Simulation of irrigation and reservoir water use in the Canyon Ferry drainage basin
by Denise Kelley DeLuca

A thesis submitted in partial fulfillment of the requirements for the degree of Master of Science in Civil Engineering
Montana State University
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Abstract:
A water rights conflict exists between hydropower and proposed future irrigation water uses in the Canyon Ferry Reservoir drainage basin of southwestern Montana. The goal of this study was to determine how projected increases in upstream irrigation development would affect power production and spill volumes at the reservoir, and whether reservoir operating policies could be modified to produce more power and less spillage under both present and projected future irrigation conditions.

Two related computer models were developed to simulate irrigation water use in the basin and subsequent water use in the reservoir downstream. Three upstream irrigation conditions were simulated: (1) no irrigation, (2) present levels of irrigation, and (3) projected future levels of irrigation, representing a 100,000 acre increase in sprinkler irrigated land.

Based on 35 simulated years of data, it was found that a 15.8% increase in irrigated acreage would cause a 3% reduction in average annual reservoir inflow volume, a 1.3% reduction in average annual power production, and a 15.8% reduction in average annual spill volume. Average monthly inflows and power production, however, would become more uniform throughout the year. It was also found that more power and less spillage would be generated under both present and projected future irrigation conditions if the reservoir's spring target elevation were lowered and the summer fill date were delayed.

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A thesis submitted in partial fulfillment
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Bozeman, Montana

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ABSTRACT

A water rights conflict exists between hydropower and proposed future irrigation water uses in the Canyon Ferry Reservoir drainage basin of southwestern Montana. The goal of this study was to determine how projected increases in upstream irrigation development would affect power production and spill volumes at the reservoir, and whether reservoir operating policies could be modified to produce more power and less spillage under both present and projected future irrigation conditions.

Two related computer models were developed to simulate irrigation water use in the basin and subsequent water use in the reservoir downstream. Three upstream irrigation conditions were simulated: (1) no irrigation, (2) present levels of irrigation, and (3) projected future levels of irrigation, representing a 100,000 acre increase in sprinkler irrigated land.

Based on 35 simulated years of data, it was found that a 15.8% increase in irrigated acreage would cause a 3% reduction in average annual reservoir inflow volume, a 1.3% reduction in average annual power production, and a 15.8% reduction in average annual spill volume. Average monthly inflows and power production, however, would become more uniform throughout the year. It was also found that more power and less spillage would be generated under both present and projected future irrigation conditions if the reservoir's spring target elevation were lowered and the summer fill date were delayed.

CHAPTER 1

INTRODUCTION

Background

During the past several years, the Montana Department of Natural Resources and Conservation (DNRC) has deferred action on numerous applications for water-use permits in the Canyon Ferry drainage basin pending resolution of objections filed by downstream senior water rights holders. Under the Water Use Act (1973) the DNRC must confirm and insure protection of the existing water rights before it can grant any additional upstream water-use permits. The two major objectors, the Montana Power Company (MPC) and the U. S. Bureau of Reclamation (USBR), argue that there is no unappropriated water above Canyon Ferry reservoir, and that any additional appropriations would deplete water needed for hydropower and existing downstream irrigation. Both objectors agree that during certain months of some years water exists in excess of their rights; however, the quantity and regularity of water availability are still open to question.

Water availability studies for the basin above Canyon Ferry Reservoir have been carried out by several investigators. Fitz (1981) and Thompson (1983) reported on the water availability and MPC and USBR water usage in the Upper Missouri River basin. These reports outlined how much water is potentially available for future upstream irrigation appropriations. However, the hydrologic effects of each water use on the basin and its other water users are complex and are often not immediately apparent. For example, Flanagan (1983) found that improving upstream irrigation efficiency would result in more variable

Canyon Ferry inflows and subsequent reductions in average annual power production potential. Continuing this study, Brustkern (1986) found that increasing upstream irrigation would have "minimal and mixed impacts" on the Canyon Ferry reservoir operations. Specifically Brustkern concluded that although annual power production would be slightly reduced, spring flood control would be enhanced and winter power production would be increased. Increasing upstream irrigation efficiency, however, was found to both increase spring flood potential and decrease annual power production. This suggests that increasing irrigation efficiency would have almost the opposite effect of increasing irrigated acreage. Brustkern's study considered the individual impacts of increasing irrigation efficiency and irrigated acreage, leaving the combinations of such effects open to further investigation.

Since virtually all of the land suitable for flood irrigation in the Canyon Ferry basin is in use, it is projected that any future irrigation development would be under the more efficient sprinkler type systems. Therefore, the combined effects of the projected increases in irrigated acreage with the corresponding increase in irrigation efficiency must be better understood. Accordingly, the goal of this project is to determine the effects of projected increases in upstream irrigation development on potential water uses at Canyon Ferry reservoir under different operating criteria.

Objectives

The project goal was attained by completing the following

objectives: (1) determine how the projected levels of upstream irrigation development would modify the monthly and annual inflows to Canyon Ferry reservoir, (2) determine how the modified inflows would affect reservoir water uses, including monthly and annual power production and spillage, and (3) determine what modifications, if any, could be made in the current reservoir operating criteria to increase annual power production and/or decrease annual spillage under both current and projected future levels of upstream irrigation development.

These objectives were accomplished by developing separate computer simulation models for the water use area above Canyon Ferry Reservoir and for the reservoir itself. These models, which are based on a water balance over a monthly time step, were run in series. The water use model simulates the interactions between irrigation water use, groundwater storage and streamflows above Canyon Ferry, and subsequently develops monthly reservoir inflow sequences. Hence this model can determine the monthly inflow sequence to Canyon Ferry reservoir corresponding to any specified level of upstream irrigation development. This model represents an extension of the Brustkern (1986) model in that it, among other things, differentiates between numbers of flood and sprinkler irrigated acres. The second model takes the inflow sequences generated by the basin model, passes them through the Canyon Ferry reservoir, and computes the amount of power and the volume of spillage produced at the reservoir during each month. The Canyon Ferry reservoir model is also capable of simulating the effects of alternative reservoir operation policies. The steps taken in accomplishing the outlined objectives are summarized below.

Irrigation Water Use

Data Collection. The initial project step involved gathering information describing basin hydraulic and hydrologic characteristics and historical irrigation activities. These data are presented in Appendix A.

Development of the Irrigation Water Use Model. The basin water use model was developed to simulate the interactions between irrigation activities in the basin and basin outlet streamflows. This model consists of a series of water balance equations which account for streamflow, diversion, conveyance, evapotranspiration, and return flow on a monthly time step.

Generation of the Natural Reservoir Inflows. The natural inflows represent the inflows to Canyon Ferry reservoir that would have occurred under natural or "no-irrigation" conditions in the basin. They were developed by running the model in reverse with 35 years of historical monthly Canyon Ferry inflows and input parameters describing historical irrigation conditions in the basin. Once developed, the natural inflow sequence became part of the input parameter set for the basin model and was used throughout the rest of the simulation runs. The concept of using natural inflows was developed by Flanagan (1983) and Brustkern (1986).

Reservoir Operations

Data Collection. This step involved gathering information describing the hydraulic characteristics and operating policies of the Canyon Ferry reservoir. The major sources of these data were Brustkern

(1986) and the USBR Technical Report of Design and Construction for Canyon Ferry Dam and Power plant (1957).

Development of the Reservoir Operation Model. The reservoir operation model is also based on a series of water balance equations. Major output variables include monthly releases, spills, power production, and reservoir water surface elevations.

Simulation Runs

Simulation of Irrigation Water Use for Various Levels of Upstream Irrigation Development. The basin model was initially used to simulate six different levels of irrigation development in the basin by running the model with varying numbers of flood and sprinkler irrigated acres. The six conditions represented natural, historical, present, and present plus 25, 50, 75, and 100 thousand additional sprinkler irrigated acres. The "present" level of irrigation represents 1984 conditions when there were an estimated 493,985 acres under flood irrigation and 139,329 acres under sprinkler irrigation. After examining the resulting reservoir inflow sequences, it was decided that only the inflow sequences generated under the (1) "natural" (no-irrigation), (2) "present" irrigation, and (3) "projected future" (present + 100,000 acres) irrigation conditions should be run through the reservoir model, as the effects of other incremental levels were relatively minor.

Simulation of Reservoir Operations and Water Use. The three inflow sequences described above were run through the reservoir operations model using the current published operating criteria. The

resulting average monthly power production and spill volume values were plotted and the full output record was examined for extremes in reservoir elevation, power production, and spill volumes.

Optimization of Reservoir Operating Criteria. After examination of the results of the reservoir water use simulation runs, it was decided that lowering the spring reservoir drawdown level and delaying the summer reservoir fill date would be desirable reservoir operation modifications to investigate. The present and projected future inflow sequences were run through the reservoir model a number of times, lowering the spring drawdown level by one foot with each run. This procedure was repeated using an August 1st rather than the original July 1st fill date.

The following report will describe the Canyon Ferry drainage basin study area, explain the development of the basin and reservoir models, present the results of each project objective, and finally discuss the conclusions drawn from the study results.

CHAPTER 2

STUDY AREA

The Canyon Ferry drainage basin covers the 15,900 square miles of southwestern Montana east of the Continental Divide and west of the Bridger and Gallatin ranges (Figure 1). Mountain snowmelt creates the many small streams that feed the Madison and Gallatin rivers along with the Big Hole and Beaverhead tributaries of the Jefferson river. Together these streams form the headwaters of the Missouri river and pour more than 4 million acre-feet of water into Canyon Ferry reservoir each year (USGS, 1984). The geography of the basin is characterized by its many mountain ranges, forests, and broad river valleys. The rigorous climate is considered semi-arid, with an average of 15" of precipitation falling in the river valleys annually (Flanagan, 1983).

Land use in the basin is dominated by agriculture. With the decline of the gold rush, and the passage of several federal land acts around the turn of the century, agriculture surpassed mining to become Montana's primary source of income. The most productive lands in the Canyon Ferry drainage are the irrigated areas on the valleys, benches, and alluvial fans along the headwater rivers. Although the growing season is short, the inherently fertile soils in this region lend themselves well to the production of small grain and forage crops.

Because of the dry climate these crops are irrigated where possible. Currently there are approximately 630,000 irrigated acres in the basin, although historically this value has ranged from a maximum

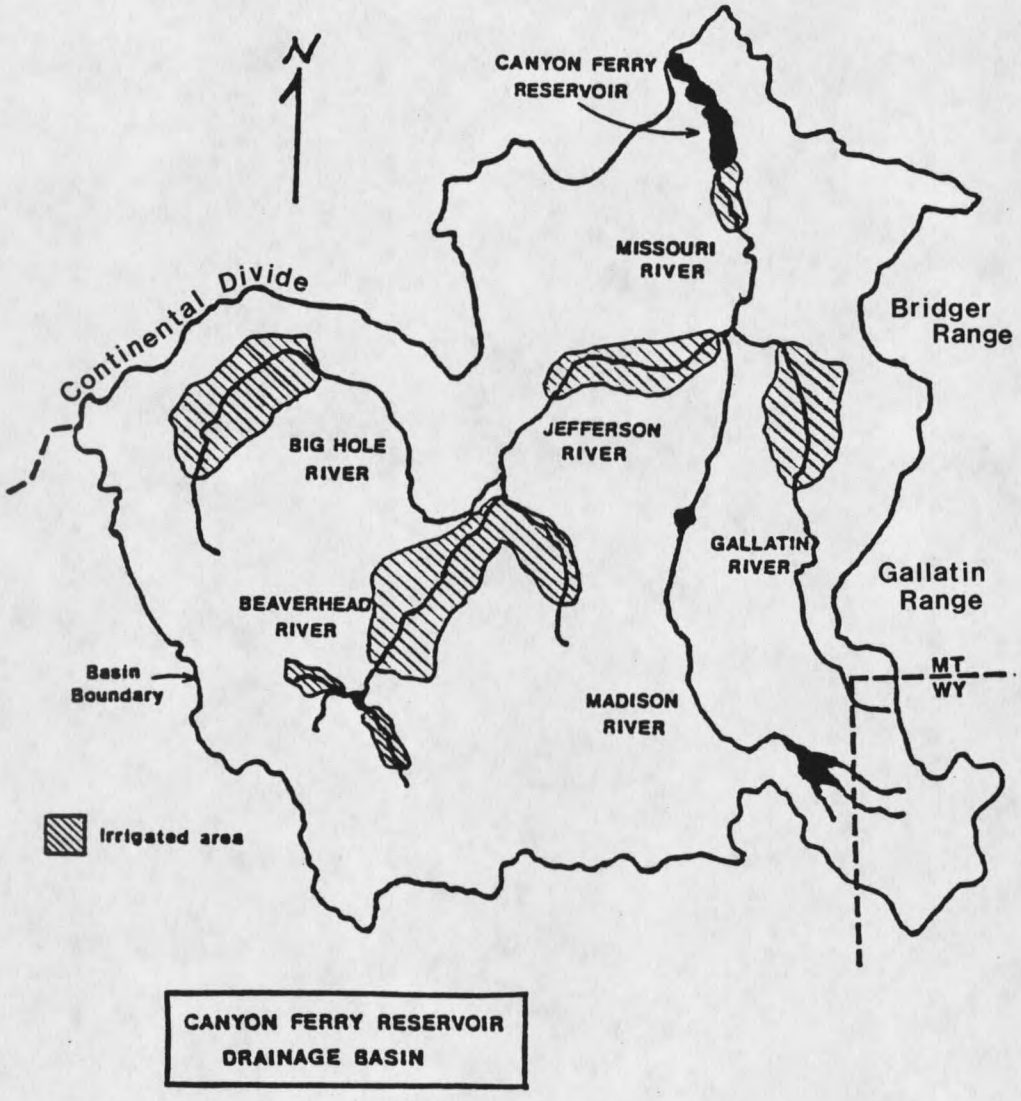


Figure 1. Major rivers and irrigated areas in the Canyon Ferry Reservoir drainage basin

of 713,000 acres in 1954 down to 525,000 acres in 1983 (Figure 2)(MBSA, 198-). About 90% of the irrigated land is devoted to forage crops, with the rest planted in small grains, potatoes, and various small horticultural crops (MT Ag. Stats., 1985). Until the mid-1950's, flood-type irrigation systems covered virtually all of the irrigated acreage in the basin. Since then the more efficient sprinkler type systems have become increasingly popular and now account for over 20% of the basin's irrigation (MBSA, 198-). Although irrigated fields can be found along streams located throughout the basin, the irrigation practices and subsequent hydrologic responses of these different areas are quite similar, as described below.

The irrigation process begins when water is diverted from a local stream into a typically unlined canal for conveyance to the fields. Approximately twice as much water is diverted from the stream as will be applied to the fields (SCS, 1978). Some of the diverted water, called carriage water, is necessary to maintain water levels that permit diversions from the canals. The carriage water runs through the conveyance system then returns to the source stream. The rest of the excess diverted water is either not used and returned with the carriage water, infiltrated through the canal beds into the surrounding soil, or consumed by phreatophytes and evaporation.

The portion of irrigation water that reaches the field is applied by either surface or sprinkler irrigation methods (Figure 3). Gilley et al. (1982), discusses what happens to the water once it is applied to the field using both surface and sprinkler irrigation systems. With surface irrigation, water flows by gravity from the upper to the lower

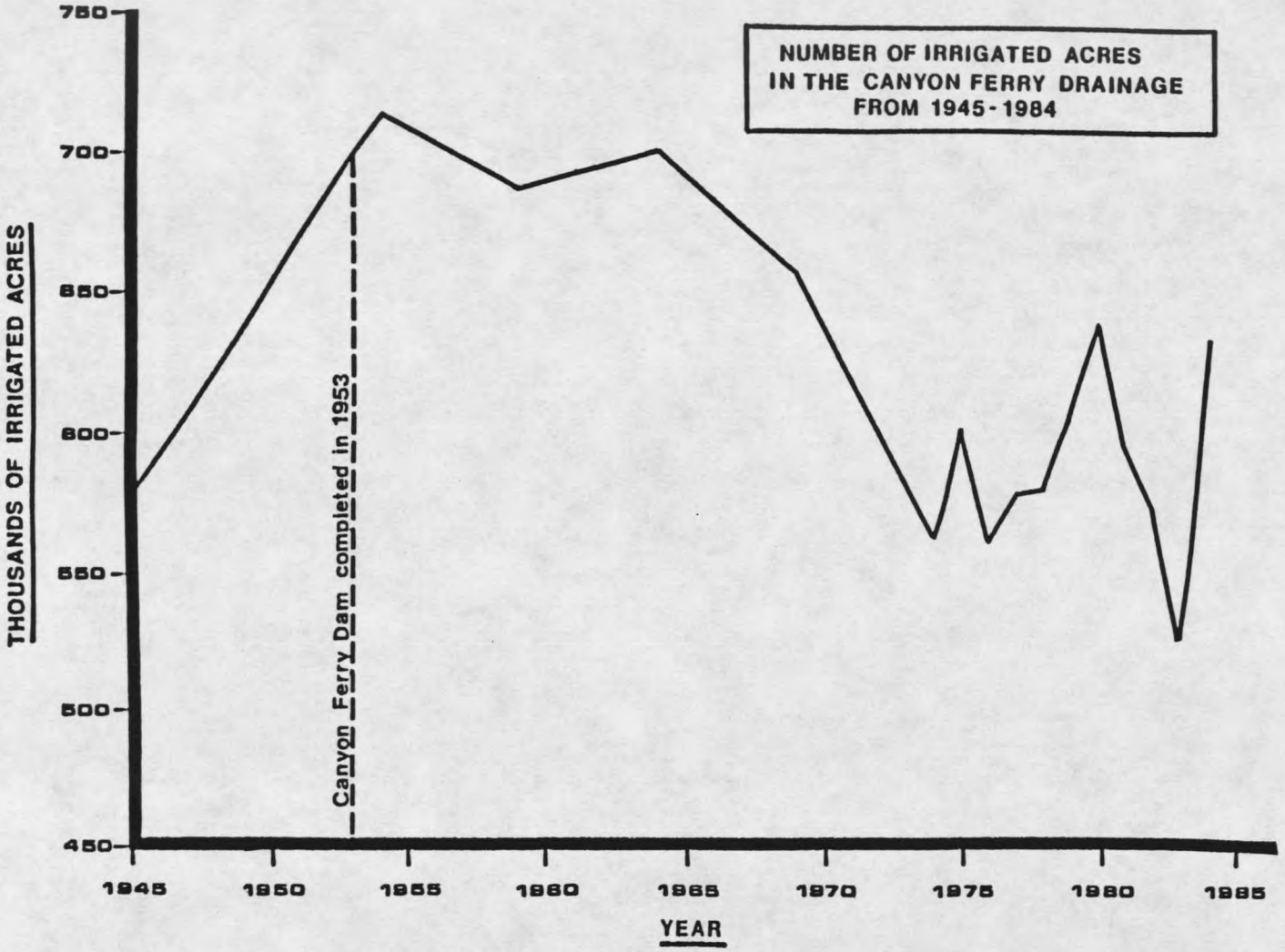


Figure 2. Total numbers of irrigated acres in the Canyon Ferry drainage basin between 1945 and 1984

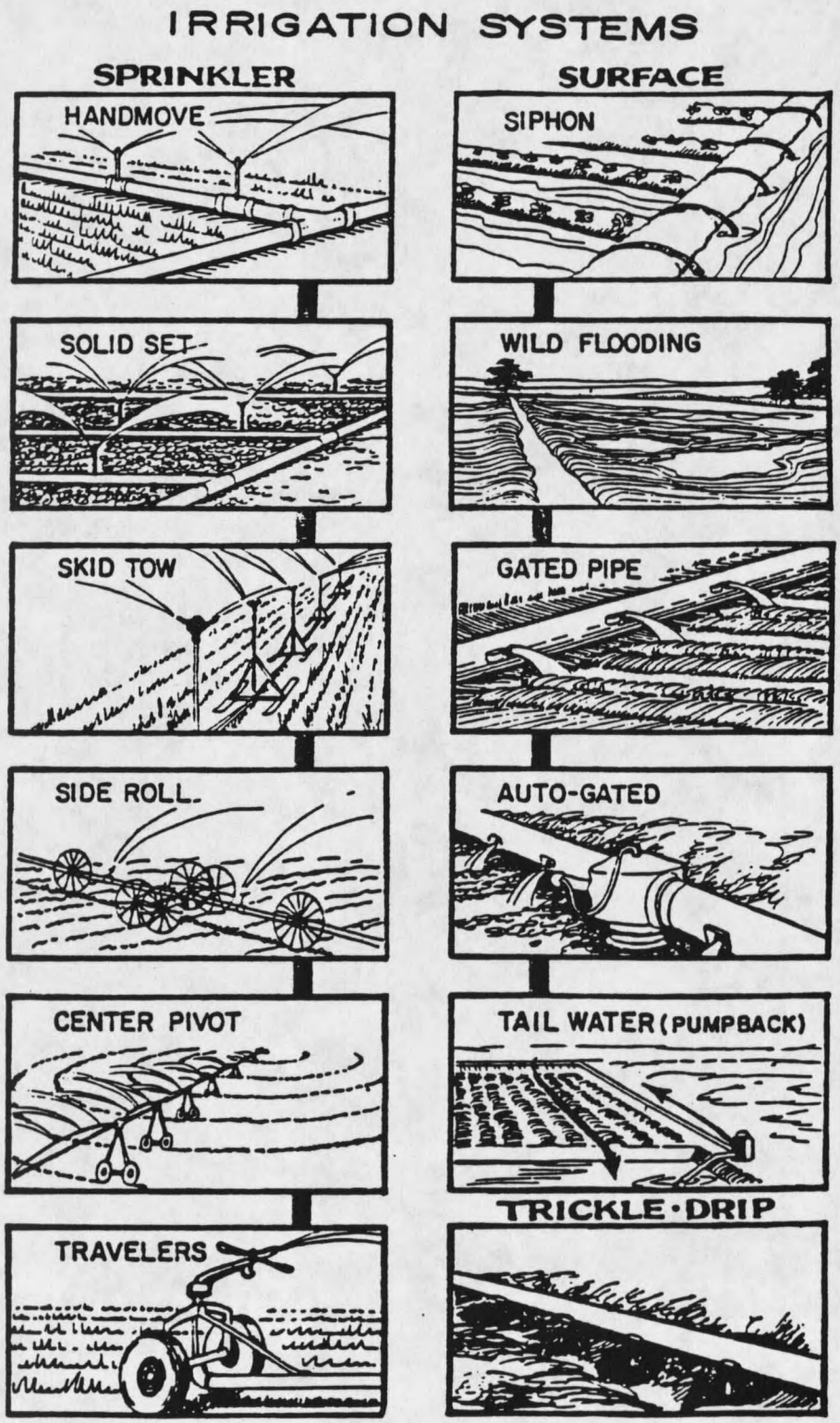


Figure 3. Examples of surface and sprinkler irrigation systems (Gilley et al.,1982)

end of the field. The simplest version of this method is called "wild flooding." In this case the end of the irrigation ditch is blocked, causing the water to flow out over the sides of the ditch and across the field. Other surface methods allow better control by employing siphon tubes to transfer the water to either furrow or border irrigated fields.

