storing water underground. Primarily this report deals with the general concepts and how the idea may be further studied. The overall obejctive is to present the concept in sufficient detail that others may later consider underground reservoirs as an alternative method of storage. The basic objectives of this report are:

1. To study the basic conepts of storing water underground and to study whether these concepts have application in Idaho.
2. To define the general potential benefits and environmental impacts of an underground reservoir system.
3. To present how an underground barrier might be constructed and what types of effects on the ground water system might be expected.
4. To present a siting procedure that could be used to define and evaluate potential sites in Idaho.

Initally to accomplish these objectives various concepts of storing water underground were found in publications and from discussions with interested people. The concepts were grouped and analyzed for potential and for relative impacts. From the initial analysis the underground barrier concept appears to have the most potential for Idaho. The barrier concept was then further studied as to how it might be accomplished and to determine the impact on the ground water flow system. A series of computer models were developed to illustrate some of the effects of the barrier and to further present the barrier concept. A siting procedure was developed and presented as a guide to the location and evaluation of potential sites.

PRELIMINARY CONCEPTS

The basic concept of an underground reservoir involves an underground location where water is collected and stored for later use. To accomplish this requires being able to define or control where the water is and its availability for use. The key is man's ability to control and manage the water system to better utilize the water available.

Many underground reservoir concepts have been suggested by various sources duirng the study and have been found to fall into four general categories.

1. Natural basins with artificial recharge
2. Natural underground caverns
3. Man-made underground reservoirs
4. Reservoirs formed behind underground barriers

Each conceptual category has been examined in general for storage potential, means of supplying and removing the stored water, the reservoir's impact on the surrounding areas, and the possible beneficial uses.

Natural Basins With Artificial Recharge

Articial recharge of aquifers has been extensively studied and is being used in many places (Richter and Chun, 1959; Todd, 1959; Signor, Grawitz, and Kan, 1970). California has been the most active state in artificial recharge and this practice is incorporated into their state water plan. As early as 1958, 276 active artificial recharge projects were reported in California (Richter and Chun, 1959).

Artificial recharge projects may usually be classified by methods into the following groups: 1) basins, 2) pits and shafts, 3) ditches and furrows, 4) flooding, 5) induced recharge, 6) injection wells, 7) hydraulic connectors, and 8) modified stream beds. Additional and large scale artificial recharge systems will probably be developed in the future. An example is a study in Russia of dam sites earlier ruled infeasible because of high infiltration rates which now could be used to recharge declining ground water systems (Zajicek, 1967). With ever increasing demands on ground water, artificial recharge will be needed to supplement natural recharge and replace the natural recharge lost by man's modifications to the land surface. Information on the various forms of artificial recharge, factors relating to sections of sites, and the management of the systems can be found in various reports (Richter and Chun, 1959; Todd, 1965; Committee on Ground Water, 1972).

When artificial recharge is used in conjunction with surface and ground water resources the natural aquifers can become an effective transmission and storage system. Conjunctive use with and without artificial recharge has been studied in various areas and is being practiced in some areas (Buras, 1963 and 1972; Hall and Dracup, 1970; Committee on Ground Water, 1972).

In Idaho artificial recharge has been studied primarily in general considerations and in relation to the Snake Plain aquifer. Appendix A contains a list of references related to artificial recharge pertinent to Idaho including drainage wells and conjunctive use. The main studies of the Snake Plain include a reconnaissance-grade investigation by the U.S. Bureau of Reclamation (USBR, 1962), the results of recharge studies presented in the U.S. Geological Survey Open File report (Mundorff, 1962) and the results of a pilot project by the Idaho Department of Water Resources (Anderson, 1974). An interesting conjunctive use study of the Little Lost River System in Idaho has also been conducted (Saunders, 1967; Milligan, 1970). Since artificial recharge and conjunctive use have been explored and reported for parts of Idaho, no further investigation of this concept by itself will be done in this report.

Natural Underground Caverns

The concept of sealing a natural underground cavern and using it as a storage reservoir was examined. It would be possible to seal a cave using existing techniques with cement mixtures and plastic type paints. Most caves would require pumping water into and/or out of the cave. In caves of irregular shape and form, extensive vent and drain systems might be needed.

Information from an Idaho Bureau of Mines and Geology publication (Ross, 1969) was utilized to evaluate the possibilities of this concept in Southern Idaho. The publication shows the areas where major cave areas exist in Idaho and gives detailed information on some of the major caves. Several caves located near canal systems were evaluated and their relative storage capacities are given below:

1. Survey Point Cave--East of Bliss Point - several acre-foot

2. Kuna Cave--South of Kuna Butte - around ten acre-foot
3. Mammoth Cave--North of Shoshone - several hundred acre-foot.

Natural caverns could be possibly used for small underground reservoirs but would usually be limited to less than several hundred acre-foot of storage. Since the purpose of the study was to investigate large reservoirs this concept was not found to be feasible for the desired magnitude of storage.

Man-Made Underground Reservoirs

Man-made underground reservoirs can be made by excavating underground caverns. In Chicago, Illinois a system of deep underground tunnels and reservoirs has been started for overflows from the combined sanitary and storm sewers (Engineering News Record, 1974), an 80,000 acre-foot underground reservoir in the McCook area is planned and would be excavated in shales at a depth of 330 feet. It is planned to be 500 to 1200 feet wide and about 2½ miles long. It has been proposed to build 125 miles of tunnels which contribute significantly to the storage. The 18-foot 4-inch diameter portions of the 25,764 feet Lawrence Avenue pilot tunnel represents about 32 acre-foot of storage per mile and the proposed Phase I 20-foot diameter tunnels represent about 38 acre-foot of storage per mile. The excavation of this underground storage is costly and requires extensive grouting to minimize infiltration into the storage system.

The utilization of old mines as potential reservoirs has been suggested. Old mines which have volumes of 900 to 4,000 million gallons (2760 to 12,270 acre-foot) of potential storage have been studied in Britain (Cairney, 1973). Some of the problems in the utilization of the mines are interconnection (flooding of adjoining mines), mineral contamination (long term leaching and leaching of minerals oxidized when dry), potential land subsidence (weakening of mine structure by dewatering and refilling), means of filling, venting, and draining (water source, exit location, and pumping requirement), and mining methods (open pillar and stall or collapsing).

The idea of using a man-made underground reservoirs in conjuction with power generation by pumped storage has been written about several times. In 1960, a study was published of a proposed pumped storage project using an abandoned limestone mine with a 2300-foot drop (Harza, 1960). The early studies of the Chicago overflow system included a proposed 1,300,000 Kw (Kilowatts) pumped storage system utilizing a 700-foot deep tunnel 20 miles long and 30 feet by 60 feet in size (Engineering News Record, 1965). Pumped storage in the Chicago system is still being actively considered but no location or capacity has been determined (Engineering News Record, 1974).

Single purpose pumped storage facilities with a newly mined underground chamber have been also proposed (Sorensen, 1969). The plants could possibly be located near the power load center with minimal disruption of the surface environment. The siting would then be controlled more by geologic factors than by topographic factors. Most major load centers in the United States are located near large bodies of water with an adequate water source for the power generation units.

Power centers could be developed using combined nuclear and underground pumped storage units. The pumped storage would supply about 20 percent of power during peak demand periods and the nuclear plant supplying the other 80 percent as well as the dump power for the pumped storage during low demand periods (Engineering News Record, 1968a). Underground pumped storage using sea water also has been proposed near population centers. The 1968 cost estimates, including mining of the reservoir, range from $79 per Kw for 200,000 Kw to $58 per Kw for 800,000 Kw (Engineering News Record, 1968b).

Another method of man-made underground reservoir construction would be by underground explosion. A Geneva firm in 1968 estimated that a 10 kiloton explosion would create a vault of 2.8 million cubic feet (64 acre-foot) at a cost of about $1.5 million and that a 100 kiloton explosion would create a vault of 16 million cubic feet (367 acre-foot) at a cost of about $2 million (Engineering News Record, 1968a). The storage would normally be quite deep (high pumping requirements) and public acceptance would probably be hard to achieve.

Man-made underground reservoirs present some interesting possibilities but in general have a high cost either in construction or operation or both. The pumped storage schemes with an underground reservoir would probably have the most potential of the man-made underground caverns. Since the intent of the study is in the other forms of storage no further investigation of this concept will be undertaken in this report.

Reservoirs Formed Behind Underground Barriers

The storage of water behind an underground barrier would be similar to that of a surface reservoir behind a dam. The barrier could be used by only modifying the ground water flow or could be used in conjunction with the surface water flow system with artificial recharge. The barrier used could be a natural barrier such as a fault line or could be a man-made barrier like that of a grouting curtain below a dam. A schematic sketch of an underground reservoir formed behind a man-made barrier is shown in Figure 1.1.

Alluvial faults are being used in the storage and retention of ground water in Owens Valley in California (Williams, 1970). Alluvial fans in the valley are cut by numerous faults in a direction transverse to the ground water movement which retards the ground water flow. The fault gouge layer is a semipervious barrier which causes a water level differential across the fault. The faults in Owens Valley showed a correlation between the degree of semiperviousness and the age of the fault with the older faults having more gouge development.

The Owens Valley is part of the Los Angeles aqueduct system and the alluvial faults are utilized as storage dams. The alluvial fans are selectively recharged up gradient from prominent fault zones during runoff periods and then pumped immediately up gradient from the fault zones when surface

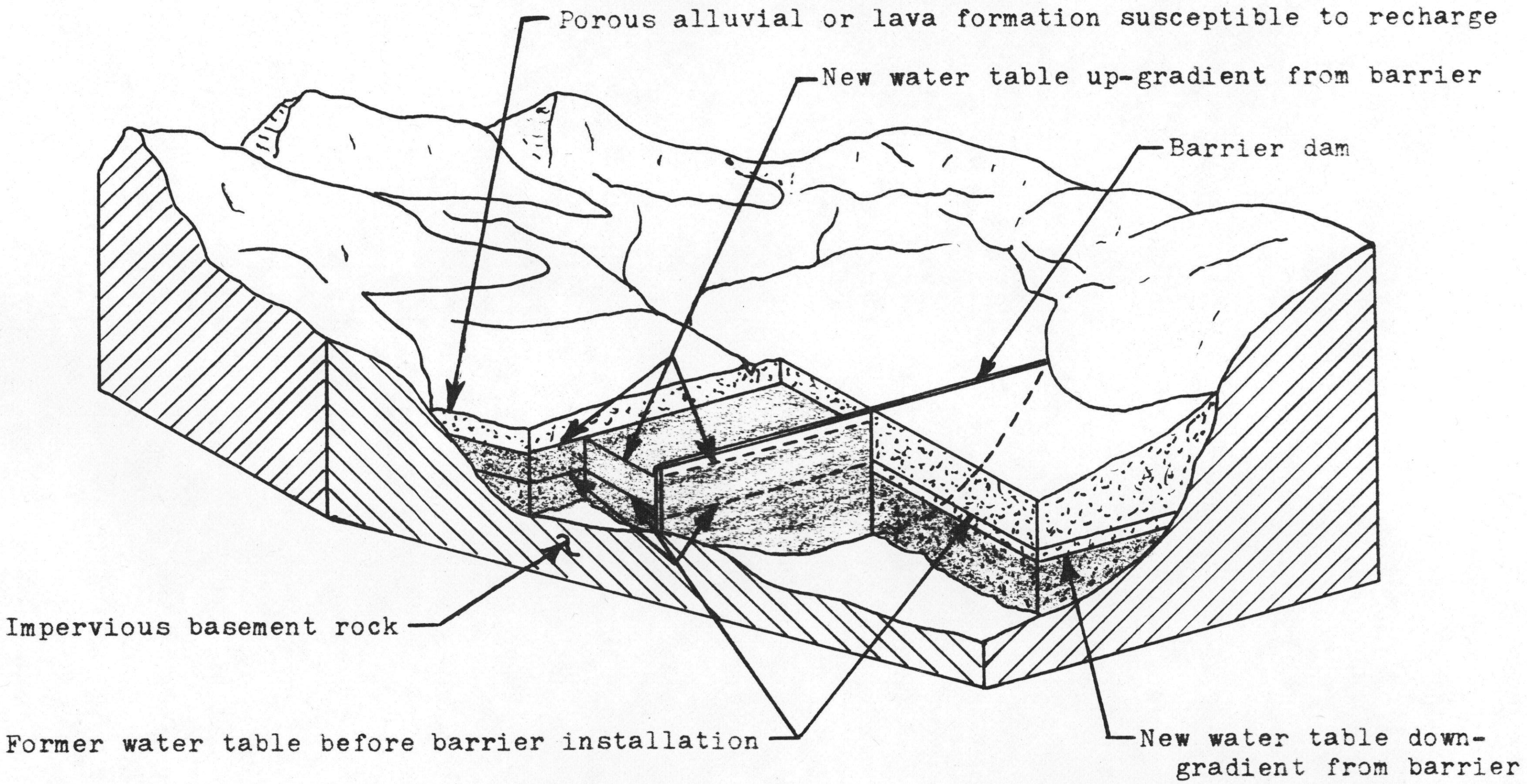


Figure 1.1 -- Oblique Schematic Sketch of Underground Water Reservoir

runoff cannot meet the demand. The theory of the flow through the faults and to the wells by the faults is given in an article by Dennis Williams in 1970.

An example of a natural barrier in Idaho can be seen in the Great Rift area which extends across the Snake Plain from the Craters of the Moon south southeast to the Bonanza Lake area. This geologic disturbance has resulted in a region of low permeability with a steep hydraulic gradient. This can be seen in a study of the Snake Plain by Joseph DeSonneville in 1974.

Man-made barriers can cause the same effects. Grouting curtains under dams are man-made barriers to reduce the ground water flow under the dam and it is proposed to use this type of barrier as an underground dam. These underground barriers could control the ground water flow and could be operated similar to a surface dam.

Several variations of the underground barrier concept have been suggested ranging from barriers completely across a valley to partial barriers and to barriers with off stream surface storage. The barriers might be constructed by various methods such as grouting, slurry trenches, frozen ground, and compressed air. This concept of man-made underground barriers will be explored further later in this report.

GENERALIZED EFFECTS OF AN UNDERGROUND RESERVOIR SYSTEM

An underground reservoir would have basically the same benefits as artifical recharge projects. The tangible benefits from artificial recharge have been classified in two general categories: 1) Relief of overdevelopment and 2) Conjunctive use (Richter and Chun, 1959; Todd, 1965). Another tangible benefit of the underground reservoir is the reduction of evaporation losses, especially in the semi-arid conditions of Southern Idaho. The intangible benefits of underground reservoirs over a surface reservoir system include providing a high degree of protection of the water supply and environmental advantages.

Relief of Overdevelopment

The underground reservoirs could be utilized to relieve an area of overdevelopment or to further develop the ground water resources without problems of overdraft of the aquifer. The following specific benefits can be made in counteracting overdevelopment (Richter and Chun, 1959; Todd, 1965):

1. Prevent dewatering of the underground aquifer.
2. Decrease operating costs by decreasing pumping lifts.
3. Prevent costs of increasing well depths or lowering pump bowls and well abandonment.
4. Increase farm income by new or augmented, dependable water supply.

5. Increase potential municipal and industrial use from augmented water supply.
6. Prevent land subsidence by sustaining water levels.
7. Prevent release of deep-seated connate brines into aquifer or preventing sea water intrusion into coastal aquifers.

Conjunctive Use

Conjunctive use of underground reservoirs with the ground water and surface water resources can be very attractive, particularly where there are no available suitable surface reservoir sites. The following benefits can be obtained with conjunctive use (Richter and Chun, 1959; Todd, 1965):

1. Increase usable water supply.
2. Cost savings in developing equivalent usable storage in a surface reservoir.
3. Cost savings in constructing peak requirement surface distribution and storage system sizes.
4. Reduce evapotranspiration losses.
5. Greater flood control as released surface storage for recharge reduces flood control reservation.
6. Reduce canal lining needs as canal seepage becomes a beneficial recharge.
7. Smaller drainage systems as underground reservoir and pumping controls water levels.
8. Improve power demand loads by integrating surface

water and ground water pumping to minimize pumping at peak periods therefore reducing power costs.

Several potential adverse effects should also be pointed out. In areas where new high water tables would exist (possibly near barrier or recharge sites) there could be loss of water to phreatophytes. New drainage systems could be required to relieve excessive high water table locations. Also the system could encroach upon the storage required to conserve local runoff when trying to regulate imported water.

Reduction of Evaporation Losses

One of the potential benefits of underground reservoirs is the reduction of evaporation losses. To gain an idea of the significance of what this reduction might amount to, several reservoirs were selected and analyzed as to the amount of lake evaporation. The analysis consisted of taking monthly mean pan evaporation data and average monthly reservoir surface areas and determining a yearly evaporation loss (IWRB, 1969). The results of the analysis are given in Table 2.1 below and the basic calculations are given in Appendix B.

Table 2.1: Annual Reservoir Evaporation For Selected Reservoirs in Southern Idaho

Reservoir	Capacity (acre-foot)	Evaporation (acre-foot)	Rate (Inch/year)
American Falls	1,700,000	131,500	37.02
Arrowrock	286,600	6,120	37.19
Lake Lowell	190,000	19,860	31.04
Lake Walcott	107,000	57,710	50.31
Palisades	1,402,000	36,710	34.06

The actual reduction of water saved using an underground reservoir would be hard to accurately determine depending on the area, size, and possible alternative storage methods. Some evaporation losses would still occur during recharging and the magnitude would depend on the recharge method. The evapotranspiration loss could be greater than the equivalent surface reservoir lake evaporation if high water conditions are created such that phreatophytes exist.

Protection of Water Supply

Ground water systems have a high degree of protection of the water supply (Richter, 1959; Todd, 1965). Ground water systems are much less susceptible to contamination than surface water systems and will filter and improve recharge water qualities. Ground water systems are also much less susceptible to disruption than surface systems. The characteristics of the ground water system and the dispersion of outlet facilities minimize the danger of destruction and disruptions that a dam failure, a severed aqueduct, an earthquake, a hurricane (typhoon), or nuclear warfare could bring about.

