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Task V Report: Development and Evaluation of Water Supply Alternatives

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KENTUCKY RIVER BASIN WATER SUPPLY ASSESSMENT STUDY

Task V Report - Development and Evaluation of Water Supply Alternatives

L. Ormsbee
J. Herman

Prepared for:
The Kentucky River Authority

By:
The Kentucky Water Resources Research Institute
University of Kentucky
Lexington, Kentucky

DECEMBER 1996
KWRRI

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EXECUTIVE SUMMARY

This report documents the procedure and results of Task V of the KWRRI Kentucky River Water Supply Assessment Study. This study was authorized by the Kentucky River Authority in a contract with the Kentucky Water Resources Research Institute dated April 1, 1995. The major tasks of the study are outlined below:

1. Task I: Review and assess previous studies and finalize study plan
2. Task II: Assess and forecast demand and availability of water by/for off-stem users (including the upper forks of the Kentucky River).
3. Task III: Assess and forecast the demand and availability of water by/for main-stem users (including the impacts of off-stem users).
4. Task IV: Develop a drought response model for the Kentucky River Basin
5. Task V: Develop a long range water supply plan for the Kentucky River Basin (including an evaluation of water supply alternatives)

In the Task III study, aggregate water supply deficits were calculated for the Kentucky River Basin for both moderate and high demand forecasts for the years 1994, 2000, 2010, and 2020 under both 1953 and 1930 drought conditions. The 1930 drought represents the drought of record with a return interval in excess of 100 years, while the 1953 drought represents the second most severe drought of record with a return frequency of approximately 50 years. The predicted water supply deficits from the Task III study for the present river system under both moderate and high population growth rates are shown below:

Summary of Water Supply Deficits (BG) for Future Demand Forecasts for Existing River System
(M = moderate population growth rate, H = high population growth rate)

Demand Forecast	1994	2000 M	2000 H	2010 M	2010 H	2020 M	2020 H
1930 Drought	6.3	6.6	7.3	7.2	8.5	7.4	9.7
1953 Drought	2.2	2.3	2.6	2.5	3.2	2.7	3.8

The purpose of Task V is to develop and evaluate alternative plans to provide for the long-range water supply needs of the Kentucky River Basin. For the purpose of this study, the long-range water supply needs have been quantified on the basis of high-growth water demand forecasts for the years 1994, 2000, 2010, and 2020 under a 1930 drought condition. As part of the Task V study, each alternative was evaluated using the KYBASIN model (Ormsbee and Herman, 1996) developed previously as part of the Task III study. The model was used to identify the reduction in water supply deficits associated with each alternative. The cost of each alternative was then determined using "reconnaissance level" costs developed as part of this study. Potential project alternatives have been sub-divided into two major categories: 1) demand-side alternatives and 2) supply-side alternatives. Demand-side alternatives include those alternatives where future water supply deficits are reduced or managed through either long-term conservation pricing or short-term demand (drought) management strategies. Supply-side alternatives include those alternatives where future supply deficits are met through the development of additional water supplies.

One way to reduce the anticipated future deficits is to reduce demands through the use of a conservation pricing rate structure. Under an assumption of a 20% price increase, the 2020 high demand deficit of 9.7 billions gallons could be reduced to 7.9 billion gallons at a cost of at least 5 million dollars per occurrence. A second way to eliminate the anticipated future deficits is to simply curtail the demand during the drought. Use of such a strategy to reduce demands equal to the available supply for a 2020 high growth scenario is expected to result in damages of approximately 30 million dollars. Clearly, drought management alone does not provide the sole solution to the problem.

Instead of considering a complete reduction of the deficit through demand management, a more realistic measure would be consider the impact of reducing the monthly demands to winter levels (i.e., January demands). In theory, the winter demands should represent a lower estimate of the minimum sustainable demand for a particular municipality, although it is highly unlikely that such levels could be realistically maintained for an extended period during a severe drought. Reduction of all demands in the basin to January levels for 1994 conditions results in a decrease in the total basin deficit from 6.3 billion gallons to 5.3 billion gallons. For 2020 high growth conditions such a policy would decrease the deficit from 9.7 billion gallons to 7.7 billion gallons. As before, it is clear that the overall water shortage problem in the Kentucky River Basin cannot be solved through conservation or demand management alone, but will require the implementation of some type of supply-side alternative.

For the purpose of this study, three major categories of supply alternatives were considered. These included: 1) main-stem alternatives, 2) off-stem reservoirs, and 3) a treated water pipeline from Louisville to Lexington. Main-stem alternatives include the rehabilitation/reconfiguration of the Kentucky River locks and dams through 1) installation of release valves in locks and dams 9-14, 2) installation of valves in locks 9-14 and temporary crest gates on locks and dams 9-14, and 3) installation of release valves in locks and dams 10-14 along with construction of a new dam at lock and dam 8. The various alternatives finally considered in this study were developed as a result of an incremental process coupled with monthly input from the project advisory committee.

Based on an initial evaluation of the various water supply alternatives, it was concluded that the lack of low-level release valves in dams 4-8 would prevent efficient utilization of any releases upstream of pool 9. As a result, a separate strategy was investigated for dealing with these deficits in the lower basin. Three separate alternatives were investigated for reducing/eliminating the deficits in pools 2-8. These alternatives include: 1) short-term demand management, 2) relaxation of the minimum flow requirement, and 3) installation/rehabilitation of low-level release valves in dams 4-8. The cost for eliminating the deficits in pools 2-8 for a 1930 drought event under the 2020 high demand forecast using demand management was estimated to be 7.9 million dollars. Alternatively, all remaining deficits in pools 2-8 can be eliminated by mining the pools as a consequence of either relaxing the minimum flow requirement or by installing valves in dams 4-8. Based an evaluation of each of these alternatives, it is recommended that the deficits in pools 2-8 be eliminated by construction of low-level-release valves in dams 4-8.

An evaluation of the impact of the installation/rehabilitation of valves in dams 9-14 revealed that the 2020 high-demand deficit of 7.0 (in pools 9-14) can be reduced to 3.0 billion gallons. This reduction is possible as a result of the transfer of water between pools and the ability to mine the pools as a result of satisfaction of minimum flow regulations through valve releases. The remaining deficit of 3 billion gallons can be addressed through five separate strategies. These include: 1) demand management, 2) installation of temporary crest gates on dams 9-14, 3) construction of a new dam at lock and dam site 8, 4) construction of one or more off-stem reservoirs, and 5) construction of a treated water pipeline from Louisville to Lexington.

If all withdrawals from the Kentucky River are held at their winter levels, the 3.0 billion gallon residual deficit in pool 9 (i.e. 2020 high demand conditions) can be reduced to 1.1 billion gallons. It should be recognized that this represents an extreme demand management policy and one that would likely result in millions of dollars of damages as well as adverse ecological impacts. Since such a strategy does not completely eliminate the remaining deficit, it is recommended that demand management not be used as a primary means of eliminating the remaining 3.0 billion gallons, but that it be used to supplement one of the remaining water-supply alternatives.

From a purely economic perspective, the construction of valves in dams 9-14 along with the construction of temporary crest gates is the best water-supply alternative. Following this solution, the construction of a off-stem reservoir would be the most economically viable. Either alternative is able to completely eliminate the remaining deficit. The treated water pipeline would be the next most economical choice, although the current proposal leaves a residual deficit of 1.1 billion gallons for the 2020 high-demand scenario. This result is predicated on the assumption that once constructed, a minimum capacity of 15 MGD would be reserved for use for drought augmentation. It would appear that construction of a large dam at lock and dam 8 would be the least favorable alternative. Similar to the treated water pipeline, this alternative also leaves a residual deficit of 1.1 billion gallons for the 2020 high demand scenario although the remaining deficit is actually attributable to demands in pool 8.

Based on the results of this study, the following recommendations are made:

1. Provide inter-pool release capabilities for pools 4-14. It should be noted that such capabilities have already been completed for pools 11 and 12. Until such time as a comprehensive water quality study be completed, it is recommended that the pools not be drawn down beyond 4 feet below crest.

2. Determine an effective operational policy for such facilities by considering the environmental impacts associated with their operation.

3. Provide supplemental supply augmentation for Nicholasville by lowering the raw water intake (if necessary).

4. Select a secondary water supply alternative from the following list: 1) temporary crest-gates, 2) off-stem reservoirs, 3) treated water pipeline from Louisville to Lexington, and 4) main-stem dam at lock and dam 8. As previously noted, the the temporary crest-gate and the off-stem reservoir alternatives are the most economical and either completely eliminate the remaining deficit.

5. Utilize demand management to supplement the selected water supply alternative. Use of demand management in a secondary role provides a factor of safety to the overall design.

6. Continue to work toward the development of a drought management plan for use in managing the river system in the event that a severe drought occurs before the implementation of adequate water supply facilities.

It should be recognized that the validity of the conclusions of this report are inherently dependent upon the validity of the assumptions in the deficit projections. As indicated in the Task III report, variations in the KYBASIN model assumptions could increase or decrease the deficit projections by 1 to 2 billion gallons. In addition, reliance on the valve alternative for elimination of the majority of the deficit is dependent upon an assumption that such an alternative will not result in adverse environmental conditions. This question has been preliminarily addressed by Harza in their most recent study (Harza, 1996). Based on their analysis, they concluded that "pool mining will not have deleterious effects on dissolved oxygen levels". This conclusion was based on the assumption that the pools are not drawn down below four feet. A more definitive evaluation of the water quality effects of the low-level valves and crest gates is currently under way and should be completed next year.

Finally, this study has focused on conducting an in-depth hydrologic/hydraulic analysis of each alternative along with a "reconnaissance level" cost analysis for the purpose of comparing the various alternatives. More detailed studies of many aspects of any selected plan will be necessary to: finalize the selection of the optimum location and size of facilities, evaluate the potential environmental impact, optimize the engineering design of the facilities and determine the financial and political feasibility.

CHAPTER I

INTRODUCTION

1.0 Overview

This report documents the procedure and results of Task V of the KWRRI Kentucky River Basin Water Supply Assessment Study. This study was authorized by the Kentucky River Authority in a contract with the Kentucky Water Resource Research Institute dated April 1, 1995. The study was conducted in five phases. Phase V is concerned with the development and evaluation of alternative plans to provide for the long-range water supply needs for the Kentucky River Basin. For the purpose of this report, the long-range water supply needs have been quantified on the basis of forecasted demands for the years 1994, 2000, 2010 and 2020 under a 1930 drought condition.

This report is divided into four chapters. Chapter I provides an introduction to the Task V study by providing a summary of the previous Harza study along with an overview of the current KWRRI Study. Chapter II provides a review of the results of the Task III deficit analysis which serves as a basis for quantifying the water supply needs for use in this study. Chapter III provides a discussion and evaluation of alternative long range plans. Finally, chapter IV provides a summary of the study along with conclusion and recommendations.

1.1 Physical Description of Study Area

The Kentucky River Basin extends over much of the central and eastern portions of the state and is home to approximately 710,000 Kentuckians. The watershed includes all or part of 42 counties and drains over 7,000 square miles with a tributary network of more than 15,000 miles. Three forks, the North, South, and Middle, form the headwaters of the Kentucky River. These forks combine near Heidelberg and drain over 1/3 of the basin. The river reach extending from the union of the three forks near Heidelberg downstream to the river's mouth at the Ohio River near Carrollton, Ky is commonly referred to as the *main stem* of the river. The main stem is approximately 255 miles long and is divided into fourteen contiguous pools by a series of locks and dams. These locks and dams, originally established for navigation, now serve to impound the river for the 575,000 Kentucky residents that rely on the river as their primary water supply. The pools created by the lock and dams provide a year-round water supply to the surrounding municipalities, industries, and riparian farmers. Figure 1.1 is a map of the Kentucky River Basin.

Four major impoundments exist in the basin that affect water supply. The Corps of Engineers owns and operates two flood-control reservoirs in the headwaters of the Kentucky River. The larger of the two reservoirs, Buckhorn Lake, has a total storage capacity of 54,783 million gallons (MG) and impounds approximately 10,500 MG at seasonal pool. The smaller reservoir, Carr Fork Lake, is roughly 2/7 the size of Buckhorn Lake, and impounds 7500 million gallons at seasonal pool. While Buckhorn and Carr Fork are not water supply reservoirs, they augment flows in the river during low flow periods. A third impoundment, Herrington Lake, exists on the Dix River, a major tributary located in the middle of the basin. Herrington Lake is owned and operated by Kentucky Utilities for hydropower generation and has no release obligation during drought periods. The fourth major impoundment in the basin is Jacobson Reservoir, a pump storage facility used exclusively for water supply. Water from the Kentucky River is pumped into Jacobson during wet periods and used to augment water supply during dry and peak periods. Jacobson is owned and operated by Kentucky American Water Company, the largest water supplier in the river basin.