With sprinkler methods, water is pumped from the irrigation ditch to the sprinkler system where it is then sprayed on the field through a set of nozzles. The sprinkler apparatus can be moved over the field manually or automatically to uniformly distribute the water during a given irrigation cycle. With either the surface or sprinkler methods, the amount of water applied to a field must be somewhat greater than the net crop water requirement in order to compensate for unavoidable losses to surface runoff, deep percolation, nonuniformity of application, and, in the case of sprinkler systems, evaporation and wind drift losses during application. In a well-run system, the rate of irrigation water application is proportional to factors such as soil infiltration rate, field size and slope, crop type and maturity, and current climatic conditions.

Most of the inefficiencies in these systems arise from over irrigation caused by excessively high application rates and irrigation run lengths. When the irrigation application is greater than the soil infiltration capacity, excess water starts to collect on the soil surface. Most of the accumulated water eventually becomes surface water runoff, although some will stay on the soil surface and infiltrate after the irrigation period. Most of the excess infiltrated

water percolates below the root zone and thus cannot be used by the growing crops.

Irrigation water that is consumed by crops, phreatophytes, and evaporation is lost to the basin system. About 60% of the water diverted for irrigation in the Canyon Ferry basin is consumed (SCS, 1978). The remaining 40% of the diverted water is classified as either "surface" or "subsurface" irrigation losses. This water is lost to the irrigator, but not lost to the basin as a whole. For example, the carriage water and tailwater that comprise surface losses return to the source streams relatively quickly, and can be rediverted by another irrigator downstream. The subsurface losses percolate through the soil to the underlying aquifer where they become part of the groundwater system. This water also returns to the source streams, though not as quickly as do the surface losses. The aquifer acts as an underground reservoir for this water, letting it return back to the stream over a long period of time. The actual rate of return depends on the distance from the point of irrigation application to the stream and on local aquifer properties. In the Canyon Ferry basin it has been estimated that about 22% of the irrigation water that reaches the groundwater in a given month returns to the stream within that month, and that about 75% returns within 6 months (Brustkern, 1986).

CHAPTER 3

IRRIGATION WATER USE

Data Collection

Developing a detailed model to simulate the effects of basin-wide irrigation on basin outlet streamflows requires collecting geologic, hydrologic, and geographic information to describe the basin. Specifically, data are needed to define sizes and locations of irrigated fields, crop and soil types, rainfall quantities, irrigation system types and efficiencies, conveyance efficiencies, aquifer locations and properties, and streamflow patterns. In the case of the Canyon Ferry water-use model, the types and quantities of data available substantially dictated model design. Sufficient information was found to develop parameter values that could describe average annual or average monthly irrigation conditions for the basin as a whole. For the interested reader, the specific data used to develop model parameters and variables are presented in Appendix A. Since data were not available for individual farms, the model design had to represent the basin as one large, aggregated area which could be described only by generalized parameters. Even if it had been possible to model each irrigated field separately, the desired model results did not warrant such detail.

In light of the data limitations, there are several reasons why this lumped parameter representation of the basin is acceptable and even desirable. First, the purpose of the model was to generate the sequence of monthly basin outflow volumes that would occur under a

specified number of irrigated acres in the basin. Since this study was not concerned with the streamflow patterns occurring in the upper reaches of the basin, there is no reason to consider the local impacts of individual farms separately. Second, it has been shown that certain descriptive parameters, such as irrigation efficiency, can vary radically from one farm to the next in the basin, and even from one irrigation run to the next on the same field (USBR, 1970-71). To successfully use a single value to describe such a variable parameter, it would have to be used to represent the average of several fields and several irrigation runs. This is accomplished by the model by combining the many irrigated fields into just two large fields and making computations with a monthly time-step. Since the travel times for the basin are less than 5 days (Brustkern, 1986), the monthly time step can cover several irrigation runs, and thus successfully mask the individual impacts of each farm. Finally, the irrigation practices and corresponding hydrologic responses on the various farms in the basin are, in general, quite similar. This supports the use of generalized parameter values to describe the hydrologic behavior of the Canyon Ferry Drainage basin. Without such simplifying assumptions, little progress can be made towards improving water resources management. As Glover (1960) points out in the introduction to his Transient Groundwater Hydraulics text, "if the criticisms leveled at those useful assumptions were to be taken seriously, we should find ourselves obligated to discard the great bulk of engineering formulas used so successfully over the past 200 years, since a close scrutiny of their

bases will reveal shortcomings as bad or worse than those outlined above."

Basin Model Development

The Canyon Ferry basin irrigation water-use model simulates the effects of varying levels of upstream irrigation development on basin outlet streamflows. Specifically, the model carries out a series of time-stepped mass balance computations that computes the volumes of irrigation water diverted, consumed, and returned to the source streams during each month of simulation.

Although irrigated fields and source streams are found throughout the Canyon Ferry drainage, the model represents the basin with one large source stream running through one plot of sprinkler irrigated and one plot of flood irrigated land, as shown in Figure 4. As explained in the data development section, this simplified representation of the basin was necessary due to data limitations, but is still quite useful for the purposes of this project.

The basin model requires both input parameters and simulation variables. The input parameters are fixed values which describe the hydrologic response of the basin to irrigation activities. The simulation variables, which can be changed with each simulation run, describe the levels and types of irrigation development being simulated during a given model run. The input parameters include:

1. Irrigation system and conveyance efficiencies
2. Field and canal infiltration rates
3. Monthly portions of annual irrigation requirements
4. Groundwater return flow rates

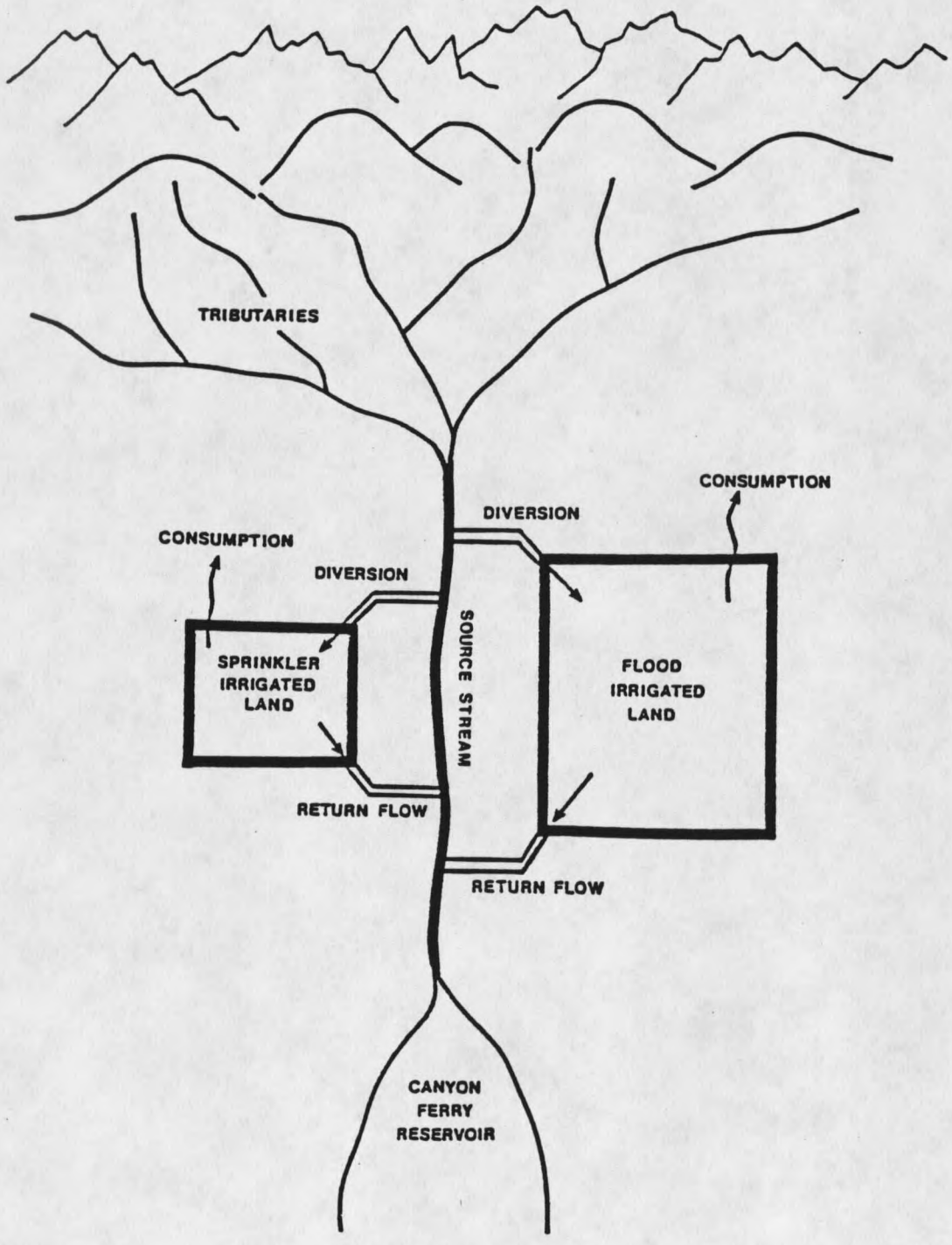


Figure 4. Simplified representation of the Canyon Ferry drainage basin

5. Non-crop consumption of irrigation water

6. Monthly basin inflows

The simulation variables include:

1. Numbers of flood and sprinkler irrigated acres

2. Annual crop irrigation requirements

For specific parameter and variable development, see the data processing section in Appendix A.

Figure 5 illustrates the flow pattern of the stream and diverted irrigation water that is assumed by the model, and also schematically represents the corresponding series of mass balance computations performed by the model for each month of simulation. In general the model computes basin outflows using the following mass balance relations:

Basin Outflow = River Bypass + Irrigation Return Flows

River Bypass = Natural Inflows - Diversions

Diversions = Crop Water Consumption + Farm Water Losses* + Canal Water Losses*

Irrigation Return Flows = Surface Return Flows + Groundwater Return Flows.

*(Farm and canal losses include both consumptive and non-consumptive losses of irrigation water)

Following along with the numbers circled on the basin model diagram, the specific mass balance computations carried out by the model are sequentially explained in the paragraphs below.

1. The model begins by determining the amount of water needed by the crops on both the sprinkler and flood irrigated fields. This is

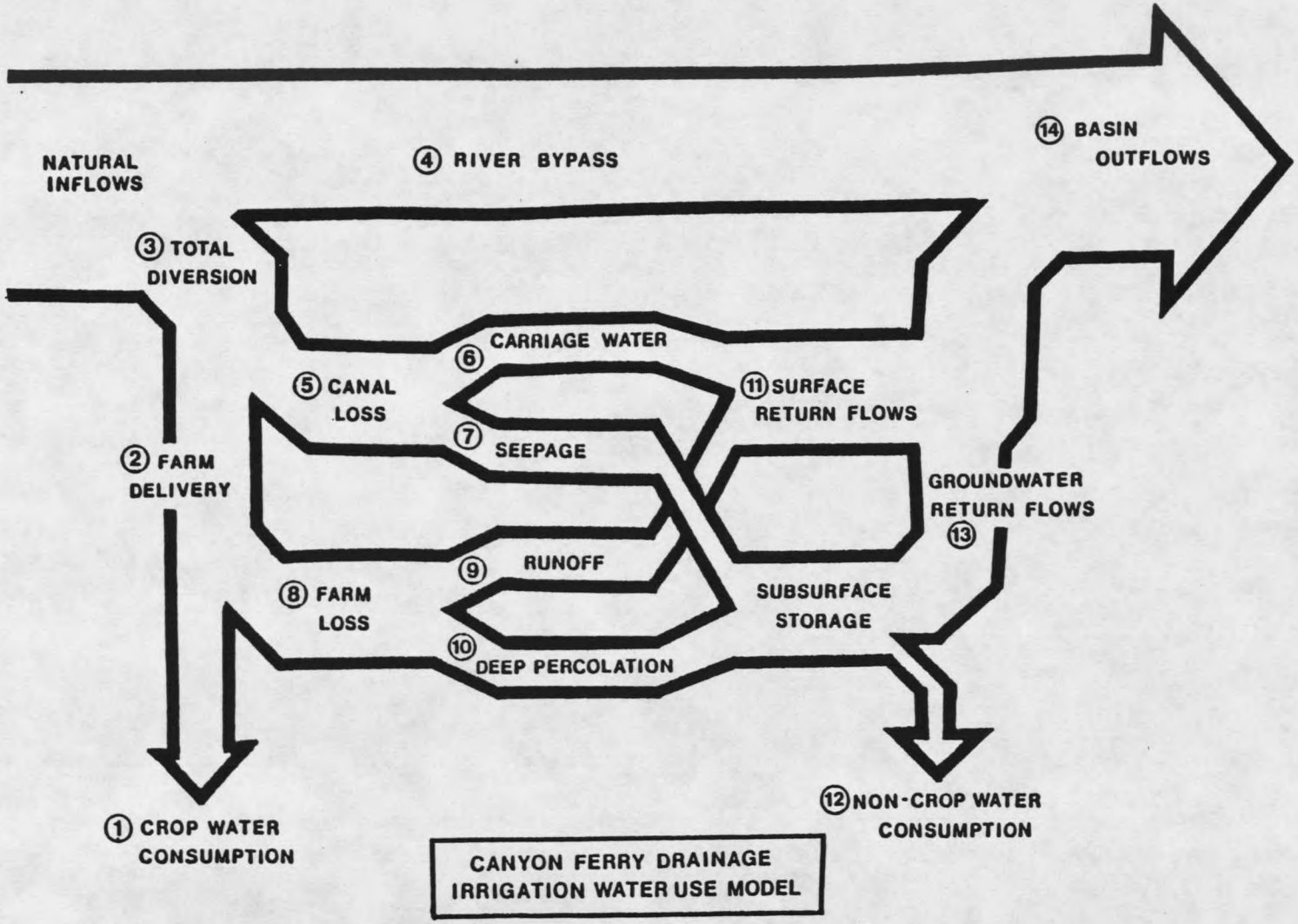


Figure 5. Simplified representation of irrigation water use in the Canyon Ferry drainage basin

accomplished by multiplying that month's portion of the annual crop irrigation water requirement by both the number of flood and the number of sprinkler irrigated acres.

2. Next the model determines how much water must be delivered to the two fields to satisfy the computed crop needs. This "farm delivery" is defined as the field water requirement divided by the respective irrigation system efficiencies.

3. The amount of water that must be diverted from the source stream to meet the irrigation requirements of the two fields is determined by adding the farm delivery requirements for the two fields and dividing their sum by the overall conveyance efficiency.

4. The river bypass is found by subtracting the diversion from the natural inflows.

5. With the required diversion computed, the model can determine the amount of water that is lost to the irrigators in conveyance to the fields. This is computed as the difference between the amount of water diverted and the amount required to satisfy farm deliveries. The model divides these canal losses into surface and subsurface losses, as dictated by the input canal infiltration rate.

6. The surface canal losses, which include carriage water, excess diversion water, and operational spills, are computed by multiplying the total canal loss by a fixed percentage.

7. The subsurface canal losses, which include canal seepage and some non-crop water consumption, are similarly computed.

8. The next set of computations involve water losses on the irrigated fields. The farm water losses, which include all the water

that is delivered to the irrigated fields but not consumed by the crops, are computed as specified percentages of the farm delivery water. Farm losses for the sprinkler and flood irrigated fields are computed separately, and are each divided into surface and subsurface losses, according to input field infiltration rates.

9. The surface farm losses include surface runoff, tailwater, and operational spills, and are computed as a fixed percentage of the total farm loss.

10. The subsurface farm losses, which include the water that infiltrates below the root zone of the crop and that either joins the groundwater or gets consumed by phreatophytes and evaporation, are also computed as fixed percentages of the total farm loss terms. The percentages used to calculate surface and subsurface losses are different for the sprinkler and the flood irrigated fields.

11. Once the losses are computed, the model can begin to compute the irrigation return flows. The surface return flows are simply the sum of the surface losses from the canals and the irrigated fields. Since this water is currently flowing through the various canals and diversion ditches, it is able to return to the source streams during the same month that it was originally diverted.

12. Before groundwater return flows can be computed, all of the non-crop water consumption in the basin is accounted for. Consumptive water losses occur during every process involved with irrigation activity. Water is constantly evaporating off the free water surfaces created in the diversion canals and tailwater ponds, as well as off the wetted soil surfaces on the fields and along the canals. Weeds and

phreatophytes found along canals and in and around fields also consume the water that is intended for crops. Since data describing evaporation and phreatophyte water consumption are not available, it is assumed for computational purposes that all non-crop water consumption comes out of the subsurface water losses. Therefore, non-crop water consumption is computed by multiplying the sum of the subsurface water losses by a fixed percentage.

13. The remaining subsurface water losses are allowed to percolate down to the underlying aquifer to join the groundwater system. Since water movement through the soil and aquifer is quite slow, only a portion of the water reaching the aquifer each month returns to the source stream during the same month that it was diverted. The rest of this water returns gradually over a number of months as dictated by aquifer hydraulic properties. The specific rates of the groundwater return flows are discussed in the Return Flow Analysis section in Appendix D.

14. The final computation performed by the model is to determine the basin outlet streamflow value. This is computed by adding the river bypass, the surface return flow, and that month's groundwater return flow. The computed basin outflows are equivalent to the Canyon Ferry reservoir inflows.

This sequence of computations is repeated for each month and year of simulation. The program output includes monthly and average value of irrigation diversions, irrigation return flows, and basin outflows. (A copy of the Irrigation Water Use Model can be found in Appendix B).

The irrigation water use model differentiates between flood and sprinkler irrigation as well as between canal and farm water losses. To illustrate these differences, the mass balance equations have been combined with the descriptive input parameters to yield flow distribution equations presented in Table 1. Using these equations, one can determine how much water is diverted, consumed, and returned for each flood and sprinkler irrigated acre in the basin annually. Based on these equations 4.90 acre-feet of water must be diverted for every flood irrigated acre from which 39% is returned to the source stream within the month as surface return flow. In addition 31% is returned slowly through the aquifer system, 8% is lost to weeds and evaporation, leaving the remaining 22% to be consumed by the crops for which the water was diverted. Sprinkler irrigation systems divert only 2.45 acre-feet of water per irrigated acre. Of this diversion 32% is returned to the source stream within the month, 20% is returned slowly through the aquifer, 5% is lost to weeds and evaporation, leaving 48% of the diverted water to be consumed by the crops.