Environmental Effects

To evaluate the potential environmental effect of the underground reservoir concept it was decided to follow the "Guideline for Implementing Principles and Standards For Multiobjective Planning of Water Resources" by the U.S. Department of Interior for the Westwide study (USDI, 1972).

The guidelines are a result of a multiagency effort to establish a reasonably consistent set of ground rules for water resources planning for the federal agencies participating in the Westwide Study. The guidelines stem from the establishment of the "Principles and Standards for Planning Water and Related Land Resources" by the Water Resources Council (WRC, 1973) pursuant to Sec 103 of the Water Resources Planning Act (P.L. 89-80).

The following environmental analysis is of a very general nature evaluating a general concept where normally one would be discussing a specific site. The evaluation categories and the basis for the evaluation statements come from Chapter 4 in the guidelines above. Also a modified factor profile (Bishop, 1972) in Figure 2-1 is used to visually delineate the potential effects of an underground reservoir system and surface reservoir system for comparison as determined by the writer. The analysis uses a double scale back to back of adverse and beneficial effects in lieu of combining the effects which tend to balance out and hide the range and magnitude of the adverse and beneficial effects. The shaded portion of the bar graphs represents the expected effect for an average project while the open boxed portions represents the extremes of the expected effect for most projects considered reasonable for development. The analysis is a limited preliminary analysis and reflects the opinion and judgement of the writer only for the purpose of illustrating potential effects of the concept. The following evaluation discussion is limited to the main potential effects in each of the categories which may be caused by an underground reservoir system.

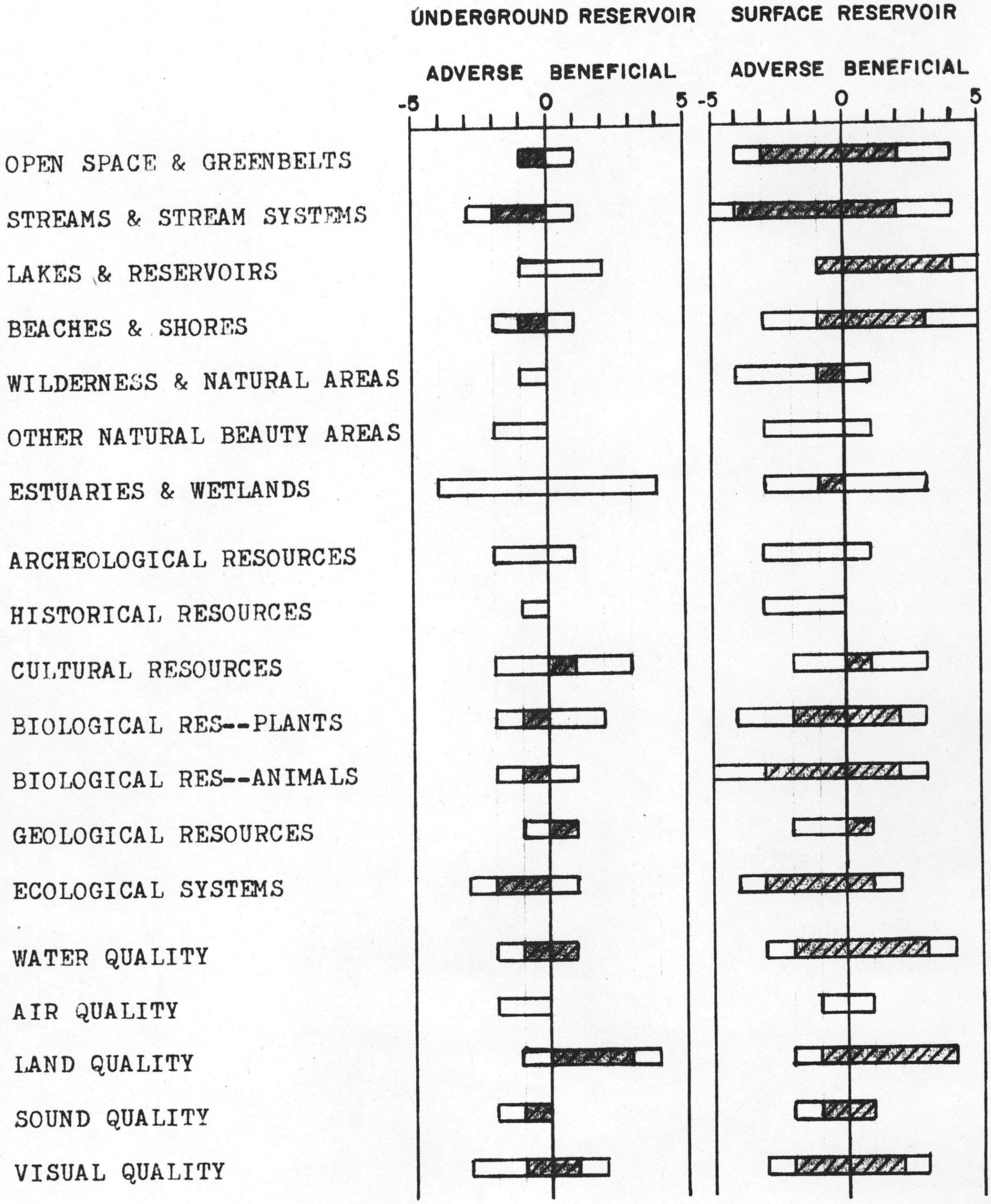


Figure 2.1 -- Relative Potential Environmental Effects of Underground Reservoir and Surface Reservoir Systems

In most cases an underground reservoir system would mean added development resulting in less open space. Green belts could result from developing recharge sites as parks and recreation areas along the streams. Green belts could also be formed around water recovery pumping plants and distribution systems or over the barrier site.

Stream systems can be affected in many ways but primarily from recharging operations. Artificial recharge operations would decrease the flow in the supplying stream which during some periods would be an adverse condition but at other times of high and flood flows would be very beneficial. In properly managed conjunctive use, stream flows could be greatly stabilized. The barrier and the change in water table could change the stream from gaining to losing or losing to gaining in relation to the ground water system and could also add stability to this relationship.

The effects on lakes and reservoirs should usually be minimal. A barrier downstream from a lake might decrease the seepage out of the lake or if upstream it could decrease the inflow into a lake or reservoir. The utilization of artificial recharge upstream of reservoirs and lakes would reduce water level fluctuations in the reservoirs and lakes. The main effects on beaches and shores would be from the changes in the lake levels and stream flows resulting from the barrier and recharge operations. The recharge sites would also modify the conditions around the stream but sites are often developed as parks and recreation areas.

Wilderness and primative areas would seldom be affected since there would normally be little justification in such areas for a reservoir. In most cases estuaries would not be affected unless the flows into an estuary were significantly reduced. Wetlands could be greatly affected or created by underground barriers. If the barrier causes the water table to rise to the surface, marshy wetland areas could be created. Also a barrier could be placed upstream from wetlands to catch and utilize the water therefore draining the downstream wetlands. Underground reservoir systems would normally have little impact on natural beauty areas which have special aesthetic appeal such as waterfalls and steep canyons.

Archeological and historical resources should not be directly affected except where construction of the barrier itself might disrupt a site. As in any large construction there is the possibility in the site investigations and during the construction of facilities that some archeological or historical sites might be found.

The cultural effect caused by underground reservoirs would usually be in perpetuating or expanding the existing life style in a region. The cultural change should usually reinforce the existing life style but in cases it could involve changing an area from a grazing to farming type of situation.

The biological resources in area would most likely be a change from the natural habitat to a developed habitat. In most areas the natural resources would be displaced with different and in some cases improved biological forms. With recharging and conjunctive use it could be possible to enhance base flows of streams, increasing minimum flows, and stabilizing stream flows which would normally be beneficial to biological resources.

The geological resources will be affected by the addition of the barrier and the raised water tables. The construction of the barrier will change the geologic conditions at that location and the raised water table behind the barrier might flood potential mining or other geological resources. A beneficial effect would come from the increased knowledge of the geological resources which would result from the investigation and construction of the barrier.

Some ecological systems would be disturbed by the added developed area and lower stream flows. The project (such as supplemental irrigation) could also stabilize the ecological systems in an area tending to balance and enrich the general quality in the case of marginal systems.

The water quality of the ground water aquifer will be affected by the recharge waters but by the filtering process passing through the soil will usually improve the recharge water quality. The waters withdrawn therefore will normally be of a better quality than the streams but there may be leaching of minerals causing higher mineral concentrations. The overall effect on the surface water quality should be beneficial with the water discharged from the aquifer normally being better than the recharge water added.

The air quality should not be significantly affected although with added development some adverse effects might be caused. Land quality normally should be improved by the addition of water since land suited for development can be better utilized. The sound quality would be affected mainly during the construction period and afterwards there should be little change except from added development. The visual quality of the land would be changed by the added development which could be of beneficial or adverse effect depending on the original setting. Some permanent adverse visual effect in the area of barrier construction might be caused by methods of construction while some beneficial effects might be made if recharge sites were developed as green belts and recreation areas.

In most cases the environmental uniqueness considerations impact should be minimal with good planning. For irreversibility considerations, the barrier would cause permanent changes in the ground water flow system which would likely never be restored even if desired.

UNDERGROUND BARRIER ANALYSIS

A man-made barrier was determined to be potentially the best concept for further study. The concept is used in a limited way in conjunction with many present surface reservoirs in the form of curtain walls to reduce the underflow beneath the dam. The proposed idea is to install barriers to control and modify the ground water flow in the aquifer to better utilize the ground water resources. The following barrier forms have been suggested and reviewed:

1) Barrier across entire width of a basin
2) Barrier across only part of the width of the basin
3) Barrier of only part of the depth of the aquifer
4) Wedge shaped barrier in basin
5) Barrier in conjunction with an offstream surface storage reservoir.

The initial questions which come up are how would one construct a barrier, what would control siting of a barrier, and how would a barrier affect the ground water flow. This section examines the construction of a barrier, the basic hydrogeologic parameters, and the effects of different types of barriers on the ground water flow system.

Techniques For Barrier Construction

Construction of an underground barrier requires replacing the aquifer material with a less permeable material or modifying the aquifer material such that it becomes less permeable. The aquifer material can be replaced as is done in dam and building construction with cutoff trenches or slurry trenches and walls. The means of modifying the aquifer material permeability include grouting methods, ground freezing, and compressed air injection.

Cutoff trenches, both open and slurry, have been utilized in construction of dams underlain by alluvium (Sherard, 1963; Cedergen, 1967; USBR, 1973). Open trenches require complete excavation of parent material down to the desired depth which economically limits their use to relative shallow depths. Another major construction problem is that open trenches require dewatering the area during construction. These constraints would probably rule out this method in most cases.

Slurry trenches have been gaining in use in the control of ground water flow and work well below the ground water levels. A vertical sided trench is excavated with a slurry mixture (usually a water-bentonite mixture) pumped in to support the trench opening. Backfill material or concrete mixtures are later placed through the slurry to the bottom displacing the slurry upward (Cedergen, 1967; USBR, 1973). Slurry walls and trenches have been installed in many places and the state of the art is increasing such that walls up to 400 feet in depth have been constructed (Clough, 1974). One of the first slurry walls used with a permanent dam was constructed under Wanapum Dam to a depth of 80 feet (Sherard, 1963). The parent material (sands, gravels, and cobbles) had an average hydraulic conductivity of about 1,000,000 feet/year while the 10 feet wide slurry cutoff material was estimated to have a hydraulic conductivity of 0.1 feet/year.

A sheet pile cutoff wall is a method in which the parent aquifer material is not removed or replaced but merely blocked by steel sheeting. This type of cutoff wall is suited for stratified soils with high horizontal and low vertical permeabilities. The steel sheeting must be carefully driven to minimize leakage through the interlocks. The sheeting can be easily damaged by boulders or buried obstructions and has a tendency to wander and break at the interlocks. This method is found to be expensive, the sheeting often leaks at the interlocks, and it is difficult to get good contact to form a seal between the bottom of the sheet piling and the impervious foundation material (Cedergen, 1967; USBR, 1973).

The most common method of modifying the permeability of the parent aquifer material is by grouting. The permeability of the parent material can be substantially reduced by the means of injecting a material which will act as a binder and filler. Common grouting materials are cement, clays, asphalt, various chemicals, and various combinations of these. Cements are limited to coarse materials due to large particle size of the cement mixture. Clays are easily carried away by seepage forces. Asphalt can work well under conditions where other grouts are carried away by the seepage forces. Chemical grouts can be injected into any soil in which water can move but are expensive. The range of applicability of common grout materials in relation to the size of the parent aquifer material is given in Figure 3.1. The selection of the proper grout is very dependent on the aquifer conditions and materials. The interested reader should

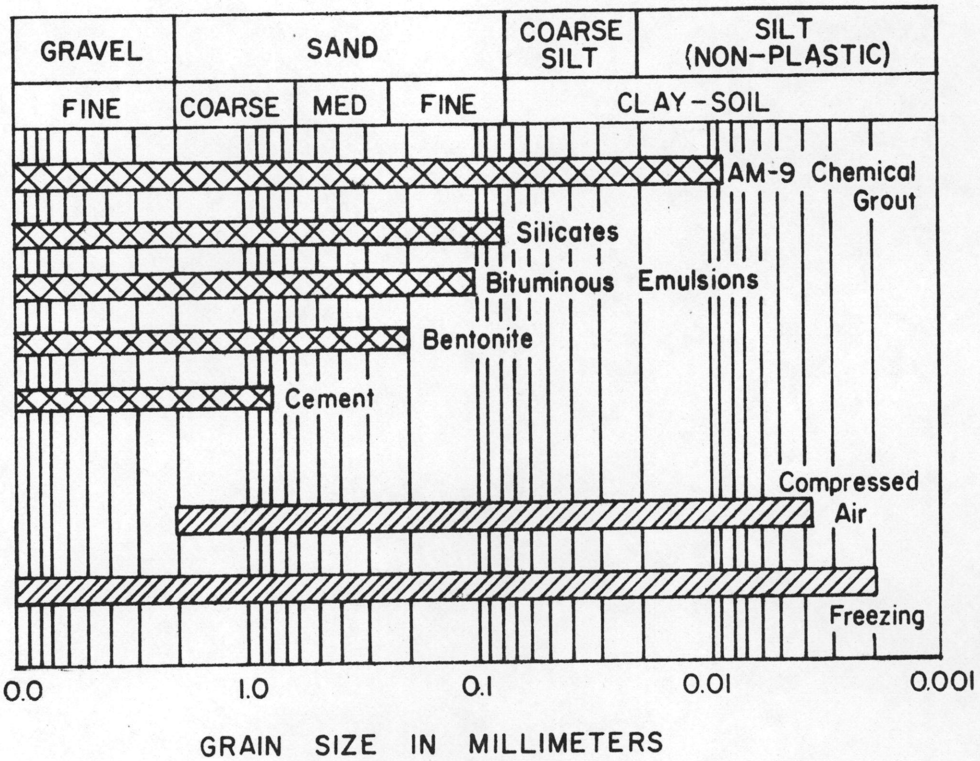


Figure 3.1 -- Applicability of Potential Barrier Materials In Respect To Size of Aquifer Material (Cedergen, 1967; American Cynamid Co., 1965)

review the information in the various references on grouting (Asphalt Institute, 1961; Sherard, 1963; American Cyanamid, 1965; Cedergen, 1967; USBR, 1973).

One of the more successful methods of grouting in alluvial material has been the "Soletanche" method using various clay and cement mixtures. The method was used to grout alluvium over 300 feet in depth for a width of about 50 feet under the Serre-Poncon Dam in the French Alps (Sherard, 1963). The alluvium was estimated to have a hydraulic conductivity of 50,000 to 100,000 feet/year which was reduced by the grouting to approximately 50 to 100 feet/year. The same French contracting firm later grouted alluvial deposits to a maximum depth of 523 feet under Mission Dam in British Columbia.

Two additional methods of controlling ground water flow used in construction are ground freezing and compressed air. In ground freezing, the water in the soil is frozen by refrigeration techniques therefore creating a solid impermeable mass of frozen soil. Ground freezing can be very effective but is very expensive for the large scale being considered in this study. A paper by Sanger in 1968 describes the basic parameters and design principles of ground freezing.

The use of air to influence ground water flow and to act a as barrier was described by Roberts in 1967. The permeability of the parent aquifer material can be reduced by the presence of the air in the intergranular spaces. The range of these two methods in relation to the parent aquifer material size is also given in Figure 3.1. Both ground freezing and air injection would be expensive but for initial pilot studies these methods might be considered because they are much more reversible (non-permanent) than the other methods given.

Methods of Analyzing Hydrologic Effects

In examining an underground barrier a main concern is how the barrier will affect the subsurface hydrologic conditions. The effect is controlled by the ground water properties of hydraulic gradient and the saturated depth, the parent aquifer permeability and storage coefficient, and the barrier width, depth, and permeability.

Darcy's Law, a basic ground water flow equation, is given in a steady state form in equation 3-1,

$$Q = KA \frac{dh}{dL} \qquad (3\text{-}1)$$

where Q is the discharge (flow), K is the hydraulic conductivity, A is the cross sectional area, and dh/dL is the hydraulic gradient. In examining a flow system without and with a barrier, for a given Q it is found in the area of the barrier the hydraulic gradient and/or the area (saturated depth) must change. Given in Figure 3.2 is a simplified two dimensional example of the barrier effect where the hydraulic gradient increases approximately inversely with the change in permeability (assuming the depth is large and the area does not significantly change). The resulting water table rise would then be the change in hydraulic gradient times the length (thickness) of the barrier.