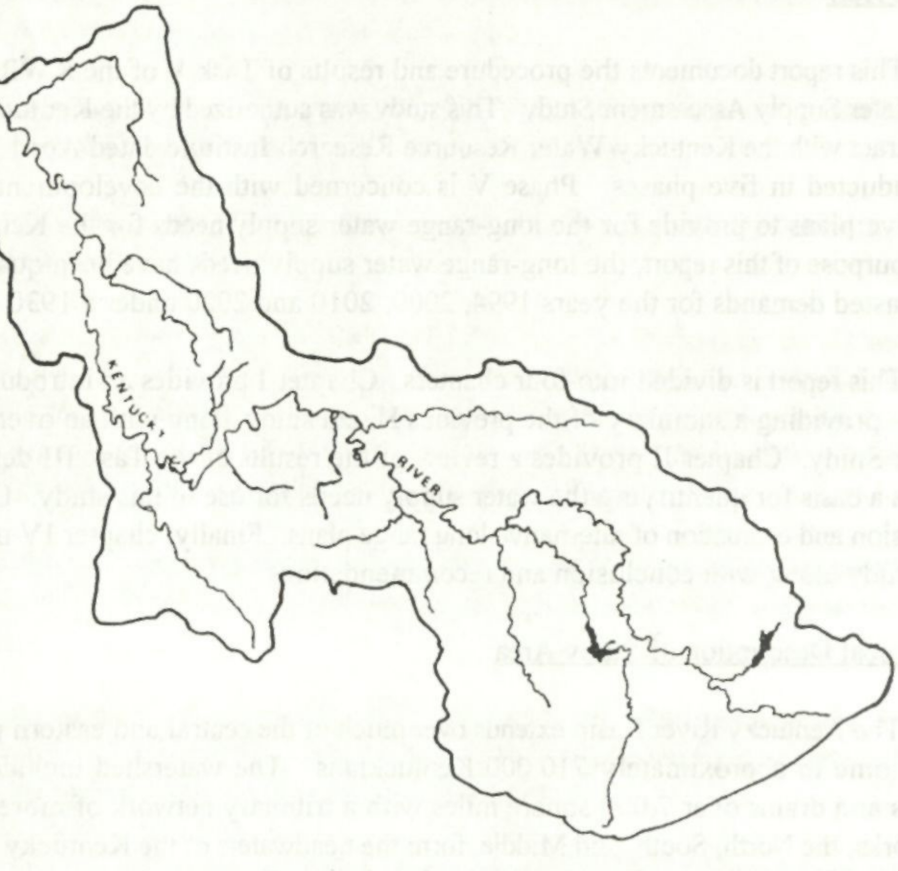

Figure 1.1 Map of Kentucky River Basin

1.2 Harza Deficit Analysis

In 1988, the Kentucky River Basin experienced a significant drought with water shortages (of varying intensity) realized in 35 counties and resulted in the declaration of a state water emergency. The attention caused by the '88 drought stimulated considerable public concern as to the availability of water in the basin during a severe drought. In response to growing public concern, a study was contracted with Harza Engineers to assist the Kentucky River Basin Steering Committee, a predecessor of the Authority, in adopting a long-range water supply plan. The purpose of the study was to quantify demand deficits occurring in the basin under several different droughts and for current and projected demand forecasts. Additionally, alternatives aimed at reducing or eliminating a design deficit were to be developed and evaluated.

The results of Harza's deficit analysis are documented in a 1990 report entitled **Phase I Interim Report Water Demands and Water Supply Yield and Deficit** (Harza, 1990). Water-supply deficits were computed for each of the Kentucky River pools between Frankfort (Pool 4) and Beattyville (Pool 14) for current water demands and for projected water demands through the year 2050. Hydrologic conditions considered included the drought of record (1930), the second most severe drought (1953) and the most recent drought (1988), as well as two "statistical" droughts (100-year and 50-year). The effects of a conservation program and a water-shortage response plan were developed. A water-supply deficit was defined as the difference between the water demand and the water supply when the water supply was less than demand. In calculating the deficit, Harza included irrigation as one of the major demands types. Table 1.1 below provided the computed total deficits for Kentucky River Pools 4 through 14 for historical droughts for 1990 and 2050 demand projections.

Table 1.1: Harza Analysis: Simulated Demand Deficits In Billion Gallons

Drought	Conservation	1990	2050
1930	No	8.1	8.7
1953	No	6.4	7.0
1988	No	1.3	1.3
1930	Yes	5.9	6.5

In each case, the deficit represents the total unsatisfied net municipal and irrigation demands that would result under the listed conditions. The deficit was quantified under the assumption that DOW minimum flow requirements in the river had to be met before withdrawals could be made. Consequently, pool storage below dam crest could not be depleted, or "mined". Additionally, the impact of Jacobson reservoir on subsidizing Kentucky-American demands during low -flow periods was not considered. Conservation impacts are based on an assumption of a 30% reduction in peak demands as a result of short-term demand management. It should be noted that the Harza study was completed prior to approval of the 1992 modification to Kentucky-American's withdrawal permit and its impacts are not reflected in their analysis.

Based on the results of the study, the report recommended the 1930 drought be used as the design drought and the design deficit be 7 billion gallons. The design deficit of 7 billion gallons was found to be the deficit for the 1930 drought for 2050 forecasted water demands with implementation of an effective water-shortage response program, rounded upward from 6.5 billion gallons to account for slightly higher forecasted demands in 2020 than in 2050. The Harza report determined that the recommended design deficit was similar to the deficit that would occur for the 100-year drought for 2020 conditions without an effective water shortage response plan.

1.3 Harza Planning Study

Based on the results of the Phase I Report, Harza completed a second study that resulted in a report entitled **Preliminary Long Range Water Supply Planning Study for the Kentucky River Basin.** (Harza, 1991). The purpose of the study was to develop, evaluate and recommend a long-range plan to provide for the projected water-supply deficits for the various communities/utilities and individuals who depend on the Kentucky River for water supply.

1.3.1 Alternative Plans

Twenty-seven alternative water-supply plans were developed and evaluated for the Phase II study. All of the plans would provide for the entire project deficit. Elements of the plans included:

1. Rehabilitation/reconfiguration of the Kentucky River Locks and Dams;
2. Small Upstream Reservoirs on Kentucky River tributaries; and
3. Pipelines from the Ohio River.

The Kentucky River plan included new dams at existing sites of Locks and Dams and at new sites. Raising pool-water levels by up to 15 feet and lowering existing water-supply intakes were considered. Small Upstream Reservoir plan elements included dams of 50 feet to 150 feet high with storage volumes of 1.2 to 7.0 billion gallons. Ohio River pipelines included pipelines from Maysville and Louisville with capacities of 40 million gallons per day (mgd) to 60 mgd and lengths of 72 miles to 155 miles. The alternative long-range plans were developed by using single plan elements capable of meeting the entire deficit and by combing smaller elements.

1.3.2 Criteria Evaluation

The plans were evaluated based on ten criteria specified by the Kentucky River Basin Steering committee including: cost; environmental, social and cultural concerns; water quality impacts; legal, administrative and operational concerns; scoring procedure that weighted the importance of the various criteria and scored each alternative's performance in meeting each criterion.

The selection of the recommended plan was based on the ranking of the 27 alternatives on all the prescribed criteria. A procedure was adopted to evaluated the diverse objective and subjective criteria. Coefficients were assigned to each of the ten criteria, reflecting their relative importance. The alternative's performance was scored for each of the criteria. The products of the scores and the importance coefficients were then summed and ranked.

1.33 Comparison of Alternatives

Long-range water supply plans utilizing dams at the existing or proposed new sites on the Kentucky River scored consistently higher that plans utilizing other elements. Plans utilizing a combination of Kentucky River sites and small Upstream Reservoirs scored slightly lower than those using only Kentucky River sites. Plans utilizing solely Small Upstream Reservoirs ranked third. Plans utilizing pipelines from the Ohio River ranked fourth.

The eleven highest ranked plans utilize new dams on the Kentucky River for all or a part of the required storage. Of these, the five most favorable plans use only the Kentucky River and include between two and four new dams. The highest ranked plan included a new a dam at a site between existing Locks and Dams 10 and 11 and a new dam at Lock and Dam 12.

Table 1.2 compares the estimated present value costs of the alternatives. Two columns are presented. The first column shows the range of estimated costs of the water-storage facilities alone. The second column shows the range of estimated costs including the estimated cost of rehabilitating/reconfiguring the Locks and Dams not part of the water storage facilities. The least cost alternative is development of Small Upstream Reservoirs. A single Small Upstream Reservoir could be developed to satisfy the projected deficit of 7 billion gallons at an estimated present value cost of approximately $111,000,000 including the cost of rehabilitating or reconfiguring the Kentucky River Locks and Dams not used for water storage purposes. This is approximately $16,000,000 less than the least costly alternative using the Kentucky River Locks and Dams.

The Recommended Plan The recommended long-range water-supply plan was to develop two or three new dams on the Kentucky River to store water for use during droughts. The new dams would replace existing locks and dams or would be constructed at new sites. The sites considered most favorable are existing Locks and Dams 10,11 and 12 and two new sites identified in the report as 10A and 12A, which are in the pools of the existing Locks and Dams 10 and 12. Combinations of new facilities at these sites consistently scored higher than all other alternatives.

The recommended plan is not the least costly alternative. Alternatives based on the Kentucky River are ranked higher than those based on Small Upstream Reservoirs because the Kentucky River alternatives are expected to result in fewer potential environmental, social and cultural impacts. On most other criteria, including legal, administrative, operation and water quality, the alternatives are generally equal.

A key element of the recommended plan was the development and implementation of conservation measures including a water-shortage response program as described in the Phase 1 report. If these measures are not implemented, or are ineffective, then the water supply deficit for the design drought will exceed the storage capacity of the recommended plan by over one billion gallons.

TABLE 1.2

Summary Comparison of Present Value Construction and Operation and Maintenance Costs

	Water Storage Plan Elements		**Water Storage Plus Rehab/Reconfig of Locks & Dams**	
Alternative	Minimum	Maximum	Minimum	Maximum
Kentucky River Dams	$ 60M	$127M	$127M	$180M
Small U/S Res and L/Ds	$ 51M	$ 82M	$124M	$149M
Small U/S Reservoirs	$ 29M	$ 57M	$111M	$139M
Pipelines & Combinations	$126M	$163M	$207M	$245M

1.4 KWRRI Study

Since the 1991 HARZA study, Kentucky-American Water Company has been granted a variance on the minimum flow requirement for pool nine from which it draws its water. Implementation of the variance could have a significant impact on the original design deficit of the Harza study and thus affect the recommendations of the Phase II report. In addition, the Kentucky River Authority has recently initiated several capital construction projects that will have an impact on the available water supply. Because the amount of additional capital construction to enhance the available water supply in the basin will be determined by the amount necessary to reduce the deficit, the Authority decided to initiate a reassessment of the basin deficit that takes into consideration these and other factors not considered by Harza study. In April 1995, the Authority executed a contract with the University of Kentucky Water Resources Research Institute to perform such a study. The major tasks of the study are outlined below:

1. Task I: Review and assess previous studies and finalize study plan
2. Task II: Assess and forecast the demand and availability of water by/for off-stem users (including the upper forks of the Kentucky River).
3. Task III: Assess and forecast the demand and availability of water by/for main-stem users (including the impacts of off-stem users).
4. Task IV: Develop a drought response model for the Kentucky River Basin
5. Task V: Develop a long-range water supply plan for the Kentucky River Basin (including an evaluation of water supply alternatives)

1.4.1 Project Advisory Committee

At the recommendation of the Kentucky River Authority, a project advisory committee was formed to provide continuing input and feedback to the KWRRI study. This committee was composed of representatives from various federal, state, and regional and local water agencies as well as representatives from various environmental groups and private utilities. A list of the committee membership is provided in Table 1.3. Information was disseminated to the committee membership through monthly progress reports and bi-monthly meetings. Input from the committee members was received by written comments or by verbal comments at the bi-monthly meetings. Although the process has led to many incremental changes with regard to the scope of the original project, the process has been found to be very helpful and highly beneficial in identifying the multiplicity of issues incompassed by such a project. The input and feedback from the committee have been truly invaluable.