Table 1. Irrigation Water Use Model Average Annual Flow Distribution Equations

---

#S = Number of sprinkler irrigated acres in the basin
#F = Number of flood irrigated acres in the basin
C = Contribution from the canal system
S = Contribution from the sprinkler irrigated acres
F = Contribution from the flood irrigated acres

Total Diversion = [(2.445)*(#S)+(4.898)*(#F)]/(#S + F) ac-ft/ac

Crop Water Consumption = 1.061 ac-ft/ac

Non-crop Water Consumption =

C: [(0.088)*(#S)+(0.177)*(#F)]/(#S + #F) ac-ft/ac

S: 0.037 ac-ft/sprinkler irrigated acre

F: 0.208 ac-ft/flood irrigated acre

Surface Return Flows =

C: [(0.611)*(#S)+(1.222)*(#F)]/(#S + #F) ac-ft/ac

S: 0.151 ac-ft/sprinkler irrigated acre

F: 0.692 ac-ft/flood irrigated acre

Groundwater Return Flows =

C: [(0.354)*(#S)+(0.708)*(#F)]/(#S + #F) ac-ft/ac

S: 0.147 ac-ft/ac

F: 0.832 ac-ft/ac

Note that the annual groundwater return flows computed above would not all return within one year, but would be spread out over a series of 36 months as dictated by the return flow factors.

Natural Inflows

"Because simulation entails a mathematical abstraction of real world systems, some degree of misrepresentation of system behavior can occur. The extent to which the model and system output vary depend on many factors. The test of a developed simulation model consists of verification by demonstrating that the behavior is consistent with the known behavior of the physical system." (Viessman, et al., 1977)

Verifying the Canyon Ferry water-use model would require running the model using known historical basin inflows with the estimated historical descriptive parameters, and comparing the computed basin outflows with the historical basin outflow records. However, this type of calibration process was impossible to carry out for the Canyon Ferry model. Although there are adequate streamflow records to cover the historical basin outflows, there are no such records available to represent the inflows to the basin, as it is represented in the model. This is because the basin model inflows, called "natural inflows" in the model, are hypothetical streamflows which do not correspond to any physical location or quantities in the real basin. They represent the inflows to Canyon Ferry reservoir that would have occurred under the natural, no-irrigation conditions. Specifically, they are the flows generated when the model is run 'backwards', with the known historical basin outflows used as basin inflows. In this manner, the streamflows that are generated represent the historical basin outflows with the effects of irrigation removed.

Comparisons were made between the computed natural inflows to streamflow records from several gages located throughout the basin. Straight line double mass plots indicated that the natural inflows generated by the model followed the same annual trends as the actual

streamflows found in the basin. Plotted hydrograph shapes showed good comparisons between the generated natural inflows and actual basin streamflows on a monthly time scale. However, it is important to note that since the natural inflows are hypothetical, there is no way to calibrate the model or test the model's ability to accurately represent the effects of irrigation on basin outlet streamflows.

CHAPTER 4

RESERVOIR OPERATIONS

Reservoir Description

The Canyon Ferry reservoir was built in 1954 as part of the Missouri River Basin project. The intended purpose of the project was to provide regulation of runoff for power generation and to permit increased diversions in the upper Missouri River Basin, both upstream and downstream from the dam. The proposed diversions included water for irrigation of 305,500 irrigable acres of new land, and for supplemental irrigation supplies for another 187,700 acres. Although irrigation and low-cost power production are the two major benefits of this reservoir, other benefits include flood control, water provisions for municipalities, pollution abatement, silt control, recreation, and fish and wildlife resource enhancement (USBR, 1957).

When filled to its maximum water surface elevation of 3800 feet, the reservoir has a capacity of 2,040,900 acre-feet, a surface area of 35,700 acres, a length of 25 miles, and a maximum width of 4.5 miles. For purposes of operations, the reservoir is vertically divided into 4 sections (Figure 6). As of 1966 the top 3 feet, of the total capacity is allocated to the U.S. Army Corps of Engineers for exclusive flood control purposes. The next 27 feet of capacity is the joint-use storage. This space is normally used for power production, but can be evacuated for flood control if refill during the spring runoff season is reasonably assured. The active conservation storage takes up the remaining 42 feet of capacity above the inactive and dead storage (USBR, 1957). This space was designed to be used for power production

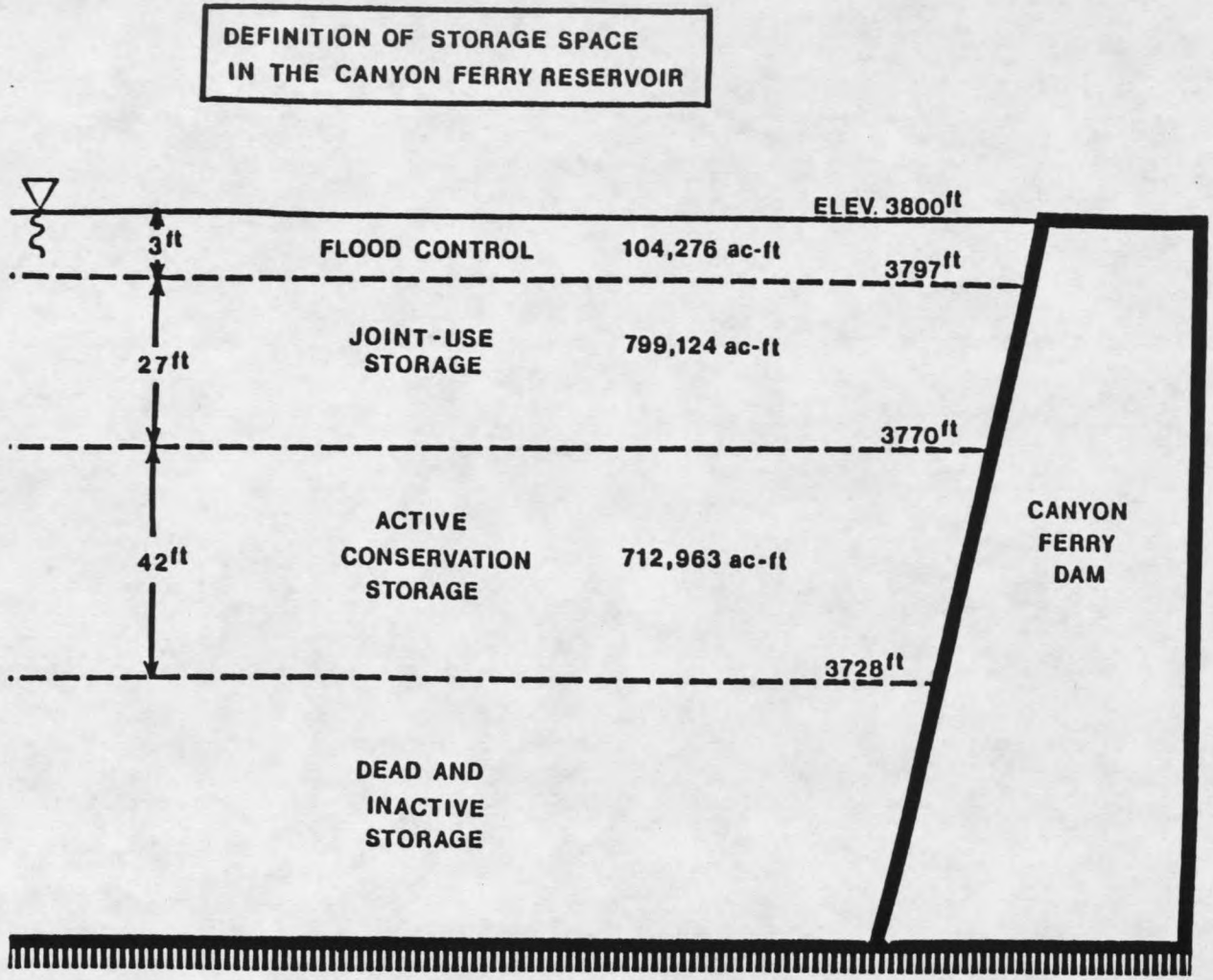


Figure 6. Vertical storage space allocations in the Canyon Ferry Reservoir

and to provide replacement storage for several new irrigation developments. To date, however, the conservation storage has been used primarily for power production (Thompson, 1984).

Inflows to the reservoir range from an average low of 171 thousand acre-feet in August to an average peak of 813 thousand acre-feet in June. The annual average inflow to the reservoir is approximately 4.1 million acre-feet (Brustkern, 1986).

The Canyon Ferry Dam, located at the north end of the reservoir, is a concrete gravity structure containing 3 power penstocks, one pumping intake, 4 river outlets, and a spillway controlled by 4 radial gates. The power plant, located at the downstream toe of the dam on the right abutment, contains three Francis-type turbines with 3 corresponding generators that have a combined installed capacity of 50,000 kw. (USBR, 1957).

The stated objectives of operations at Canyon Ferry reservoir are to meet all conservation commitments, to provide flood control in cooperation with the Army Corps of Engineers, and to coordinate all operations with the Montana Power Company to achieve optimum benefits from the water resource. Since Canyon Ferry is the first in a series of hydropower plants on the Missouri River, its operation must also be coordinated with the operations of all of the plants downstream.

In the fall, when the annual inflow forecast comes in, 3 operating plans are developed corresponding to the minimum, maximum, and most probable expected inflow sequence. For each operating plan, monthly releases are scheduled so as to bring the reservoir down to an

elevation of 3787 feet by October first, to an elevation of 3783 feet by March 1, and up to an elevation of 3797 feet, or full (excluding flood control storage), by July 1. The planned releases are adjusted every month and week as snowmelt and streamflow forecasts are updated (Aycock, 1986).

Reservoir Model Development

The Canyon Ferry reservoir operation model is comprised of a series of time-stepped mass balance equations driven by a set of target elevations, and controlled by both a power production policy and a downstream flow requirement. The model is designed to take the sequence of monthly reservoir inflows generated by the basin irrigation water-use model and compute the corresponding sequences of monthly reservoir elevations, total reservoir discharges, potential power production, and spill volumes.

Two types of data are required by the model. The input parameters describe the physical characteristics of the reservoir, and are considered to be fixed values for all simulation runs. The simulation variables, which can be changed with each model run, describe the reservoir inflows and the reservoir operating policy. The input parameters are:

1. The reservoir rating curve, which relates reservoir elevations to storage volumes.

2. The penstock rating curve, which relates elevations to penstock flow capacities.

3. The power production curve, which relates power turbine discharge to power production capabilities.

4. The minimum downstream flow requirements.

The simulation variables are:

1. The monthly reservoir inflows, which correspond to specific levels of upstream irrigation development. (Note: To simplify model calculations, the volume of water that is pumped to the Helena Valley irrigation unit each month is subtracted from the reservoir inflow volumes before they are entered into the model.)

2. The time schedule of target water surface elevations, which collectively define the reservoir operating policy.

Figure 7 illustrates the basic flow pattern through the reservoir, dam, and powerplant that is assumed by the model. It also schematically represents the sequence of mass balance computations performed by the model for each month of simulation.

The model begins by using the schedule of target elevations (the operating criteria) to determine the number and length of the forecast periods to be used in computations for every year of simulation. The forecast periods are the 2 to 5 month time intervals between those months for which target elevations have been set. With the forecast periods established, the model will perform a series of mass balance computations first over the length of the forecast period, and then again over each month within the period. In general, the model computes change in storage, outflows, and spillage during each forecast period using the following mass balance relations:

Change in Reservoir Storage Over Forecast Period =

End-of-Period Target Storage - Starting Storage

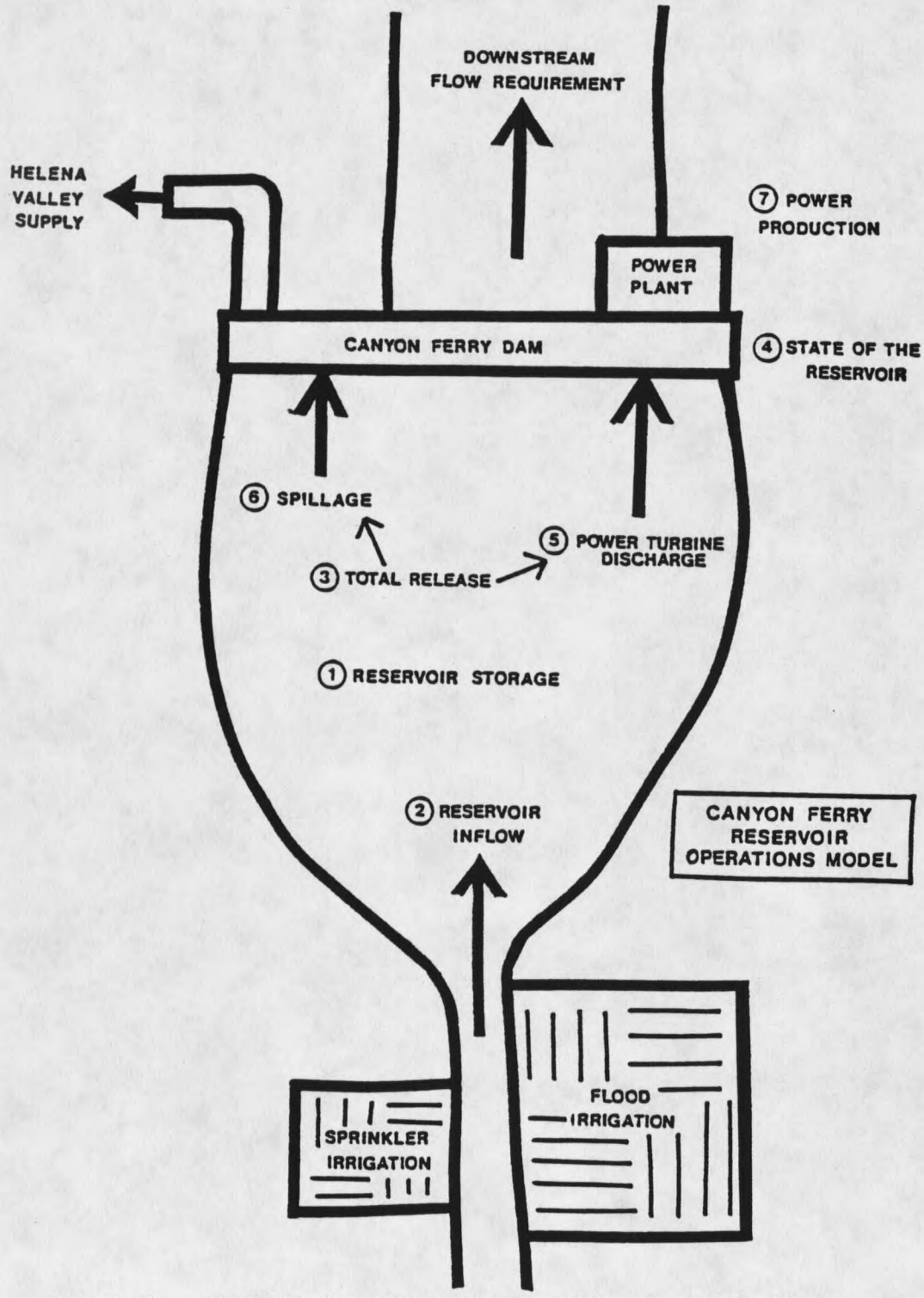


Figure 7. Simplified representation of water use in the Canyon Ferry Reservoir

Total Reservoir Outflow During Forecast Period =

Total Inflow - Change in Storage During Forecast Period

Reservoir Spillage = Total Outflow - Penstock Capacity

The specific model computations are explained sequentially in the paragraphs below. The step numbers correspond with those shown on Figure 7.

1. The first step is to compute the volume of water that must be added to or subtracted from the starting reservoir storage in order to reach a target elevation and corresponding reservoir storage by the end of the forecast period.

2. Next, the total volume of water flowing into the reservoir during the forecast period is computed by summing the known monthly reservoir inflows.

3. Knowing the total inflow volume and the desired change in reservoir storage for the forecast period, the total reservoir release required to reach the target elevation is computed. The monthly reservoir release is computed by dividing the total release for the period by the number of months in the period. If the computed monthly release is less than the minimum downstream flow requirement of 2500 cfs, the model sets the average monthly release equal to the minimum required. This insures that reservoir operations will not impair downstream fisheries or irrigation.

4. The sum of the inflows minus the sum of the releases is then used to determine the reservoir storage volume and elevation that is reached by the end of the forecast period.

5. At the end of each month within the forecast period, the model computes the net head on the power turbines and uses the penstock rating curve to determine the corresponding penstock discharge capacity. If the monthly reservoir release is greater than the penstock discharge capacity, the power turbine discharge is set equal to the penstock capacity. Otherwise, the power turbine discharge is set equal to the total monthly reservoir release. This approach insures the maximum possible power production and minimum possible spill volume for a given combination of reservoir inflows and releases.

6. The monthly spill volume is the difference between the total reservoir release and the power turbine discharge.

7. The amount of power that is generated during each month is computed as a function of power turbine discharge and reservoir storage volume. The model limits monthly production to the maximum amount of power ever produced in one month over the history of the reservoir. Theoretically, the powerplant could produce as much as 45.8 million kw-hrs in a one month period, but daily fluctuations in reservoir elevation, etc. seem to set the practical upper limit of power production at approximately 44.6 million kw-hrs monthly.

As indicated above, this set of computations are repeated for each forecast period and for each month throughout the duration of the simulation run.

It should be noted that the reservoir model, unlike the real reservoir, has perfect forecasting abilities throughout each forecast period, and can thus be operated under a fixed set of operating rules.

However, the fact that the model does not include the factors of uncertainty and variability that are a part of real reservoir operations greatly facilitates the comparison of results from different simulation runs. (A copy of the reservoir operations model can be found in Appendix C.)

CHAPTER 5

RESULTS AND DISCUSSION

Effects of Increased Upstream Irrigation on Canyon Ferry Inflows

The relationship between upstream irrigation and Canyon Ferry inflow is governed by both the size of the irrigated area and the irrigation efficiency. If irrigated area is increased (without changing efficiency) the general result is reduced spring and summer flows (due to increased diversion for irrigation) followed by increased fall and winter flows (resulting from increased groundwater return flow from the previous season's increased diversions). The net result is a smoother flatter annual hydrograph.

Increasing irrigation efficiency has the opposite effect on streamflows as increasing irrigated acreage. Since more efficient systems divert, consume, and return less water to the source stream, increased efficiency will increase spring and summer flows and decrease fall and winter flows.

The foregoing generalizations provide the background for analyzing the Canyon Ferry monthly inflow hydrographs developed from the simulation model discussed in Chapter 3. These results, presented in Figure 8, compare the average monthly Canyon Ferry inflows for three increasing levels of upstream irrigation development. The "natural" condition represents no upstream irrigation in the basin. The "present" irrigation condition is assumed to be 493,985 acres under flood irrigation and 139,329 acres under sprinkler irrigation, with an overall irrigation efficiency of 26%. The "future" condition

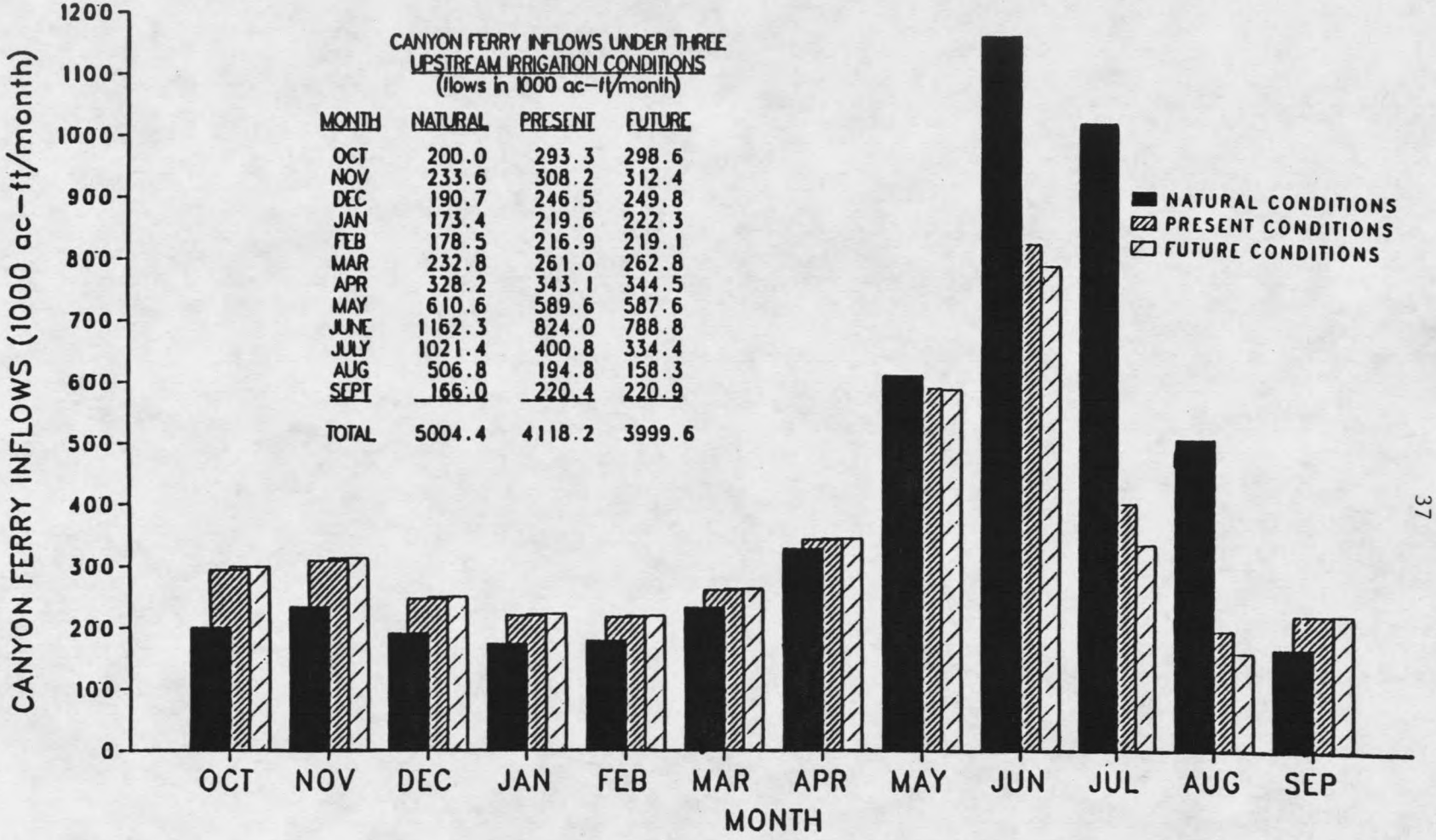


Figure 8. Average monthly Canyon Ferry inflows under natural, present, and projected future levels of upstream irrigation

represents the present level with an additional 100,000 acres under sprinkler irrigation and an overall efficiency of 30%.