The storage coefficient is important because it is a

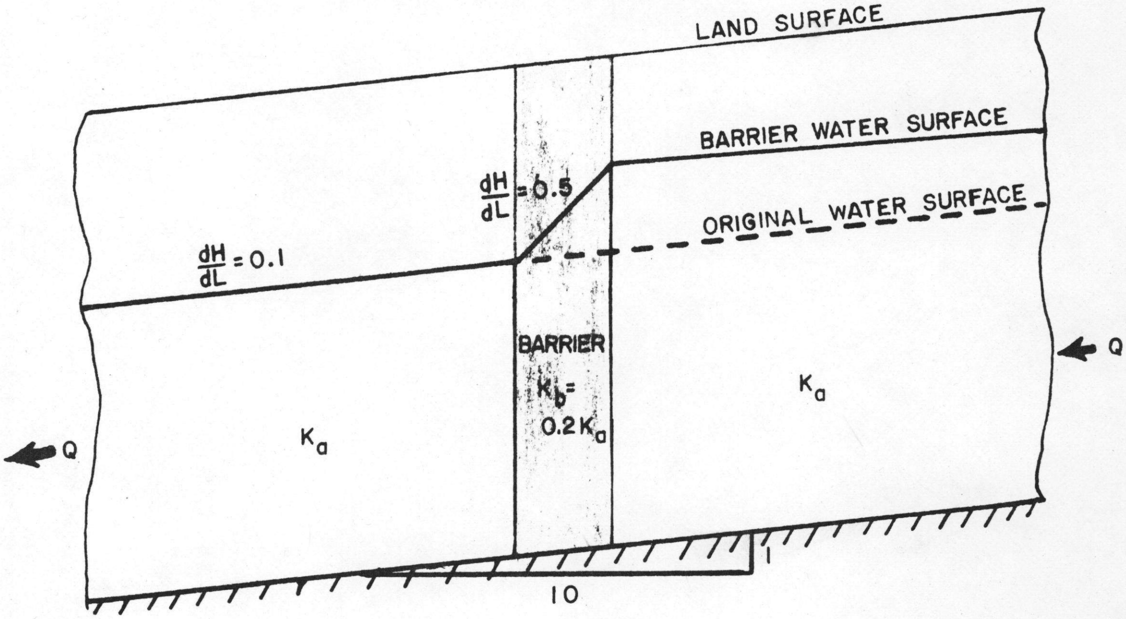


Figure 3.2 -- Simplified Example of the Barrier Effect

measurement of the storage capability and an important factor in unsteady flow which controls the length of time it takes a system to reach steady state conditions. Typical storage coefficient values for various aquifer materials can be found in most ground water references and textbooks (Todd, 1959b; Davis and DeWiest, 1966).

In an actual system the analysis of a barrier can become very complicated with variations in permeability, cross sectional areas, hydraulic gradients, boundary conditions and the three dimensional effects. Several methods are available which can be used to analyze various barrier parameters. The methods include analytic solutions of the partial differential equations of flow, approximate solutions of the equations based on limiting assumptions, flow net analysis, electrical analog simulation, viscous fluid modeling, and numerical analysis solutions (Todd, 1959b; Davis and DeWiest, 1966). Solutions of the partial differential equations become very complicated even for limited analysis as is shown in a paper on the flow around sheet piles (Reddy, Mishra, and Seetharamiah, 1971). Flow net analysis is relatively simple for a single permeability and two dimensional analysis (Cedergen, 1967). Electrical analog methods are a means of solving the partial differential equations and have been used to model ground water systems including potential artificial recharge effects on the Snake Plain in Idaho (Norvitch, Thomas, and Madison, 1969). Viscuous fluid modeling is limited and complicated but has been used in modeling impermeable walls (Matsuo and Kono, 1970). Numerical analysis methods which give approximate solutions to the partial differential equation have been computerized. This method was selected in this study to analyze various barrier parameters because of availability and flexibility of several computer programs.

Two different types of ground water computer programs were selected to model various barrier parameters. One is an unsteady state finite difference program to model the effects of the barrier on a ground water basin. The second is a steady state finite element program to study the flow through the barrier cross section.

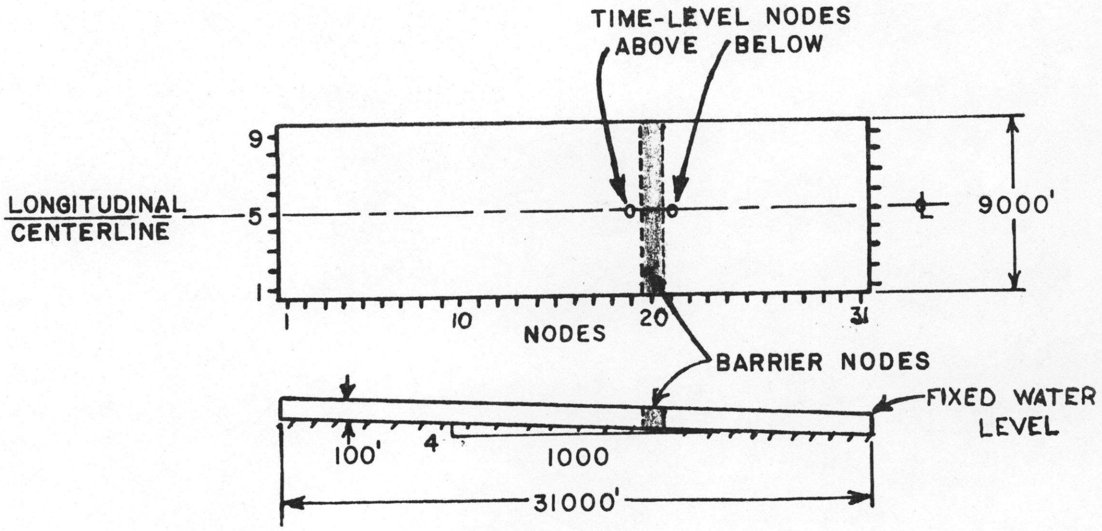
The finite difference program used was developed by the Illinois State Water Survey to simulate non-steady flow of ground water (Prickett and Lonnquist, 1971). The version used in this study was the composite aquifer simulation program with various printout options added. The program can handle heterogeneous aquifers, water table, nonleaky and leaky aquifer conditions, time varying pumping, natural and artificial recharge, and water exchange between surface and ground water systems (springs and stream leakage). For details of the computer program, including theory, use, and program listing, see the Illinois State Water Survey Bulletin 55 (Prickett and Lonnquist, 1971).

The finite element program is one developed by R.L. Taylor at the University of California, Berkeley which is used by the U.S. Bureau of Mines (Kealy and Busch, 1971). The program can handle two dimensional confined and water table flow conditions and uses an iterative technique to locate the steady state phreatic surface for free surface points. The cross section is input as a mesh configuration defining the geometry of the problem, the boundary conditions, flow inputs or outputs, and permeability characteristics. For details of the program, including theory, use, and program listing, see the U.S. Bureau of Mines Report of Investigations 7477 (Kealy and Busch, 1971).

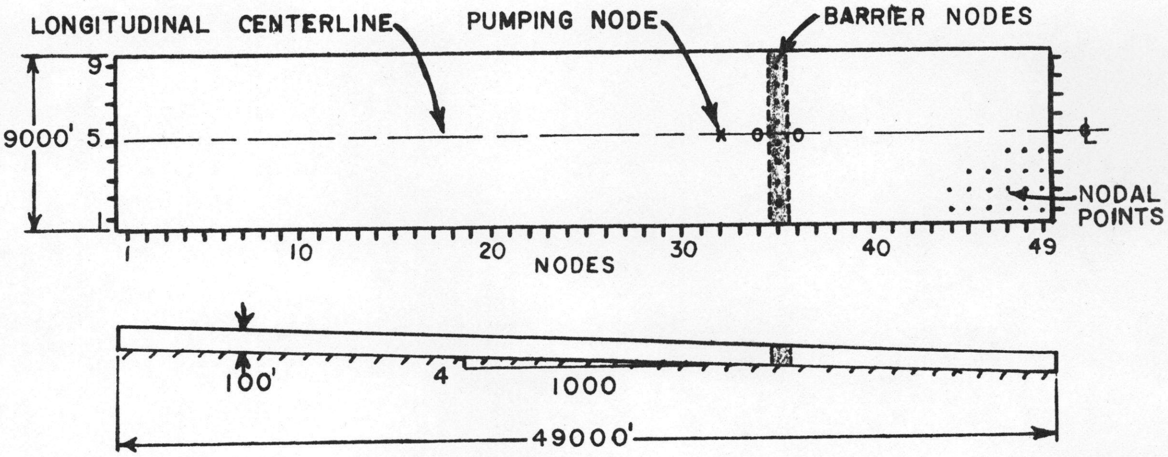
Results of Some Barrier Modeling

The finite difference program enables one to study the effects and time relationship of a barrier in a basin. Two basic models were used with the main difference being the basin length (Figure 3.3). An idealized rectangular basin was constructed based upon information gathered from reported hydrogeologic properties of alluvial valleys around the Snake Plain. The basic aquifer properties used in the modeling were a coefficient of permeability of 1,000 gallons per day per square foot, a storage coefficient of 0.2, and a hydraulic gradient of 4 feet per 1,000 feet (21.1 feet per mile). The saturated depth of 100 feet and the width and lengths were picked for convenience and program size limitations. The assumed boundary conditions included a constant flow input at the upstream end and a constant water level at the downstream end of the basin. The barriers penetrate the entire saturated depth of the aquifer. The "basic" effective permeability for the barrier nodes used were 1/10 of the parent aquifer permeability. The output from the computer models in the following finite difference series are expressed in the change of water levels from the original

Short Basin Configuration



Long Basin Configuration



Basic Aquifer Properties: Permeability = 1000 gpd/ft^2
Storage Coefficient = 0.2

Basic Barrier Properties: Permeability = 100 gpd/ft^2
Storage Coefficient = 0.2

Figure 3.3 -- Basic Finite Difference Model Basins

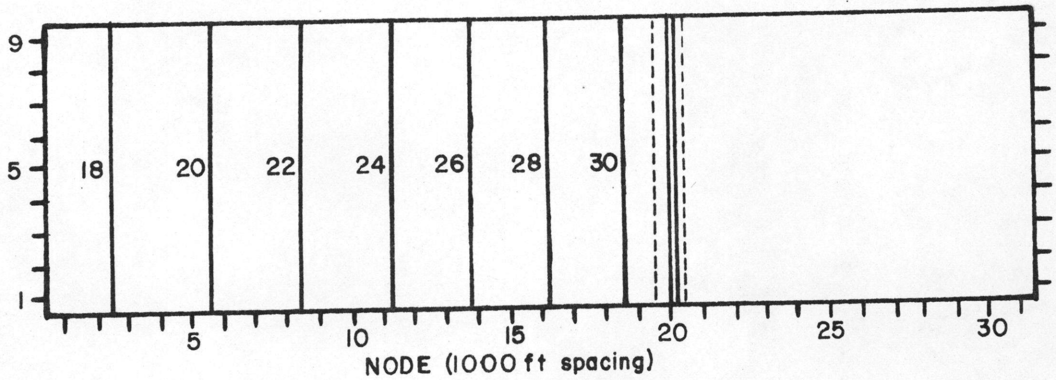
basin without any changes, and when the basin has approximately reached a new steady state condition.

The first series of computer models shown in Figure 3.4 gives the basic ground water level change resulting from various barrier configuration forms. The permeability values of the barrier nodes in this series were the basic 1/10 of the parent aquifer permeability. The results illustrate that the configuration of the barrier in the basin as well as barrier length control the change in water levels.

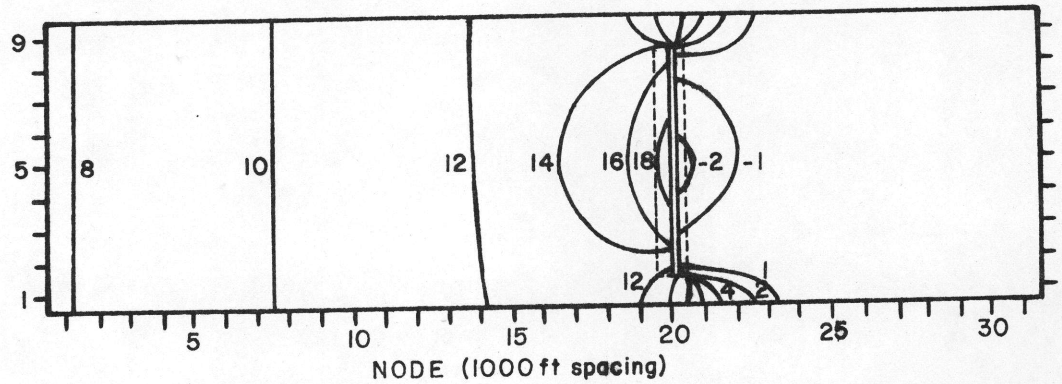
The objective of the second series of model operations was the comparison of different barrier nodal permeability values with a complete barrier across the basin. Figure 3.5 shows the basin longitudinal changes in water levels resulting from the different complete barrier permeability values. The water level changes increase behind the barrier as the barrier permeability decreases in relation to the parent aquifer permeability. Figure 3.6 shows the time-level graphs for the center nodes that are located one above and below the barrier. The node above the barrier illustrates the water level rise until steady state is achieved. The node below the barrier shows the downstream effect with the magnitude of the effect increasing as the barrier permeability decreases. The time it takes for the maximum effect increases as the barrier permeability decreases.

A comparison model showing the effect of a fifty percent reduction (0.2 to 0.1) in storage coefficient is shown in Figure 3.7. The major effect of this change is the decrease in time to

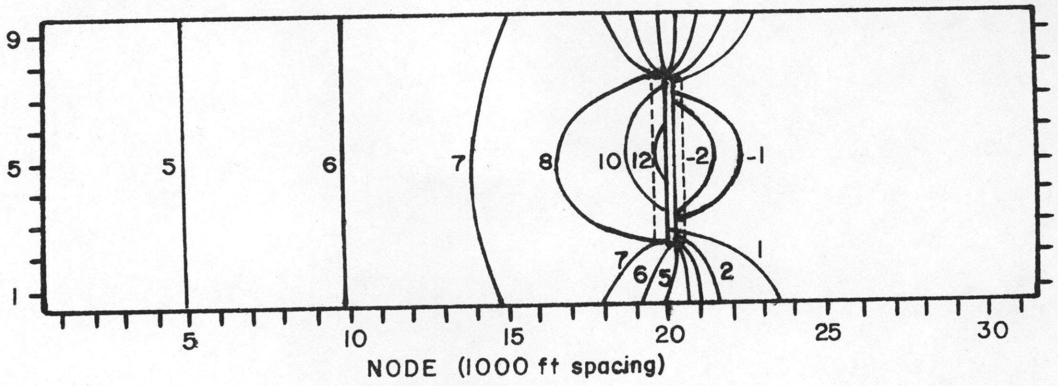
Basic Complete Barrier



Barrier With Both Sides Open (1 Node)



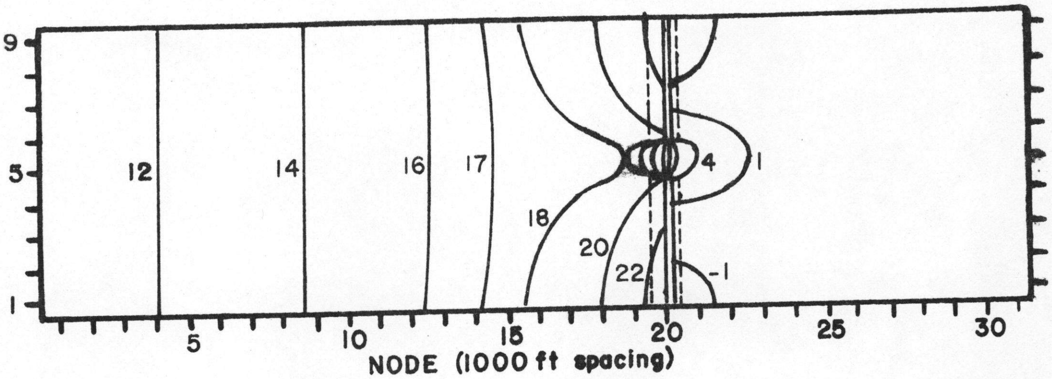
Barrier With Both Sides Open (2 Nodes)



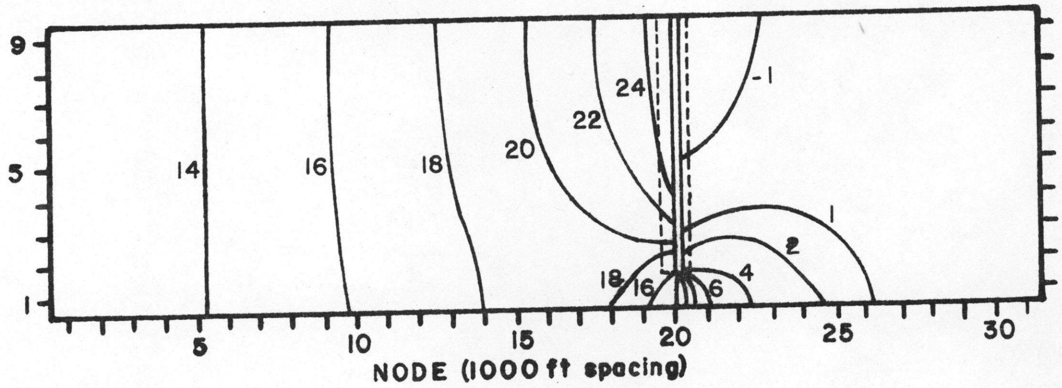
Contours given in feet of change from original levels after 84 years.

Figure 3.4 -- Water Level Change Contours For Various Barrier Configurations

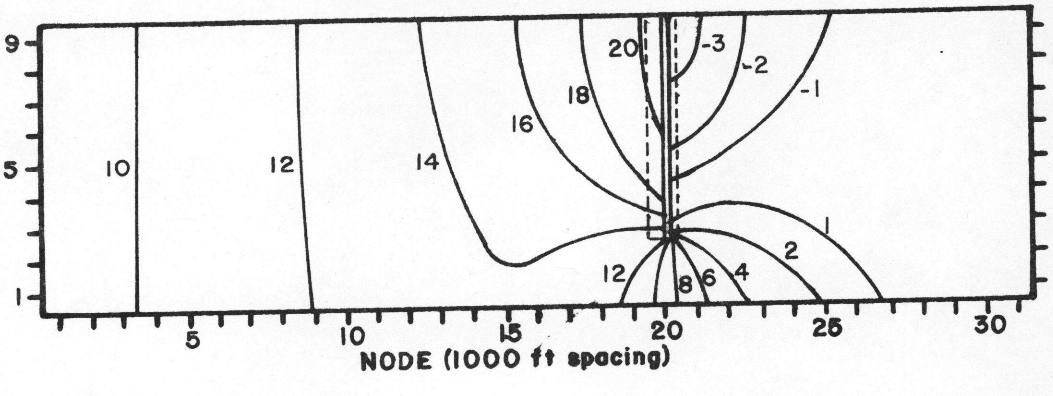
Barrier With Center Node Open



Barrier With One Side Open (1 Node)



Barrier With One Side Open (2 Nodes)



Contours given in feet of change from original levels after 84 years.