Table 1.3 Project Advisory Committee

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The Honorable E. T. Kash
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CHAPTER II

WATER SUPPLY NEEDS

2.0 Introduction

For the purpose of this report, the long-range water supply needs for the Kentucky River Basin have been quantified as the deficit values resulting from the imposition of historic drought conditions on the existing supply system under current and projected demand forecasts. Estimated values for the resulting water supply needs have been developed as part of the Task III Study discussed earlier. As part of this study a water supply analysis was performed using the computer program KYBASIN (Ormsbee and Herman, 1996) along with different combinations of historic streamflow sequences and future demand forecasts.

2.1 Historic Streamflow Sequences

Simulations of water movement and exchanges in the Kentucky River Basin were performed using a hydrologic routing model (KYBASIN) of the main stem of the Kentucky River to identify the location and magnitude of water shortages resulting from the imposition of two historical droughts. The two droughts examined were those occurring in 1930 and 1953. These droughts represent the two most severe droughts on record in the basin. The two droughts were defined by the estimated daily river inflows that occurred during the drought. Historic temperature and rainfall conditions for each drought were used to adjust municipal, industrial, and irrigation demands to account for variances in water usage resulting from the imposition of drought conditions.

Droughts are characterized in the model by the daily inflows into the river that occurred during the drought. Historic annual streamflow traces were used to estimate the daily inflows into the river that occurred during a drought. River inflows were used to characterize/define a drought instead of the actual historic streamflows, in order to accurately model the impacts of the drought on the present river system. Streamflows are the combined result of natural weather conditions and system characteristics (e.g., reservoir releases, municipal withdrawals and returns, irrigation demands, dam leakage, etc). Use of historic streamflow traces would impose the historical system characteristics on the present system. The use of river inflows eliminates the bias resulting from historic system conditions and operation. During simulation of the drought with the model, the historical inflows are coupled with the present system characteristics and operational policies to generate the streamflow trace resulting from the imposition of a historical drought on the current system. A more complete discussion of the generation and application of the associated streamflow traces is provided in the **Task III Report: Deficit Analysis** (Ormsbee and Herman 1996).

2.2 Forecasted Demand Scenarios

Municipal, industrial, and commercial demands on the basin were estimated from Division of Water surface water withdrawal permits. All permitted withdrawals were considered in the analysis. Withdrawals were grouped by intake location into individual stream reaches. Withdrawals were further classified as either main-stem or tributary withdrawals. Main-stem withdrawals were used to define daily pool deficits. Tributary withdrawals were used to adjust lateral inflows into main stem and headwater reaches. Demands in the headwater reaches were used to adjust inflows into Pool 14. Adjustment to main stem and headwater lateral inflows were made to acknowledge the impacts of the off-stem demands on main stem water supply, but water supply deficits occurring on tributaries or in the headwaters were not quantified.

Division of Water 1994 monthly withdrawal data was used to estimate municipal, industrial, and commercial demands on the basin for 1994, 2000, 2010, and 2020. Water use was estimated for summer and winter months using a separate mathematical regression model. The models use estimates for population, economic and demographic factors, public water and sewer use, and per capita demand to predict present and future water use. Two separate model structures were investigated to evaluate the impacts of future changes in per capita water use: 1) an incremental growth model (linear trend model) and a constant per capita model (year end dummy model). Based on an evaluation of the resulting forecasts the "constant per capita model" was selected for use in generating the subsequent deficit forecasts. U.S. Census data from 1970-1993 were used as a basis for estimating the model parameters. Population estimates for future years were obtained from the Louisville Data Center. Two population projections were obtained for each future year; one assuming a moderate growth rate, and one assuming a high growth rate. This resulted in two separate sets of demand forecasts, one for moderate and one for high growth conditions.

All demand forecasts, including both current (1994) and projected demand predictions, were adjusted to account for variations in water use attributable to differences in weather conditions (i.e., temperature and precipitation) between the drought and demand years. The weather-augmented demands were used to acknowledge the increase in water consumption resulting from the onset of the extended hot and dry conditions associated with drought periods. A more complete explanation of the demand forecasts can be found in the companion report entitled **Task V Report: Water Use Estimation and Forecasting for the Kentucky River Basin.** (Blomquist, et al., 1996).

2.3 Deficit Analysis

Simulations of the Kentucky River Basin under the existing supply system were performed to quantify the current and future susceptibility of the basin to a severe drought. To assess the capacity of water supply during a severe drought, the KYBASIN model was used to simulate water transfer and movement in the basin for current and future demands under the imposition of both the 1930 and 1953 droughts. Through use of the model, the location and magnitude of water supply deficits on main stem of the river were identified. Deficits were defined as unsatisfied permitted demand withdrawals and were calculated over an entire 12-month analysis period.

2.4 Deficit Results

Simulation of the Kentucky River Basin under the existing supply system for 1930 and 1953 drought conditions was performed using the KYBASIN model. Water supply deficits for current (1994) and projected demands for 2000, 2010, and 2020 were predicted by the model. The baseline deficits for the basin (i.e., the anticipated deficits that would occur under 1994 demand forecasts for 1930 and 1953 drought conditions) were determined to be 6.3 and 2.2 BG, respectively. Deficits of varying intensity were experienced on all main stem pools that supported permitted demands. Simulation of the basin under both historical droughts indicated that approximately 62% of the basin deficit was attributable to Ky-American Water Co. (pool 9), the largest single municipal withdrawal on the river.

The total annual basin deficits resulting from simulation of the basin under future demand forecasts are summarized in Table 2.1 below. Values in the table represent the anticipated basin deficit that would occur under 1930 and 1953 drought conditions for existing water supply resources. Future demand forecasts were developed from two population growth rates, termed *moderate* and *high*. The predicted water supply deficits under both population growth rates are identified in the table.

Table 2.1: Summary of water supply deficits (BF) for future demand forecasts (M - moderate population growth rate, H = high population growth rate)

Demand Forecast	1994	2000 M	2000 H	2010 M	2010 H	2020M	2020 H
1930 Drought	6.3	6.6	7.3	7.2	8.5	7.4	9.7
1953 Drought	2.2	2.3	2.6	2.5	3.2	2.7	3.8

The deficits presented in Table 2.1 are highly sensitive to the estimates for the lock and dam leakage, transmission losses for Buckhorn and Carr Fork reservoirs, and minimum flow requirement values. The accuracy of the deficit predictions are conditional upon the validity of the estimates for these parameters. For example, an increase in the assumed transmission loses from 0 to 30% would result in an increase in the predicted deficit by approximately 20%. Conversely, reduction in the assumed lock leakage from 50 cfs to 0 would reduce the predicted deficit by approximately 10%. Imposition of water distribution system leakage reduction activities along with projected conservation programs can be expected to reduce the projected deficits by an additional 10%, thus potentially canceling out the impact of increased transmission losses.

2.5 Design Drought

For the purpose of the Task V water supply alternative evaluation, the 1930 drought has been selected as the design drought. This is consistent with the recommendation of the previous Harza Study (1990) and is reflective of a decision to plan for water supply needs on the basis of the drought of record. However, unlike the Harza Study, all seven deficit values in Table 2.1 (for 1930) have been carried forward in the alternative evaluation phase in order to provide for some additional sensitivity in evaluating the alternatives.

2.6 Impact of Value Installation

Since the completion of the Task III report, work has continued on the repair/rehabilitation of the locks and dams. Along with this process has come the installation of low level release valves in dams 11 & 12. Current plans are to install similar facilities in dams 13 & 14. Inter-pool transfer of water between pools 9 and 10 can currently be accomplished by using gates in lock 10. These developments provide a way to reduce the original baseline deficit estimate through pool mining/transfers while still satisfying the minimum flow requirements. As a result, the deficit values associated with the Task III report have been significantly reduced. The exact impact of these modifications are discussed in detail in the next chapter.

CHAPTER III
DEVELOPMENT AND EVALUATION OF ALTERNATIVE LONG-RANGE PLANS

3.1 Overview

The purpose of Task V is to develop and evaluate alternative plans to provide for the long-range water supply needs of the Kentucky River Basin. For the purpose of this study, project alternatives have been sub-divided into two major categories: 1) demand-side alternatives and 2) supply-side alternatives. Demand-side alternatives include those alternatives where future supply deficits are either reduced or managed through long term conservation pricing or short-term demand (drought) management strategies. Supply-side alternatives include those alternatives where future supply deficits are met through the development of additional water supplies. For the purpose of this study, three major categories of supply alternatives were considered. These included: 1) main-stem alternatives, 2) off-stem reservoirs, and 3) a treated water pipeline from Louisville to Lexington. Main-stem alternatives include the rehabilitation/reconfiguration of the Kentucky River locks and dams through 1) installation of release valves in the locks and dams upstream of pool 8, 2) installation of valves in locks 9-14 and temporary crest gates on locks and dams 9-14, and 3) installation of release valves in locks and dams 10-14 along with construction of a new dam at lock and dam 8. The various alternatives finally considered in this study were developed as a result of an incremental process coupled with monthly input from the project advisory committee.

3.2 Evaluation Matrix

As discussed previously in Chapter 2, each potential project alternative has been evaluated for seven separate drought scenarios, reflecting the impact of a 1930 drought under future demand conditions for both a moderate and high population growth horizon. The associated results provide decision makers with a matrix of deficits and costs for use in examining the impacts of phased construction and the relative sensitivity of one potential solution to another. Such a matrix should provide a basis for identifying the optimal project configuration for a range of water supply objectives.

3.3 Economic Analysis

For the purpose of this study, the cost of each demand management plan has been quantified on a single drought year occurrence using 1996 costs. Each long-range water supply plan has been evaluated on the estimated present value of the costs associated with each alternative. Economic evaluation of water supply alternatives may be accomplished by comparing the costs of construction, operation, and maintenance of each alternative. When costs or benefits occur in different periods of time, a method for aggregating values which are realized at different moments in time must be utilized. Two issues arise. The first issue is whether to measure the values in dollars of the year in which the costs or benefits occur or in constant dollars. In the current study, estimates of future benefits and costs are based on the present price level. In other words, future benefits are measured using constant dollars with the constant dollars reflecting the price level at the time the benefit-cost analysis is being conducted (Freeman, 1993).

The second issue is the rate at which to discount future benefits and costs back to the present. Given that benefits and costs are being measured in constant dollars, the appropriate discount rate should not have inflationary expectations built into it. In other words, the appropriate discount rate is a real rate, not a nominal interest rate. Freeman (1993) and Zerbe and Dively (1994) have reviewed estimates of real rates and have found them to fall in the range of 1% to 7%. In the current study, an average rate of 4% has been assumed. Additional assumptions in the economic analysis of project alternatives are summarized as follows:

1. All water supply alternatives are built at the present time. Cost comparisons are in "1996 dollars".
2. Annual or periodic charges such as operational and maintenance (O&M) expenses, are expressed in terms of their "present value" - the lump sum cost in 1996 dollars equivalent to the total of the O&M expenses.
3. For the basis of comparing different projects, a design life of 50 years is assumed.
4. Costs that would be the same for every alterative including (i.e., financing of bonds, administration of a development agency, O&M costs not related to the water supply plan and costs of maintaining navigation) are not included in the analysis, since they would not affect the comparison of alternatives.

As with the previous Harza (1991) study, the estimated costs in this report have been prepared at a "reconnaissance level". This means that they are suitable for comparing various alternatives with similarly prepared cost estimates. More detailed feasibility level design studies of selected plans will be required to determine more accurate final cost estimates.

3.4 Demand-Side Alternatives

Two different demand-side alternatives were investigated for use in reducing/managing the associated design deficits. These included both long-term (conservation pricing) alternatives and short-term (demand management) alternatives. In each case, the cost and impacts of the corresponding policies were predicted using an aggregate water-demand curve for the entire region.