Figure 8 illustrates the moderating effect that increased irrigation has on the monthly Canyon Ferry inflow hydrograph. Comparison of the "natural" and "present" condition hydrographs shows that the present level of upstream irrigation substantially reduces June, July and August inflows while inflows for September through April show moderate increase. Comparison of "present" and "future" conditions reveals the same basic pattern, however, the magnitude of monthly streamflow differences is much smaller. This is due in part to the assumption used in the simulation model that all of the additional 100,000 acres represented in the "future" condition would be sprinkler irrigated. As previously discussed, increased irrigation efficiency (alone) has the opposite effect on downstream flows to that of increased irrigated acreage. Thus the additional 100,000 acres, assumed to be sprinkler irrigated, causes minimal monthly variation from the "present" inflow hydrograph.

The data in Figure 8 provides an indication of the decrease in annual inflow associated with each increase in the level of irrigation. Here it is shown that the average annual inflow drops from 5,004,400 acre-ft for "natural" conditions to 4,118,200 acre-ft for "present" conditions, and finally to 3,999,600 acre-ft for "future" conditions. Thus present irrigation practice accounts for a 876,000 acre-ft decrease in annual inflow compared with "natural" conditions. Similarly, if a 100,000 acre (15.8%) increase in irrigated acreage is

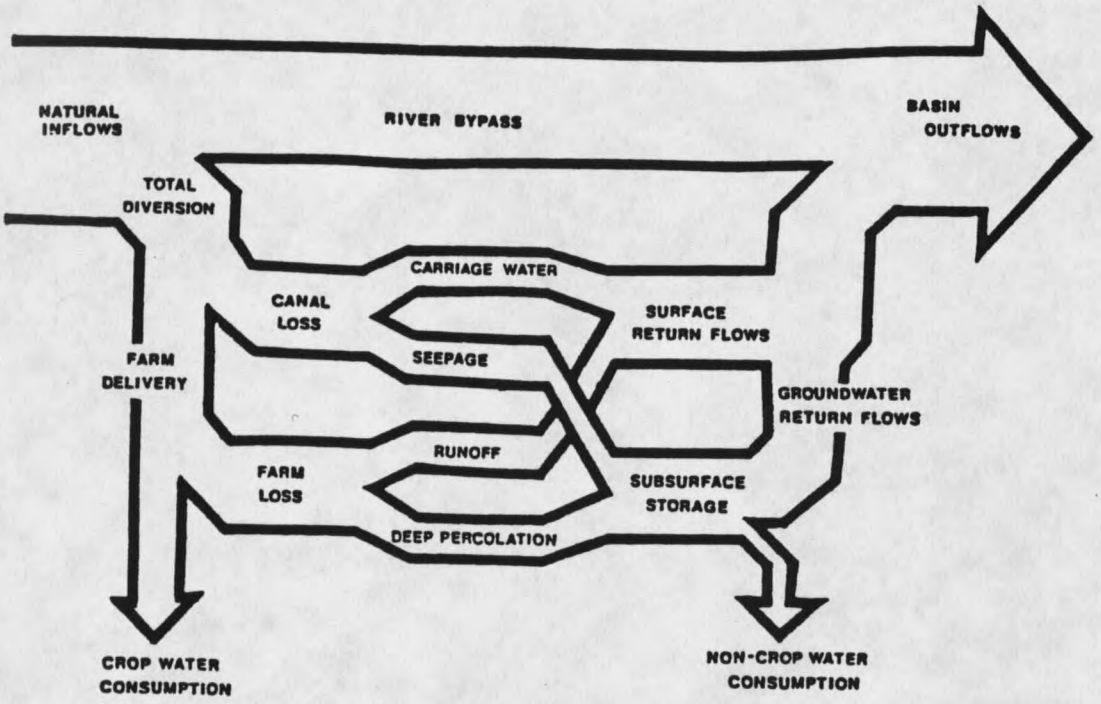
specified, the simulation results indicate an annual flow decrease of 118,600 acre ft (3%).

Figure 9 illustrates how increasing irrigation from present to future levels of irrigation affects total diversion, total consumption, and surface groundwater return flow within the Canyon Ferry drainage basin. Note that the 15.8% increase in irrigated acreage (represented by the future condition) would only cause a 13.5% increase in total water consumption and an 8.9% increase in total upstream diversion.

Effect of Increased Upstream Irrigation on Water Use at the Canyon Ferry Reservoir

Hydropower

Monthly power production values, which were generated by the Canyon Ferry reservoir model using the three inflow sequences presented in the previous section, appear in Figure 10. As discussed in Chapter 4, monthly hydropower production is a function of reservoir outflow and reservoir storage. Since both outflow and storage depend in part on reservoir inflow, the smoother flatter annual inflow hydrograph resulting from increased upstream irrigation subsequently results in a smoother flatter annual power production curve. However, since the model fixes the monthly reservoir outflows at a constant value within a forecast period, the power production curves only mimic the inflow hydrographs when compared across the duration of each forecast period.



NET EFFECT OF IRRIGATION ON BASIN WATER SUPPLIES UNDER THREE IRRIGATION CONDITIONS			
	volumes in thousands of acre-feet		
	PRESENT	FUTURE	MARGINAL
TOTAL DIVERSION	2761	3006	245 (8.9%)
TOTAL CONSUMPTION	879	998	119 (13.5%)
SURFACE RETURNS	1052	1128	76 (7.2%)
GROUNDWATER RETURNS	830	880	50 (6.0%)

Figure 9. Comparison of net irrigation water use under present and projected future irrigation conditions

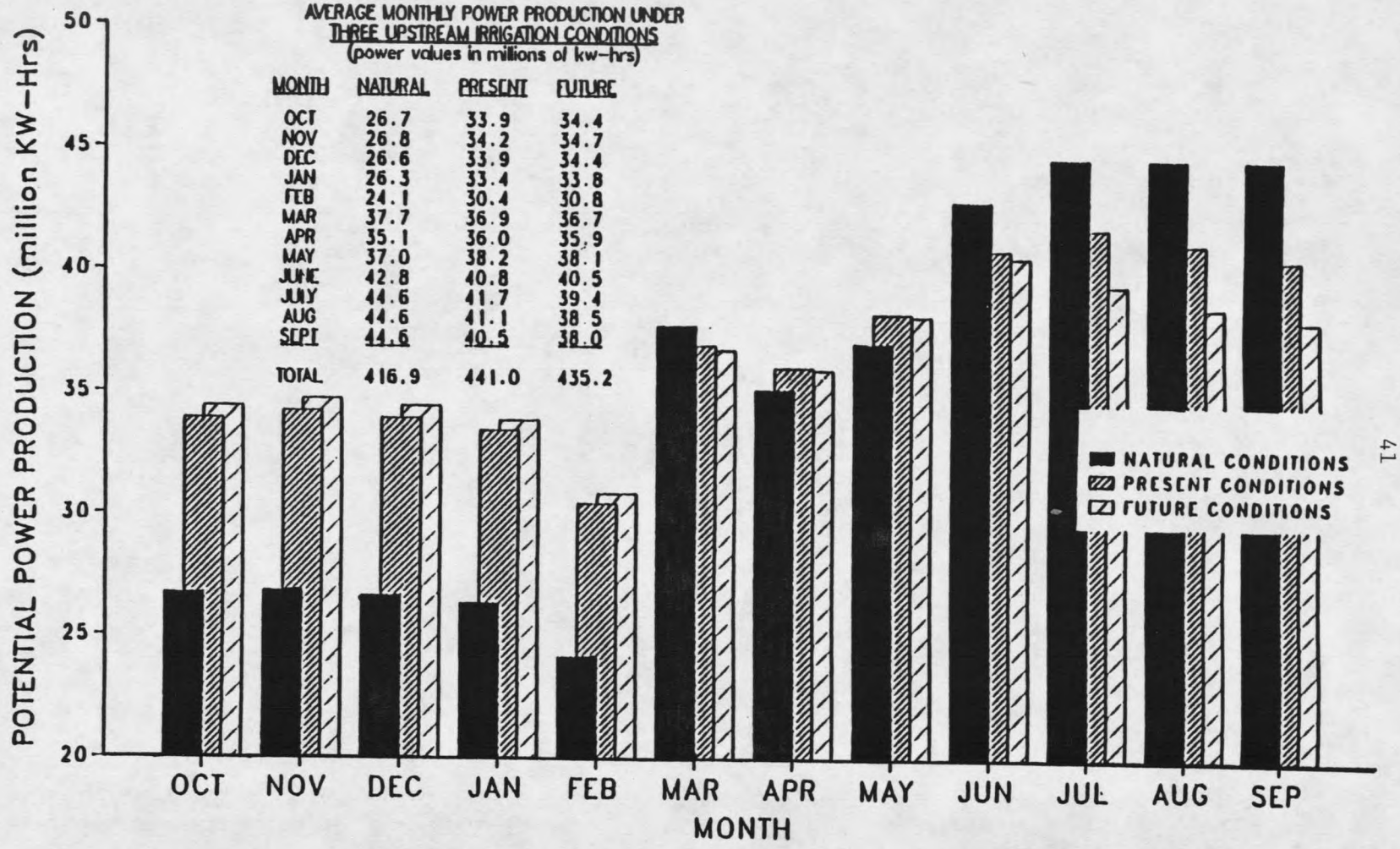


Figure 10. Average monthly power production at Canyon Ferry Dam under natural, present, and projected future levels of upstream irrigation

Three forecast periods are generated by the model: (1) The "winter period" from October 1st to March 1st, (2) the "spring period" from March 1st to July 1st, and (3) the "summer period" from July 1st to October 1st. The specific combinations of reservoir inflows, outflows, and storage levels that occur during each forecast period influences monthly power production as described below.

During the winter period reservoir storage reaches the annual minimum, allowing minimal power production. Under the natural (no irrigation) condition, minimum monthly inflows combine with low storages to yield very low power production values for the period. Inflows under the present and future conditions maintain average levels and thus yield low, but significantly higher power values than do inflows under the no irrigation condition. Increasing irrigation increases power production as a direct result of increased groundwater return flows and subsequent increased reservoir inflows.

During the spring period maximum monthly reservoir inflows occur under all three irrigation conditions. However, because the reservoir is filling and storage is initially at its minimum, both discharge and head are limiting, allowing only average levels of power production. The no irrigation condition yields the greatest amount of power during this period, but since the effects of both irrigation diversions and return flows are minimal during the spring period, all three conditions yield approximately equal power values.

During the summer period, the reservoir starts out full, allowing sustained power production at maximum or near maximum capacity. Under the no irrigation condition inflows maintain high enough levels to

yield the maximum possible power production during all three months. Under the present and future conditions, reservoir inflows are at their monthly maximum, thus power production is high but not the maximum possible. Increasing irrigation over present levels causes a reduction in power production during this period, again as a result of reduced reservoir inflows.

On an annual basis simulation results indicate that a 15.8% increase in irrigation (represented by the future irrigation condition) would cause a 1.3% loss in average annual power production. However, only the power production values for the summer months are significantly reduced. The increased fall and winter inflow volumes would allow for increased power production during the months of October through February. If power is worth more in the winter than the summer, then increasing the upstream irrigation could potentially increase annual power revenues.

Comparison of the total annual power production values under the three irrigation conditions (Figure 10) suggests that a maximum annual power value exists under some level of upstream irrigation between the natural and future conditions. By manipulating the numbers of sprinkler and flood irrigated acres used in the basin model, an inflow hydrograph could be developed that would potentially be optimal or most beneficial to reservoir operations. In this way upstream irrigation could be used as a reservoir management tool.

Spills

Monthly spill volumes generated by the reservoir model are the difference between total reservoir discharge and penstock capacity.

As with power production, monthly spills depend on total reservoir outflow and reservoir storage. The average monthly spill volumes generated for the three upstream irrigation conditions are presented in Figure 11.

During the winter period, no spillage occurs because reservoir inflows and storage levels are minimal under all three irrigation conditions, allowing the total reservoir discharge to be sent through the power turbines. During the spring and summer periods, reservoir inflows are high, causing outflows to increase beyond penstock capacities and thus spillage to occur. Comparing the natural to present, and present to future irrigation conditions shows that reducing summer reservoir inflows leads to the expected reduction in summer spill volumes. Summer spillage is exceptionally high under the natural conditions because high inflows occur when the reservoir is essentially full.

On an annual basis model results indicate that the 15.8% increase in irrigated acreage (represented by the future condition) would cause a 15.8%, or 48,000 acre-ft decrease in the average annual spill volume. (Note: It is purely coincidental that the percent decrease in spill volume is the same as the percent increase in irrigated acreage). In general, increasing upstream irrigation will reduce both monthly and annual spill volumes. Flood control and flood damage savings gained with such additional irrigated acreage could outweigh the potential revenue lost from the reduction in average annual power production.

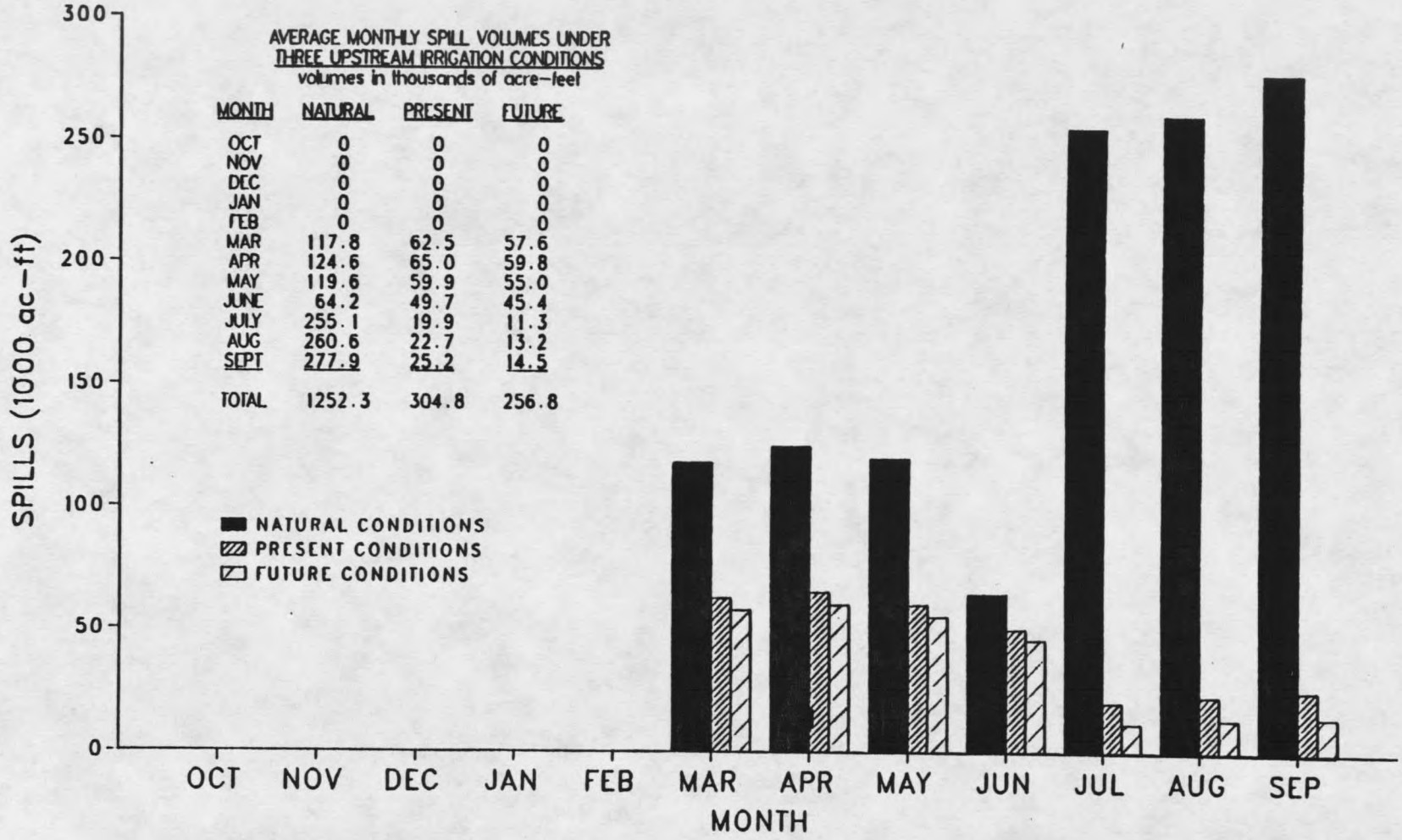


Figure 11. Average monthly spill volumes at Canyon Ferry Dam under natural, present, and projected future levels of upstream irrigation

Modified Reservoir Operating Criteria to Maximize Power Production and Minimize Spill Volumes

The third objective of this study was to determine what modifications, if any, could be made in the current reservoir operating criteria to either maximize power production and/or minimize spill volumes under both current and projected future levels of upstream irrigation development. Two types of modifications were investigated; (1) lowering the spring (March) reservoir target elevation and (2) delaying the summer fill date. Both modifications would be expected to reduce the potential for spills and trade some spring and summer power for more fall and winter production.

Lowering the March target elevation would require increasing reservoir discharge during the months of the winter period. The increased discharge would allow for increased power production during this period until the drawdown becomes so low as to make head on the power turbines a limiting factor. Since reservoir storages and outflows are low during the winter period, the additional discharge would not cause spills to occur until the target elevation is set so low that the reservoir must spill water simply to meet the low drawdown. During the spring period, lower March reservoir elevations would allow less discharge and thus less power production and less spillage. The summer period should remain unaffected.