Figure 3.4 (Cont) -- Water Level Change Contours For Various Barrier Configurations

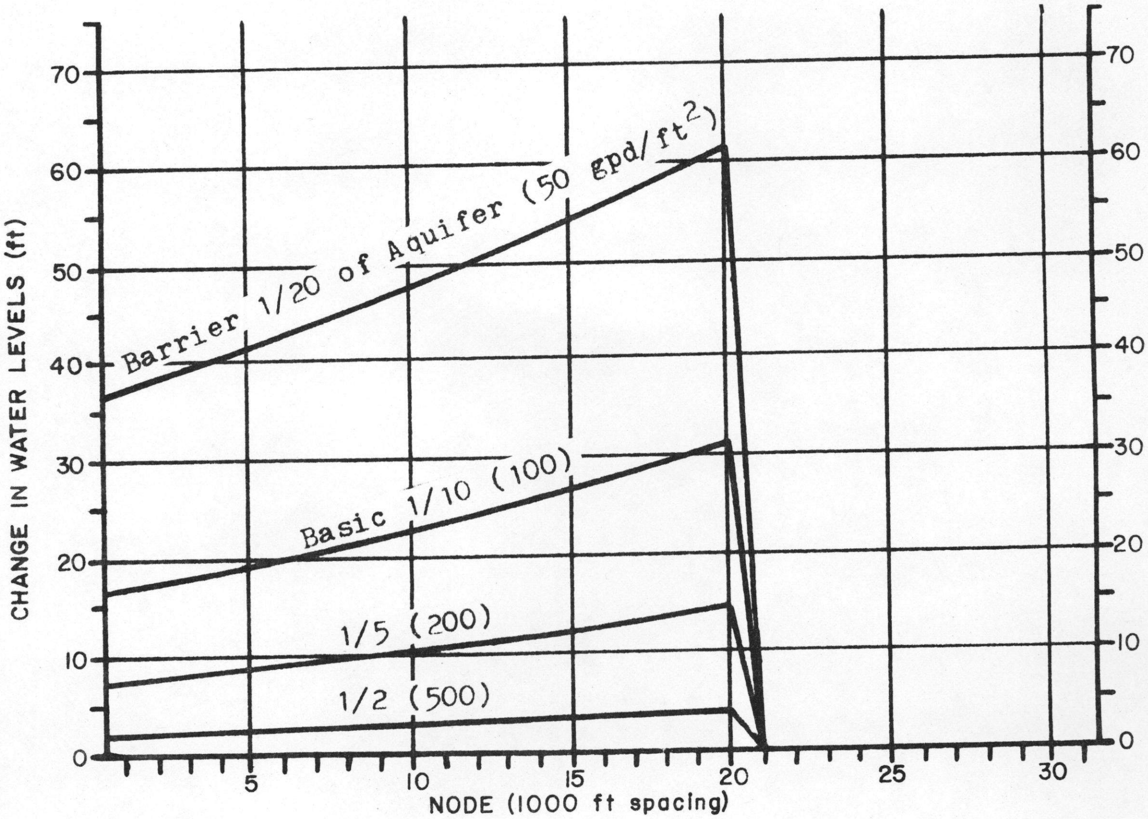


Figure 3.5 -- Basin Longitudinal Centerline Change in Water Levels for Complete Barrier With Different Barrier Permeabilities

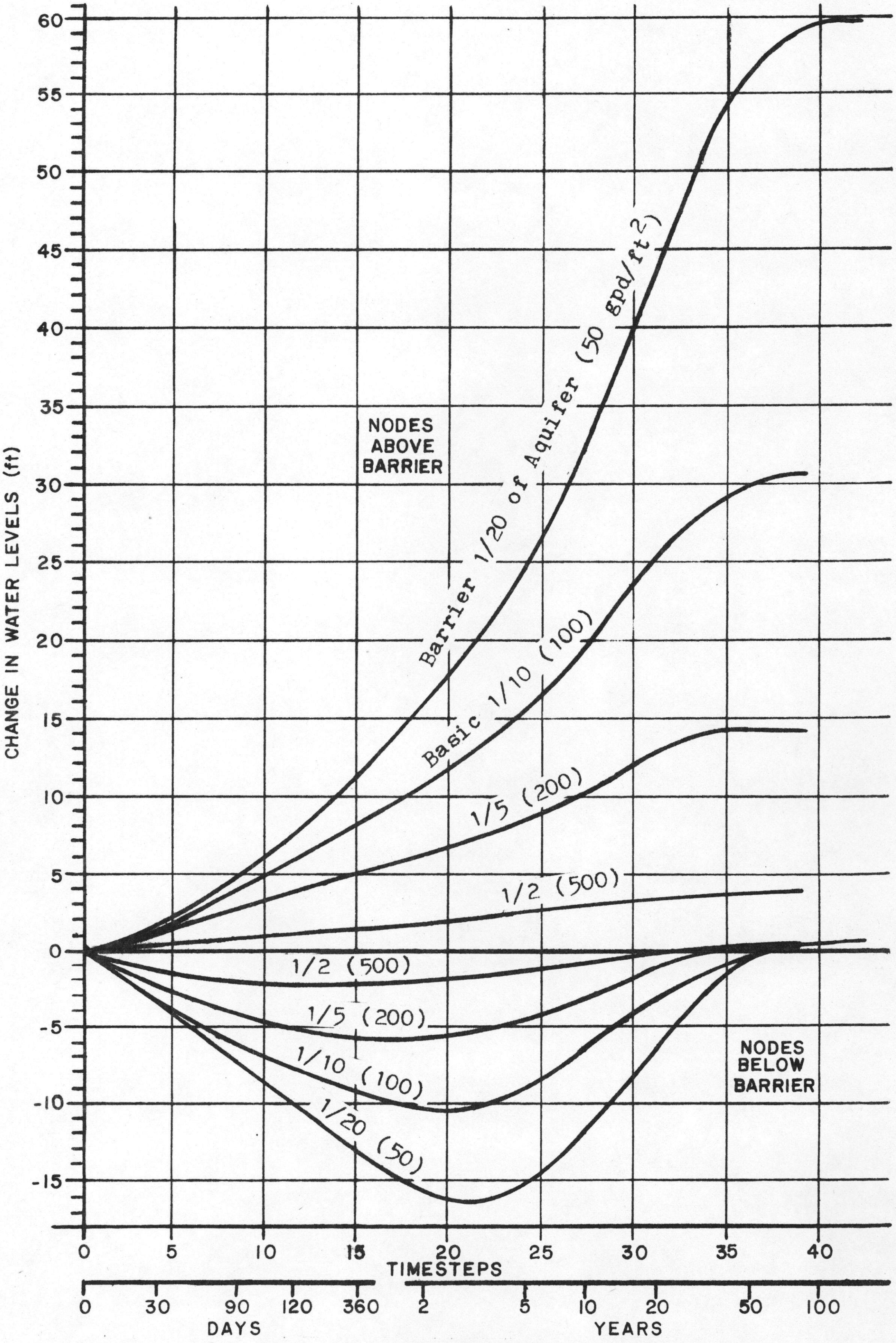


Figure 3.6 -- Time-Level Graphs For Complete Barrier With Different Barrier Permeabilities

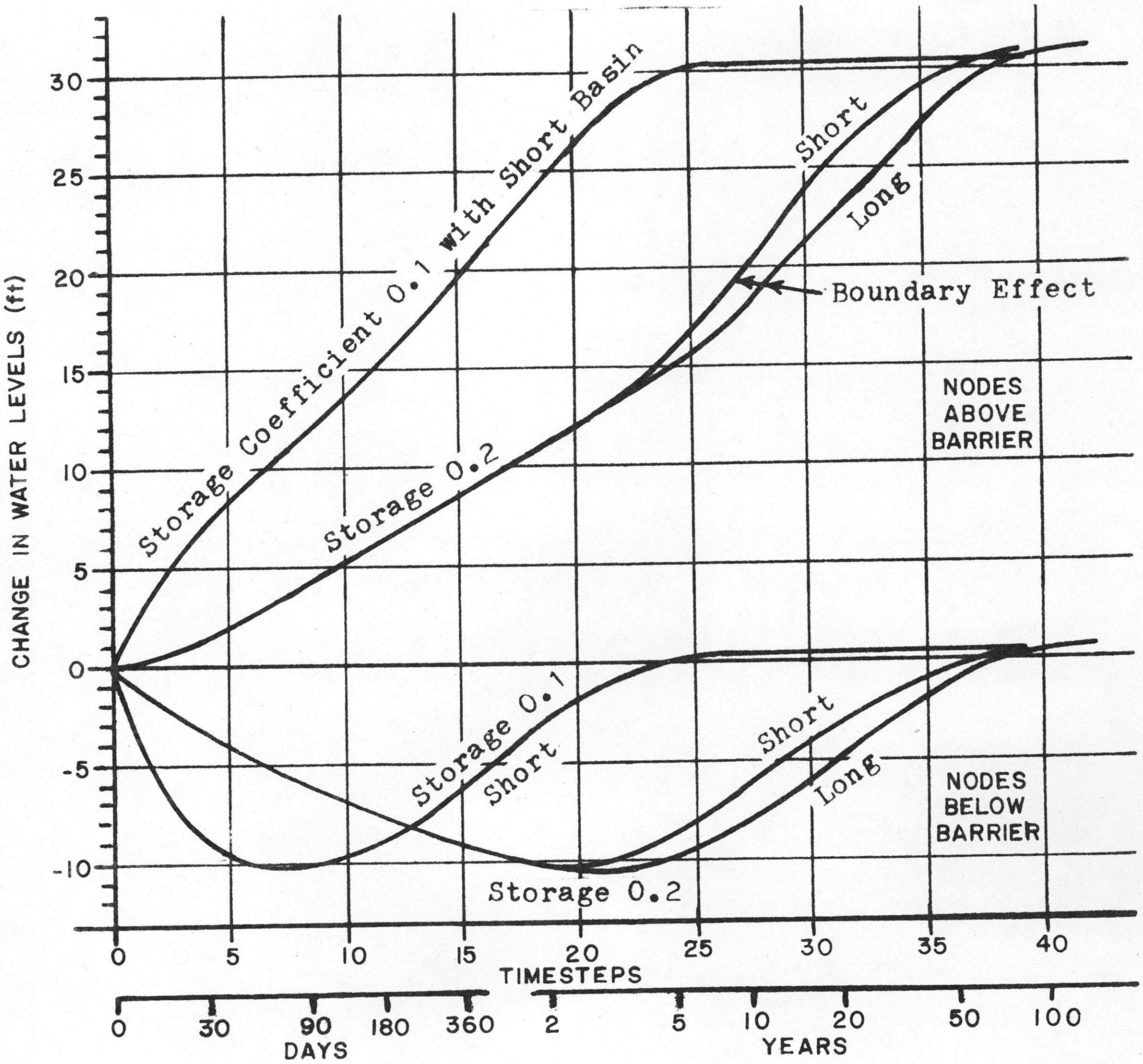


Figure 3.7 -- Time-Level Graphs For Complete Barrier With Different Storage Coefficients And Different Size Basins

reach steady state which would be expected since only half as much water would go into storage. Also in the figure an upstream boundary effect is shown by the results of the short and long basin configurations. When the upstream effect reaches the upper boundary, the amount of water storage required per unit of water level change behind the barrier becomes less than without the boundary effect. Therefore the short configuration water levels start rising faster than the long configuration water levels when the boundary effect starts, as seen in Figure 3.7.

The next series of computer models varied the slope of basin while the flows were kept constant (the saturated depth changed). The time-level graphs for the center nodes that are located one above and below the complete basic barrier are shown in Figure 3.8. The graphs show that magnitude of the water level changes near the barrier increase as the slope of the basin increases. Figure 3.9 shows the longitudinal changes in the water levels for the different basin slopes. The far upstream effect is found to be greater with decrease in basin slope. The results appear to indicate that the actual amount of water added into storage does not significantly change with the slope although the water levels configurations are definitely different.

A series of operational runs with different constant pumping rates were conducted for a basin with and without a complete basic barrier. The pumping well node was located on the basin centerline three nodes (3,000 feet) upstream from the barrier nodes.

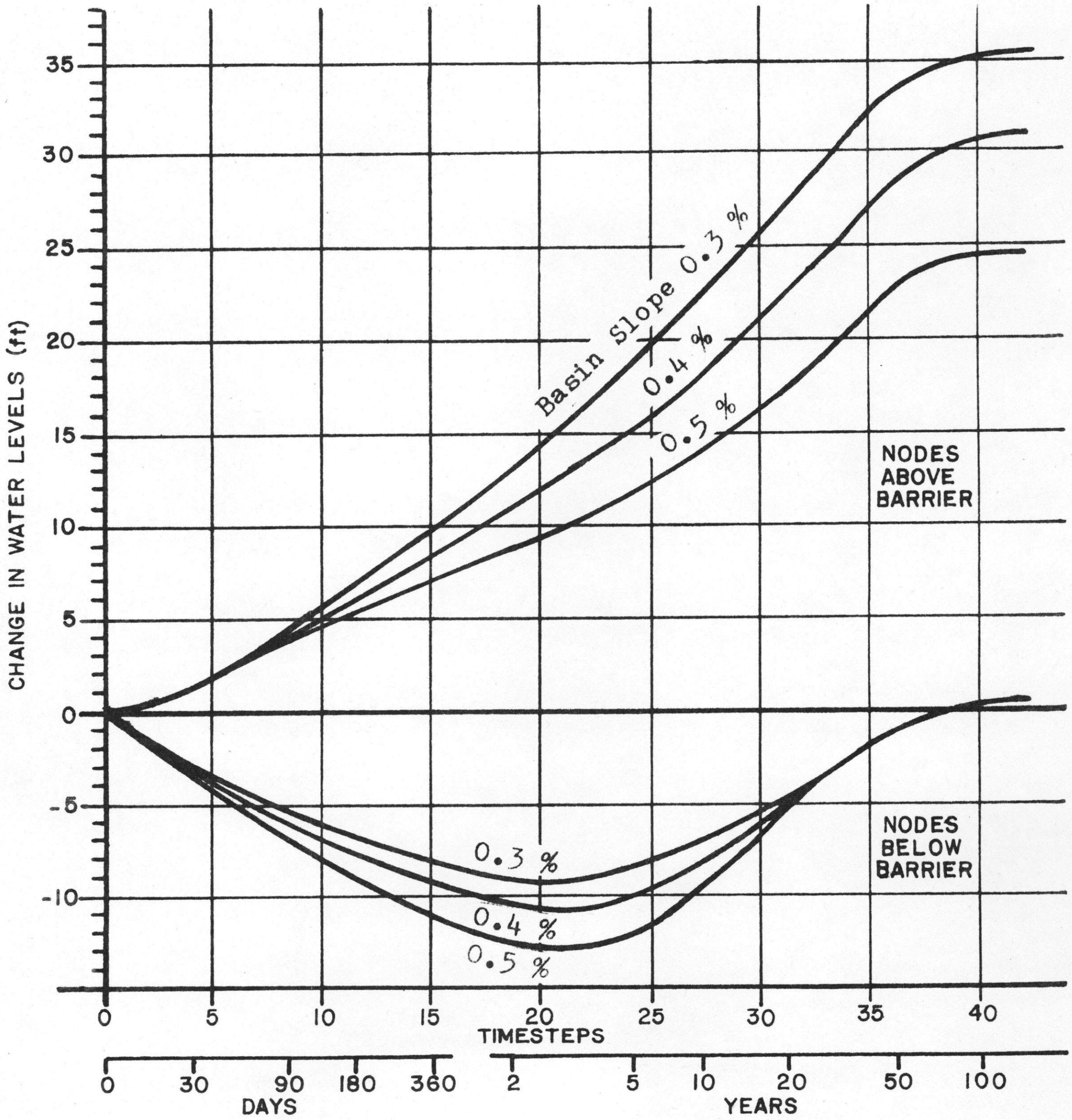


Figure 3.8 -- Time-Level Graphs For Complete Barrier With Different Basin Slopes

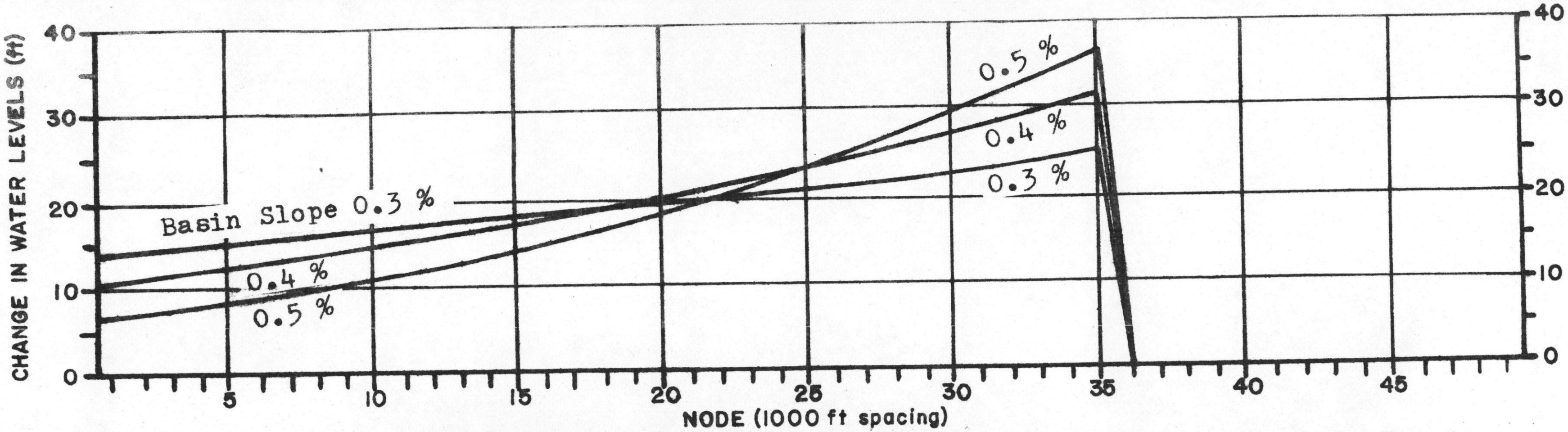


Figure 3.9 -- Basin Longitudinal Centerline Change in Water Levels For Complete Barrier With Different Basin Slopes