3.4.1 Aggregate-Demand Curve

The cost or damages associated with a reduction of demand through imposition of demand side management can be estimated by determining the area under the water-demand curve for the interval defined by the reduction. In order to estimate the costs of such policies for the Kentucky

River Basin, two separate water demand curves were constructed for the Kentucky River Basin, one for the peak season (June through September) and one for the off-peak season (October - May). Each demand curve was constructed from an analysis of historical demands for the Lexington area using data obtained from the Kentucky American Water Company. Based on that analysis, a demand elasticity of -0.69 was used for the peak curve, while a demand elasticity of -0.31 was used for the off-peak curve. Given the nature of the estimates for the KAWC area, these values are quite consistent with the recent AWWA review of demand studies (AWWA, 1996). For a more in-depth discussion of the aggregate demand curve, see the **Task IV Report: Estimation of the Responsiveness of Water Use to Changes in Rate** (Blomquist and Hoyt, 1996).

3.4.2 Conservation Pricing

One way to reduce the anticipated future deficits is to reduce future demands through the use of a conservation pricing rate structure. In order to investigate the possible impact of such a strategy, a moderate 20% price increase was assumed and the associated decrease in demand was calculated using the aggregate demand curve. For example, if the (real) rate increases from $1.80 to $2.16, an increase of 20%, peak per capita use would decrease by (.69)(20) = 13.8%. Based on June 1993 per capita use, the reduction would be approximately 27.9 gallons per capita.

3.4.2.1 Deficit Results

Under an assumption of a 20% price increase, new monthly demands were projected for each pool using one of the aggregate demand curves discussed previously. In this case, the demands in each pool were reduced as a result of a 20% increase in the rate of water as drawn from each pool. On average, this would yield a corresponding demand reduction of 14%. The resulting reduction in the total deficit for the drought period is shown in Table 3.1 for each of the projected deficits.

Table 3.1 Project Deficits (BG) with a 20% Price Increase

Year	2000 M	2000 H	2010 M	2010 H	2020 M	2020 H
Original Deficit	6.6	7.3	7.2	8.5	7.4	9.7
Reduced Deficit	5.3	5.8	5.8	6.9	6.0	7.9

3.4.2.2 Policy Cost

The cost of the conservation pricing strategy for each individual drought year can be determined by summing the monthly increase in water cost associated with for each pool. The monthly cost for a particular pool can be approximated by integrating the aggregate demand curve between the original unrestricted demand and the new demand resulting from the imposition of the conservation pricing strategy. This cost reflects the expected cost to the consumer that would occur as a result of this policy. The resulting costs associated with the various drought scenarios is provided in Table 3.2 below.

Table 3.2 Annual Costs (in Millions of Dollars) of Conservation Pricing Strategy for 1930 Drought Conditions

Year	2000 M	2000 H	2010 M	2010 H	2020 M	2020 H
Policy Cost	4.0	4.2	4.2	4.6	4.3	5.0

In examining the costs in Table 3.2, it should be emphasized that these represent the costs for a single drought year. In the event a long-term conservation pricing strategy is implemented, then associated costs would be generated each year, not just for the drought years. As a result, the aggregate cost for such a policy would require amortization of the projected costs over a specified project life (e.g., 50 years) and not just for a single year. Nevertheless, these costs do provide the basis for comparing the impacts of a 20% price increase as the total demand increases over the next several decades.

3.4.3 Short-Term Demand Management

A second way to eliminate the anticipated future deficits is to simply curtail the demand during the drought. This can be done through a multitude of policy strategies such as voluntary demand reduction, odd-even day lawn watering, mandatory rationing, etc. Although such a strategy does provide a possible way to "manage" the deficit, it should be recognized that such a policy has an associated cost resulting from both environmental damages and lost revenues. One way to attempt to quantify these costs is by examining the increased price that consumers would be willing to pay to avoid such shortfalls. An estimate of the total cost can be quantified by integrating the associated demand curve between the unrestricted demand level and the level required to reduce or eliminate the deficit. In an attempt to quantify the cost of eliminating the forecasted deficits solely through short-term demand management, individual demand curves were developed for each pool on the Kentucky River. For each month in which a deficit occurred in a particular pool, the individual demand curve for each pool was used to quantify the associated costs or damages resulting from unmet demands. As discussed previously, an estimate of this cost was obtained by integrating the associated demand curves over the domain of the unsatisfied demand. The total costs for each pool for each month were then summed to obtain a total cost for the entire deficit. The results of this analysis for each of the seven demand forecasts is provided in Table 3.3.

Table 3.3 Projected Deficits (BG) and Annual Costs (Million Dollars) for Eliminating Deficits Through Short-Term Demand Management

Year	1994	2000 M	2000 H	2010 M	2010 H	2020 M	2020 H
Original Deficit	6.3	6.6	7.3	7.2	8.5	7.4	9.7
Projected Costs	17.6	18.4	20.3	20.2	24.2	20.9	27.8

It should be emphasized that the costs in Table 3.3 are only for a single deficit year. As a result, these costs ignore any long-term damages or economic costs associated with such a policy. In addition, it is unrealistic to assume that all of the forecasted deficit will be eliminated solely through short-term demand management. Nonetheless, this analysis does provide a lower estimate of the expected costs of such a policy, as well as providing a comparison of the costs for different years.

3.4.4. Baseline Demand Reduction

Instead of considering a complete reduction of the deficit through demand management, a more realistic measure would be consider the impact of reducing the monthly demands to winter levels (i.e., January demands). In theory, the winter demands should represent a lower estimate of the minimum sustainable demand for a particular municipality, although it is highly unlikely that such levels could be realistically maintained for an extended period during a severe drought. Reduction of all demands in the basin to January levels for 1994 conditions would result in a decrease in the total deficit from 6.3 billion gallons to 5.3 billion gallons. For 2020 high demand conditions such a policy would decrease the deficit from 9.7 billion gallons to 7.7 billion gallons.

3.5 Supply-Side Alternatives

Five major supply-side alternatives were considered for augmenting the existing water supply for the Kentucky River. These included: 1) installation of low-level release valves in locks 9-14, 2) installation of temporary crest-gates on dams 9-14, 3) construction of a new dam at lock and dam 8, 4) construction of one or more off-stem reservoirs, and 5) construction of a treated-water pipeline from Louisville to Lexington. As will be shown in subsequent results, none of these alternatives is able to eliminate the projected water supply deficits in pools 2-8. Because of the lack of low-level release valves in dams 2-8, any water supply alternative upstream of pool 8 that is designed to eliminate deficits in pools 2-8 must provide enough water to volumetrically satisfy both the projected demand deficits *and* the amount of water required to augment all downstream river flows to minimum flow requirement levels. Because of the extremely low-flow levels during a drought, this requirement effectively eliminates the practical use of water supply facilities upstream of pool 8 for eliminating deficits in pools 2-8. As a result, all supply-side alternatives located upstream of pool 9 have been designed to satisfy the deficits in pools 9-14 only. It is proposed that the remaining deficits in pools 2-8 be addressed using a separate set of alternatives.

3.6 Water Supply Alternatives for Pools 2-8

Three separate alternatives were investigated for reducing/eliminating the deficits in pools 2-8. These alternatives include: 1) short-term demand management, 2) relaxation of the minimum flow requirement, and 3) installation/rehabilitation of low-level release valves in dams 4-8. Each of these alternatives is discussed in the following sections.

3.6.1 Short-Term Demand Management

One way to eliminate the remaining deficit downstream of pool 8 would be through short-term demand management. Implementation of such a policy to eliminate the remaining deficit would result in the costs/damages shown in Table 3.4. Once again, it should be emphasized that these costs only reflect the expected costs for a single drought year and do not include possible residual costs in other years.

Table 3.4 Projected Costs (Million Dollars) for Eliminated Deficits in Pools 2-8
Through Short Term Demand Management

Year	1994	2000 M	2000 H	2010 M	2010 H	2020 M	2020 H
Deficits	2.1	2.2	2.3	2.3	2.5	2.4	2.8
Projected Costs (M$)	6.1	6.3	6.6	6.7	7.3	6.9	7.9

3.6.2 Relaxation of the Minimum Flow Requirement

If the minimum flow requirement for pools 2-8 were relaxed in the event of the 1930 drought, all remaining deficits in pools 2-8 could be eliminated by mining the water in the pools. This assumes a complete relaxation of the minimum flow requirement and an assumed leakage rate of 50 cfs through each dam.

3.6.3 Installation/Rehabilitation of Valves in Dams 4-8

It remains unclear whether or not the state's minimum flow requirement would be completely relaxed during a severe drought, even in the case of a declaration of a state water emergency. However, the same benefit associated with such a relaxation could be achieved by installation/rehabilitation of low-level release valves in dams 4-8 of sufficient capacity to permit passage of the minimum flow. Under such a situation, the storage in pools 4-8 could be mined to satisfy municipal withdrawals. Although outside the original scope of work, a preliminary evaluation of this alternative has revealed that such a strategy would in fact eliminate all of the remaining deficits in pools 2-8. Further flow augmentation could possibly be achieved through controlled releases from Herrington Lake. In the event that the valve installation/rehabilitation costs are comparable to those for dams 9-14, it is estimated that the cost of this alternative would be approximately one million dollars.

In considering the installation/rehabilitation of valves in dams 4-8 it is assumed that each pool will not be drawn down more than 4 feet below the dam crest. This assumption was influenced by the results of the recent Harza study (1996) and the current lack of sufficient data to evaluate the water quality impacts associated with withdrawals below that level. In order to make full use of this reduction in pool 8, it is determined that the Nicholasville intake may need to be lowered. Harza has estimated that the Nicholasville intake can be lowered for approximately 0.5 million dollars (Harza, 1996).

3.7 Water Supply Alternatives for Pools 9-14

Five separate water supply alternatives were considered for pools 9-14. These alternatives included: 1) installation of release valves in the locks and dams upstream of pool 8, 2) construction of temporary crest gates on locks and dams 9-14, 3) installation of release valves in locks and dams 10-14 along with construction of a new dam at lock and dam 8, 4) construction of one or more off-stem reservoirs, and 5) construction of a treated water pipeline from Louisville to Lexington. Because of the extreme efficiency of the valve alternative and the fact that part of this solution has already been implemented, the valve alternative was considered a primary alternative with the remaining four alternatives evaluated as supplemental alternatives to be considered in combination with the valve alternative. As a result, the valve alternative is considered first, followed by combinations of the valve alternative and the remaining secondary alternatives.

3.7.1 Valve Alternative

This alternative would involve the installation of low-level release valves in pools 11-14 along with rehabilitation/replacement of lock filling/emptying valves for pools 9-10. Discounting existing investments in lock and dams 11 and 12, Harza Engineers, has estimated the current cost of this alternative to be approximately 1 million dollars (Harza, 1996). In order to evaluate the impact of the valve alternative, the alternative was simulated using the KYBASIN model (Ormsbee and Herman, 1996). In performing the analysis, it was assumed that no pool could be lowered more than 4 feet below the dam crest. A summary of the deficit reductions for the 1930 drought are shown in Table 3.5. The detailed results are provided in Appendix B.

As can be seen from Table 3.5, the valve alternative will not completely eliminate the 1930 drought year deficits in pools 9-14. Additional deficit reduction could, however, be achieved if the pools were mined more than 4 feet. For example, if the pools were allowed to be mined up to six feet, the 2020 high-demand deficit of 6.6 could be reduced to 1.8 billion gallons. If the pools were reduced an additional two feet (a total of 8 feet of drawdown) the deficit could be reduced further to a value of 1.4 billion gallons.

Table 3.5 Projected Deficits (BG) in Pools 9-14 for Valve Alternative
(With maximum pool mining of 4 feet)

Year	1994	2000 M	2000 H	2010 M	2010 H	2020 M	2020 H
Original Deficit	3.9	4.1	4.6	4.5	5.6	4.7	6.6
Remaining Deficit in	0.3	0.5	1.0	0.9	2.1	1.1	3.0

Another way to eliminate the remaining deficits in Table 3.5 would be through the drought management strategy discussed previously. Implementation of such a policy to eliminate the remaining deficit could result in the costs/damages shown in Table 3.6. Once again, it should be emphasized that these costs are only for the year in which the drought occurred and do not include any residual damages that could occur in following years.

Table 3.6 Projected Costs (Million Dollars) for Eliminating the Residual Deficits in Pools 9-14
for Valve Alternative Through Short Term Demand Management

Year	1994	2000 M	2000 H	2010 M	2010 H	2020 M	2020 H
Projected Costs ($)	0.6	1.0	2.3	2.1	5.3	2.8	7.8

As in the previous discussion, it is unlikely that all of the residual deficit would be absorbed solely through demand management. If, however, the demands were reduced to the winter baseline levels, the residual deficit would be reduced from 0.30 to 0.0 billion gallons for 1994 conditions and from 3.0 to 1.1 billion for 2020 high-demand conditions. Once again, it should be recognized that this represents an extreme demand management policy and one that would likely result in millions of dollars of damages, as well as adverse ecological impacts.