The effect of lowering the March target elevation on annual power production and spillage depends on the relative increases and decreases in power and spillage that occur during each forecast period. It can be seen from Table 2 and corresponding Figure 12 that lowering

Table 2. Average annual power production and spill volume at Canyon Ferry Dam under varying March reservoir target elevations

MARCH TARGET ELEV.	PRESENT LEVEL OF IRRIGATION		PROJECTED FUTURE LEVEL OF IRRIGATION	
	AVERAGE ANNUAL POWER PRODUCTION	AVERAGE ANNUAL SPILL VOLUME	AVERAGE ANNUAL POWER PRODUCTION	AVERAGE ANNUAL SPILL VOLUME
feet	10^6 kw-hr	10^3 ac-ft	10^6 kw-hr	10^3 ac-ft
3770	436.0	189.3	427.4	153.7
3771	437.4	188.8	429.1	151.9
3772	438.3	189.8	430.5	152.0
3773	439.4	192.7	431.4	153.6
3774	440.3	196.7	432.7	156.3
3775	441.5	202.0	433.5	160.6
3776	442.3	209.1	434.7	166.2
3777	442.7	217.5	435.5	173.8
3778	443.1	227.2	436.1	182.4
3779	442.8	238.0	436.3	192.7
3780	443.0	249.7	436.3	203.8
3781	442.5	262.3	436.2	215.8
3782	442.3	275.7	435.6	228.7
3783	441.9	289.8	435.4	242.5
3784	441.2	304.8	435.1	256.8

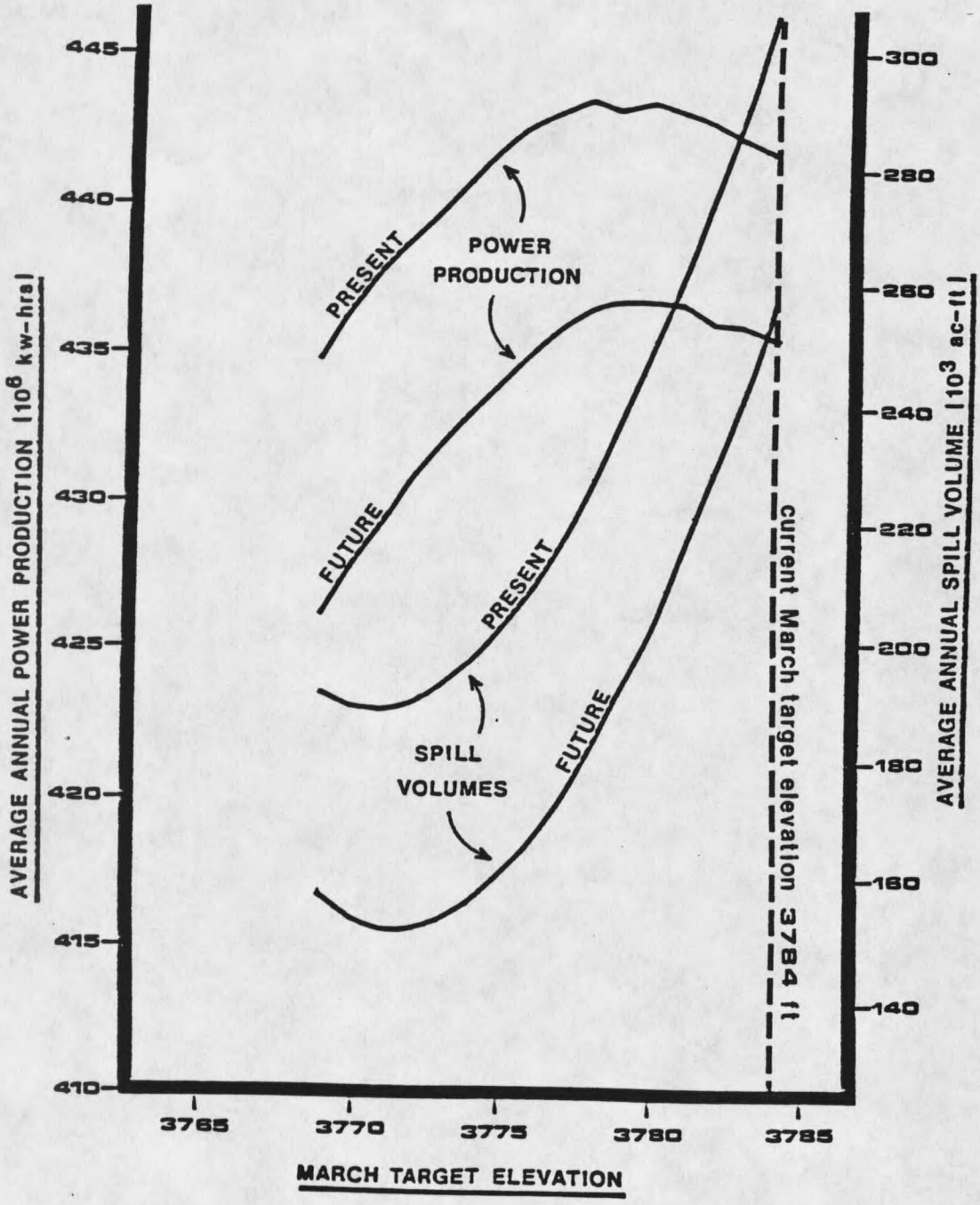


Figure 12. Average annual power production and spill volume at Canyon Ferry Dam under varying March reservoir target elevations and a July 1st reservoir fill date

the March target elevation from the current 3784 ft initially increases average annual power production and decreases average annual spillage. The maximum average annual power production occurs with a March target of 3778 ft under present levels of irrigation, and with a target of 3780 ft under projected future levels of irrigation. Average annual spillage is minimized with a March target elevation of 3771 ft under both present and projected future levels of irrigation.

Delaying the reservoir fill date from July to August would allow less discharge during the spring period, but more discharge during the summer forecast period. As a result of these changes in discharge, both power production and spillage would be decreased during the spring period. Delaying the summer fill date should have no effect on winter period reservoir operations.

The combined effects of lowering the March target elevation and delaying the summer fill date are presented in Table 3 and corresponding Figure 13. With the two modifications, maximum average annual power production is achieved with a March target of 3778 ft under present, and 3781 ft under projected future levels of upstream irrigation. Minimum average annual spillage occurs with a March target of 3771 ft under present, and 3772 ft under projected future levels of irrigation. By comparing Tables 2 and 3 or Figures 12 and 13, it can be seen that more power and less spillage would be produced annually with the delayed reservoir fill date under all March target elevations.

The plotted curves of Figure 13 reveal four sets of "optimal" operating criteria corresponding to: (1) maximum power production

Table 3. Average annual power production and spill volume at Canyon Ferry Dam under varying March reservoir target elevations and an August 1st reservoir fill date

MARCH TARGET ELEV.	PRESENT LEVEL OF IRRIGATION		PROJECTED FUTURE LEVEL OF IRRIGATION	
	AVERAGE ANNUAL POWER PRODUCTION	AVERAGE ANNUAL SPILL VOLUME	AVERAGE ANNUAL POWER PRODUCTION	AVERAGE ANNUAL SPILL VOLUME
feet	10^6 kw-hr	10^3 ac-ft	10^6 kw-hr	10^3 ac-ft
3770	436.6	186.8	428.4	153.2
3771	438.0	185.2	430.4	149.9
3772	439.1	185.7	432.0	148.4
3773	440.1	187.3	433.1	148.8
3774	441.3	190.0	434.4	150.0
3775	442.5	194.0	435.6	152.2
3776	443.4	199.4	436.7	155.5
3777	444.0	206.5	437.7	160.3
3778	444.5	215.0	438.6	166.2
3779	444.1	225.0	438.9	173.5
3780	444.2	235.9	439.3	182.0
3781	443.8	247.7	439.6	191.8
3782	443.7	260.6	439.1	202.3
3783	443.4	274.5	439.0	214.2
3784	442.9	289.2	438.3	226.9

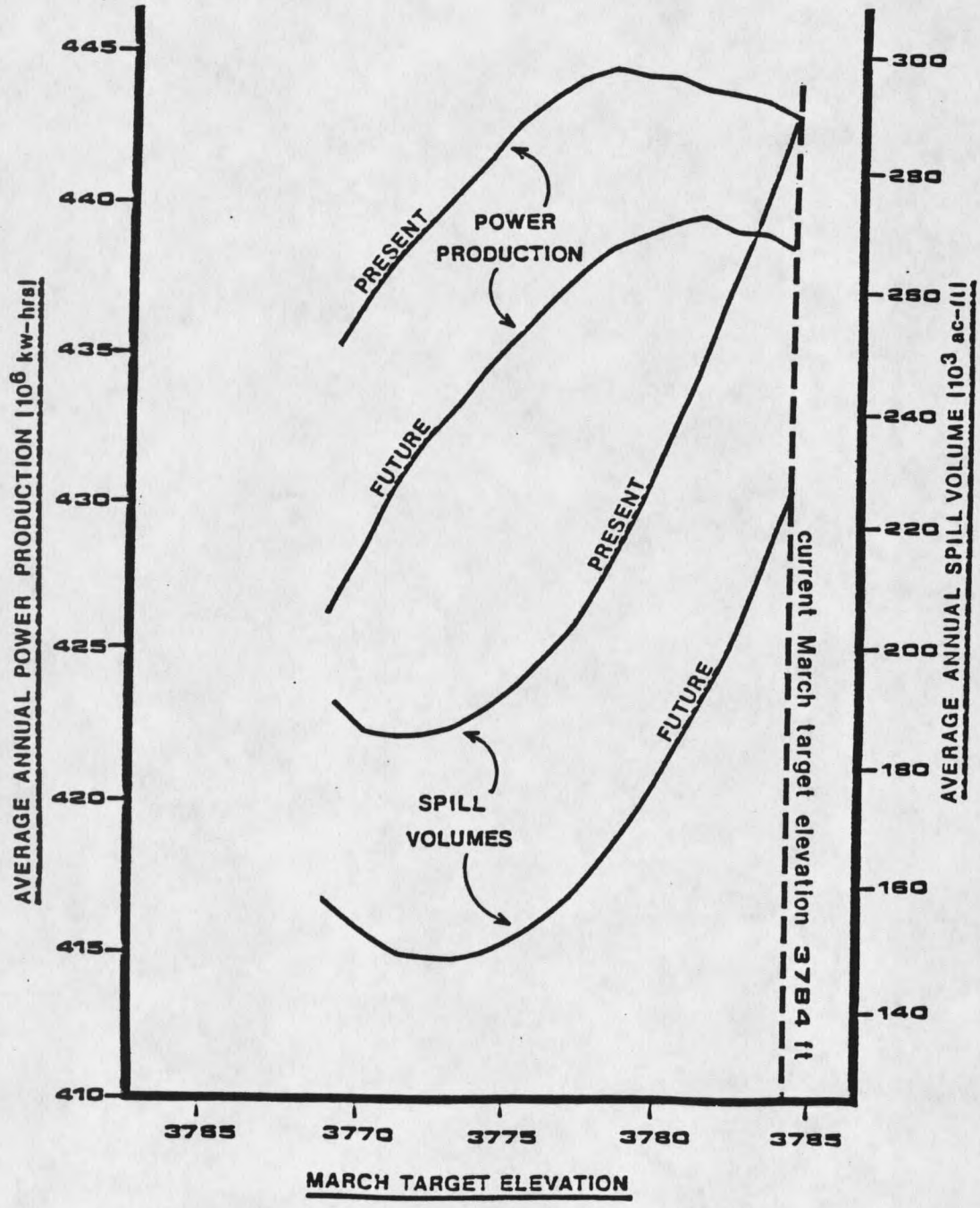


Figure 13. Average annual power production and spill volume at Canyon Ferry Dam under varying March reservoir target elevations and an August 1st reservoir fill date

under present irrigation conditions, (2) maximum power under projected future irrigation conditions, (3) minimum spillage under present irrigation conditions, and (4) minimum spillage under projected future irrigation conditions. The full output record from each of these runs was examined for extremes as a qualitative type of risk analysis.

A summary of the four "optimal" policies, shown in Table 4, shows that the additional irrigation always causes a reduction in both average annual spillage and power production over current levels. However, if current reservoir operations were adjusted to the policy that maximizes power under present irrigation conditions, the 15.8% increase in irrigated acreage would cause less than a 0.3% reduction in average annual power production. Adjusting to this policy would also yield a 38% reduction in annual spill volume.

The monthly power and spill distributions created by the four optimal policies are shown in Figures 14 through 17. Note that each of the optimal policies allow for more power production during the winter months. Figure 14 presents average monthly power production under the two optimal policies, as well as the current policy, for present irrigation conditions. Under the maximum power policy some spring and summer power is traded for more fall and winter power production. The result is more uniform monthly power production and a net increase in annual production. The minimum spill policy sacrifices a greater amount of spring and summer power for increased fall and winter production with the net result of an annual reduction in power production.

OPERATING CRITERIA		AVERAGE ANNUAL POWER PRODUCTION		AVERAGE ANNUAL SPILL VOLUME		
		(10^6 kw-hrs)		(10^3 ac-ft)		
MONTH	TARGET ELEV. (feet)	PRESENT*	FUTURE*	PRESENT*	FUTURE*	POLICY DESCRIPTION
OCTOBER MARCH JULY	3787 3784 3797	441.2	435.1	304.8	256.8	Current Policy
OCTOBER MARCH AUGUST	3787 3778 3797	444.5	438.5	215.0	188.2	Maximizes Power under Present levels of Irrigation
OCTOBER MARCH AUGUST	3787 3781 3797	443.8	439.6	247.7	191.8	Maximizes Power under projected Future levels of Irrigation
OCTOBER MARCH AUGUST	3787 3771 3797	438.0	430.4	185.2	148.9	Minimizes Spills under Present levels of Irrigation
OCTOBER MARCH AUGUST	3787 3772 3797	439.1	432.0	185.7	148.4	Minimizes Spills under projected Future level of Irrigation

*Level of Irrigation

Table 4. Summary of the four "optimal policies" for Canyon Ferry Reservoir operations.

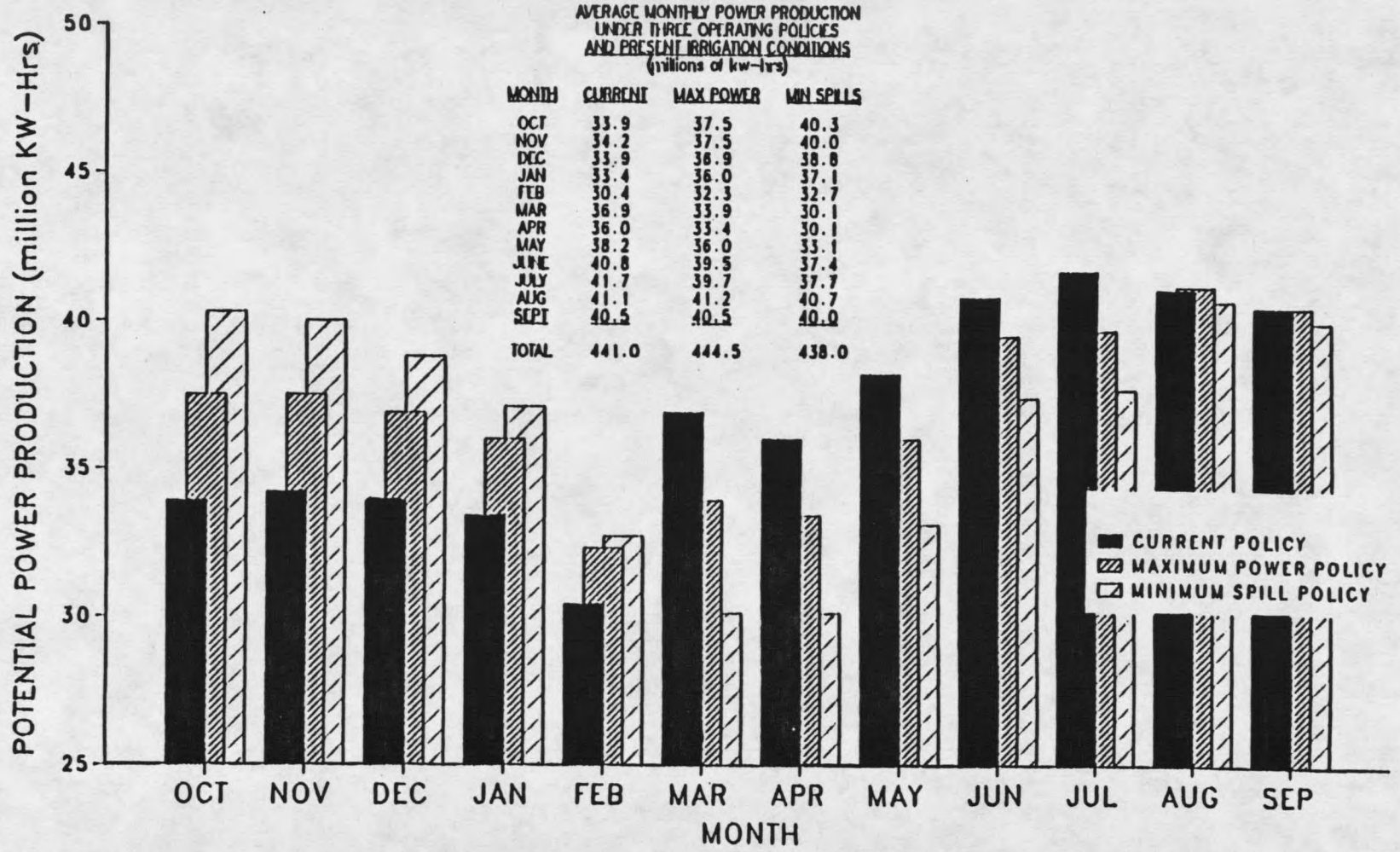


Figure 14. Average monthly power production at Canyon Ferry Dam under present irrigation conditions and three operating policies

Figure 15 presents average monthly spill volumes under the two optimal policies, as well as the current policy, for present upstream irrigation conditions. Because both optimal policies allow less reservoir outflow during the spring and summer and more in the winter, they both cause reductions in net annual spill volumes.

Figures 16 and 17 for future irrigation conditions are the analogous to Figures 14 and 15. As with present conditions, Figure 16 shows that both optimal policies sacrifice some spring and summer power for increased fall and winter production. With the maximum power policy, the result is a net increase in annual power production, however it is still slightly less than the amount of power being produced under the current policy and present irrigation condition. The minimum spill policy exaggerates the same effect but leads to a net reduction in annual power production.

Figure 17 shows the same pattern of monthly spills for future conditions as were found under similar policies for present irrigation conditions. Note however that both monthly and net annual spills are valued with increase irrigation.

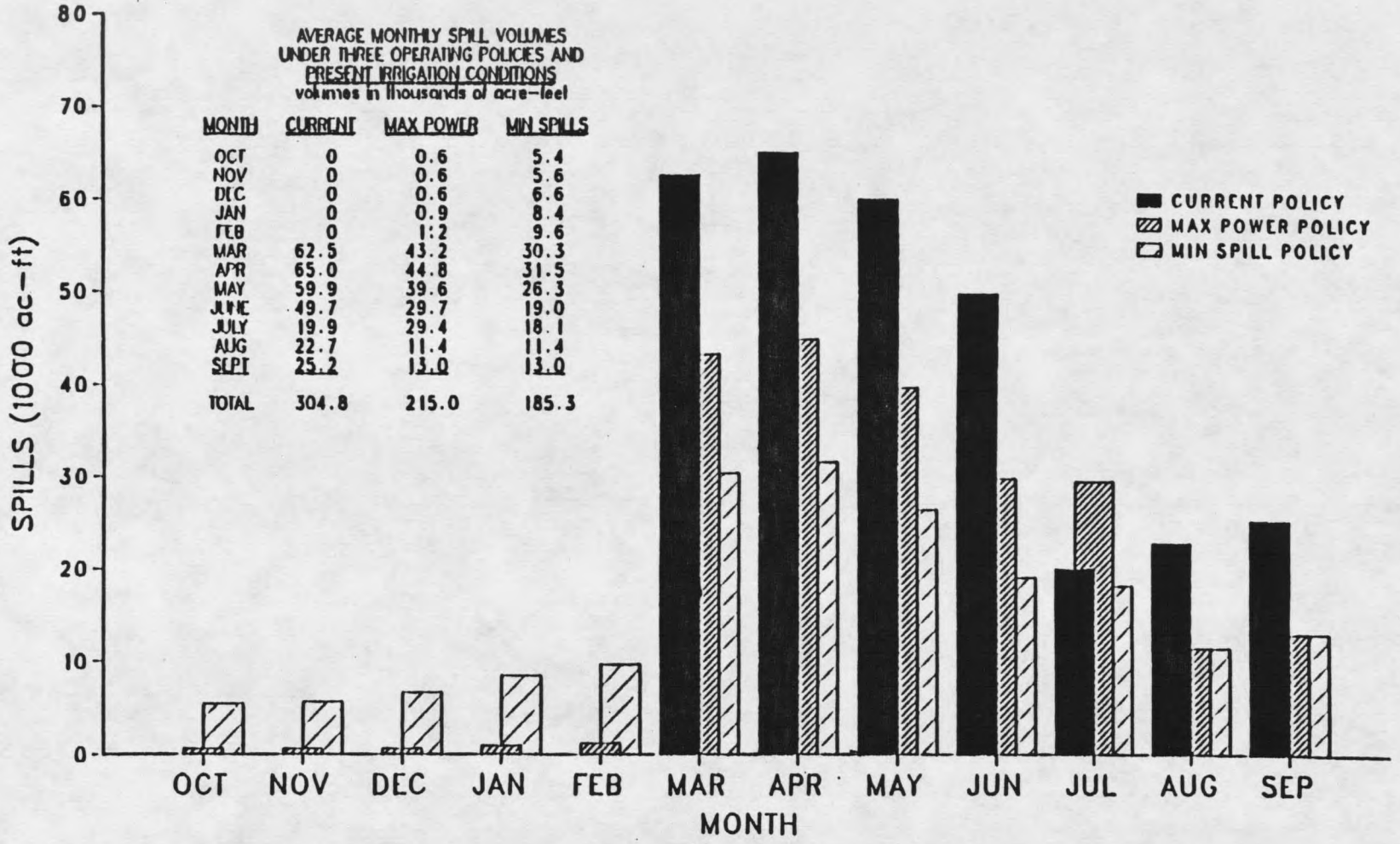


Figure 15. Average monthly spill volumes at Canyon Ferry Dam under present irrigation conditions and three operating policies