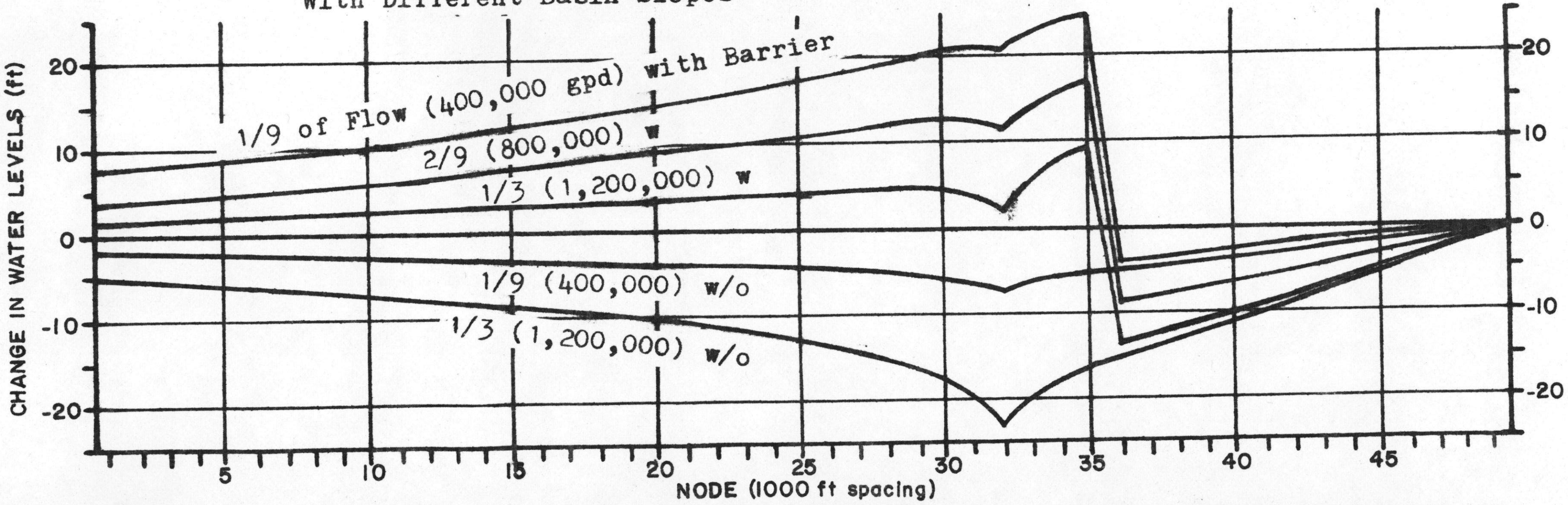
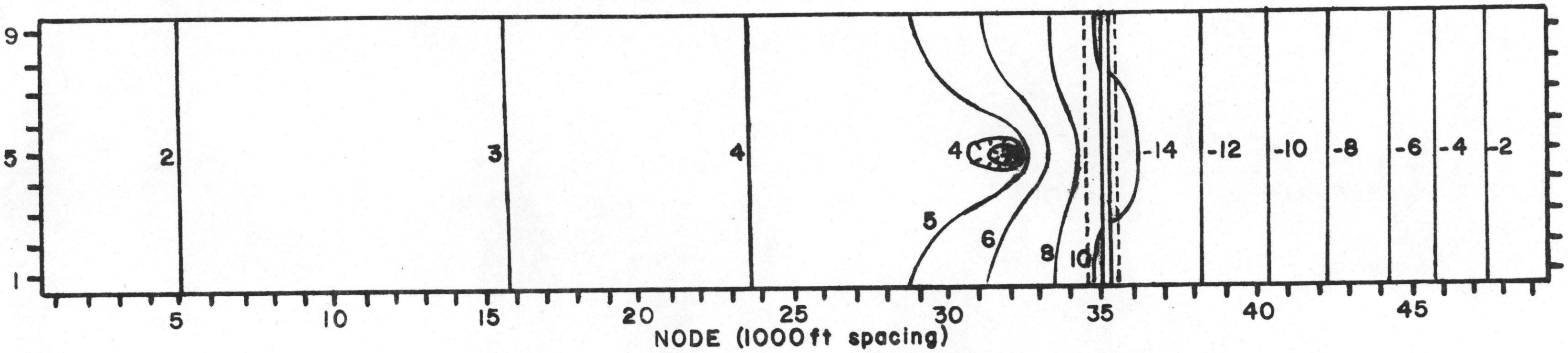


Figure 3.10 -- Basin Longitudinal Centerline Change in Water Levels For With and Without Complete Barrier and Different Pumping Rates

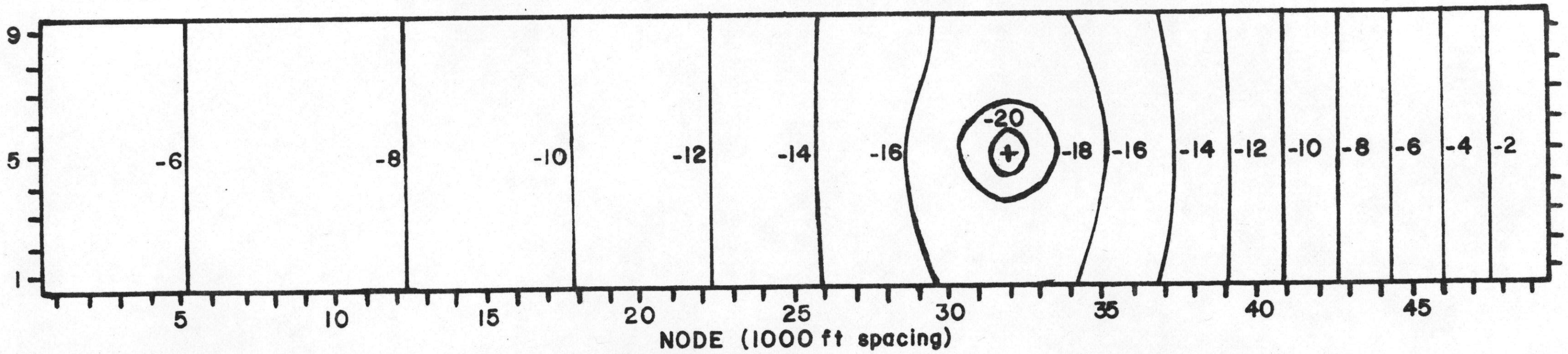
The pumping rates are given as the proportional amount of the total flow being input into the basin at the upstream boundary. The longitudinal centerline changes in water levels at the new steady state are shown in Figure 3.10. The expected drawdown caused by the pumping without a barrier is clearly seen. With the barrier added and pumping a third (1/3) of the original flow in the basin the upstream water levels are still greater than before at the new steady state. Figure 3.11 shows the entire simulated basin and the change in water levels for both with and without a barrier for the one-third (1/3) input flow pumping rates. Figure 3.12 shows the relative time-level effects for the area of the pump well. The actual drawdown at the well would be greater than the value given because the value represents the average water level for all the nodal area. A correction factor to determine the well drawdown can be found in the Illinois State Water Survey Bulletin 55 (Prickett and Lonnquist, 1971).

Figure 3.13 shows the effects of a partial barrier (side open 2 nodes) in the varied slope configuration. A slight variation of the long basin results in comparison to the short basin results in Figure 3.4 can be seen. A wedge shaped barrier configuration was also attempted but very inconsistent results from the program were obtained. The wedge was input as a symmetric configuration but the results were very uneven and not symmetric. In examining the symmetric configurations in Figure 3.4 some slight nonsymmetric variations can also be seen. These variations may be attributed primarily to the computation method

Basin With Complete Barrier and Pumping 1,200,000 gpd (1/3 of Flow)



Basin Without Barrier and Pumping 1,200,000gpd (1/3 of Flow)



Contours given in feet of change from original levels after 145 years.

Figure 3.11 -- Water Level Change Contours For With and Without Complete Barrier at the Same Pumping Rate

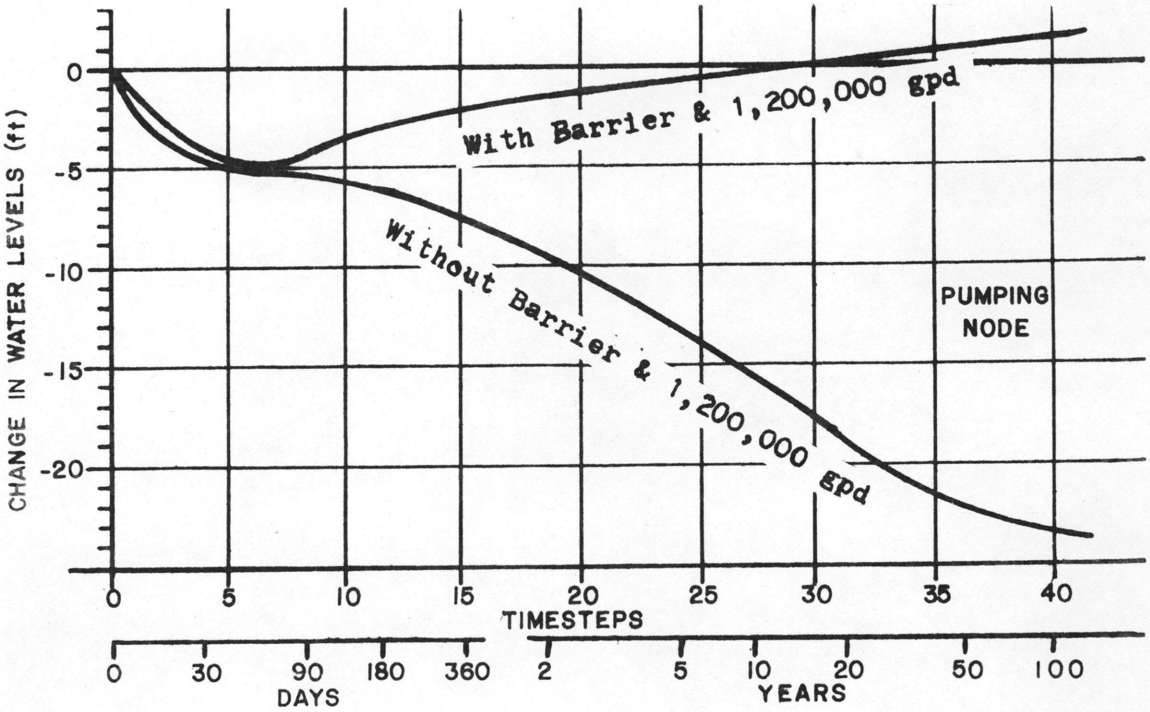


Figure 3.12 -- Time-Level Graphs For Pumping Node With And Without Barrier at the Same Pumping Rate

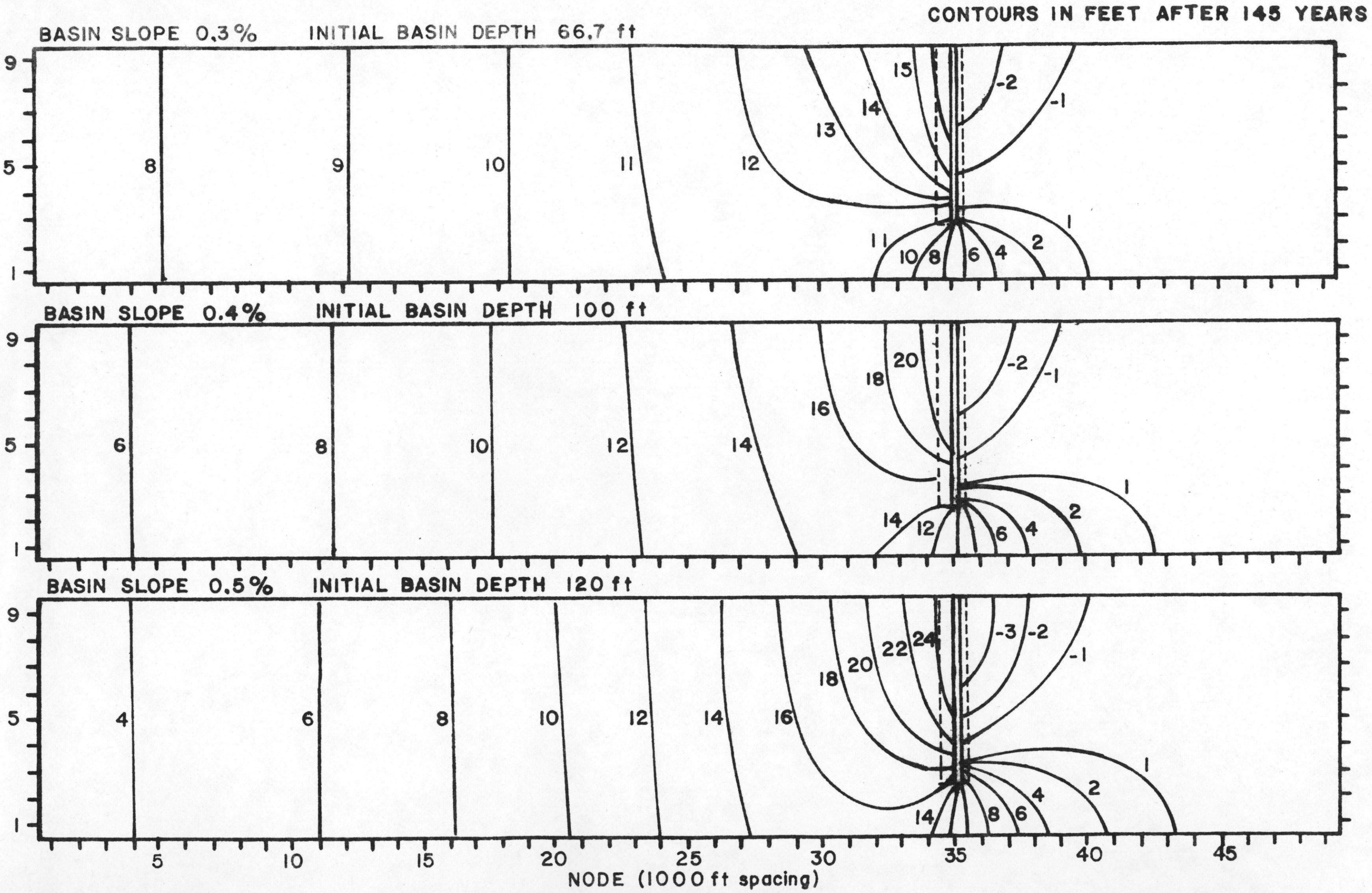


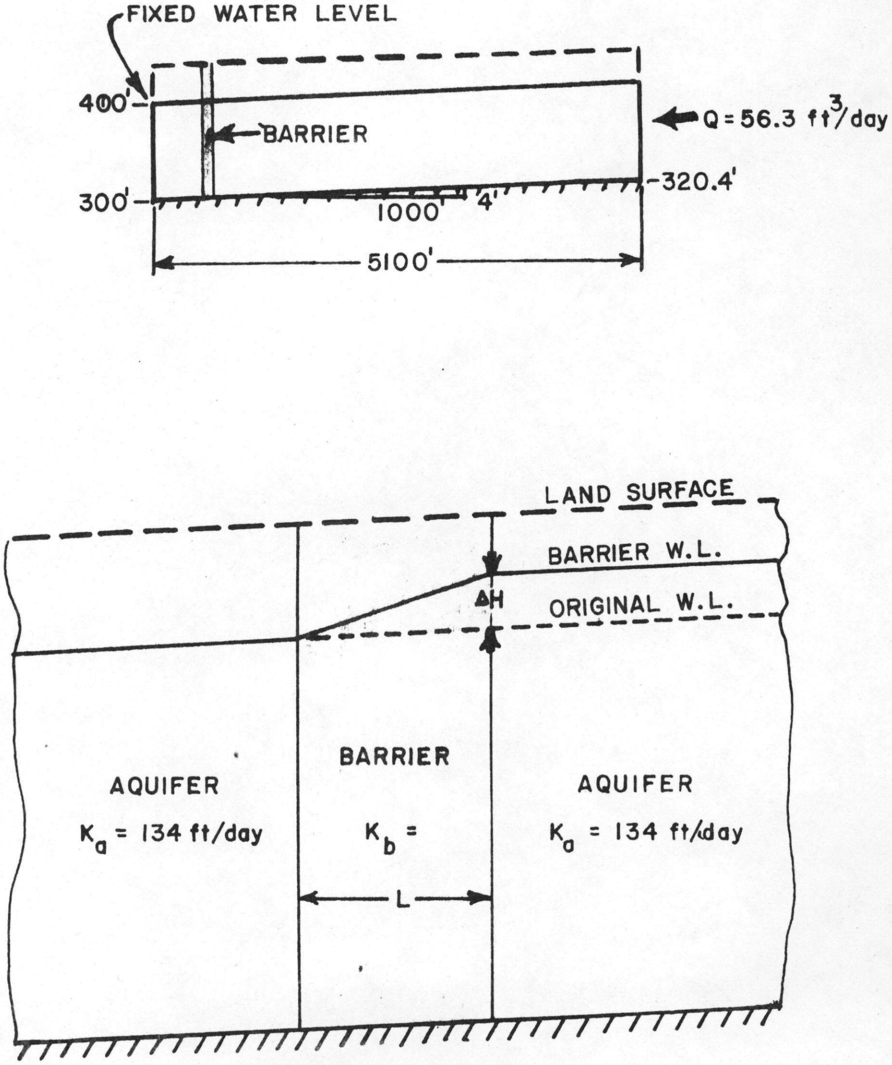
Figure 3.13 -- Water Level Change Contours For Partial Barrier With Different Basin Slopes and With the Same Basin Flows

of going across the row calculations in the same direction every iteration. Some of the variation may also be due to the error tolerance values used for each time step.