3.7.2 Valve/Crest Gate Alternative

This alternative would involve the installation of release valves in pools 11-14, the rehabilitation/replacement of lock-filling/emptying valves in pools 9 and 10, and the installation of temporary crest gates on dams 9-14. The capital cost of this alternative involves the cost of the valves and the cost of the crest gates. As previously discussed, Harza has estimated the cost of the valve alternative be approximately 1 million dollars. The cost of the crest gates is highly dependent upon the type and height of crest gate proposed. Assuming crest gates of a maximum height of 4 feet, Harza obtained the cost estimates for various types (Harza, 1996). A preliminary estimate of the total cost for the additional crest gates can be obtained by multiplying the unit cost of the gate times the number of gates installed (see Table 3.7). For a detailed discussion of each type, the reader is referred to **Feasibility and Environmental Assessment for Providing Additional Storage At Kentucky River Lock and Dams 8-14** (Harza, 1996).

In order to evaluate the impact of the valve/crest gate alternative, the alternative was simulated using the KYBASIN model. As discussed previously, the simulations were made under the assumption that the pools could not be mined beyond 4 feet below crest. Under this assumption the valve/crest gate solution would eliminate all remaining deficits. Detailed results are provided in Appendix C.

Table 3.7 Cost Estimates (Millions Dollars) for Crest Gate Alternatives
(Based on a 50 year life cycle)

Method	Estimated Cost per Dam (Million $)
Hinged Steel Crest Gates - Hydraulically Operated	2.8
Bulkhead - Entire Dam	1.9
Hinged Steel Crest Gates - Operated by Inflatable Rubber Bladder	2.2
Inflatable Rubber Bladder	2.1
Flash board - Entire Dam	1.3
Fixed Crest With Hinged Steel Crest Gate in one Bay	1.5
Fixed Crest	0.6

3.7.3 Valve/Dam Alternative

This alternative would involve the installation of release valves in pools 10-14 and the construction of a new dam at Lock and Dam 8. The proposed dam would be approximately 52 feet high with a crest elevation of approximately 554 feet. This structure would create a pool exceeding the top of Lock and Dam 9 by approximately 5 feet. It is estimated that the proposed structure would cost approximately 100 million dollars. This cost estimate is derived from previous cost estimates of on-stem structures as provided by the 1991 Harza study. The proposed estimate includes land purchases to accommodate the increase in the normal pool. However, the cost does not include new lock facilities nor modifications to raw water intake facilities.

In order to evaluate the impact of the valve/dam alternative, it was simulated using the KYBASIN model. A summary of the deficit reductions for the 1930 drought are shown in Table 3.8. Detailed results are provided in Appendix D.

Table 3.8 Projected Deficits (BG) in Pools 8-14 for Valve/Dam Alternative

Year	1994	2000 M	2000 H	2010 M	2010 H	2020 M	2020 H
Original Deficit	0.3	0.5	1.0	0.9	2.1	1.1	3.0
Remaining Deficit	0.0	0.0	0.0	0.0	0.1	0.0	1.1

3.7.4 Valve/Off -Stem Reservoirs Alternative

Eight small off-stem reservoir sites were considered for use in meeting the design deficits for each of the seven demand forecasts. A list of the eight reservoirs, their associated pool, and their assumed design capacities is provided in Table 3.9. Six of them were considered by Harza in their study and passed their secondary screening (Harza, 1991). Two additional reservoir sites were selected from the previous U.S. Army Corps of Engineers Red River Study (USCE, 1978). The additional reservoirs sites were included so as to provide at least one reservoir site tributary to each deficit pool upstream of pool nine. Preliminary environmental assessments of each site have been performed in previous studies and are not repeated here. Of the four Station Camp Creek sites proposed, only alternative site 4 has been considered in this study. This site was selected due to the minimum anticipated environmental impacts. Descriptions of each site are provided in Appendix E.

3.7.4.1 Cost Functions

Cost functions for the six Harza sites were obtained by updating the original cost data from the Harza report (Harza, 1991). Cost functions for the remaining two reservoirs were obtained using site data from the previous Red River Report (USCE, 1978) and updating the costs to the present. Detailed cost calculations for each site are provided in Appendix E.

3.7.4.2 Capacity Analysis for Off-Stem Reservoirs

There exist many combinations of reservoirs that could be used for each design deficit. In order to obtain the optimal mix of reservoirs, the aggregate deficit problem was formulated as a mixed-integer programming problem and solved using a linear programming optimizer coupled with a monthly mass-balance spreadsheet of the river system. Based on a forecasted monthly deficit trace for each pool, the algorithm determines the least-cost combination of reservoirs that would eliminate the total deficit. Along with the combination and maximum capacity of the reservoirs, the algorithm also determines their average monthly releases. Utilization of such an approach provides an efficient way to evaluate a multitude of potential reservoir combinations while providing for the least-cost solution. Application of this approach to the design deficits resulted in the optimal design costs shown in Table 3.10. Detailed results are provided in Appendix E.

Table 3.9 Off-Stem Reservoir Sites

Reservoir Site	Associated Pool	Drainage Area (mi^2)	Maximum Capacity (BG)
Lower Devils Creek	14	13	2.6
Contrary Creek	14	17	2.0
Sturgeon Creek	13	80	9.5
Station Camp #4	11	41	6.7
Drowning Creek	11	29	4.2
Upper Howard Creek	10	13	2.6
Fourmile Creek	10	25	3.3
Boone Creek	9	40	1.7

Table 3.10 Projected Total Storage Capacity (BG) and Reservoir Costs (Million Dollars) for Valve/Off-Stem Reservoir Alternative

Year	1994	2000 M	2000 H	2010 M	2010 H	2020 M	2020 H
Required Capacity (BG)	0.3	0.5	1.0	0.9	2.1	1.1	3.0
Design Capacity (BG)	0.7	0.9	1.5	1.5	2.9	1.8	4.1
Projected Costs ($)	12.3	12.7	14.1	13.9	17.0	14.5	19.5

3.7.5 Valve/Treated Water Pipeline Alternative

A fifth alternative for reducing deficits in pools 9-14 involves the construction of a treated water pipeline. This alternative has been proposed by Kentucky American Water Company and consists of the construction of a 51-mile, 36-inch diameter, treated-water pipeline from Louisville to Lexington along with two booster pump stations. The pipeline has been sized to provide a design capacity of 15 MGD with a maximum capacity of 22 MGD. In order to maintain the pipeline operation, a baseflow of 2.4 MGD will be required. A complete description of the results of the pipeline alternative is provided in Appendix F.

3.7.5.1 Cost Analysis

The cost of the pipeline may be broken into capital construction costs and O&M costs. The capital costs include the cost of the pipe and the associated pump stations. The O&M costs include the normal maintenance costs for the pipeline along with the operational cost to provide the baseline flow of 2.4 MGD. The net present value of these cost are summarized in Table 3.11 and are based on a project life of 60 years and an interest rate of 4%. In order to properly compare the cost of the pipeline alternative to those water supply alternatives associated with withdrawals from the Kentucky River, it is necessary to subtract the avoided cost of expanding the existing Richmond Road Treatment Facility along with the avoided maintenance and operating cost of treating the baseline demand of 2.4 MGD. The avoided costs are summarized in Table 3.11. By subtracting the avoided costs from the original pipeline costs the net cost can be obtained.

3.7.5.2 Deficit Reduction Results

In order to estimate the deficit reduction associated with both the valve and the pipeline, pool 9 daily demands were reduced by 15 MGD for each month in which a drought occurred. The incremental operational cost for supplying the additional water was based on an assumed rate of $954 day/MG i.e. $1142 day/MG - $188 day/MG). In order to evaluate the impact of the valve/dam alternative, it was simulated using the KYBASIN model. A summary of the deficit reductions for the 1930 drought are shown in Table 3.12. Detailed results are provided in Appendix F. As can be seen from the table, some residual deficits remain for both the 2010 high-demand and 2020 high-demand scenarios. A further analysis of the pipeline alternative has revealed that a pipeline with a capacity of 25 MGD will be required to completely eliminate the deficit for these conditions.

Table 3.11 Adjusted Pipeline Costs (Million Dollars) (Based on 60 year life cycle)

Item	Unit Cost (M$)	Total Cost (M$) (60 year project life)
Pipeline Costs		
Capital Cost of Pipeline	47.9	47.9
O&M costs for 2.4MGD Baseline Demand	1.0/yr ($1142 day/MG)	22.6
Normal maintenance	0.9/yr	20.6
Replacement	5.9 in year 30	1.8
Subtotal		92.9
Avoided Costs		
Capital Cost of Treatment (Phase I)	28.5	28.5
O&M Cost for 2.4MGD Baseline Demand	0.164/yr ($188 day/MG)	3.7
Normal maintenance	0.139/yr	3.1
Capital Cost of Treatment (Phase II)	8.6 in year 10	5.8
Replacement		5.1
Subtotal		46.2
Net Cost		46.7

Table 3.13 Projected Deficits (BG) in Pools 9-14 for Valve/Pipeline Alternative

Year	1994	2000 M	2000 H	2010 M	2010 H	2020 M	2020 H
Original Deficit	0.3	0.5	1.0	0.9	2.1	1.1	3.0
Remaining Deficit in Pools 9-14	0.0	0.0	0.0	0.0	0.3	0.0	1.1

CHAPTER IV
SUMMARY AND RECOMMENDATIONS

4.1 Summary

The objective of this report was to identify and evaluate possible strategies to provide for the long-range water supply needs of the Kentucky River Basin. The examined strategies have been grouped into two major categories: demand-side strategies and supply-side strategies. The demand side strategies examined included both long-term (conservation pricing) management and short-term demand management. For 2020, it was estimated that the conservation pricing policy would cost approximately 5 million dollars and would reduce the deficit from 9.7 to 7.9 billion gallons. Alternatively, the cost of damages resulting from absorbing the 2020 deficit exclusively through short-term demand management was conservatively estimated to be 27.9 million dollars. For both the conservation pricing and demand management solutions, it should be emphasized that the resulting costs are for a single year only. As discussed previously, the true cost of the conservation pricing policy would require a complete amortization of the yearly costs over the project horizon. Similarly, the cost of the short-term demand management solution is only for a single drought year. As a result, these cost estimates do not include any additional costs that may be incurred in other years resulting from the onset of droughts of less severity. Similarly, the long-term effects of demand management on industrial growth/migration are not included in the estimates. As an alternative to absorbing all of the deficit through demand management, a more realistic (although still extreme) reduction may be examined. As an example, by reducing demands during a drought year to the baseline winter demands, the total deficit can be reduced from 9.7 to 7.7 billion gallons for 2020 high-demand conditions. Clearly, some additional water supply will be necessary.

Five separate supply-side alternatives were examined as part of this study. These included: 1) installation of low-level release valves in locks 9-14, 2) installation of crest gates on dams 9-14, 3) construction of a new dam at lock and dam 8, 4) construction of one or more off-stem reservoirs, and 5) construction of a treated water pipeline from Louisville to Lexington. The various alternatives finally considered were developed as a result of an incremental process coupled with monthly input from the project advisory committee. Based on an initial evaluation of the various water supply alternatives, it was concluded that the current lack of low-level release valves in dams 4-8 would prevent the efficient utilization of any releases upstream of pool 9. As a result, a separate strategy was investigated for dealing with the deficits in pools 2-8. These alternatives included: 1) short-term demand management, 2) relaxation of the minimum flow requirement, and 3) installation/rehabilitation of low level release valves in dams 8-4. The cost for eliminating the deficits in pools 2-8 for the 1930 drought under the high demand forecast for 2020 was estimated to be 7.9 million dollars. Alternatively, all remaining deficits in pools 2-8 can be eliminated by mining pools either from a complete relaxation of the minimum flow requirement or through the installation of valves in dams 4-8. Since relaxation of the minimum flow requirements could have significant environmental impacts, it is recommended that the valve alternative be pursued instead. Finally, in order to take advantage of the resulting storage in pool 8, it may be necessary to lower the Nicholasville raw water intake.