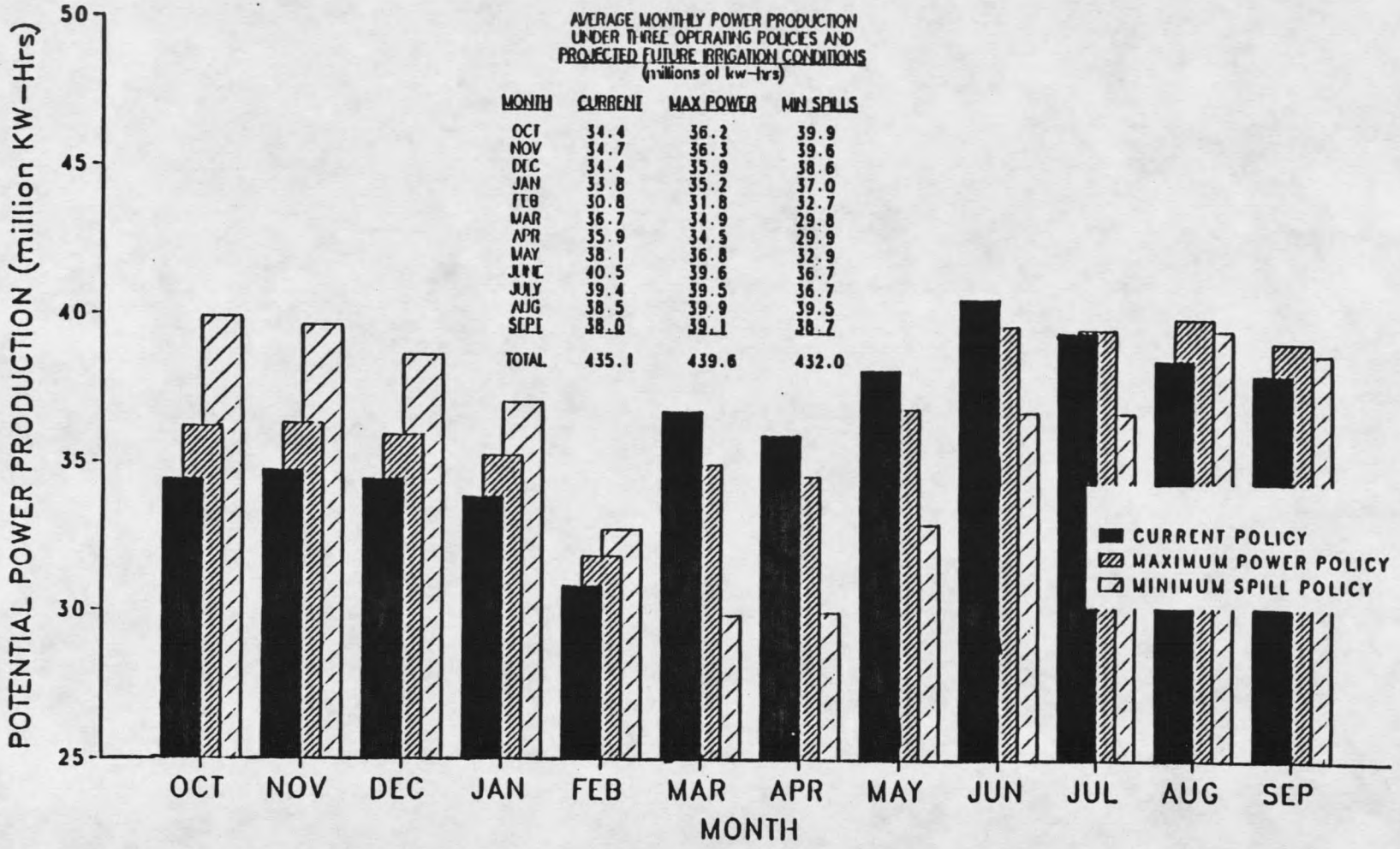


Figure 16. Average monthly power production at Canyon Ferry Dam under projected future irrigation conditions and three operating policies

AVERAGE MONTHLY SPILL VOLUMES
UNDER THREE OPERATING POLICIES AND
PROJECTED FUTURE IRRIGATION CONDITIONS
volumes in thousands of acre-feet

MONTH	CURRENT	MAX POWER	MIN SPILLS
OCT	0	0.1	5.0
NOV	0	0.1	5.0
DEC	0	0.1	6.1
JAN	0	0.2	7.6
FEB	0	0.3	8.7
MAR	57.6	39.9	24.7
APR	59.8	41.4	25.5
MAY	55.0	36.7	20.9
JUNE	45.4	28.2	14.6
JULY	11.4	28.6	14.2
AUG	13.2	7.6	7.6
SEPT	14.5	8.5	8.5
TOTAL	256.9	191.8	148.5

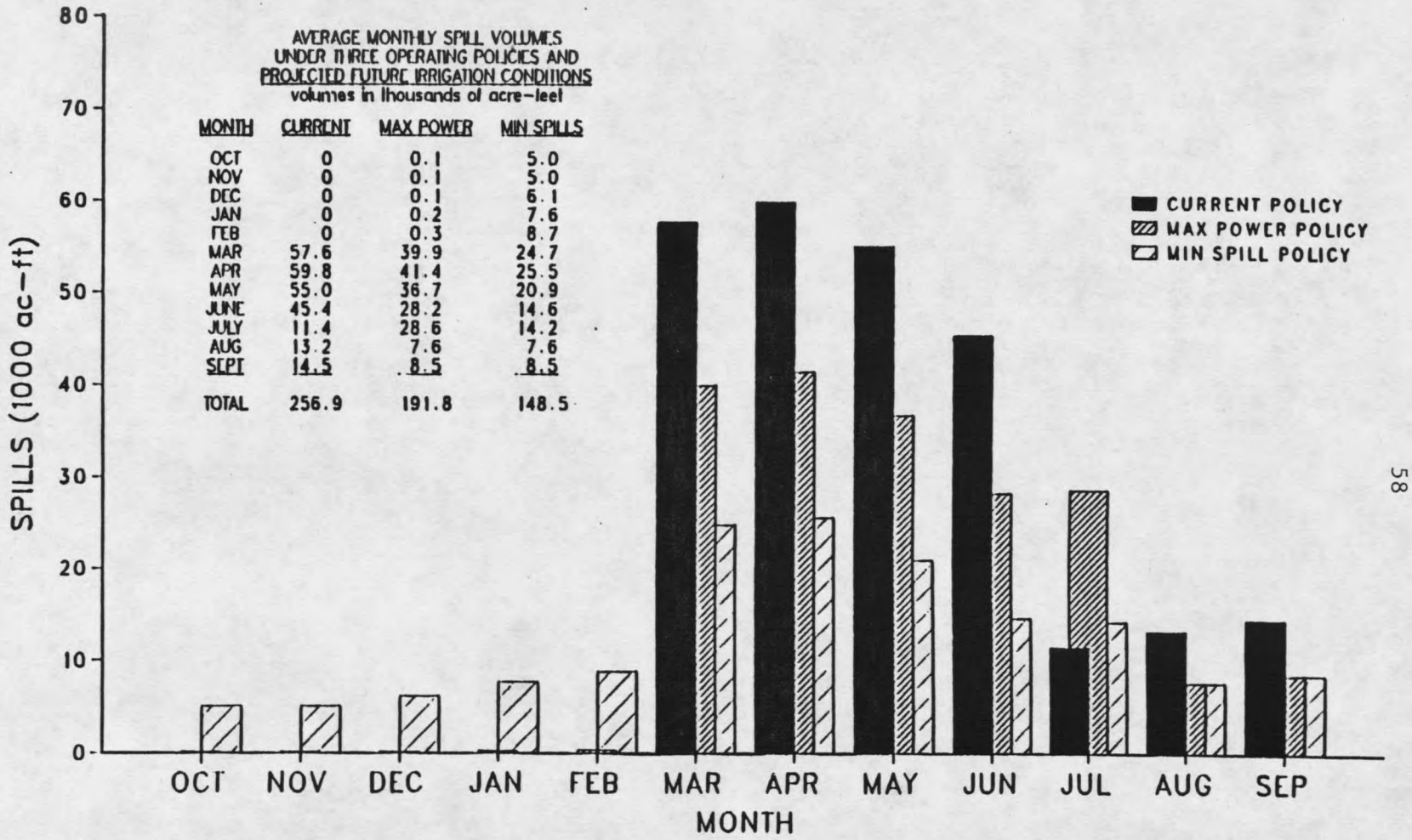


Figure 17. Average monthly spill volumes at Canyon Ferry Dam under projected future irrigation conditions and three operating policies

CHAPTER 6

CONCLUSIONS

The goal of this project was to determine the effects of projected increases in irrigation development on potential water uses at the Canyon Ferry Reservoir under different reservoir operating criteria. Two related computer models were used to simulate varying levels of irrigation water use above Canyon Ferry and subsequent reservoir operations.

The irrigation water-use model, which is comprised of a series of monthly water balance equations, is capable of simulating varying numbers of flood and sprinkler irrigated acres, conveyance and irrigation efficiencies, infiltration and consumptive loss rates, irrigation schedules, annual crop water requirements, and basin wide aquifer properties. The model simulates irrigation activities in the basin and computes monthly and annual basin outflows. Numerous simplifying assumptions were required to develop and run this model. The most important simplification was using lumped parameters to describe the irrigation activities and hydrologic responses of basin. Because of this simplification, the model was unable to consider the localized effects of individual irrigation developments within the basin.

Three upstream irrigation scenarios were simulated using the basin model: (1) no irrigation in the basin, (2) present levels of irrigation, and (3) projected future levels of irrigation, representing a 100,000 acre or 15.8% increase over present levels.

The results from simulating the three upstream irrigation scenarios produced the following observations:

(1) Increasing upstream irrigation would reduce summer peak reservoir inflows, increase fall and winter low inflows, and reduce the average annual reservoir inflow volume.

(2) In general, increasing upstream irrigation would cause a smoother, flatter basin outflow and subsequent reservoir inflow monthly hydrograph. Specifically, a 15.8% increase in upstream irrigated acreage would cause a 3.0% reduction in average annual reservoir inflow volume.

(3) The relationships found between upstream irrigation activities and reservoir inflows suggest that upstream water use could be used to modify the monthly reservoir inflow hydrograph to a shape that would be most beneficial to reservoir operations. Regulation of upstream irrigation activities, therefore, could be considered as a reservoir management tool.

The reservoir operations model simulates the monthly and annual reservoir storages and water surface elevations, total outflows, power production, and spills that would occur with any given sequence of monthly inflows. The model is driven by the specified set of target water surface elevations and dates which comprise the reservoir operating criteria. The reservoir model has "perfect forecast" ability during the months between the target dates, but no forecast capability beyond the current target date and into the next forecasting period.

The monthly reservoir inflow sequences corresponding to the three upstream irrigation scenarios were run through the reservoir model.

In addition, two types of modifications in reservoir operating criteria were investigated: (1) lowering the spring reservoir water surface target elevation and (2) delaying the summer reservoir fill date from July 1st to August 1st.

The results of the reservoir simulations indicate that increasing irrigation would have mixed impacts on power production and spill volumes as presented below.

(1) Increasing upstream irrigation would cause a reduction in summer power production, an increase in winter production, and an overall reduction in average annual power production at the reservoir. Increasing irrigation would also cause reductions in both monthly and annual spill volumes. Specifically, a 15.8% increase in upstream irrigated acreage would cause a 1.3% reduction in the average annual power production and a 15.8% reduction in the average annual spill volume.

(2) Significant reduction in the average annual spill volume could be achieved by both lowering the spring (March) reservoir target elevation and delaying the reservoir fill date without adversely affecting power production capabilities.

Further investigations into refining the operating criteria must consider the uncertainties involved with actual reservoir forecasting and operations. In addition, more accurate field data needs to be collected describing upstream irrigation practices, irrigation water flow patterns, soil drainage characteristics, non-crop water consumption, and especially aquifer properties. With such detailed data, the

simulation models developed for this study would become even more useful tools in irrigation and reservoir water use management.

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REFERENCES CITED

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APPENDICES

APPENDIX A

DATA PROCESSING

APPENDIX A

DATA PROCESSING

Basin Model Parameters

The nine input parameters used to describe the flow behavior of the diverted irrigation water throughout the basin model are defined below.

1. CEFF = Conveyance efficiency
2. CLSP = Portion of canal losses that deep percolate
3. SSEFF = Sprinkler irrigation system efficiency
4. FSEFF = Flood or surface irrigation system efficiency
5. FLDP = Portion of sprinkler irrigated field losses that deep percolate
6. PANDE = Portion of the percolated losses that are consumed by phreatophytes and evaporation
7. F(I) = Return flow factors; I=1 to 36 months
8. PCIR(I) = Portion of annual crop irrigation requirement applied during month I; I=1 to 12 months.

The following section outlines the data sources used to estimate parameter values and presents the final values chosen for use in the model. (See the references cited section for the sources associated with the numbers listed).

Estimates of CEFF, SSEFF, and FSEFF

S = (CEFF)*(SSEFF)
F = (CEFF)*(FSEFF)
NAS = # sprinkler irrigated acres
NAF = # of flood irrigated acres
T = (CEFF)/[NAS+NAF] * [(NAS)*(SSEFF)+(NAF)*(FSEFF)]

SOURCE	ESTIMATE	COMMENTS
12	F=0.215 S=0.431	Estimated for the Canyon Ferry Basin
18	T=0.19 CEFF=0.45	Estimated for the Canyon Ferry Basin
17	CEFF=0.69	Estimated for the Grand Valley of Colorado, which is geographically similar to the Canyon Ferry basin, but which probably has more lined canals
9	SSEFF=0.75 FSEFF 0.75	General estimates

19	SSEFF=0.70	Estimated from areas around the Dillon and Helena Valley regions of Montana
	CEFF=0.57 SSEFF=0.76 FSEFF=0.38	Values chosen for the model

Estimates of CLSP

17	CLSP=0.42	Estimated for the Grand Valley of Colorado
	CLSP=0.42	Value chosen for the model

Estimates of FLDPS and FLDPF

17	FLDPF=0.23	Estimated for the Grand Valley, CO
9	FLDPS=0.28 FLDPF=0.02	Estimated for the general region type
19	FLDPS=0.55	Estimated for the Dillon and Helena Valley regions
	FLDPS=0.55 FLDPF=0.60	Values chosen for the model

Estimate of PANDE

17	PANDE=0.51	Estimated for the Grand Valley, CO which has higher mean temperatures and a longer growing season
1		Used to compare the climate in the Canyon Ferry basin to that in the Grand Valley
	PANDE=0.20	Value chosen for the model

Estimates of F(I)

3		Values chosen for the model taken directly from this source

Estimates of PCIR(I)

19	APR=0.06 MAY=0.14 JUNE=0.20 JULY=0.44 AUG=0.21 SEPT=0.10	Estimated for two locations in the Canyon Ferry drainage basin

5	APR=0.00 MAY=0.02 JUNE=0.23 JULY=0.44 AUG=0.27 SEPT=0.04	Estimated for the weighted average of three crops in ten locations throughout the basin for both dry and normal conditions. Also the values chosen for the model

Simulation Variables

The six simulation variables used to describe the levels and types of irrigation development simulated during a given model run are defined below.

1. NYRS = Number of years to be simulated
2. NR = First year of simulation
3. NAS(J) = Number of acres under sprinkler irrigation in the basin during year J
4. NAF(J) = Number of acres under flood irrigation in the basin during year J
5. CIR(J) = Annual crop irrigation water requirement per average acre for year J
6. FLOIN(I) = Natural inflow to the basin for month I
   OR
   TOST(I) = Known basin outflow for month I (used as basin inflows to develop the natural inflows).

The following section outlines the data sources used to estimate variable values and presents the final values chosen for use in the model. (See the references cited section for the sources associated with the numbers listed).

Estimates of NAS(J) and NAF(J)

SOURCE	COMMENTS
12	The MBSA performed a thorough evaluation of all available sources to determine the total number of irrigated acres in the Canyon Ferry drainage basin (above the node designated at Toston, MT) from 1944 to 1978. In addition, they took a survey to determine the numbers of flood and sprinkler irrigated acres in the basin during 1978.
6,11	Personal communication with Fergusen and Kennedy provided estimates for when use of sprinkler irrigation first started in the area and how it's use has grown to the present. Total irrigated acreage values were taken from the MBSA study along with the NAS/NAF breakdown for 1978. Information provided by the aforementioned

SOURCE	COMMENTS
	individuals was used to estimate the NAS/NAF breakdown for the remaining years. For a complete listing of these values see the input file given at the end of this section.

Estimates of CIR(J)

12	Values chosen for the model were taken directly from the MBSA study. (See input file at the end of this section).

Estimates of TOST(I)

7,15	Fitz (1981) determined that increasing the streamflows recorded by USGS gage #545 on the Missouri River at Toston, MT. by 4% would provide good estimates of Canyon Ferry reservoir inflows. These values were chosen for the model to generate natural inflows.

Estimates of FLOIN(J)

3	Development of the natural inflows was discussed earlier in the report. See the input file at the end of this section for a complete listing of the values used in the model.

Table 5. Canyon Ferry Drainage Basin Irrigation Water Use Model Input Data File

Descriptive Parameters

```
0.57        CEFF
0.42        CLSP
0.76        SSEFF
0.33        FSEFF
0.55        FLDPS
0.60        FLDPF
0.20        PANDE
RETURN FLOW FACTORS
0.22247 0.18426 0.11896 0.09261 0.07417 0.06971
0.04811 0.03907 0.03094 0.02518 0.02029 0.01635
0.01318 0.01062 0.00856 0.00689 0.00556 0.00448
0.00361 0.00291 0.00235 0.00189 0.00152 0.00122
0.00099 0.00080 0.00064 0.00052 0.00042 0.00034
0.00027 0.00022 0.00017 0.00014 0.00011 0.00009
PCIR VALUES
0.00    0.00    0.00    0.00    0.00    0.00
0.00    0.02    0.23    0.44    0.27    0.04
```

Simulation Variables

```
  39   NYRS
1944   NR (FIRST YEAR)

# SPRINKLER ACRES
     0       0       0       0   13332   13642
 13950   14258   35376   35107   34838   34570
 34301   34435   34568   34701   34835   34965
 34537   34106   47144   53188   59059   63735
 80403   83950   87010   89917  101585  100753
109692  115949  126751  139953  130856  125812
115557  139329

# FLOOD ACRES
605485  620586  635670  651162  653296  668433
683545  698636  672137  667030  661926  656824
651727  654258  656794  659325  661858  664341
656199  648007  626340  611664  597157  573611
538083  515691  493056  472067  495971  459006
467635  463795  476824  496198  463943  446062
469703  493985

CROP IRRIGATION
 REQUIREMENT
 1.03    0.95    1.24    0.84    0.94    1.11
 1.23    1.09    1.12    1.25    1.11    1.06
 1.00    1.23    1.30    0.95    1.10    0.90
 0.80    1.25    1.11    0.90    1.07    1.12
 1.16    1.12    1.16    1.32    0.90    1.03
 0.99    0.97    1.30    0.85    1.00    1.00
 0.98    0.95
```

INPUT FILE. cont.