Finite element analyses were used to examine the steady state flow through a cross-section of the barrier. Four basic cross-sections were examined. The first cross-section consisted of an aquifer equivalent to the basic parameters of finite difference models with the hydraulic gradient of 4 feet per 1,000 feet, and hydraulic conductivity (K_a) of 134 feet per day (permeability of 1,000 gpd/ft^2). The second cross-section models more of a water cascade condition with a hydraulic conductivity (K_a) of 1,000 feet per day and hydraulic gradient of 40 feet per 1,000 feet. The third cross-section models an aquifer of two material layers with a barrier going down to only the second layer. The fourth cross-section models a confined aquifer system.

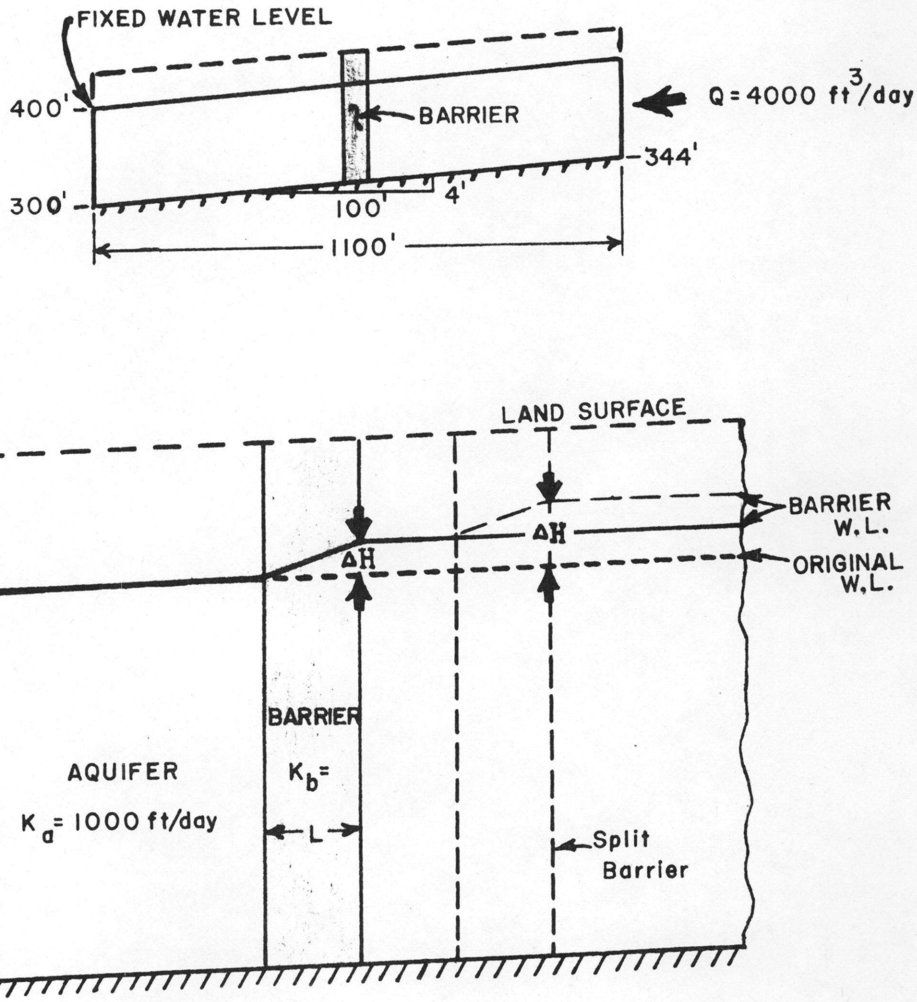
The initial series of computer runs examine the effect of various barrier widths and hydraulic conductivities on the water level behind the barrier. Figure 3.14 and 3.15 shows the increase in water level changes (ΔH) with the decrease of barrier hydraulic conductivities (K_b) and/or increase of barrier length (L).

The results of a partial barrier and the effects of different vertical hydraulic conductivities are shown in Figure 3.16. The basic effect of the partial barrier examined is small ($\Delta H = 0.9$ ft) compared to a complete barrier (Figure 3.14, $\Delta H = 24.6$ ft). As the vertical hydraulic conductivity (K_v) decreases the barrier is found to become more effective and a downstream effect appears and increases in magnitude.



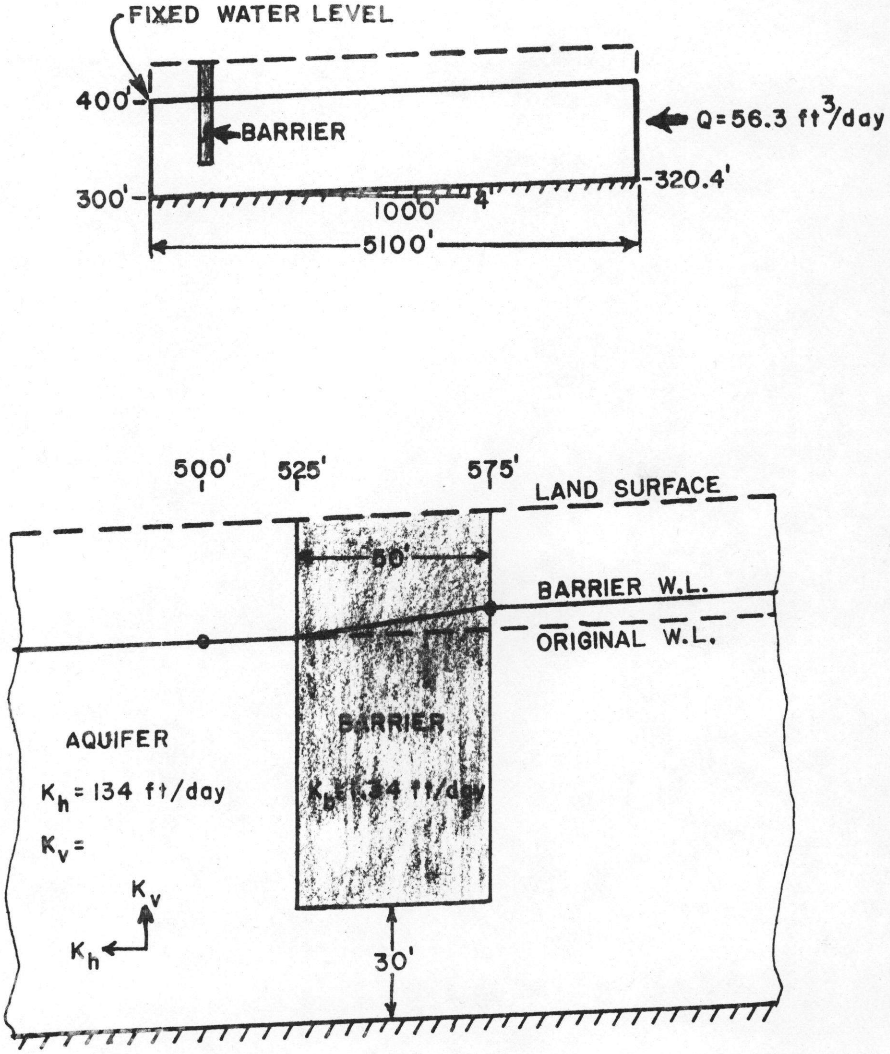
L (ft)	BARRIER K_b (ft/day)	CHANGE IN WATER LEVEL ΔH (ft)
25	13.4	0.9
25	6.7	2.0
25	1.34	10.6
50	13.4	1.8
50	1.34	24.6
100	13.4	4.0

Figure 3.14 -- Complete Barrier With Different Barrier Properties



BARRIER L (ft)	 K_b (ft/day)	CHANGE IN WATER LEVEL ΔH (ft)
25	100	8.8
25	10	73.9
50 (2-25 split)	100	16.6
50	100	16.7
50	10	122.8
75	100	24.0
Comparison Run With 0.4 % Slope And Q = 400 ft³/day		
50	100	1.55

Figure 3.15 -- Complete Barrier With Different Barrier Properties in a Cascade Condition

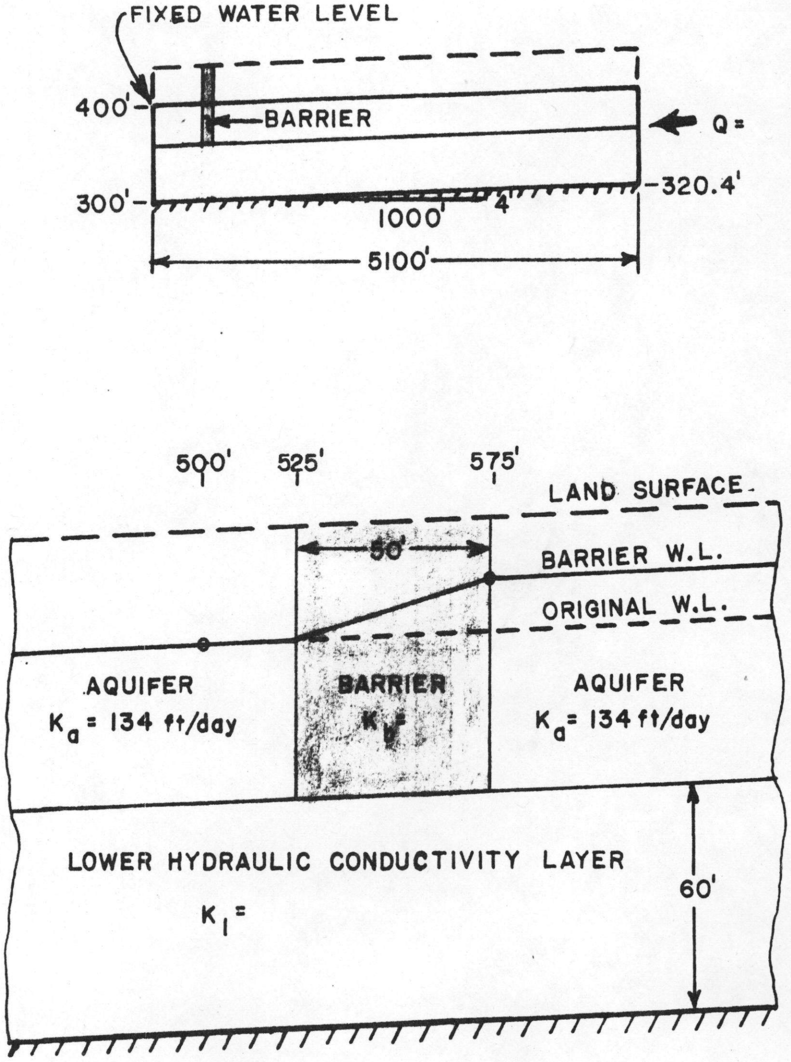


K_v (ft/day)	Water Levels (ft) at 500	at 575
No Barrier	402.0	402.3
134.0	402.0	403.2
33.5	401.7	403.3
13.4	401.6	403.8
1.34	401.0	406.2

Figure 3.16 -- **Partial Barrier in an Aquifer With Different Vertical Hydraulic Conductivities**

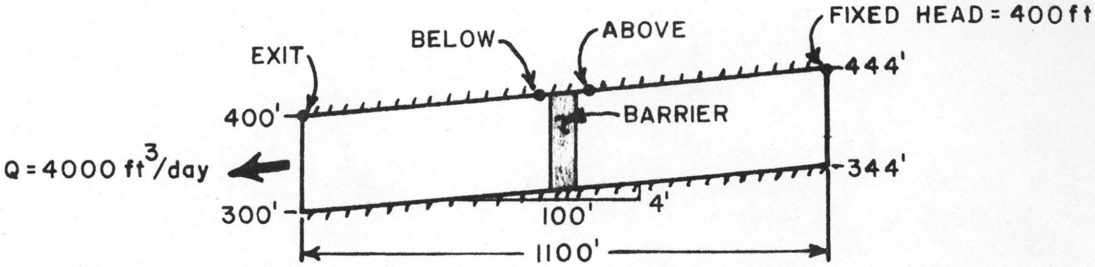
The concept of a partial barrier going down only to a layer of lower hydraulic conductivity was examined and the results summarized in Figure 3.17. A bottom layer with a lower hydraulic conductivity is shown to have a significant impact as does the barrier hydraulic conductivity.

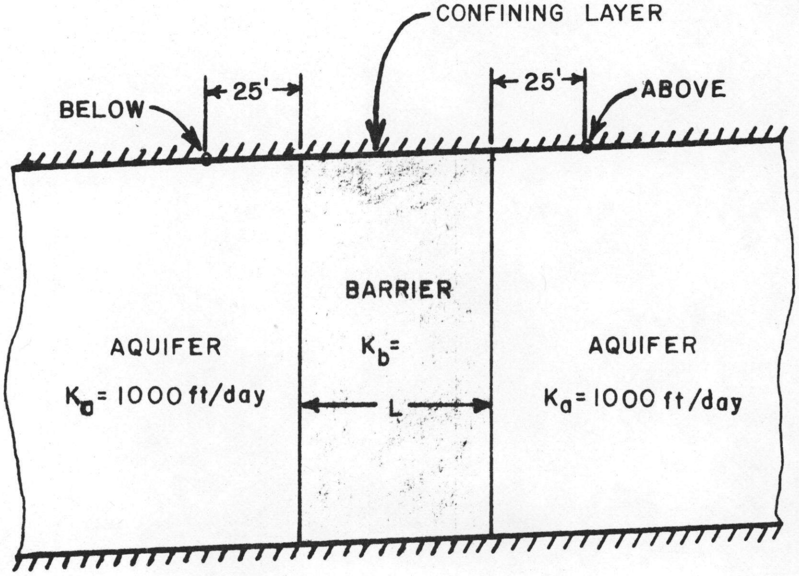
Figure 3.18 shows that a barrier in a confined aquifer basically would normally have detrimental effect of decreasing the downstream pressure heads. The decrease in pressure could be a beneficial effect if it would result in decreased outflows. The results also show the decrease in pressure head varies with the decrease in barrier hydraulic conductivity (K) and/or the increase barrier length (L).



K_b (ft/day)	K_l (ft/day)	Q (ft^3/day)	Water Levels (ft) at 500	at 575
134.0	1.34	21.8	401.2	401.3
1.34	1.34	21.8	401.8	411.4
0.134	1.34	21.8	403.0	435.2
0.134	13.4	24.7	401.6	403.8

Figure 3.17 -- Partial Barrier Down to Lower Hydraulic Conductivity Layer





BARRIER		CALCULATED CONFINING HEAD (ft)		
L (ft)	K_b (ft/day)	Exit	Below	Above
No Barrier		399.1	399.4	399.5
25	100	389.9	390.2	399.6
25	10	298.4	298.6	399.7
50	100	380.8	381.1	399.6
50	10	198.7	198.9	399.9

Figure 3.18 -- Complete Barrier in a Confined Aquifer With Different Barrier Properties

SITE EVALUATION PROCESS

The current trend of site investigations for projects includes a thorough evaluation of many potential sites with the subsequent selection of the best site. The process has been expanding due to the increased environmental concern, public awareness, and the concern of the various impacts from the development of a site.

A systems approach has been developed for underground reservoir site evaluation based on a power plant siting approach (Calvert and Heilman, 1972). The systems approach is a systematic attempt to analyze the various considerations of the potential sites and evaluate them uniformly and completely. This report only covers the definition of the approach and the preliminary steps of checking and testing the applicability of the approach to the underground reservoir concept.

The initial portion of any study should include the definition of objectives, basic considerations, and constraints on the study. After the scope of the study is set then the evaluation procedure is started by determining potential sites and collecting the basic data for each site. In the following sections the basic considerations of the underground reservoir concept will be defined, the evaluation procedure presented and the preliminary application to the study area of Southern Idaho will be discussed.

Basic Considerations

The basic considerations of an underground reservoir site can be defined by the following elements. The basic elements which define the siting factors fall into three general categories: 1) physical and engineering parameters, 2) environmental effects and public acceptance, and 3) economic factors.

In considering the physical and engineering parameters for an underground reservoir system the following factors have been identified:

1. Water availability -- what water is available in the area in the form of surface flow, ground water flow, and unused flood discharges?
2. Geologic structure and topography -- what are the geologic formations and topography of the site which control the water flow and make the underground zone a potential reservoir site?
3. Aquifer properties -- what are the aquifer characteristics, the water table levels, coefficient of storage, and transmissibility of the aquifer materials?
4. Type of reservoir -- what form of underground reservoir should be considered for the site?
5. Recharge method -- what method of recharging the aquifer or underground reservoir zone could be used and by what means will the water be brought to the recharge area?
6. Flood protection -- will the site be exposed to flood flows and if so will it be possible to use part of the flood flows for filling the underground reservoir?

7. Potential water and land use -- what potential water use and land use in the area can benefit from the water controlled by the underground reservoir?
8. Site access -- what forms of transportation and utilities are in the area and what effect will the project development cause in interfering with these or in requiring additional facilities?

The considerations and factors that have been identified for environmental effect, and public acceptance are as follows:

1. Water quality -- what effect will the development have on local surface and ground water quality? What will the expected recharge water quality and temperature be and will the recharge water require treatment?
2. Water use -- what are the existing water uses and water rights of the area and the potential water needs? What will the downstream impact be?
3. Land use -- what are the existing land uses in the area and the potential land use needs?
4. Scenic effects -- what will be the visual effect of the project? Will the barrier location and recharge facilities fit into the natural topography and groundcover or will additional work be required to minimize the visual impact?
5. Recreation effect -- will the development improve or harm the local recreation possibilities? Will the recharge and storage operations deplete or stabilize streamflows used for recreation?