The five supply-side alternatives discussed previously were designed to satisfy the deficits in pools 9-14. A summary of the costs of each of these alternatives along with the remaining deficits for the 2020 high demand forecast is shown in Table 4.1. As can be seen from Table 4.1, the most cost-effective solution is the combination of the low-level release valves and the temporary-crest-gate solution. This is followed in cost by the off-stem reservoir solution and then the treated-water pipeline. The main-stem dam at lock and dam 8 is the least cost-effective of the alternatives. While both the crest-gate solution and the off-stem reservoir solutions completely eliminate the deficit for the 2020 high-demand condition, a residual deficit of 1.1 billion gallons remains for both the treated-water pipeline solution and the main-stem dam solution.

Table 4.1 Summary Results for Alternative Water Supply Plans (Pools 9-14)
for 2020 High Demand Scenario

Alternative	Estimate Cost (million dollars)	Remaining Deficit in Pools 9-14 (billion gallons)
Existing Condition	--	7.0
Valve Alternative	1.0	3.0
Valve/Crest-Gate	17.6	0.0
Valve/Off-Stem Reservoir	20.5	0.0
Valve/Pipeline	47.7	1.1
Valve/Main-Stem Dam	100.0	1.1

As a final consideration, the possibility of combining the valve alternative with demand management was investigated. If all withdrawals from the Kentucky River are held at their winter levels, the 3.0 billion gallon residual deficit in pool 9 (i.e. 2020 high demand conditions) can be reduced to 1.1 billion gallons. However, it should be recognized that this represents an extreme demand management policy and one that would likely result in millions of dollars of damages, as well as adverse ecological impacts. Since such a strategy does not completely eliminate the remaining deficit, it is recommended that demand management not be used in combination with the valve alternative, but that it be used to supplement one of the remaining four water-supply alternatives. This recommendation also insures that demand management is available as a safety net to provide a factor-of-safety in the event that more severe conditions than anticipated arise.

4.2 Conclusions

Because of the lack of low-level release valves in pools 2-8, it was concluded that any water supply alternative located upstream of pool 8 would have minimum impact on eliminating the associated deficits in these pools. As a result, three separate strategies were investigated for dealing with the deficits in pools 2-8 that were independent of the water supply alternatives considered for pools 9-14. A preliminary evaluation of pools 2-8 has revealed that the associated deficits can be eliminated through the installation of low-level release valves in dams 4-8.

All supply-side alternatives located upstream of pool 9 were designed to satisfy the deficits in pools 9-14 only. An evaluation of these alternatives revealed that installation/rehabilitation of valves in dams 9-14 can result in a reduction of the 2020 high demand deficit in pools 9-14 from 7.0 to 3.0 billion gallons. This reduction is possible from the transfer of water between pools and the ability to mine the pools resulting from satisfaction of minimum flow regulations through with releases. As can be seen from Table 4.1, the remaining deficit of 3 billion gallons can be addressed through four additional strategies. These include: 1) installation of temporary crest gates on dams 9-14, 2) construction of a new dam at lock and dam site 8, 3) construction of one or more off-stem reservoirs, and 4) construction of a treated-water pipeline from Louisville to Lexington. In evaluating each alternative, it is assumed that the associated pools may not be mined more than 4 feet below crest.

From a purely economic perspective, the construction of valves in dams 9-14 along with the temporary crest-gates is the best alternative. Following that solution, the construction of an off-stem reservoir is the most economically viable. Following the off-stem reservoir solution, the treated-water pipeline is the next economically attractive alternative, although this alternative does leave a residual deficit of 1.1 billion gallons. The pipeline alternative is predicated on the assumption that once constructed, a minimum capacity of 15 MGD would be reserved for use for drought augmentation. The construction of a large dam on the Kentucky River is the most expensive alternative and leaves a residual deficit of 1.1 BG under the 2020 high demand condition for the 1930 drought.

It should be recognized that the validity of the conclusions of this report are inherently dependent upon the validity of the assumptions in the deficit projections. As pointed out in the Task III report, variations in the KYBASIN model assumptions could increase or decrease the deficit projections by 1 to 2 billion gallons. In addition, reliance on the valve alternative for elimination of the majority of the deficit is dependent upon an assumption that such an alternative will not result in adverse environmental conditions. This question has been preliminarily addressed by Harza in their most recent study (Harza, 1996). Based on their analysis of pool mining up to 4 feet, they concluded that "pool mining will not have deleterious effects on dissolved oxygen levels." A more definitive evaluation of the water quality effects of the low-level valves and crest gates is currently under way and should be completed next year.

Finally, this study has focused on conducting an in-depth hydrologic/hydraulic analysis of each alternative along with a "reconnaissance-level" cost analysis for the purpose of comparing the various alternatives. More detailed studies of many aspects of any selected plan will be necessary to: finalize selection of the optimal location and size of facilities, evaluate the potential environmental impact, optimize the engineering design of the facilities and determine the financial and political feasibility.

4.3 Recommendations

Based on the results of this study, the following recommendations are made:

1. Provide inter-pool release capabilities for pools 4-14. It should be noted that such capabilities have already been completed for pools 11 and 12. Until such time as a comprehensive water quality study be completed, it is recommended that the pools not be drawn down beyond 4 feet below crest.

2. Determine an effective operational policy for such facilities by considering the environmental impacts associated with their operation.

3. If necessary, provide supplemental supply augmentation for Nicholasville by lowering the raw water intake.

4. Select a secondary water supply alternative from the following list: 1) temporary crest-gates, 2) off-stem reservoirs, 3) treated water pipeline from Louisville to Lexington, and 4) main-stem dam at lock and dam 8. As previously noted, either the the temporary crest-gate alternative and the off-stem reservoir alternative are the most economical and either completely eliminate the remaining deficit.

5. Utilize demand management to supplement the selected water supply alternative. Use of demand management in a secondary role provides a factor of safety to the overall design.

6. Continue to work toward the development of a drought management plan for use in managing the river system in the event that a severe drought occurs before the implementation of adequate water supply facilities.

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APPENDIX A
KYBASIN Detailed Results for Existing System

A.1 Overview

This appendix contains the predicted demand deficits in Ky. River mainstem pools resulting from simulation of the Ky. River Basin with the KYBASIN model under the present, or existing, supply system for demand forecasts for 1994, 2000, 2010, and 2020. Two deficit traces are provided for each of the projected demand years (e.g. 2000, 2010, and 2020) to reflect two different population growth projections: *moderate* and *high*. Deficits reflect simulation of the present supply system under the effects of historic 1930 drought conditions. No structural modifications or demand curtailments are assumed in existing supply system simulations and the predicted deficits for these simulations denote the impact of a 1930 drought on the river basin if water supplies are not augmented. These results have been excerpted from the Task 3 report (Ormsbee & Herman, 1996) and do not include the 1992 modification to Ky-American Water Co.'s withdrawal permit issued by the Division of Water.

The water supply deficits for each demand forecast are given in the tables below. Deficits are identified by pool as the sum of all daily deficits (i.e. unmet demands) occurring in the pool over the 12-month simulation period. All deficits identified in the tables are given in billion gallons (BG).

Table A.1: Deficits in main stem pools for the existing supply system under 1930 drought conditions, no conservation, and 1994 demands.

KY River Pool	Deficit (BG)
Pool #14	0.034
Pool #13	0
Pool #12	0
Pool #11	0.039
Pool #10	0.208
Pool #9	3.875
Pool #8	0.430
Pool #7	0.146
Pool #6	0.063
Pool #5	0.408
Pool #4	1.065
Pool #3	0.030
Pool #2	0
Total for Basin	***6.299***

Table A.2: Deficits in main stem pools for the existing supply system under 1930 drought conditions, no conservation, and 2000 (moderate) demands.

KY River Pool	Deficit (BG)
Pool #14	0.034
Pool #13	0
Pool #12	0
Pool #11	0.042
Pool #10	0.219
Pool #9	4.074
Pool #8	0.453
Pool #7	0.152
Pool #6	0.068
Pool #5	0.430
Pool #4	1.070
Pool #3	0.031
Pool #2	0
Total for Basin	***6.572***

Table A.3: Deficits in main stem pools for the existing supply system under 1930 drought conditions, no conservation, and 2000 (high) demands.

KY River Pool	Deficit (BG)
Pool #14	0.034
Pool #13	0
Pool #12	0
Pool #11	0.045
Pool #10	0.235
Pool #9	4.601
Pool #8	0.496
Pool #7	0.156
Pool #6	0.075
Pool #5	0.449
Pool #4	1.098
Pool #3	0.031
Pool #2	0
Total for Basin	***7.220***

Table A.4: Deficits in main stem pools for the existing supply system under 1930 drought conditions, no conservation, and 2010 (moderate) demands.

KY River Pool	Deficit (BG)
Pool #14	0.035
Pool #13	0
Pool #12	0
Pool #11	0.047
Pool #10	0.242
Pool #9	4.515
Pool #8	0.507
Pool #7	0.158
Pool #6	0.078
Pool #5	0.473
Pool #4	1.088
Pool #3	0.031
Pool #2	0
Total for Basin	***7.173***

Table A.5: Deficits in main stem pools for the existing supply system under 1930 drought conditions, no conservation, and 2010 (high) demands.

KY River Pool	Deficit (BG)
Pool #14	0.034
Pool #13	0
Pool #12	0
Pool #11	0.054
Pool #10	0.272
Pool #9	5.616
Pool #8	0.592
Pool #7	0.167
Pool #6	0.094
Pool #5	0.519
Pool #4	1.139
Pool #3	0.032
Pool #2	0
Total for Basin	***8.518***

Table A.6: Deficits in main stem pools for the existing supply system under 1930 drought conditions, no conservation, and 2020 (moderate) demands.

KY River Pool	Deficit (BG)
Pool #14	0.035
Pool #13	0
Pool #12	0
Pool #11	0.052
Pool #10	0.255
Pool #9	4.678
Pool #8	0.539
Pool #7	0.163
Pool #6	0.085
Pool #5	0.500
Pool #4	1.093
Pool #3	0.031
Pool #2	0
Total for Basin	***7.430***

Table A.7: Deficits in main stem pools for the existing supply system under 1930 drought conditions, no conservation, and 2020 (high) demands.

KY River Pool	Deficit (BG)
Pool #14	0.034
Pool #13	0
Pool #12	0
Pool #11	0.065
Pool #10	0.299
Pool #9	6.579
Pool #8	0.678
Pool #7	0.175
Pool #6	0.109
Pool #5	0.580
Pool #4	1.177
Pool #3	0.032
Pool #2	0
Total for Basin	***9.727***

APPENDIX B
KYBASIN Detailed Results for Valve Alternative

B.1 Overview

This appendix contains the predicted demand deficits in Ky. River mainstem pools resulting from simulation of the Ky. River Basin with the KYBASIN model under the valve alternative for demand forecasts for 1994, 2000, 2010, and 2020. Two deficit traces are provided for each of the projected demand years (e.g. 2000, 2010, and 2020) to reflect two different population growth projections: *moderate* and *high*. Deficits reflect simulation of the present supply system with the addition of low-level valves in lock and dams #9 - #14 under the effects of historic 1930 drought conditions.

Low level valves are assumed to allow depletion of pool storage below crest as long as the DOW minimum flow requirement policy is heeded. In addition, valves are permitted to transfer unused/surplus storage in upstream pools to downstream locations. In either case, pool depletion was prohibited at water levels more than 4 feet below the dam crest.

The water supply deficits for each demand forecast are given in the tables below. Deficits are identified by pool as the sum of all daily deficits (i.e. unmet demands) occurring in the pool over the 12-month simulation period. All deficits identified in the tables are given in billion gallons (BG).

The schedule of valve releases used to deplete unused upstream storage is referred to as the pool transfer strategy. The pool transfer strategy used in each simulation is provided below each deficit trace. The pool transfer strategy denotes the average daily release (through the valves) from a pool in each month. Pool transfers in the tables appear in units of million gallons per day (mgd). Blank values denote that no release is specified from the pool through the valves.

Note that for simulations involving pool transfers with low-level valves, deficit traces may be misleading. Pool transfer policies can result in a migration of basin deficits upstream if to much water is depleted from upper pools to satisfy downstream demands. In our analysis care was taken not to migrate deficits to upstream pools.

Table B.1: Deficits in main stem pools for the valve alternative under 1930 drought conditions, no conservation, and 1994 demands.