NATURAL
INFLOWS

179004.4	205632.1	230636.5	187737.1	176374.2	298989.6
443583.4	841110.6	1255809.6	995128.9	499652.6	185216.5
216758.1	216339.9	230657.0	206195.8	181700.4	256950.2
493240.1	939544.0	1579775.3	1008195.2	519124.4	159270.7
180576.5	199915.4	188166.7	158802.5	162258.5	252365.3
485096.7	670903.1	973680.1	988918.1	529459.7	133405.8
123557.2	152414.3	139925.4	131434.3	162248.0	211964.2
274424.0	345906.3	1026221.3	934578.3	477933.1	190768.7
214318.1	218220.5	223246.5	171162.0	187861.6	231075.0
324419.8	716611.5	909709.7	872450.6	518196.7	171936.8
171247.7	187209.3	149943.9	152848.5	188394.9	238581.3
494158.2	958059.5	1151802.3	1091437.8	558064.4	154462.9
122061.4	168169.3	192728.7	202864.6	159131.5	184205.2
203764.6	312555.8	1406391.3	1164341.8	572718.1	105953.7
134930.6	178827.2	148687.9	123439.2	166775.4	167883.9
202111.3	332923.2	795270.8	1039243.6	525394.8	85886.0
114622.5	157318.5	105284.1	113201.8	104223.9	142261.0
190947.9	375679.0	947482.3	1118737.3	507264.5	79738.5
90998.8	151892.9	164947.5	174226.8	110074.3	263249.6
371257.3	773001.8	1128580.0	1052248.3	564624.9	95443.2
110131.9	202701.8	129014.6	91810.9	142532.2	190403.6
222072.7	619337.1	1157085.5	1005289.8	489058.9	106168.1
170105.0	218538.7	174018.7	150073.7	156586.9	190097.4
243643.4	591519.8	914041.7	961585.9	493411.3	92512.6
140412.0	182122.4	165183.2	141137.7	117320.2	211772.3
262900.3	323534.0	1083495.3	966189.9	438105.5	93953.9
277200.6	324823.5	317113.9	160014.9	177420.9	329311.9
408176.4	484153.9	892317.1	955089.2	524436.0	73815.8
59560.6	129920.8	128420.2	126764.3	144722.5	151741.6
114890.8	217318.0	798756.5	980140.6	507900.0	101894.8
184785.0	220405.5	111788.7	91883.5	149400.9	197732.6
359477.8	503162.8	1010148.8	928445.7	498305.8	160723.4
202675.6	238951.8	198517.2	130857.8	240019.3	194661.3
217779.5	511770.8	1267679.1	1044144.1	500706.5	143853.3
144207.0	213878.8	135892.9	149556.7	143903.6	179364.1
228759.8	495550.2	1436295.6	1054850.9	470557.7	169005.7
165357.3	234767.5	181022.5	218081.0	197937.5	208538.6
380282.7	643381.7	1402873.1	1174081.4	519469.9	239357.2
279580.4	328629.9	208022.9	197194.2	183066.1	221086.5
249277.5	305844.8	707108.9	975933.1	500307.2	52243.4
136255.4	200013.0	132055.1	154938.7	144371.1	164762.8
186856.2	601861.5	1710886.9	1212549.8	513265.3	138763.0
203492.6	234190.9	167529.1	178098.0	209720.0	253093.6
281590.5	484123.1	1391843.3	957105.7	528841.2	254863.8
245002.4	265330.5	197938.4	189859.2	212688.1	289037.9
600840.9	944686.3	1046928.2	1138158.3	535926.7	150144.0
240034.0	234823.5	195520.9	188608.5	181192.4	211652.6
242441.8	754568.5	1532959.9	1179139.3	536698.7	211426.6
242651.0	272123.0	205415.9	217905.8	234672.2	216637.8
391353.4	827486.4	1491561.4	1219243.9	563675.8	241343.8
261054.8	273815.0	194301.8	210516.8	220891.7	311198.5
387033.4	607393.9	1337337.5	948802.4	513379.3	192804.6
274502.1	297712.5	175121.8	186359.9	186179.7	233520.4
272476.4	461198.4	802077.9	854984.7	442330.8	176174.7
189766.7	256034.2	201326.2	184493.4	189237.9	252009.4
404294.5	575456.1	1450864.4	1041912.7	538311.9	152978.4
204342.6	199223.4	202850.5	165764.4	160089.0	229090.8
275931.4	648679.8	1476677.3	1414698.4	615774.3	248509.5

INPUT FILE, cont.

```
322308.9   330460.4   317618.1   256591.7   213892.7   294826.4
525460.4  1187389.9  1221848.8   951035.5   530523.1   281055.8
355721.2   332593.4   248950.2   196467.1   190054.6   203665.5
282568.3   229243.0   613430.4   662783.8   374748.9   150460.5
219854.7   226202.6   203976.3   195951.1   183363.5   311509.6
424351.0   623808.1   986942.6   962470.8   439596.7   246218.9
254223.5   244157.0   199447.6   151298.2   185925.3   293663.4
373019.8   638934.4   867876.5   900973.6   503767.6    95793.2
 98183.3   180653.4   165422.6   133044.5   172020.0   210309.4
334818.4   708964.6  10784459.6   808351.9   397760.2   222581.3
227229.4   268819.8   243144.9   210184.6   185931.2   217324.7
267444.4   842839.1  13712144.4   827593.9   409999.9   100729.9
213500.7   238969.6   212529.3   171091.8   218344.9   260642.5
343562.5   750029.2  13827728.5  1182926.1   478035.9   257241.5

291259.6   308908.6   231284.3   239626.9   210289.1   282364.7
321687.6   520903.3  10411102.2  1080773.0   500648.3   274934.3
337261.8   381497.3   229231.6   278409.6   233685.2   290135.7
387055.8   829534.7  15179651.1  1160451.3   620174.0   315420.9
```

APPENDIX B

IRRIGATION WATER USE COMPUTER MODEL

Figure 18. Canyon Ferry Drainage Basin Irrigation Water Use Model

```
      DIMENSION CROPET(270),F(36),FLOIN(270),FDS(270),FDF(270),
     &DIV(270),OPSP(270),SEEP(270),TWS(270),DPS(270),TWF(270),
     &DPF(270), SSS(270), SRF(270), GW(270), RETFLO(270),
     &FLOND(270), FLOOUT(270), RELFLO(270), PCIR(270), NAF(25),
     &NAS(25), CIR(25), NYR(25), RFLO(270), TFLOIN(270),
     &TDIV(270), TGW(270), TRFLO(270), TFLOOUT(270),
     &AVMIN(270), AVMDIV(270), AVMGW(270), AVMR(270),
     &AVMOUT(270), AVREL(270)

      BASIN MODEL INPUT PARAMETERS

      READ IN THE CONVEYANCE EFFICIENCY (OFF-FARM)
      READ (105,10) CEFF
   10 FORMAT (1F8.0)

      READ IN THE PORTION OF CANAL LOSSES THAT ARE INFILTRATED
      READ (105,20) CLSP
   20 FORMAT (1F8.0)

      READ IN THE SPRINKLER SYSTEM EFFICIENCY (ON-FARM)
      READ (105,30) SSEFF
   30 FORMAT (1F8.0)

      READ IN THE FLOOD SYSTEM EFFICIENCY (ON-FARM)
      READ (105,40) FSEFF
   40 FORMAT (1F8.0)

      READ IN THE PORTION OF FIELD LOSSES THAT ARE
      UNDER SPRINKLER IRRIGATION
      READ (105,50) FLDPS
   50 FORMAT (1F8.0)

      READ IN THE PORTION OF FIELD LOSSES THAT ARE INFILTRATED
      UNDER FLOOD IRRIGATION
      READ (105,60) FLDPF
   60 FORMAT (1F8.0)

      READ IN THE PORTION OF SUBSURFACE LOSSES THAT ARE CONSUME
      CONSUMED BY EVAPORATION AND PHREATOPHYTES
      READ (105,70) PANDE
   70 FORMAT (1F8.0)

      READ IN THE RETURN FLOW FACTORS
      READ (105,80) (F(I),I=1,36)
   80 FORMAT (6F8.0)

      READ IN THE MONTHLY PORTIONS OF CROP
      IRRIGATION REQUIREMENTS
      READ (105,90) (PCIR(I),I=1,12)
   90 FORMAT (6F8.0)
```

```
      SIMULATION VARIABLES

      READ IN THE NUMBER OF YEARS TO BE SIMULATED
      READ (105,100) NYRS
  100 FORMAT (I8)
      NMO=12*NYRS
      YRS=1.0*NYRS

      READ IN THE FIRST YEAR OF SIMULATION DATA
      READ (105,115) NR
  115 FORMAT (I8)
      FIRST=NR+3
      LAST=NR+NYRS-1

      READ IN THE NUMBER OF SPRINKLER IRRIGATED
      ACRES FOR EACH YEAR
      READ (105,110) (NAS(I),I=1,NYRS)
  110 FORMAT (6F8.0)

      READ IN THE NUMBER OF FLOOD IRRIGATED
      ACRES FOR EACH YEAR
      READ (105,120) (NAF(I),I=1,NYRS)
  120 FORMAT (6F8.0)

      READ IN THE ANNUAL CROP IRRIGATION REQUIREMENTS
      (ACRE-FT/ACRE)
      READ (105,130) (CIR(I), I=1,NYRS)
  130 FORMAT (6F8.0)

      READ IN THE NATURAL INFLOWS TO THE BASIN FOR EACH MONTH
      READ (105,140) (FLOIN(I), I=1,NMO)
  140 FORMAT (6F10.1)


      COMPUTATIONS


      DO 150 I=1,NMO-12
      PCIR(I+12)=PCIR(I)
  150 CONTINUE

      DO 170 J=1,NYRS
         DO 170 I=12*J-11,12*J

         CROPET(I)=CIR(J)*PCIR(I)

         FDS(I)=CROPET(I)*NAS(J)/SSEFF
         FDF(I)=CROPET(I)*NAF(J)/FSEFF

         DIV(I)=(FDS(I)+FDF(I))/CEFF

         OPSP(I)=(1-CEFF)*DIV(I)*(1-CLSP)
         SEEP(I)=(1-CEFF)*DIV(I)*CLSP

         TWS(I)=(1-SSEFF)*FDS(I)*(1-FLDPS)
         TWF(I)=(1-FSEFF)*FDF(I)*(1-FLDPF)


         DPS(I)=(1-SSEFF)*FDS(I)*FLDPS
         DPF(I)=(1-FSEFF)*FDF(I)*FLDPF

         SSS(I)=SEEP(I)+DPS(I)+DPF(I)
         SRF(I)=OPSP(I)+TWS(I)+TWF(I)
          GW(I)=SSS(I)*(1-PANDE)

  170 CONTINUE
```

```
      SUBSURFACE RETURN FLOW ANALYSIS

      DO 180 I=1,NMO
      DO 180 J=1,NMO
      REAL R(270,270)
      R(I,J)=0.0
  180 CONTINUE

      DO 185 I=1,NMO
      IF (I.LE.36) THEN
         K=I
      ELSE
         K=36
      END IF
      RETFLO(I)=0.0

         DO 185 J=1,K
         R(I,I+1-J)=GW(I+1-J)*F(J)

  185 RETFLO(I)=RETFLO(I)+R(I,I+1-J)


      TAVMIN=0.0
      TAVMD=0.0
      TAVMGW=0.0
      TAVMR=0.0
      TAVMT=0.0
      TOTQ=0.0



      DO 190 I=1,NMO
         FLOND(I)=FLOIN(I)-DIV(I)
         RFLO(I)=RETFLO(I)+SRF(I)
         FLOOUT(I)=FLOND(I)+RFLO(I)
         TOTQ=TOTQ+FLOOUT(I)
  190 CONTINUE

      DO 191 I=1,12
         AVMIN(I)=0.0
         AVMDIV(I)=0.0
         AVMGW(I)=0.0
         AVMR(I)=0.0
         AVMOUT(I)=0.0
      DO 191 J=I+36,12*NYRS-12+I,12
            AVMIN(I)=AVMIN(I)+FLOIN(J)/(YRS-3.0)
            AVMDIV(I)=AVMDIV(I)+DIV(J)/(YRS-3.0)
            AVMGW(I)=AVMGW(I)+GW(J)/(YRS-3.0)
            AVMR(I)=AVMR(I)+RFLO(J)/(YRS-3.0)
            AVMOUT(I)=AVMOUT(I)+FLOOUT(J)/(YRS-3.0)
  191 CONTINUE


      DO 193 I=1,12
         TAVMIN=TAVMIN+AVMIN(I)
         TAVMD=TAVMD+AVMDIV(I)
         TAVMGW=TAVMGW+AVMGW(I)
         TAVMR=TAVMR+AVMR(I)
         TAVMT=TAVMT+AVMOUT(I)
  193 CONTINUE

      DO 194 I=1,12
         AVREL(I)=100*AVMOUT(I)/(TAVMT/12)
  194 CONTINUE
```

```
      QMAVE=TOTQ/NMO
      DO 200 I=1,NMO
      RELFLO(I)=100*FLOOUT(I)/QMAVE
  200 CONTINUE

      DO 208 J=1,NYRS
         TFLOIN(J)=0.0
         TDIV(J)=0.0
         TGW(J)=0.0
         TRFLO(J)=0.0
         TFLOOUT(J)=0.0
      DO 208 I=J*12-11,J*12
         TFLOIN(J)=TFLOIN(J)+FLOIN(I)
         TDIV(J)=TDIV(J)+DIV(I)
         TGW(J)=TGW(J)+GW(I)
         TRFLO(J)=TRFLO(J)+RFLO(I)
         TFLOOUT(J)=TFLOOUT(J)+FLOOUT(I)
  208 CONTINUE

      PRINT STATEMENTS

      WRITE (108,210)
  210 FORMAT (//,35X,'CANYON FERRY DRAINAGE BASIN MODEL')

      WRITE (108,215)
  215 FORMAT (/,35X,'CANYON FERRY INFLOW GENERATION RUN')

      WRITE (108,216)
  216 FORMAT (/,29X,'***1984 LEVEL OF IRRIGATION
     +-----------ACRES***')

      WRITE (108,220) CEFF
  220 FORMAT (////,2X,'CONVEYANCE EFFICIENCY=',F4.2)

      WRITE (108,230) SSEFF
  230 FORMAT (/,2X,'SPRINKLER SYSTEM EFFICIENCY=',F4.2)

      WRITE (108,240) FSEFF
  240 FORMAT (/,2X,'FLOOD SYSTEM EFFICIENCY=',F4.2)

      WRITE (108,250) CLSP
  250 FORMAT (//,2X,'PORTION OF CANAL LOSSES THAT
     INFILTRATE=',F4.2)

      WRITE (108,260) FLDPS
  260 FORMAT(/,2X,'PORTION OF SPRINKLER LOSSES
     THAT INFILTRATE=',F4.2)

      WRITE (103,270) FLDPF
  270 FORMAT (/,2X,'PORTION OF FLOOD LOSSES
     THAT INFILTRATE=',F4.2)

      WRITE (108,280) PANDE
  280 FORMAT (/,2X,'PORTION OF INFILTRATED LOSSES
     CONSUMED=',F4.2)

      WRITE (108,290)
  290 FORMAT (///,2X,'(FLOWS SHOWN BELOW ARE IN
     ACRE-FT PER MONTH)')
```

```
      DO 310 J=4,NYRS
         NYR(J)=J+NR-1

      WRITE (108,320) NYR(J)
320   FORMAT (////,'YEAR=',I5)
      WRITE (108,330) NAS(J)
330   FORMAT (/,'SPRINKLER SYSTEM, ACRES=',I8)
      WRITE (108,340) NAF(J)
340   FORMAT (/,'     FLOOD SYSTEM, ACRES=',I8)
      WRITE (108,345) CIR(J)
345   FORMAT (/,'CROP IRRIGATION REQUIREMENT,
      AC-FT/AC=',F5.2)

      WRITE (108,350)
350   FORMAT(/,23X,'MONTH  NATURAL INFLOW  DIVERSION
     &'GW RECHARGE  RETURN FLOW  CANYON FERRY INFLOW
     & % AVE')

      WRITE (108,355)
355   FORMAT (/)

      DO 380 I=12*J-11,12*J
             L=I-(J-1)*12
      WRITE (108,360) L, FLOIN(I), DIV(I), GW(I),
     &RFLO(I), FLOOUT(I), RELFLO(I)
360   FORMAT (25X,I2,4X,F10.1,3X,F10.1,3X,F10.1,
     &4X,F10.1,7X,F10.1,6X,F7.1)

380   CONTINUE

      WRITE (108,370) TFLOIN(J), TDIV(J), TGW(J), TRFLO(J),
     &TFLOOUT(J)
370   FORMAT (//,14X,'ANNUAL TOTALS:',4X,F10.1,2X,F10.1,3X,
     &F10.1,4X,F10.1,8X,F10.1)

310   CONTINUE

      WRITE (108,400)
400   FORMAT (////,'*     *     *     *     *     *     *')

      WRITE (108,410)
410   FORMAT (//,'AVERAGE VALUES OVER PERIOD OF SIMULATION')

      WRITE (108,420) FIRST, LAST
420   FORMAT (2X,I4,' - ',I4)

      WRITE (108,430)
430   FORMAT (//,24X,'MONTH        NATURAL INFLOW
     &'DIVERSION     CANYON FERRY INFLOW  % AVE')

      WRITE (108,435)
435   FORMAT (/)

      DO 440 I=1,12
      WRITE (108,450) I, AVMIN(I), AVMDIV(I),
      AVMOUT(I), AVREL(I)
450   FORMAT (25X,I2,F20.1,F20.1,F20.1,F10.1)
440   CONTINUE

      WRITE (108,460) TAVMIN, TAVMD, TAVMT
460   FORMAT (//,6X,'AVERAGE ANNUAL TOTALS:',F20.1,
      F20.1,F20.1)

      END
```