6. Wildlife effect -- what impact will the development and its construction have on wildlife habitat? Will the development eliminate, stabilize, or aid the wildlife habitat, especially along stream courses?
7. Local impact -- what effect will the project have on local areas, the people and their life style?

There are many economic factors that are important in determining if a site is worthwhile. Some economic factors are contained in the elements in the first two categories. The direct economic factors are included in the following elements:

1. Barrier cost -- what will be the cost of developing and maintaining the barrier?
2. Recharge cost -- what will be the cost of developing and maintaining the recharge facilities?
3. Property and water rights costs -- what property and right-of-way costs will be required? Will there be costs of acquiring or compensating for water rights affected by the development?
4. Benefits -- what improvement in goods and services will the development provide and what external benefits will accrue such as flood control, decreased pumping costs, new and better irrigated lands, and new or better supported industry?

The Evaluation Procedure

The basic steps of a proposed underground reservoir site evaluation process are shown in Figure 4.1. The process is

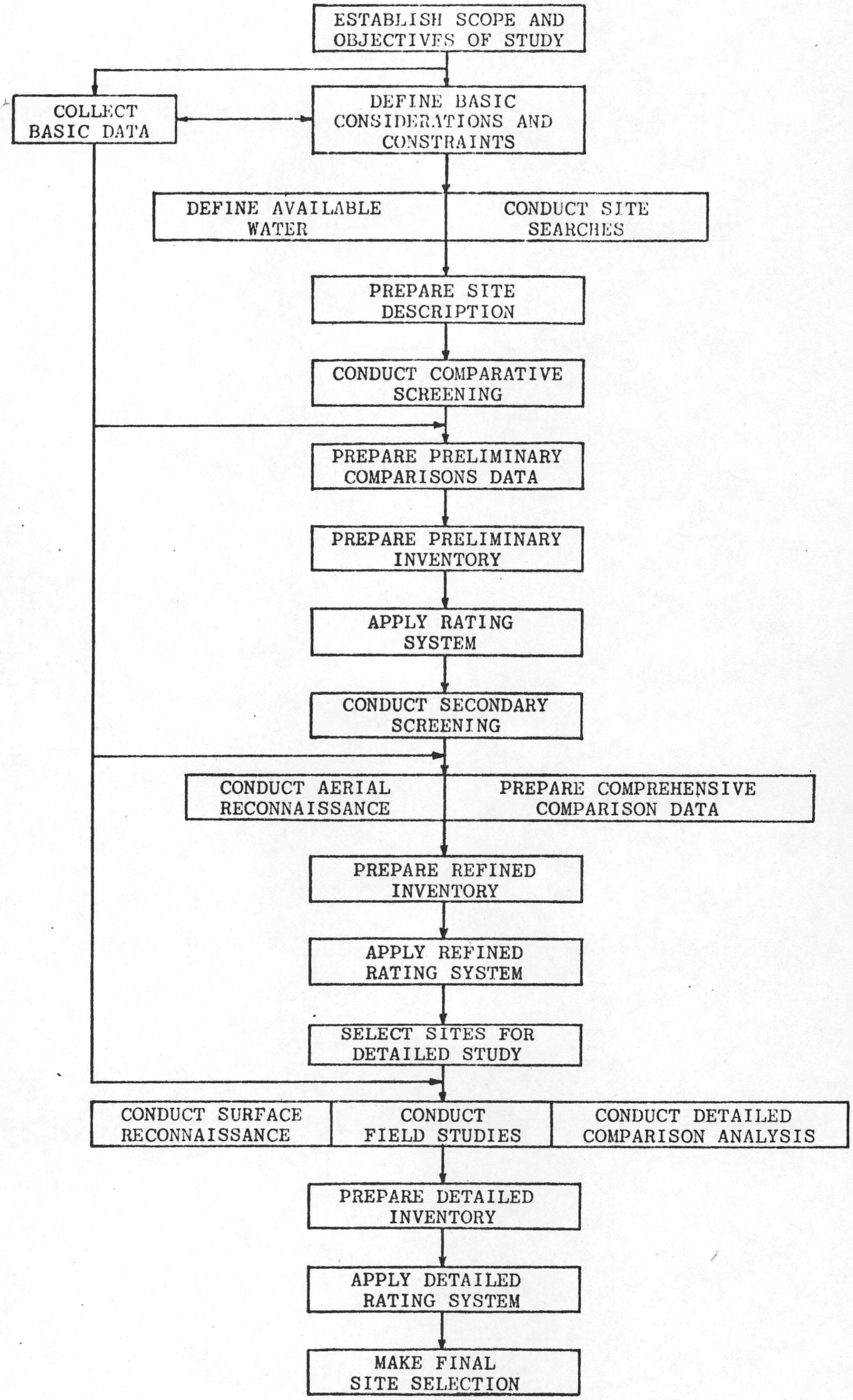


Figure 4.1 -- Underground Reservoir Site Evaluation Procedure

based upon a power plant siting procedure (Calvert and Heilman, 1972). The procedure has a cyclic nature increasing in the degree of analysis and detail which results in a final selected site and an inventory of possible alternate sites. The procedure can be altered or terminated as the comparisons and circumstances require within the constraints of the study objectives.

The initial scope, primary considerations and constraints, would normally be contained within the technical proposal of the project leaving only the basic considerations to be expanded and defined. For this study the basic elements have been defined based on the proposal and refined to those given in the preceding section.

The collection of data answering the basic questions is an important and extensive phase. The data collection effort forms the ground work and potential quality of the study. The bulk of the basic data collection should be done early in the study.

To determine the available water in the study area a basic hydrological study should be done drawing upon existing records, surveys, and reports. A generalized water situation of the different areas in the basins should be initially developed. Key hydrologic stations should also be defined throughout the basin and the relationships between these stations will be needed to evaluate downstream impacts.

In defining the siting parameters and limits, the key considerations in relation to the physical and geologic features of potential sites should be emphasized. The limits imposed can be in the nature of the boundaries of the search area, aquifer types, maximum water transfer height and distance, and barrier size.

The map searches for possible sites would involve listing of all locations that fall within the siting parameters and limits defined. The search could initially be done utilizing topographic and geologic maps.

The first comparative screening will entail taking each site, listing the very basic characteristics of the site, eliminating those sites that are obviously inferior for some reason. This initial screening should be done very judiciously and the reasons for elimination recorded.

Following the first screening the first analysis of engineering feasibility, environmental and public impacts and rough cost estimates would be developed. Some of the basic elements would be of subjective nature but various evaluation procedures have been suggested for environmental and multiobjective planning (Leopold, Clarke, Hanshaw, and Balsley, 1971; Bishop, 1972; USDI, 1972; WRC, 1973). Each of the basic elements should be defined for each site in at least a general nature and numerical estimates of the main characteristics should be given when possible.

An inventory of the preceding data should be made, listing a summary of pertinent information for each site. A rating system then should be developed and applied to the basic considerations in the inventory. In this initial rating system the economic factors should not be overly weighted to eliminate sites without proper consideration of environmental and public acceptance factors. With the inventory and rating system, a selection matrix can be formed by which the secondary screening can be based (Calvert and Heilman, 1972).

The study cycle now starts to repeat itself. An aerial survey of the sites should be made of the sites to check the map and land use data. Additional data should be obtained and analyzed, refining the information of all the sites. A refined inventory and rating system should be developed and applied.

At this point a decision should be made as to whether the best three to five sites can be determined from the refined ratings. If the number of sites desired cannot be determined another cycle of further refining may be required or a comparative analysis might be used to narrow the number of sites (Bishop, 1972). When the final sites have been selected, the detailed analysis of engineering, environmental, public acceptance, and economic factors should be conducted including field studies. A final inventory and rating system can be applied resulting in a site selection and the best alternative sites.

Application to Sites in Southern Idaho

The purpose of the study was to study the possibilities of underground reservoirs and application for use in Southern Idaho. It was decided that a preliminary siting study would be conducted using the man-made underground barrier concept. The following is a summarized discussion of a preliminary siting analysis, used primarily to check the procedure and basic considerations defined earlier in this chapter.

The scope and objectives of the siting study were basically those defined in the original research proposal and those in the introduction of the report. The basic considerations were those defined earlier in this chapter. The basic constraints of the siting study were that the scope include only the Snake River Basin in Southern Idaho and sites considered be only for the underground barrier.

The collection of basic data needed to start to answer the questions posed in the basic considerations began the extensive site description process. The "Idaho Water Resources Inventory" (IWRB, 1968) is a good basic reference and the bibliography and cited references give the initial additional sources of information related to Idaho.

The economic factors are the hardest to define because a preliminary project design at the site must be done to get the parameters with which to start the economic analysis. Some planning agencies and reports have rough preliminary cost and benefit equations on generalized parameters for typical water resources projects which may be applied with limits (Campbell and Lehr, 1973; Dawes, 1970; Todd, 1965).

To define the available water initially a general definition of the water resources committed and uncommitted is needed and can be found in the "Idaho Water Resources Inventory" in the stream flow commitments, water rights, and ground water sections. After the sites have been defined, key points of surface flows can be defined noting locations of recording stations, major diversion points and river confluences. At these key points the water flows would be analyzed in respect to amounts and occurrence intervals to determine available water (Norvitch, Thomas, and Madison, 1969). The ground water flows also should be checked for these key points to account for subsurface flows. For example ground water inflow to American Falls Reservoir is approximately thirty-seven percent (37%) of the outflow from the reservoir (Castelin, 1974).

Another interesting point in relation to the water availability is the potential legal problems in Idaho with artificial recharge. In a recent court case, Baker vs. Ore-Idaho Foods, Inc., the court prohibited withdrawals in excess of average natural recharge, therefore artificial recharge would not justify additional withdrawals in a critical area (Ralston, Grant, Schatz, and Goldman, 1974). One of the purposes of the St. Anthony pilot recharge project was to test the legal procedures in providing for the recharge project (Anderson, 1975). The project was issued a water permit for research purposes for the initial phase. The St. Anthony Union Canal Company presently would like to continue the project but in the recent Idaho Department of Water Resources' report (Anderson, 1975, p. 26) the conclusions include:

> "A question still to be answered is how a water right can be established for a recharge project on the Snake Plain Aquifer. Demonstrating beneficial use of the water and identifying who the beneficiaries are pose a difficult problem. Also a legal question arises as to what entity or organization can sponsor a recharge project."

The legal considerations of artificial recharge seem to be relatively unresolved. If artificial recharge were used in conjunction with an underground reservoir the identification of the beneficiaries and benefits could be shown.

The initial siting search was based on geologic criteria using geologic maps and data. The basic criteria was for alluvial valleys or other normal water bearing formations bounded by relatively impermeable formations between which a barrier could be constructed. The sites selected and their locations are given in Table 4.1 and Figure 4.2.

The next step was to prepare site descriptions for each site defining the basic properties relating to the underground reservoir siting considerations. In this initial inventory of the site information only the general parameters need be defined to see if the site is feasible. The basic general parameters determined to be required were:

1. Water Availability -- is there potential water to store and use.
2. Aquifer Properties -- is there room for storage (water level depth and aquifer type).
3. Barrier Size -- what is the approximate length, depth, and potential construction method.
4. Recharge Methods -- expected types of recharge.
5. Potential Water and Land Use -- is there a need for the storage.
6. Existing Water and Land Use -- is there potential conflicts in area and downstream.

An inventory of the selected sites is given in Table 4.2 and a typical site description information sheet is given in Figure 4.3.

TABLE 4.1: Listing of Sites Selected for Initial Screening With Site Numbers as in Figure 4.2

UPPER SNAKE RIVER BASIN

South of Snake River

1. Oakley Valley (Goose Creek)
2. Basin (Near Oakley)
3. Albion Valley
4. Raft River Valley
5. Rock Creek
6. Upper Bannock Creek (Arbon Valley)
7. Marsh Creek (Portneuf River)
8. Upper Portneuf Valley
9. Gray's Lake Area

North Upper Snake River

10. Swan Valley
11. Teton-Driggs Area
12. Henry's Lake Area

North of Snake Plain

13. Birch Creek
14. Little Lost River Valley
15. Big Lost River Valley
16. Star Hope Creek
17. Little Wood River
18. Copper Creek
19. Big Wood River
20. Silver Creek
21. Camas Prairie

SOUTHWEST IDAHO BASINS

Boise River System and North of Snake River

22. Lime Creek
23. Little Camas Area
24. Long Tom Area
25. Prairie Area
26. Idaho City Area
27. Grimes Creek

Payette River System

28. Garden Valley
29. Horseshoe Bend Area
30. Squaw Creek (Black Canyon)
31. Deadwood Area
32. Lower Cascade
33. Upper Cascade

Weiser River System

34. Council Area
35. Midvale Area
36. Lower Weiser Area

South of Snake River

37. Upper Jordon Valley
38. Castle and Catherine Creeks
39. Little Valley and Bruneau
40. Blue Creek

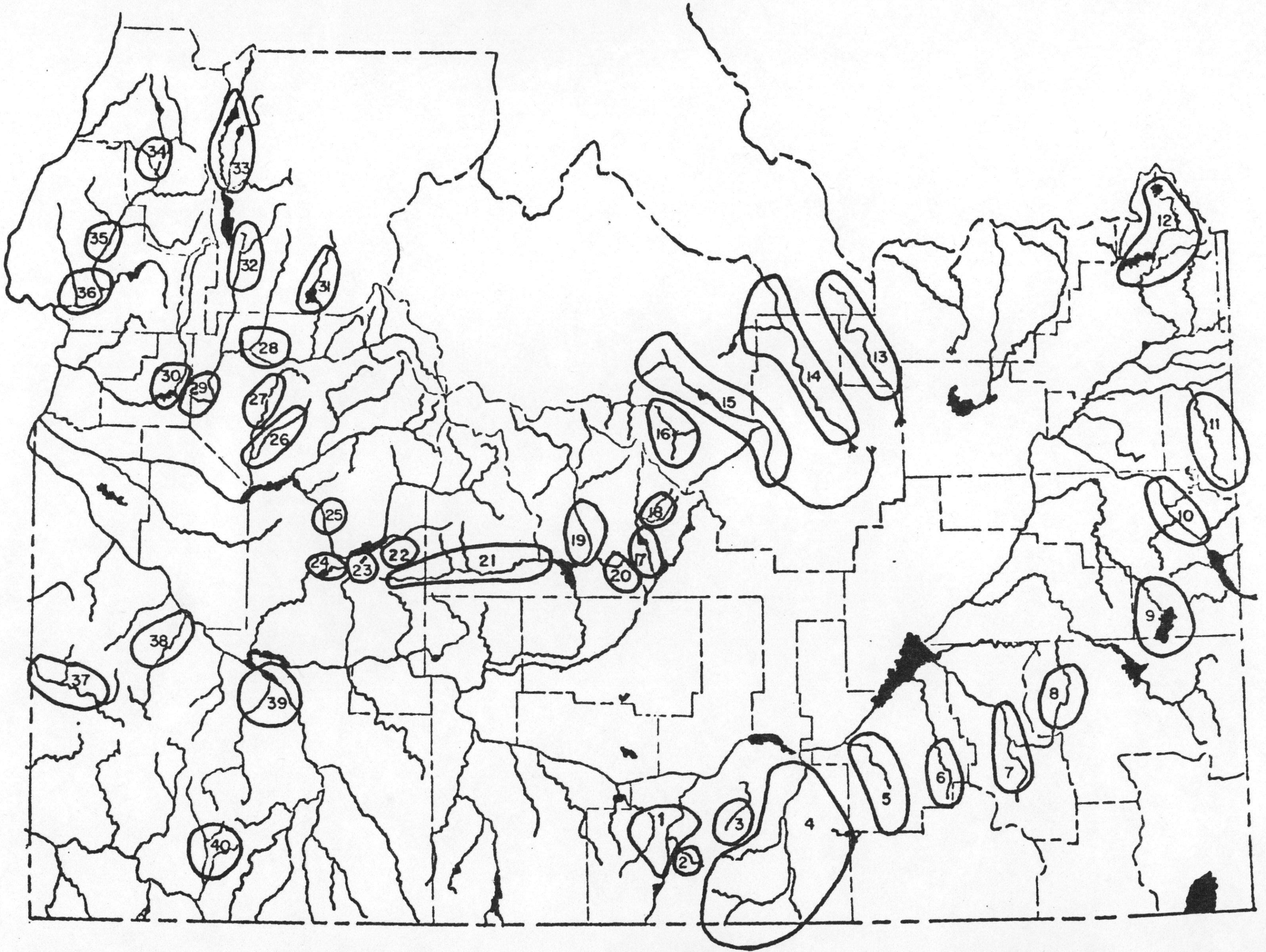


Figure 4.2 -- Map of Sites Selected for Initial Screening

NO	SITE NAME	WATER OUTFLOW SURFACE	GROUND	AQUIFER TYPE	LEVELS	BARRIER LENGTH	DEPTH	METHOD
1	Oakley Valley	little outflow	13,000+ ac ft	alluvial basalt	80-300 ft	8-10 mi	300-600 ft	grout slurry
2	Basin	few hundred ac ft	2,000 ac ft	alluvial basalt		less than mile	?	grout slurry
3	Albion Valley	?	?	alluvial layered	varied confined	1-7 mi	300 complete	slurry grout
4	Raft River	1,900 ac ft	80,000 ac ft	alluvial basalt	30-100+ ft	12-14 mi Hegler	1400-1500 complete	grout
5	Rock Creek	14,000 ac ft	?	alluvial sandstone	40-120+ ft some confined	4-10 mi	100+ ft	slurry grout
6	Bannock Creek	17,000 ac ft	3,000 ac ft	alluvial gravels	20-80+ ft	3-6 mi Arbon	apx 550 ft	slurry grout
7	Marsh Creek	140,000 ac ft ?	63,000 ac ft ?	basalt alluvial	30-150 ft	1-3 mi	?	grout
8	Upper Portneuf	138,000 ac ft	56,000 ac ft south	basalt alluvial	shallow to 50-100 ft	7-9 mi Hatch	apx 200 ft	grout
9	Gray's Lake	150,000 ac ft	?	alluvial	shallow ?	6+ mi	?	
10	Swan Valley	Snake R flow	?	alluvial		varied longitudinal		slurry grout