KY River Pool	Deficit (BG)
Pool #14	0
Pool #13	0
Pool #12	0
Pool #11	0
Pool #10	0
Pool #9	0.271
Pool #8	0.465
Pool #7	0.103
Pool #6	0.050
Pool #5	0.316
Pool #4	0.976
Pool #3	0.019
Pool #2	0
Total for Basin	***2.200***

Table B.2: Pool transfer strategy for the valve alternative under 1930 drought conditions, no conservation, and 1994 demands.

Pool	Jun	Jul	Aug	Sep	Oct	Nov	Dec
#14	25	10	5	5	5	10	10
#13	35	20	15	25	20	25	25
#12	45	35	30	45	40	50	50
#11	45	35	30	45	40	50	50
#10	55	45	40	55	50	55	55
#9							

Table B.3: Deficits in main stem pools for the valve alternative under 1930 drought conditions, no conservation, and 2000 (moderate) demands.

KY River Pool	Deficit (BG)
Pool #14	0
Pool #13	0
Pool #12	0
Pool #11	0
Pool #10	0
Pool #9	0.458
Pool #8	0.499
Pool #7	0.106
Pool #6	0.053
Pool #5	0.333
Pool #4	0.978
Pool #3	0.019
Pool #2	0
Total for Basin	***2.444***

Table B.4: Pool transfer strategy for the valve alternative under 1930 drought conditions, no conservation, and 2000 (moderate) demands.

Pool	Jun	Jul	Aug	Sep	Oct	Nov	Dec
#14	25	10	5	5	5	10	10
#13	35	20	15	25	20	25	25
#12	45	35	30	45	40	50	50
#11	45	35	30	45	40	50	50
#10	55	45	40	55	50	55	55
#9							

Table B.5: Deficits in main stem pools for the valve alternative under 1930 drought conditions, no conservation, and 2000 (high) demands.

KY River Pool	Deficit (BG)
Pool #14	0
Pool #13	0
Pool #12	0
Pool #11	0
Pool #10	0
Pool #9	0.968
Pool #8	0.546
Pool #7	0.106
Pool #6	0.057
Pool #5	0.343
Pool #4	0.996
Pool #3	0.018
Pool #2	0
Total for Basin	***3.035***

Table B.6: Pool transfer strategy for the valve alternative under 1930 drought conditions, no conservation, and 2000 (high) demands.

Pool	Jun	Jul	Aug	Sep	Oct	Nov	Dec
#14	25	10	5	5	5	10	10
#13	35	20	15	25	20	25	25
#12	45	35	30	45	40	50	50
#11	45	35	30	45	40	50	50
#10	55	45	40	55	50	55	55
#9							

Table B.7: Deficits in main stem pools for the valve alternative under 1930 drought conditions, no conservation, and 2010 (moderate) demands.

KY River Pool	Deficit (BG)
Pool #14	0
Pool #13	0
Pool #12	0
Pool #11	0
Pool #10	0
Pool #9	0.891
Pool #8	0.588
Pool #7	0.107
Pool #6	0.060
Pool #5	0.362
Pool #4	0.990
Pool #3	0.019
Pool #2	0
Total for Basin	***2.986***

Table B.8: Pool transfer strategy for the valve alternative under 1930 drought conditions, no conservation, and 2010 (moderate) demands.

Pool	Jun	Jul	Aug	Sep	Oct	Nov	Dec
#14	25	10	5	5	5	10	10
#13	35	20	15	25	20	25	25
#12	45	35	30	45	40	50	50
#11	45	35	30	45	40	50	50
#10	55	45	40	55	50	55	55
#9							

Table B.9: Deficits in main stem pools for the valve alternative under 1930 drought conditions, no conservation, and 2010 (high) demands.

KY River Pool	Deficit (BG)
Pool #14	0
Pool #13	0
Pool #12	0
Pool #11	0
Pool #10	0
Pool #9	2.091
Pool #8	0.634
Pool #7	0.111
Pool #6	0.070
Pool #5	0.390
Pool #4	1.050
Pool #3	0.017
Pool #2	0
Total for Basin	***4.363***

Table B.10: Pool transfer strategy for the valve alternative under 1930 drought conditions, no conservation, and 2010 (high) demands.

Pool	Jun	Jul	Aug	Sep	Oct	Nov	Dec
#14	20	10	5			10	10
#13	30	20	15	25	20	25	25
#12	40	35	30	45	40	50	50
#11	40	35	30	45	40	50	50
#10	45	45	40	55	50	55	55
#9							

Table B.11: Deficits in main stem pools for the valve alternative under 1930 drought conditions, no conservation, and 2020 (moderate) demands.

KY River Pool	Deficit (BG)
Pool #14	0
Pool #13	0
Pool #12	0
Pool #11	0
Pool #10	0
Pool #9	1.143
Pool #8	0.585
Pool #7	0.110
Pool #6	0.064
Pool #5	0.382
Pool #4	0.994
Pool #3	0.018
Pool #2	0
Total for Basin	***3.295***

Table B.12: Pool transfer strategy for the valve alternative under 1930 drought conditions, no conservation, and 2020 (moderate) demands.

Pool	Jun	Jul	Aug	Sep	Oct	Nov	Dec
#14	20	10	10			10	10
#13	30	20	20	25	20	25	25
#12	40	35	35	45	40	50	50
#11	40	35	35	45	40	50	50
#10	45	45	50	55	50	55	55
#9							

Table B.13: Deficits in main stem pools for the valve alternative under 1930 drought conditions, no conservation, and 2020 (high) demands.

KY River Pool	Deficit (BG)
Pool #14	0
Pool #13	0
Pool #12	0
Pool #11	0
Pool #10	0
Pool #9	3.038
Pool #8	0.706
Pool #7	0.113
Pool #6	0.080
Pool #5	0.429
Pool #4	1.084
Pool #3	0.016
Pool #2	0
Total for Basin	***5.467***

Table B.14: Pool transfer strategy for the valve alternative under 1930 drought conditions, no conservation, and 2020 (high) demands.

Pool	Jun	Jul	Aug	Sep	Oct	Nov	Dec
#14	20	10	5			10	10
#13	30	20	15	25	20	25	25
#12	40	35	30	45	40	50	50
#11	40	35	30	45	40	50	50
#10	45	45	40	55	50	55	55
#9							

APPENDIX C

KYBASIN Detailed Results for Valve and Crest Gate Alternative

C.1 Overview

This appendix contains the predicted demand deficits in Ky. River mainstem pools resulting from simulation of the Ky. River Basin with the KYBASIN model under the valve and crest gate alternative for demand forecasts for 1994, 2000, 2010, and 2020. Two deficit traces are provided for each of the projected demand years (e.g. 2000, 2010, and 2020) to reflect two different population growth projections: *moderate* and *high*. Deficits reflect simulation of the present supply system, with the addition of low-level valves and crest gates in/on lock and dams #9 - #14, under the effects of historic 1930 drought conditions.

The valves are assumed to allow depletion of pool storage below crest as long as the DOW minimum flow requirement policy is heeded. In addition, valves are permitted to transfer unused/surplus storage in upstream pools to downstream locations. In either case, pool depletion was prohibited at water levels more than 4 feet below the dam crest.

All crest gates are assumed to be four feet in height and span the entire length of the existing dam. Crest gates are raised at the beginning of the simulation and lowered at the end to ensure that storage behind crest gates has adequate time to fill.

The water supply deficits for each demand forecast are given in the tables below. Deficits are identified by pool as the sum of all daily deficits (i.e. unmet demands) occurring in the pool over the 12-month simulation period. All deficits identified in the tables are given in billion gallons (BG).

The schedule of valve releases used to deplete unused upstream storage is referred to as the pool transfer strategy. The pool transfer strategy used in each simulation is provided below each deficit trace. The pool transfer strategy denotes the average daily release (through the valves) from a pool in each month. Pool transfers in the tables appear in units of million gallons per day (mgd). Blank values denote that no release is specified from the pool through the valves.

Note that for simulations involving pool transfers with low-level valves, deficit traces may be misleading. Pool transfer policies can result in a migration of basin deficits upstream if to much water is depleted from upper pools to satisfy downstream demands. In our analysis care was taken not to migrate deficits to upstream pools.

Table C.1: Deficits in main stem pools for the valve and crest gate alternative under 1930 drought conditions, no conservation, and 1994 demands.

KY River Pool	Deficit (BG)
Pool #14	0
Pool #13	0
Pool #12	0
Pool #11	0
Pool #10	0
Pool #9	0
Pool #8	0.347
Pool #7	0.086
Pool #6	0.044
Pool #5	0.292
Pool #4	0.907
Pool #3	0.017
Pool #2	0
Total for Basin	***1.693***

Table C.2: Pool transfer strategy for the valve and crest gate alternative under 1930 drought conditions, no conservation, and 1994 demands.

Pool	Jun	Jul	Aug	Sep	Oct	Nov	Dec
#14	20	10	20			10	25
#13	30	20	30	25	20	25	50
#12	40	35	45	45	40	50	50
#11	40	35	50	50	40	50	35
#10	45	45	55	60	50	55	25
#9							

Table C.3: Deficits in main stem pools for the valve and crest gate alternative under 1930 drought conditions, no conservation, and 2000 (moderate) demands.

KY River Pool	Deficit (BG)
Pool #14	0
Pool #13	0
Pool #12	0
Pool #11	0
Pool #10	0
Pool #9	0
Pool #8	0.378
Pool #7	0.088
Pool #6	0.048
Pool #5	0.308
Pool #4	0.914
Pool #3	0.017
Pool #2	0
Total for Basin	***1.753***

Table C.4: Pool transfer strategy for the valve and crest gate alternative under 1930 drought conditions, no conservation, and 2000 (moderate) demands.

Pool	Jun	Jul	Aug	Sep	Oct	Nov	Dec
#14	20	10	20			10	25
#13	30	20	30	25	20	25	50
#12	40	35	45	45	40	50	50
#11	40	35	50	50	40	50	35
#10	45	45	55	60	50	55	25
#9							

Table C.5: Deficits in main stem pools for the valve and crest gate alternative under 1930 drought conditions, no conservation, and 2000 (high) demands.

KY River Pool	Deficit (BG)
Pool #14	0
Pool #13	0
Pool #12	0
Pool #11	0
Pool #10	0
Pool #9	0
Pool #8	0.451
Pool #7	0.090
Pool #6	0.052
Pool #5	0.321
Pool #4	0.946
Pool #3	0.016
Pool #2	0
Total for Basin	***1.877***

Table C.6: Pool transfer strategy for the valve and crest gate alternative under 1930 drought conditions, no conservation, and 2000 (high) demands.

Pool	Jun	Jul	Aug	Sep	Oct	Nov	Dec
#14	20	10	20			10	25
#13	30	20	30	25	20	25	50
#12	40	35	45	45	40	50	50
#11	40	35	50	50	40	50	35
#10	45	45	55	60	50	55	25
#9							

Table C.7: Deficits in main stem pools for the valve and crest gate alternative under 1930 drought conditions, no conservation, and 2010 (moderate) demands

KY River Pool	Deficit (BG)
Pool #14	0
Pool #13	0
Pool #12	0
Pool #11	0
Pool #10	0
Pool #9	0
Pool #8	0.459
Pool #7	0.091
Pool #6	0.055
Pool #5	0.342
Pool #4	0.940
Pool #3	0.016
Pool #2	0
Total for Basin	***1.903***

Table C.8: Pool transfer strategy for the valve and crest gate alternative under 1930 drought conditions, no conservation, and 2010 (moderate) demands.

Pool	Jun	Jul	Aug	Sep	Oct	Nov	Dec
#14	20	10	20			10	25
#13	30	20	30	25	20	25	50
#12	40	35	45	45	40	50	50
#11	40	35	50	50	40	50	35
#10	45	45	55	60	50	55	25
#9							

Table C.9: Deficits in main stem pools for the valve and crest gate alternative under 1930 drought conditions, no conservation, and 2010 (high) demands

KY River Pool	Deficit (BG)
Pool #14	0
Pool #13	0
Pool #12	0
Pool #11	0
Pool #10	0
Pool #9	0
Pool #8	0.544
Pool #7	0.089
Pool #6	0.060
Pool #5	0.347
Pool #4	0.963
Pool #3	0.013
Pool #2	0
Total for Basin	***2.016***

Table C.10: Pool transfer strategy for the valve and crest gate alternative under 1930 drought conditions, no conservation, and 2010 (high) demands.