APPENDIX C

RESERVOIR OPERATIONS COMPUTER MODEL

Figure 19. Canyon Ferry Reservoir Operations Simulation Model

```
      DIMENSION MINREL(12),MOTAREL(12),TAREL(12),
     & TITLE(3,20), IPERIOD(12), QREL(1130),
     & ELEV(1130),  QREL1(100,12), ELEV1(100,12),
     & AVGREL(12), AVGELEV(12), AVGSPILL(12),
     & CFSTOR(95), QMO(100,12), QPOWER(1000),
     & QPOWER1(100,12), POWER1(100,12), AVGPOWER(12),
     & TQREL(100), TQPOWER(100), TPOWER(100),
     & Q(1000), QCFS(100,12), STORAGE(0:1130),
     & SPILL(1000), CFELEV(95), POWER(1000),
     & IYEAR(1000), AVGQPOWER(12), TSPILL(100)


   READ IN JOB DESCRIPTION
      DO 10 I=1,3
      READ (105,1) (TITLE(I,J),J=1,20)
    1 FORMAT(20A4)
   10 CONTINUE

   READ JOB CONTROL VARIABLES:
      READ(105,2) NMONTH,IMO,IYR,NTAREL
    2 FORMAT(4I8)
      READ(105,3) BRESEL,MAXEL,SPILLEL,RELCAP
    3 FORMAT(4F8.0)

 READ IN MINIMUM MONTHLY TOTAL RELEASES....1-12
      READ(105,4)(MINREL(I),I=1,12)
    4 FORMAT(12F6.0)

 READ MONTHS FOR WHICH TARGET EL. SET (MUST=NTAREL)
      READ(105,5)(MOTAREL(I),I=1,NTAREL)
    5 FORMAT(12I8)

 READ TARGET ELEVATIONS    (MUST=NTAREL)
      READ(105,6)(TAREL(I),I=1,NTAREL)
    6 FORMAT(12F8.0)

  READ IN RATING TABLE FOR CF RESERVOIR
      READ(105,8)(CFELEV(I),I=1,80)
      READ(105,8)(CFSTOR(I),I=1,80)
    8 FORMAT(10F8.3)

  READ IN INFLOW SEQUENCE BY YEAR AND CONVERT TO YEAR/MONTH
      READ(105,7)(Q(I),I=1,NMONTH)
    7 FORMAT (12F6.0)
      J=1
      K=IMO
      IYEAR(1)=IYR
      I=1
   19 QCFS(J,K)=Q(I)
      IF(K.EQ.12) IYEAR(J) = IYR+J-1
      NYEARS=IYEAR(J)-IYR+1
      IF(K.EQ.12) J=J+1
      IF(K.EQ.12) K=1;GO TO 15

      K = K+1
   15 CONTINUE
      I = I+1
      IF(I.LE.NMONTH) GO TO 19
```

```
WRITE OUT SUMMARY OF INPUT DATA

      WRITE(108,21)
 21   FORMAT (1H1,33X,'***CANYON FERRY RESEVOIR
      OPERATION MODEL***'//)

      WRITE (108,22) (TITLE(1,J),J=1,20)
 22   FORMAT ('SIMULATION CONDITION:',20A4)

      WRITE (108,23)
 23   FORMAT (//,'---INPUT DATA SUMMARY--------',//)

      WRITE (108,24) NMONTH
 24   FORMAT (5X,'# OF MONTHS OF SIMULATION:',I5)

      WRITE (108,25) IYR
 25   FORMAT (5X,'FIRST YEAR OF SIMULATION:',I5)

      WRITE (108,26) BRESEL
 26   FORMAT (5X,'STARTING RESERVOIR ELEV:',F7.1,1X,'(FT)')

      WRITE (108,27) MINREL(1)
 27   FORMAT (5X,'MIN. MONTHLY RELEASE:',F6.0,1X,'(CFS)',/)

      WRITE (108,28) NTAREL
 28   FORMAT (5X,'# OF TARGET ELEVATIONS PER YEAR:',I2,/)

      WRITE (108,29)
 29   FORMAT (5X,'MONTH',1X,'TARGET ELEV.')

      DO 30 I=1,NTAREL
 30   WRITE (108,31) MOTAREL(I), TAREL(I)
 31   FORMAT (6X,I2,5X,F7.1)

      WRITE (108,32)
 32   FORMAT (//,'CANYON FERRY INFLOWS (CFS)')

      WRITE (108,650)
650   FORMAT ('(ADJUSTED FOR HELENA VALLEY IRRIGATION
      DIVERSIONS)',/)

      WRITE (108,310)
310   FORMAT (14X,'OCT',5X,'NOV',5X,'DEC',5X,'JAN',
     &5X,'FEB',5X,'MAR',5X,'APR',5X,'MAY',5X,'JUN',
     &5X,'JUL',5X,'AUG',5X,'SEPT',/)

      DO 40 I=1,NYEARS
 40   WRITE(108,33) IYEAR(I),(QCFS(I,J),J=1,12)
 33   FORMAT(1X,I8,1X,12F8.0)


START COMPUTATIONS FOR RESERVOIR RELEASES BASED
ON MEETING TARGET ELEVATIONS

COMPUTE TIME INTERVALS BETWEEN TARGET PERIODS...

      DO 51 I=1,NTAREL
         IPERIODONE = MOTAREL(1) - 1
         IPERIOD(NTAREL) = 12 - MOTAREL(NTAREL) + MOTAREL(1)
         IF(I.EQ.NTAREL) GO TO 70
      IPERIOD(I) = MOTAREL(I+1) - MOTAREL(I)
 70   CONTINUE
 51   CONTINUE

      OUTPUT IPERIODONE
      OUTPUT IPERIOD
```

```
COMPUTE STARTING RESERVOIR STORAGE

      J=1
     CALL ELSTOR (CFELEV, CFSTOR, BRESEL, VT)
        IF(IPERIODONE.EQ.0) VFINAL = VT
     OUTPUT BRESEL
     OUTPUT VT
     OUTPUT"--------"


 THE "DO 100" LOOP COMPUTES RELEASES, ELEV, SPILLS, ETC.
 FOR EACH TIME PERIOD... THE FIRST PART (DOWN TO 80)
 COMPUTES FOR THE FIRST TIME PERIOD ONLY FOR THE CASE
 WHERE IPERIODONE NOT EQUAL TO "0"...


 75 CONTINUE

     DO 100 I=1,NTAREL
        IF(IPERIODONE.EQ.0) GO TO 80
        IF(J.GT.1)GO TO 80

COMPUTE BEGINNING RESERVIOR STORAGE
     VOLUMEI = ((BRESEL-3000.)/360.13)**18.315
     CALL ELSTOR(CFELEV,CFSTOR,BRESEL,VOLUMEI)

COMPUTE VOL TO BE ADDED (SUBTRACTED) TO GET
TO FIRST TARGET ELEV.
     CALL ELSTOR (CFELEV, CFSTOR, TAREL(1), VT1)
        VONE = VOLUMEI - VT1
     OUTPUT TAREL(1)
     OUTPUT VT1
     OUTPUT"------------"

COMPUTE INFLOW VOLUME DURING FIRST PERIOD
     OUTPUT VOLUMEI
     OUTPUT VONE
        QTEMP = 0.0
     DO 50 K = 1,IPERIODONE
 50 QTEMP = QTEMP + Q(K)
     OUTPUT QTEMP

CONVERT TO ACRE-FT
        VTEMP = 60.27*QTEMP
     OUTPUT VTEMP

COMPUTE AVG. RELEASE AS R = (INFLOW VOL +
 TAR. EL. VOL.)/TIME
         RELEASE = ((VTEMP + VONE)/IPERIODONE)/60.27
        IF(RELEASE.LT.MINREL(I)) RELEASE = MINREL(I)
     OUTPUT RELEASE

 VFINAL = VTEMP - (RELEASE*IPERIODONE*60.27) + VOLUMEI
        CALL STOREL(CFELEV, CFSTOR, VFINAL, ELFINAL)
     OUTPUT ELFINAL
     OUTPUT VFINAL

     CALL ELSTOR (CFELEV, CFSTOR, BRESEL, VT2)
        STORAGE(0) = VT2
     OUTPUT BRESEL
     OUTPUT VT2
     OUTPUT"-------------"

        ASTORAGE = STORAGE(0)
     OUTPUT ASTORAGE
```

```
      DO 60 K=1,IPERIODONE
         QREL(K) = RELEASE
         DELTAV = (Q(K) - QREL(K))*60.27
         STORAGE(K) = DELTAV + STORAGE(K-1)
      SPILL(K) = 0.0

      ST1 = STORAGE(K)
         CALL STOREL(CFELEV,CFSTOR, ST1, ELEV(K))

   58 CONTINUE
      AQREL = QREL(K)
      ADELTAV = DELTAV
      ASTORAGEK = STORAGE(K)
      AELEV = ELEV(K)
      OUTPUT AQREL
      OUTPUT ADELTAV
      OUTPUT ASTORAGEK
      OUTPUT AELEV
   60 CONTINUE

      J = J + IPERIODONE
      OUTPUT J
      OUTPUT"..............................."

COMPUTE AVG. RELEASE FOR REMAINING PERIODS


   80 CONTINUE


COMPUTE VOL. ADDED (SUBTRACTED) TO GET
TO NEXT TARGET EL. (VOL)

      IF(I.EQ.NTAREL) TAREL(I+1) = TAREL(1)
      OUTPUT VFINAL
         ATAREL = TAREL(I+1)
      OUTPUT ATAREL
      CALL ELSTOR (CFELEV,CFSTOR,TAREL(I+1),VTEMP1)
         VOL = VFINAL - VTEMP1
      OUTPUT VTEMP1
      OUTPUT"* * * * * * * * "
      STORAGE(0) = VFINAL
      OUTPUT VOL


COMPUTE INFLOW VOLUME DURING NEXT FORCAST PERIOD

         QTEMP = 0.0
      OUTPUT ". . . . . "


 COMPUTE INFLOW VOLUME FOR PRESENT FORECAST PERIOD (VTEMP)

      DO 120 K = J,J+IPERIOD(I)-1
  120 QTEMP = QTEMP + Q(K)
      OUTPUT QTEMP

CONVERT TO ACRE-FT
         VTEMP = 60.27*QTEMP
      OUTPUT VTEMP

COMPUTE AVERAGE RELEASE FOR TARGET PERIOD
         RELEASE = ((VTEMP+VOL)/IPERIOD(I))/60.27
      IF(RELEASE.LT.MINREL(I)) RELEASE = MINREL(I)
      OUTPUT RELEASE

      VFINAL=VTEMP-(RELEASE*IPERIOD(I)*60.27)+VFINAL
```

```
COMPUTE FINAL RESERVOIR ELEV. (END OF PERIOD)

      CALL STOREL(CFELEV, CFSTOR, VFINAL, ELFINAL)
      OUTPUT ELFINAL
      OUTPUT K

      OUTPUT"111111111111111"

COMPUTE RES. ELEV FOR EACH MONTH IN
GIVEN FORECAST PERIOD


      DO 130 K = J,J+IPERIOD(I)-1
         QREL(K) = RELEASE
         DELTAV = (Q(K) - QREL(K))*60.27
      Q1 = Q(K)
      OUTPUT Q1
      OUTPUT RELEASE
      OUTPUT DELTAV
         STORAGE(K) = DELTAV + STORAGE(K-1)

      STEMP = STORAGE(K)
      CALL STOREL( CFELEV, CFSTOR, STEMP, ELEV(K))


 COMPUTE SPILL  (SPILL=TOTAL RELEASE - POWER RELEASE)

         HEAD = ELEV(K) - 3650.5
         QPMAX = 3561.11 + 19.44*HEAD
         SPILL(K) = QREL(K) - QPMAX
      IF(SPILL(K).LE.0.0) SPILL(K) = 0.0
      IF(QREL(K).GE.QPMAX) QPOWER(K) = QPMAX
      IF(QREL(K).LT.QPMAX) QPOWER(K) = QREL(K)


 COMPUTE HYDROPOWER PRODUCTION BASED ON ELEV(K)

      CALL HP (STORAGE(K), QPOWER(K), POWER(K))



      STOR1 = STORAGE(K)
      ELK1 = ELEV(K)
      OUTPUT ELK1
      OUTPUT STOR1
      OUTPUT S1
      OUTPUT"222222222222222"
130   CONTINUE

FORCAST PERIOD LOOP COMPLETED


 INCREMENT J TO START NEXT FORECAST PERIOD

         J = J + IPERIOD(I)
      IF(J.GE.NMONTH-(IPERIODONE+1)) GO TO 76
      OUTPUT NMONTH
      OUTPUT IPERIODONE
         JJ=J
      OUTPUT JJ

100   CONTINUE
      GO TO 75

C-----------------------------------------------------------------

 76   CONTINUE
```

```
REORGANIZE VARIABLES BY YEAR/MONTH
      J=1
      K=IMO
      IYEAR(1)=IYR
      I=1
170 QREL1(J,K) = QREL(I)
      QMO(J,K) = Q(I)
      ELEV1(J,K) = ELEV(I)
         AF = 1.0
         IF(K.EQ.5) AF=.92
      SPILL1(J,K) = SPILL(I)*AF
      POWER1(J,K) = POWER(I)*AF
      QPOWER1(J,K) = QPOWER(I)
      IF(K.EQ.12) IYEAR(J) = IYR + J -1
      NYEARS = IYEAR(J) - IYR + 1
   IF(K.EQ.12) J=J+1
   IF(K.EQ.12) K=1; GO TO 175
      K= K+1
175 CONTINUE
      I = I + 1
      IF(I.LE.NMONTH) GO TO 170

C-----------------------------------------------------------------
COMPUTE AVG MONTHLY STATISTICS FOR YRS 2 THROUGH NYEARS-1

   DO 200 J=1,12
      SUM1=0.0
      SUM2=0.0
      SUM3=0.0
      SUM4=0.0
      SUM5=0.0
   DO 210 I=2,NYEARS-1
      SUM1 = SUM1 + QREL1(I,J)
      SUM2= SUM2 + ELEV1(I,J)
      SUM3= SUM3 + SPILL1(I,J)
      SUM4=SUM4 + POWER1(I,J)
      SUM5= SUM5 + QPOWER1(I,J)
210 CONTINUE
      AVGREL(J) = SUM1/(NYEARS-2)
      AVGELEV(J) = SUM2/(NYEARS-2)
      AVGSPILL(J) = SUM3/(NYEARS-2)
      AVGPOWER(J) = SUM4/(NYEARS-2)
      AVGQPOWER(J) = SUM5/(NYEARS-2)
200 CONTINUE


   ATREL=0.0
   ATSPILL=0.0
   ATPOWER=0.0
   ATQPOWER=0.0

   DO 600 J=1,12
      ATREL=ATREL+(AVGREL(J)/12)*723.57
      ATSPILL=ATSPILL+(AVGSPILL(J)/12)*723.57
      ATPOWER=ATPOWER+AVGPOWER(J)
      ATQPOWER=ATQPOWER+(AVGQPOWER(J)/12)*723.57
600 CONTINUE
   DO 700 I=2,NYEARS-1
      TQREL(I)=0.0
      TQPOWER(I)=0.0
      TPOWER(I)=0.0
      TSPILL(I)=0.0
   DO 700 J=1,12
      TQREL(I)=TQREL(I)+QREL1(I,J)
      TQPOWER(I)=TQPOWER(I)+QPOWER1(I,J)
      TPOWER(I)=TPOWER(I)+POWER1(I,J)
      TSPILL(I)=TSPILL(I)+SPILL1(I,J)
700 CONTINUE
```

```
PRINT OUT VARIABLES BY YEAR/MONTH....

      WRITE (108,320)
320   FORMAT(///,'--RESULTS OF RESERVOIR MODEL--')

      WRITE (108,340)
340   FORMAT (/,10X,'TOTAL RESERVOIR RELEASE (CFS)')

      WRITE (108,350)
350   FORMAT (10X,'POWER TURBINE RELEASE (CFS)')

      WRITE (108,360)
360   FORMAT (10X,'RESERVOIR ELEVATION (FEET)')

      WRITE (108,370)
370   FORMAT (10X,'POWER OUTPUT (MILLIONS OF KW-HRS)')

      WRITE (108,380)
380   FORMAT (10X,'SPILL (CFS)',//)

      DO 180 I=2,NYEARS-1
      WRITE (108,173) IYEAR(I)
      WRITE(108,174)
      WRITE(108,178) (QREL1(I,J),J=1,12), TQREL(I)
      WRITE(108,178) (QPOWER1(I,J),J=1,12), TQPOWER(I)
      WRITE(108,178) (ELEV1(I,J),J=1,12)
      WRITE(108,178) (POWER1(I,J),J=1,12), TPOWER(I)
      WRITE(108,179) (SPILL1(I,J),J=1,12), TSPILL(I)
173   FORMAT ('YEAR:',I4,/)
174   FORMAT(4X,"OCT",5X,"NOV",5X,"DEC",5X,"JAN",
     &5X,'FEB',5X'MAR',5X,"APR",5X,"MAY",5X,"JUN",
     &5X,'JUL',5X,'AUG',5X,'SEP',4X,'TOTAL',/)

178   FORMAT (12F8.1,1X,F8.1)
179   FORMAT (12F8.1,1X,F8.1,///)
180   CONTINUE

PRINT-OUT AVERAGE MONTHLY STATISTICS

      WRITE(108,230)
230   FORMAT (///,'---AVERAGE VALUES OVER PERIOD OF RECORD----
      WRITE (108,400)
400   FORMAT (6X,'(EXCEPT FIRST AND LAST YEARS)',//)

      WRITE(108,236)
      WRITE(108,231) (AVGREL(J),J=1,12)
      WRITE(108,232) (AVGQPOWER(J),J=1,12)
      WRITE(108,233) (AVGELEV(J),J=1,12)
      WRITE(108,234) (AVGPOWER(J),J=1,12)
      WRITE(108,235) (AVGSPILL(J),J=1,12)

231   FORMAT ('TOTAL RELEASE: ',12F8.1)
232   FORMAT ('POWER RELEASE: ',12F8.1)
233   FORMAT ('ELEVATION:     ',12F8.1)
234   FORMAT ('POWER OUTPUT:  ',12F8.1)
235   FORMAT ('SPILLS:        ',12F8.1)
236   FORMAT (19X,'OCT',5X,'NOV',5X,'DEC',5X,'JAN',
     &5X,'FEB',5X,'MAR',5X,'APR',5X,'MAY',5X,'JUN',
     &5X,'JUL',5X,'AUG',5X,'SEP',/)
```

```
      WRITE (108,510)
510   FORMAT (///,5X,'AVERAGE ANNUAL TOTALS:')

      WRITE (108,520) ATREL
520   FORMAT (//,5X,'TOTAL RESERVOIR RELEASE:',F9.1,1X,
     (ACRE-FT)')

      WRITE (108,530) ATQPOWER
530   FORMAT (5X,'POWER TURBINE RELEASE:',2X,F9.1,1X,
     '(ACRE-FT)')

      WRITE (108,540) ATSPILL
540   FORMAT (5X,'SPILLS:',F9.1,1X,'(ACRE-FT)')

      WRITE (108,550) ATPOWER
550   FORMAT (5X,'POWER PRODUCTION:',F6.1,1X,
      '(MILLION KW-HRS)')


      END



*****    SUBROUTINES    ***********


      SUBROUTINE ELSTOR(CFELEV,CFSTOR,ELIN,STOROUT)
      REAL CFELEV(*),CFSTOR(*),ELIN,STOROUT
    THIS SUBROUTINE CONVERTS ELEVATIONS INTO STORAGES

    ELEV = FT.
    STORAGES = ACRE-FT.

      I=1
100   IF(ELIN.GT.CFELEV(I)) THEN
         I=I+1
         GO TO 100
      ELSE
         DSTOR = CFSTOR(I) - CFSTOR(I-1)
         DELEV = CFELEV(I) - CFELEV(I-1)
         STOROUT=CFSTOR(I-1)+DSTOR*(ELIN-CFELEV(I-1))/DELEV
      ENDIF
      END



      SUBROUTINE STOREL(CFELEV, CFSTOR, STORIN, ELOUT)
      REAL CFELEV(*), CFSTOR(*), STORIN, ELOUT

       THIS SUBROUTINE CONVERTS STORAGES INTO ELEVATIONS.

STORAGES ARE IN ACRE-FT. AND ELEV IS IN FT.

      I=1
100   IF(STORIN.GT. CFSTOR(I)) THEN
         I=I+1
         GO TO 100
      ELSE
         DSTOR = CFSTOR(I) - CFSTOR(I-1)
         DELEV = CFELEV(I) - CFELEV(I-1)
         ELOUT=CFELEV(I-1)+DELEV*(STORIN-CFSTOR(I-1))/DSTOR
      ENDIF
      END
```

```
SUBROUTINE HP( STORAGE , QPOWER, POWER)

REAL STORAGE , QPOWER , POWER

   STOR = STORAGE/1000.
OUTPUT STOR

IF (QPOWER.LT.3300) THEN
   PG=0.004936*(STOR**0.43936)
ELSEIF (QPOWER.LT.5500) THEN
   PG=0.006420*(STOR**0.40117)
ELSE
   PG=0.006235*(STOR**0.40117)
ENDIF

   Q1000 = QPOWER/1000.
   POWER = PG*Q1000*60.27
IF (POWER.GT.44.6) POWER=44.6
OUTPUT POWER
END
```

APPENDIX D

RETURN FLOW ANALYSIS

APPENDIX D

RETURN FLOW ANALYSIS

One of the most crucial elements of the irrigation water use model is the timing of the groundwater return flows. As described earlier, a portion of the water flowing through the conveyance canals along with a portion of that applied to the fields percolates through the soil and reaches the groundwater system. Since this water travels through the soil and aquifer slowly, it returns to the source stream gradually over a number of months. The actual rate of return depends on the distance from the point of irrigation application to the stream and on the underlying aquifer properties.

Glover (1960) developed a mathematical procedure for computing such groundwater return flows based on the parallel drain concept. Hurley (1968) successfully used this procedure to quantify return flows to the Rio Grande from irrigation in the Mesilla Valley of New Mexico. Brustkern (1986) used the procedure to develop a set of "return flow factors" for irrigation in the Canyon Ferry drainage basin. The return flow factors determine what portion of the irrigation water reaching the groundwater during a given month returns to the source stream during that, and each subsequent month. The distribution of these factors follow the exponential decay pattern shown in Figure 19. For specific factor values, see the input data file given at the end of Appendix A.

The factors indicate that, for example, if 100,000 acre-feet of irrigation water percolates down to the groundwater system during the

month of July, 22,000 ac-ft (22%) will return to the source stream during July, 18,000 ac-ft during August, 12,000 ac-ft during September, and so on. Though the exponentially decaying factors, and thus return flows, never reach zero, they do become negligibly small and are assumed to be zero after 36 months. Actually over 99.9% of a given month's application has returned during this 36 month period.

Groundwater return flows from individual monthly irrigation applications are additive. For example, the total groundwater return in October will consist of the combined returns from October and the previous 35 months (22% of October's, 18% of September's, 13% of August's, etc.). For a detailed description of the theory and methodology used to develop these values, see Brustkern (1986).

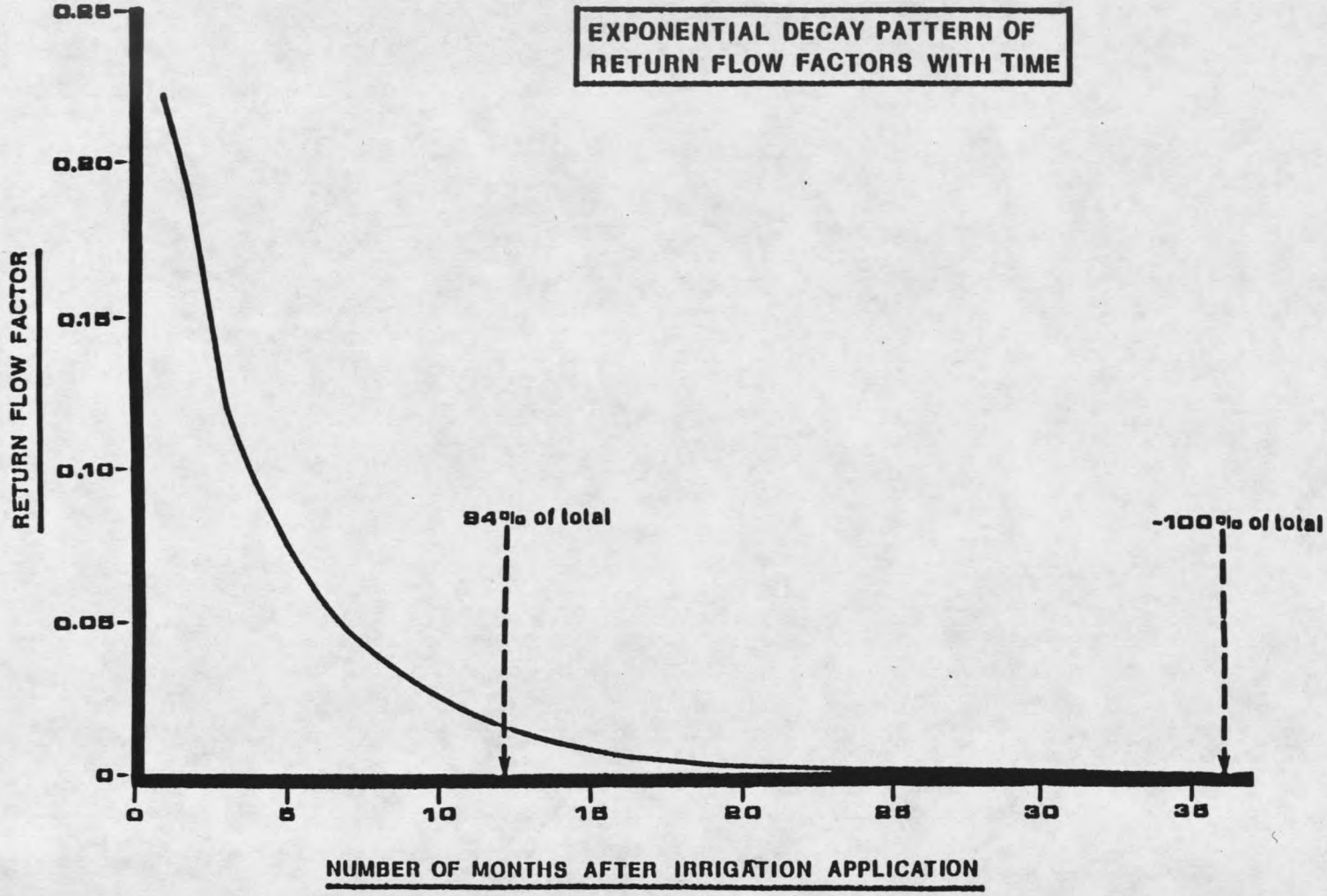

Figure 20. Distribution of the return flow factors with time developed for the Canyon Ferry drainage basin

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