TABLE 4.2 -- SITE DESCRIPTION INVENTORY FOR SOUTHERN IDAHO

PART 1A

NO	RECHARGE	WATER USE		DOWNSTREAM EFFECT	LAND USE	
		EXISTING	POTENTIAL		EXISTING	POTENTIAL
1	ponding connectors	irrigation	more irrigation	supplies water critical area	farming ranching	farming
2	ponding stream mod	irrigation	more irrigation	supplies water critical area	farming ranching	farming
3	stream mod connectors	all surface flow used	more irrigation	private storage	farming dryland	supplemental irrigation
4	import, pond stream mod	heavy demand water critical	farming	little nearby	farming grazing	good farm land irrigation
5	stream mod ponding	some irrigation	more irrigation	limited	dry farming	irrigation
6	stream mod ponding	some irrigation	limited but downstream	Indian usage	farming dryland	more irrigated farming
7	flood flows ponding	irrigation	irrigation industry	limited American Falls	farming dryland	farming irrigation
8	stream mod	irrigation	more irrigation	summer flow demands	dryland farming	farming
9	stream mod	irrigation	irrigation	little	ranching	ranching irrigation
10	stream mod ponding	irrigation	irrigation	limited	ranching	ranching

TABLE 4.2 -- SITE DESCRIPTION INVENTORY FOR SOUTHERN IDAHO PART 1B

NO	SITE NAME	WATER OUTFLOW		AQUIFER		BARRIER		
		SURFACE	GROUND	TYPE	LEVELS	LENGTH	DEPTH	METHOD
11	Teton Driggs	285,000 ac ft	25-50,000 ac ft	alluvial basalt	shallow	5-8 mi	300+ ft	slurry grout
12	Henry's Lake	978,100 ac ft	little (Ashton)	alluvial basalt	shallow ?		shallow	slurry
13	Birch Creek	58,000 ac ft	70,000 ac ft	alluvial basalt		7-8 mi Reno	?	grout
14	Little Lost River	10,000 ac ft	157,000 ac ft	alluvial	25-80 ft	7-9 mi Howe	apx 170 ft	slurry grout
15	Big Lost River	54,000 ac ft	308,000 ac ft	alluvial basalt	shallow	6-10 mi	up to 2,000 ft	grout
16	Star Hope Creek	56,000 ac ft	11,000 ac ft	alluvial	?	1-4 mi	?	
17	Little Wood River	97,000 ac ft	8,000 ac ft	alluvial basalt	shallow to 150 ft	2-3 mi	200+ ft	grout
18	Copper Creek	?	?	alluvial basalt dam	?	2 mi	?	grout
19	Big Wood River	214,000 ac ft	outflow small	alluvial gravel	25-75 ft below	2-6 mi Gannett	200-300 ft	slurry grouting
20	Silver Creek	112,000 ac ft	38,000 ac ft	alluvial basalt	50+ ft cascading	2-4 mi Priest	300+ ft	grouting slurry

TABLE 4.2 -- SITE DESCRIPTION INVENTORY FOR SOUTHERN IDAHO

PART 2A

NO	RECHARGE	WATER USE		DOWNSTREAM EFFECT	LAND USE	
		EXISTING	POTENTIAL		EXISTING	POTENTIAL
11	stream mod	irrigation	supplemental & more irrig.	limited	farming ranching	farming
12	stream mod	irrigation	supplemental & more irrig.	limited	farming ranching	farming recreation
13	stream mod ponding	irrigation	more irrigation	Rights on edge of Snake Plain	ranching farming	farming short season
14	stream mod ponding	irrigation	supplemental & more irrig.	Snake Plain little	farming ranching	farming
15	stream mod ponding	irrigation	supplemental & more irrig.	Snake Plain little	farming ranching	farming
16	stream mod ponding	irrigation ranching	downstream usage	supplies Big Lost Area	ranching	ranching
17	ponding stream mod	irrigation	more irrigation	Snake Plain	farming	farming
18	stream mod ponding	ranching	downstream usage	Little Wood users	ranching	recreation ranching
19	canals ponds	heavy demand in & below	supplemental irrigation	problem at Magic	farming recreation	farming recreation
20	stream mod ponding	summer irrig. & recreation	downstream irrigation	summer-prob winter-little	recreation farming	recreation farming

TABLE 4.2 -- SITE DESCRIPTION INVENTORY FOR SOUTHERN IDAHO PART 2B

NO	SITE NAME	WATER OUTFLOW SURFACE	GROUND	AQUIFER TYPE	LEVELS	LENGTH	BARRIER DEPTH	METHOD
21	Camas Prairie	127,000 ac ft	20,000 ac ft	sand & clay basalt	shallow & confined	8-10 mi	up to 550 ft	grout slurry
22	Lime Creek	65,000 ac ft	?	alluvial	?	1-2 mi	?	
23	Little Camas Area	3,000+ ac ft	?	alluvial basalt	?	1-2 mi	?	
24	Long Tom Area	20,000+ ac ft	?	alluvial	?	1-2 mi	?	
25	Prairie Area	718,200+ ac ft	?	basalt	?	1-5 mi	?	
26	Idaho City	50,000 ac ft	?	alluvial	shallow ?	~1 mi	shallow?	slurry
27	Grimes Creek	236,700- ac ft	?	alluvial	shallow ?	1-3 mi	shallow?	slurry
28	Garden Valley	945,500 ac ft	?	alluvial	shallow ?	1-3 mi	shallow?	slurry
29	Horseshoe Bend	2,323,000 ac ft	?	alluvial	?	~1 mi	?	
30	Squaw Creek	?	?	alluvial	?	1-2 mi	?	

TABLE 4.2 -- SITE DESCRIPTION INVENTORY FOR SOUTHERN IDAHO

PART 3A

NO	RECHARGE	WATER USE		DOWNSTREAM EFFECT	LAND USE	
		EXISTING	POTENTIAL		EXISTING	POTENTIAL
21	ponding connectors	little irrigation	irrigation	problem at Magic	dry farming livestock	irrigated farming
22	stream mod	little	downstream irrigation	limited	ranching	ranching
23	stream mod ponding	storage for Long Tom	storage	demand below	ranching	ranching
24	stream mod ponding	storage for Mtn. Home	storage	demand below	ranching	ranching
25	stream mod ponding	little	irrigation	limited	ranching	ranching farming
26	stream mod	little	little	limited	recreation lumber	recreation lumber
27	stream mod	little	little	limited	mining lumber	mining lumber
28	stream mod ponding	irrigation	irrigation	little	ranching	ranching
29	stream mod ponding	irrigation lumber	irrigation lumber	little	ranching lumber	ranching lumber
30	stream mod ponding	irrigation	irrigation	little	ranching farming	ranching farming

TABLE 4.2 -- SITE DESCRIPTION INVENTORY FOR SOUTHERN IDAHO PART 3B

NO	SITE NAME	WATER OUTFLOW		AQUIFER		BARRIER		
		SURFACE	GROUND	TYPE	LEVELS	LENGTH	DEPTH	METHOD
31	Deadwood Area	162,200 ac ft	?	alluvial	?	1-3 mi	?	
32	Lower Cascade	742,800 ac ft	?	alluvial	?	2-4 mi	?	
33	Upper Cascade	352,600 ac ft	?	alluvial	shallow ?	6-7 mi	?	
34	Council Area	306,200 ac ft	?	basalt gravel	varied	2-3 mi	apx 250 ft	grout slurry
35	Midvale Area	645,100 ac ft	?	basalt Old Lake bed	varied confined	5-7 mi	deep basalt	grout
36	Weiser Area	875,300 ac ft	?	alluvial clays	varied			
37	Jordan Valley	144,100 ac ft	?	alluvial	shallow ?	1 mi	shallow?	slurry
38	Castle & Catherine	14,000+ ac ft	?	sand upper	confined below	1-3 mi	100+ ft	slurry
39	Little Valley & Bruneau	280,000+ ac ft	?	alluvial upper	confined below	1-2 mi	?	slurry
40	Blue Creek	?	?	alluvial	?	3-7 mi	?	

TABLE 4.2 -- SITE DESCRIPTION INVENTORY FOR SOUTHERN IDAHO

NO	RECHARGE	WATER USE EXISTING	WATER USE POTENTIAL	DOWNSTREAM EFFECT	LAND USE EXISTING	LAND USE POTENTIAL
31	stream mod	little	downstream irrigation	little	lumber ranching	lumber ranching
32	stream mod ponding	ranching irrigation	irrigation	little	ranching	ranching recreation
33	stream mod ponding	ranching irrigation	irrigation	little	recreation ranching	recreation ranching
34	stream mod pond	some irrigation lumber	irrigation	little	stock raising farming	orchard and farming
35	stream mod pond	some irrigation	irrigation	little	farming dryland	irrigated farming
36	ponding	irrigation	irrigation industrial	little	farming ranching	irrigated farming
37	stream mod	irrigation	irrigation	high demand	farming ranching	farming ranching
38	stream mod ponding	irrigation	irrigation	little	farming ranching	farming ranching
39	stream mod ponding	irrigation	irrigation	little	farming ranching	farming ranching
40	stream mod	irrigation	irrigation	water short problem area	farming ranching	farming ranching

TABLE 4.2 -- SITE DESCRIPTION INVENTORY FOR SOUTHERN IDAHO PART 4B

Figure 4.3: Example of Site Description Information -- Raft River Valley, Idaho (Site # 4)

BASIC DESCRIPTION

Location -- North-South valley in Southern Idaho, Cassia County, R26-28E and T10-16S.
Size -- 40 miles long and 12 miles wide with a couple side basins and an upper valley.
Elevation -- main valley ranges from 4350 to 5200.

WATER AVAILABILITY

Surface outflow -- 1900 acre-feet/year
Groundwater outflow -- 80,000 acre-feet/year
Potential transfer -- from Snake River (Lake Walcott)

AQUIFER PROPERTIES

A wide alluvial valley where pumping has dewatered extensive areas (30 to 50 feet) and much of the upper underground zone has available space (watertables 30 to 100 feet below land surface). Alluvial aquifer has good storage coefficient (0.15-0.2) and has basalt layers in northern part of valley.

BARRIER SIZE

A 14 mile closure between Malta Range and Chapin Mtn. in alluvial and basalt valley with depth up to 1500 feet. Straight barrier blocking groundwater flow constructed by grouting.

RECHARGE METHODS

Stream modification to better utilize the limited surface flows and possible importing water and recharging in the alluvial materials along the toe of the Malta or Sublett Mountains.

WATER AND LAND USE

Present -- Water Critical Area, irrigated areas along the river and streams with extensive pumped irrigation in northern part of basin.
Potential -- Some new Class 1 and much Class 2 land available for irrigation development along east side of valley which is now grazed or dry farmed.
Downstream effect -- minor effect on flows of springs before Thousand Springs area, little effect on Lake Walcott or irrigation in Burley-Rupert area.

Basic Sources: The Raft River Basin, Idaho-Utah, as of 1966, IDWA, WIB No. 19, August 1970.

Water Resources of the Raft River Basin Idaho-Utah, USGS WSP 1587, 1961.

State of Idaho Irrigated and Potentially Irrigable Land (MAP), IWRB, 1970.

The inventory reflects that there has been few ground water studies in the Payette and Upper Boise River systems. Also few areas have good data on the depth of the aquifer materials which the barrier must penetrate. Since aquifer depth information is not available, preliminary field investigations will probably be needed early in the evaluation procedure. The potential uses, for which data is more readily available, could be emphasized as to feasibility and used to narrow down the number of sites before the field investigations. There are a number of promising sites in Idaho. From the information reviewed the lower Little Lost River basin looks to be one of most promising due to reasonable aquifer depth (to low permeable clays) and potential use needs.

CONCLUSIONS AND RECOMMENDATIONS

During this initial phase of studying the potential of large underground reservoirs in Idaho the following conclusions have been made:

1. Natural basins with artificial recharge and conjunctive use are proven practices in many places in the world. The questionable legal status of artifical recharge in Idaho presently limits this practice for storage development.
2. Natural underground caverns may offer some storage possibilities for small volumes (less than several hundred acre-feet) but are not useful for large volumes of storage.
3. Man-made underground reservoirs utilizing constructed or mined storage areas offer possibilities for special purpose storage such as urban waste water or pumped storage. High costs would probably make this type of reservoir unacceptable for general storage in Idaho.
4. Reservoirs formed behind underground barriers appear to be a possible method of developing large underground reservoirs in Idaho. The Owens Valley, California, operations using alluvial fault lines demonstrate the application of a large underground reservoir system.
5. Underground reservoir systems offer potential benefits in relief from overdevelopment, conjunctive use of surface and ground waters, reduction of evaporation losses and protection of the water supply systems.

6. The environmental impact of an underground reservoir system should be less than for an equivalent surface reservoir system.
7. Construction of a man-made underground barrier could be done using or expanding upon existing construction methods or techniques such as grouting, slurry trenches, and ground freezing.
8. The effects of an underground barrier system on the ground water flow system can be analyzed utilizing existing analysis procedures. Computer modeling can be used in several forms to analyze various aspects of the effects.
9. The main parameters in analyzing an underground reservoir site are the parent aquifer geohydrologic properties and the barrier's configuration and basic hydraulic parameters. The variability and interaction of the properties and each site's unique boundary and flow conditions make it such that the effects and operations of each site will be different.
10. A siting procedure can be used to define and evaluate potential sites. Initial steps of the siting procedure presented have shown there are potential sites in Idaho.

Based on the information analyzed during this initial phase of research, the following recommendations of further study and work are made:

1. Work on legal clarification and definition of artificial recharge in the state of Idaho is needed to help better

develop the existing water resources.

2. Barrier construction techniques should be further studied to determine the limits and constraints of each method. Economic analyses should be done to develop cost curves for barrier configuration parameters for each construction method.
3. Geophysical and subsurface geologic data should be obtained for promising potential sites in order to expand our knowledge of the areas. This can be accomplished with geophysical surveys using seismic or resistivity methods.
4. Preliminary economic analyses for several promising potential sites should be undertaken to determine whether an underground barrier is economically feasible in Idaho.
5. More computer modeling should be done utilizing a variety of actual aquifer properties and expected barrier properties. This could be best done using models of actual ground water basins and site locations.
6. The siting procedure should be undertaken using a multi-disciplinary study group to do and refine the analysis. The group should develop uniform evaluation criteria and evaluate potential sites to determine at least for which sites detailed studies should be done.

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APPENDIX A

REFERENCES RELATED TO ARTIFICIAL RECHARGE PERTINENT TO IDAHO

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APPENDIX B

CALCULATION OF ANNUAL RESERVOIR EVAPORATION

AMERICAN FALLS (ABERDEEN) 1,700,000 ac ft capacity

	MAY	JUNE	JULY	AUG	SEPT	OCT	OTHERS
C_r	1522100	1464800	1067500	674500	496900	604800	1219800
A_r	52800	51800	43800	33000	28200	31300	47100
E_p	7.07	7.94	9.25	8.37	5.60	3.41	9.77
E_l	5.09	5.72	6.66	6.03	4.03	2.46	7.03
E_r	22400	24700	24300	16600	9500	6400	27600

TOTALS: E_p = 51.41 in E_l = 37.02 in E_r = 131,500 ac ft

ARROWROCK 286,600 ac ft capacity

C_r	258100	257100	165600	62500	29000	42800	163900
A_r	2870	2865	2170	1400	780	1050	2150
E_p	6.06	7.37	10.28	9.23	5.96	2.42	9.81
E_l	4.36	5.31	7.40	6.65	4.29	1.74	7.06
E_r	1040	1270	1340	780	280	150	1260

TOTALS: E_p = 51.65 in E_l = 37.19 in E_r = 6,120 ac ft

LAKE LOWELL (DEER FLAT) 190,000 ac ft capacity

C_r	150600	137200	88900	51500	50900	60200	117600
A_r	9450	9180	7550	5680	5620	6430	8600
E_p	5.67	6.85	7.95	6.39	4.95	3.11	8.19
E_l	4.08	4.93	5.72	4.60	3.56	2.24	5.90
E_r	3210	3770	3600	2180	1670	1200	4230

TOTALS: E_p = 43.11 in E_l = 31.04 in E_r = 19,860 ac ft

	MAY	JUNE	JULY	AUG	SEPT	OCT	OTHERS
LAKE WALCOTT (MINIDOKA) 107,000 **ac ft capacity**							
C_r	94500	94400	94300	86600	71300	66300	71800
A_r	14250	14200	14150	13750	13250	13150	13300
E_p	8.33	10.53	12.97	11.57	8.42	4.78	13.28
E_l	6.00	7.58	9.34	8.33	6.06	3.44	9.56
E_r	7130	8970	11010	9540	6690	3370	10600
TOTALS: E_p = 69.88 in E_l = 50.31 in E_r = 57,710 ac ft							
PALISADES 1,402,000 **ac ft capacity**							
C_r	1115900	1300500	1137400	942800	858300	836600	975600
A_r	13400	15500	13650	12050	11300	11080	12330
E_p	5.71	7.11	8.87	8.09	5.54	3.00*	8.99
E_l	4.11	5.12	6.39	5.82	3.99	2.16	6.47
E_r	4590	6610	7270	5840	3760	1990	6650
TOTALS: E_p = 47.31 in E_l = 34.06 in E_r = 36,710 ac ft							

* -- Estimated value

C_r -- Reservoir average monthly contents (ac ft) (IWRB, 1972)

A_r -- Reservoir surface area (ac) for the monthly contents from reservoir curves (IWRB, 1968 pp. 357-9, 365, 374)

E_p -- Average monthly pan evaporation (in) (IWRB, 1968 p. 63)

E_l -- Lake evaporation (in) = 0.72 E_p (IWRB, 1968 p. 63)

E_r -- Reservoir evaporation (ac ft) = $A_r \times E_l/12$

OTHERS -- Other six months of the year, Nov-Apr, where:

C_r is the average monthly contents for Nov-Apr,

E_p is determined from the months May-Oct being 0.82 of the average yearly E_p ($E_p = \sum_{M-O} E_p/0.82$) (IWRB, 1968 p. 63)

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