Pool	Jun	Jul	Aug	Sep	Oct	Nov	Dec
#14	20	10	20			10	25
#13	30	20	30	25	20	25	50
#12	40	35	45	45	40	50	50
#11	40	35	50	50	40	50	35
#10	45	45	55	60	50	55	25
#9							

Table C.11: Deficits in main stem pools for the valve and crest gate alternative under 1930 drought conditions, no conservation, and 2020 (moderate) demands

KY River Pool	Deficit (BG)
Pool #14	0
Pool #13	0
Pool #12	0
Pool #11	0
Pool #10	0
Pool #9	0
Pool #8	0.492
Pool #7	0.093
Pool #6	0.058
Pool #5	0.359
Pool #4	0.942
Pool #3	0.016
Pool #2	0
Total for Basin	***1.960***

Table C.12: Pool transfer strategy for the valve and crest gate alternative under 1930 drought conditions, no conservation, and 2020 (moderate) demands.

Pool	Jun	Jul	Aug	Sep	Oct	Nov	Dec
#14	20	10	20			10	25
#13	30	20	30	25	20	25	50
#12	40	35	45	45	40	50	50
#11	40	35	50	50	40	50	35
#10	45	45	55	60	50	55	25
#9							

Table C.13: Deficits in main stem pools for the valve and crest gate alternative under 1930 drought conditions, no conservation, and 2020 (high) demands

KY River Pool	Deficit (BG)
Pool #14	0
Pool #13	0
Pool #12	0
Pool #11	0
Pool #10	0
Pool #9	0
Pool #8	0.645
Pool #7	0.089
Pool #6	0.064
Pool #5	0.358
Pool #4	0.973
Pool #3	0.011
Pool #2	0
Total for Basin	***2.140***

Table C.14: Pool transfer strategy for the valve and crest gate alternative under 1930 drought conditions, no conservation, and 2020 (high) demands.

Pool	Jun	Jul	Aug	Sep	Oct	Nov	Dec
#14	20	10	20			10	25
#13	30	20	30	25	20	25	50
#12	40	35	45	45	40	50	50
#11	40	35	50	50	40	50	35
#10	45	45	55	60	50	55	25
#9							

APPENDIX D
KYBASIN Detailed Results for Valve and Dam Alternative

D.1 Overview

This appendix contains the predicted demand deficits in Ky. River mainstem pools resulting from simulation of the Ky. River Basin with the KYBASIN model under the valve and dam alternative for demand forecasts for 1994, 2000, 2010, and 2020. Two deficit traces are provided for each of the projected demand years (e.g. 2000, 2010, and 2020) to reflect two different population growth projections: *moderate* and *high*. Deficits reflect simulation of the present supply system, with the addition of a large dam at lock and dam #8 and low-level valves in lock and dams #9 - #14, under the effects of historic 1930 drought conditions.

The valves are assumed to allow depletion of pool storage below crest as long as the DOW minimum flow requirement policy is heeded. In addition, valves are permitted to transfer unused/surplus storage in upstream pools to downstream locations. In either case, pool depletion was prohibited at water levels more than 4 feet below the dam crest.

The large dam replaces the existing dam structure at lock and dam #8 and removes the existing structure at #9. The new structure is assumed to be of a similar type as the existing lock and dam structure at #8, differing only in size (the new dam is approximately 20' higher in elevation). The new dam would combine pools #8 and #9 into a single pool, providing an additional 5 feet of storage in pool #9 alone. Municipal intakes are not relocated in this alternative. The low-level valve was located 9 feet below the new dam crest, or 4 feet below the existing dam crest at #9.

The water supply deficits for each demand forecast are given in the tables below. Deficits are identified by pool as the sum of all daily deficits (i.e. unmet demands) occurring in the pool over the 12-month simulation period. All deficits identified in the tables are given in billion gallons (BG).

The schedule of valve releases used to deplete unused upstream storage is referred to as the pool transfer strategy. The pool transfer strategy used in each simulation is provided below each deficit trace. The pool transfer strategy denotes the average daily release (through the valves) from a pool in each month. Pool transfers in the tables appear in units of million gallons per day (mgd). Blank values denote that no release is specified from the pool through the valves.

Note that for simulations involving pool transfers with low-level valves, deficit traces may be misleading. Pool transfer policies can result in a migration of basin deficits upstream if to much water is depleted from upper pools to satisfy downstream demands. In our analysis care was taken not to migrate deficits to upstream pools.

Table D.1: Deficits in main stem pools for the valve and dam alternative under 1930 drought conditions, no conservation, and 1994 demands

KY River Pool	Deficit (BG)
Pool #14	0
Pool #13	0
Pool #12	0
Pool #11	0
Pool #10	0
Lex. Dam Pool	0
Pool #7	0.046
Pool #6	0.041
Pool #5	0.269
Pool #4	0.942
Pool #3	0.020
Pool #2	0
Total for Basin	***1.318***

Table D.2: Pool transfer strategy for the valve and dam alternative under 1930 drought conditions, no conservation, and 1994 demands.

Pool	Jun	Jul	Aug	Sep	Oct	Nov	Dec
#14	20	10	10			10	10
#13	30	20	20	25	20	25	25
#12	40	35	30	45	40	50	50
#11	40	35	30	45	30	50	50
#10	45	45	40	55	40	55	55
#9							

Table D.3: Deficits in main stem pools for the valve and dam alternative under 1930 drought conditions, no conservation, and 2000 (moderate) demands

KY River Pool	Deficit (BG)
Pool #14	0
Pool #13	0
Pool #12	0
Pool #11	0
Pool #10	0
Lex. Dam Pool	0
Pool #7	0.046
Pool #6	0.043
Pool #5	0.279
Pool #4	0.943
Pool #3	0.020
Pool #2	0
Total for Basin	***1.331***

Table D.4: Pool transfer strategy for the valve and dam alternative under 1930 drought conditions, no conservation, and 2000 (moderate) demands.

Pool	Jun	Jul	Aug	Sep	Oct	Nov	Dec
#14	20	10	10			10	10
#13	30	20	20	25	20	25	25
#12	40	35	30	45	40	50	50
#11	40	35	30	45	30	50	50
#10	45	45	40	55	40	55	55
#9							

Table D.5: Deficits in main stem pools for the valve and dam alternative under 1930 drought conditions, no conservation, and 2000 (high) demands

KY River Pool	Deficit (BG)
Pool #14	0
Pool #13	0
Pool #12	0
Pool #11	0
Pool #10	0
Lex. Dam Pool	0
Pool #7	0.046
Pool #6	0.045
Pool #5	0.279
Pool #4	0.925
Pool #3	0.018
Pool #2	0
Total for Basin	***1.314***

Table D.6: Pool transfer strategy for the valve and dam alternative under 1930 drought conditions, no conservation, and 2000 (high) demands.

Pool	Jun	Jul	Aug	Sep	Oct	Nov	Dec
#14	20	10	10			10	10
#13	30	20	20	25	20	25	25
#12	40	35	30	45	40	50	50
#11	40	35	30	45	30	50	50
#10	45	45	40	55	40	55	55
#9							

Table D.7: Deficits in main stem pools for the valve and dam alternative under 1930 drought conditions, no conservation, and 2010 (moderate) demands

KY River Pool	Deficit (BG)
Pool #14	0
Pool #13	0
Pool #12	0
Pool #11	0
Pool #10	0
Lex. Dam Pool	0
Pool #7	0.046
Pool #6	0.048
Pool #5	0.296
Pool #4	0.933
Pool #3	0.018
Pool #2	0
Total for Basin	***1.341***

Table D.8: Pool transfer strategy for the valve and dam alternative under 1930 drought conditions, no conservation, and 2010 (moderate) demands.

Pool	Jun	Jul	Aug	Sep	Oct	Nov	Dec
#14	20	10	10			10	10
#13	30	20	20	25	20	25	25
#12	40	35	30	45	40	50	50
#11	40	35	30	45	30	50	50
#10	45	45	40	55	40	55	55
#9							

Table D.9: Deficits in main stem pools for the valve and dam alternative under 1930 drought conditions, no conservation, and 2010 (high) demands

KY River Pool	Deficit (BG)
Pool #14	0
Pool #13	0
Pool #12	0
Pool #11	0
Pool #10	0
Lex. Dam Pool	0.117
Pool #7	0.045
Pool #6	0.048
Pool #5	0.294
Pool #4	0.936
Pool #3	0.014
Pool #2	0
Total for Basin	***1.514***

Table D.10: Pool transfer strategy for the valve and dam alternative under 1930 drought conditions, no conservation, and 2010 (high) demands.

Pool	Jun	Jul	Aug	Sep	Oct	Nov	Dec
#14	20	10	10			10	10
#13	30	20	20	25	20	25	25
#12	40	35	30	45	40	50	50
#11	40	35	30	45	30	50	50
#10	45	45	40	55	40	55	55
#9							

Table D.11: Deficits in main stem pools for the valve and dam alternative under 1930 drought conditions, no conservation, and 2020 (moderate) demands

KY River Pool	Deficit (BG)
Pool #14	0
Pool #13	0
Pool #12	0
Pool #11	0
Pool #10	0
Lex. Dam Pool	0
Pool #7	0.046
Pool #6	0.051
Pool #5	0.307
Pool #4	0.928
Pool #3	0.018
Pool #2	0
Total for Basin	***1.350***

Table D.12: Pool transfer strategy for the valve and dam alternative under 1930 drought conditions, no conservation, and 2020 (moderate) demands.

Pool	Jun	Jul	Aug	Sep	Oct	Nov	Dec
#14	20	10	10			10	10
#13	30	20	20	25	20	25	25
#12	40	35	30	45	40	50	50
#11	40	35	30	45	30	50	50
#10	45	45	40	55	40	55	55
#9							

Table D.13: Deficits in main stem pools for the valve and dam alternative under 1930 drought conditions, no conservation, and 2020 (high) demands

KY River Pool	Deficit (BG)
Pool #14	0
Pool #13	0
Pool #12	0
Pool #11	0
Pool #10	0
Lex. Dam Pool	1.107
Pool #7	0.045
Pool #6	0.051
Pool #5	0.321
Pool #4	0.929
Pool #3	0.041
Pool #2	0
Total for Basin	***2.494***

Table D.14: Pool transfer strategy for the valve and dam alternative under 1930 drought conditions, no conservation, and 2020 (high) demands

Pool	Jun	Jul	Aug	Sep	Oct	Nov	Dec
#14	20	10	10			10	10
#13	30	20	20	25	20	25	25
#12	40	35	30	45	40	50	50
#11	40	35	30	45	30	50	50
#10	45	45	40	55	40	55	55
#9							

APPENDIX E
OFF-STEM RESERVOIRS

E.1 Introduction

One way to offset the projected deficits on the main-stem of the Kentucky River is by the construction of off-stem reservoirs, which can hold and release stored water to the river during times of drought. In investigating this alternative, eight separate sites were selected for consideration. A list of the eight reservoirs sites, their associated pool and relevant data are provided in Table E.1. A map of the reservoir locations is provided in Figure E.1. The eight reservoirs were selected based on the following criteria:

1) At least one reservoir site was selected for each tributary pool that contained a water supply withdrawal point.

2) Each reservoir site had to have a tributary watershed greater than 10 square miles to insure that it could re-fill following a drought.

3) Each reservoir site had to have a maximum capacity greater that 5000 ac-ft in order to make it economically feasible.

4) Each reservoir site had to be a feasible site as identified by previous engineering studies. (Sites 1-6 passed the secondary screening of the Harza (1991) study while sites 7-8 were examined by the Corps of Engineers (1978) Red River Study).

E.2 Reservoir Capacities

Maximum reservoir capacities for the sites were determined from an examination of site topography. Once the maximum capacity was determined, a maximum usable capacity was then determined by discounting the total storage to account for sediment storage, evaporation losses, and transit losses. For the purposes of this study, sediment storage was assumed to be equal to 15 percent of the total maximum storage (Harza, 1991). The required evaporation storage was determined by multiplying the mean surface area of the reservoir by the aggregated evaporation losses for 1930. Transit losses were computed as 1 percent of the total release per mile of stream from the dam site to the Kentucky River. The resulting net maximum useable storage is shown in Table E.1.

E.3 Basin Yield Analysis

In order to insure that each reservoir was capable of refilling following a 1930 drought event, a basin yield analysis was performed for each site. The methodology employed is identical to that used in the 1991 Harza study. Assuming a 2-year return frequency basin yield of 139 million gallons per square mile, each site was capable of being refilled the year after the drought.

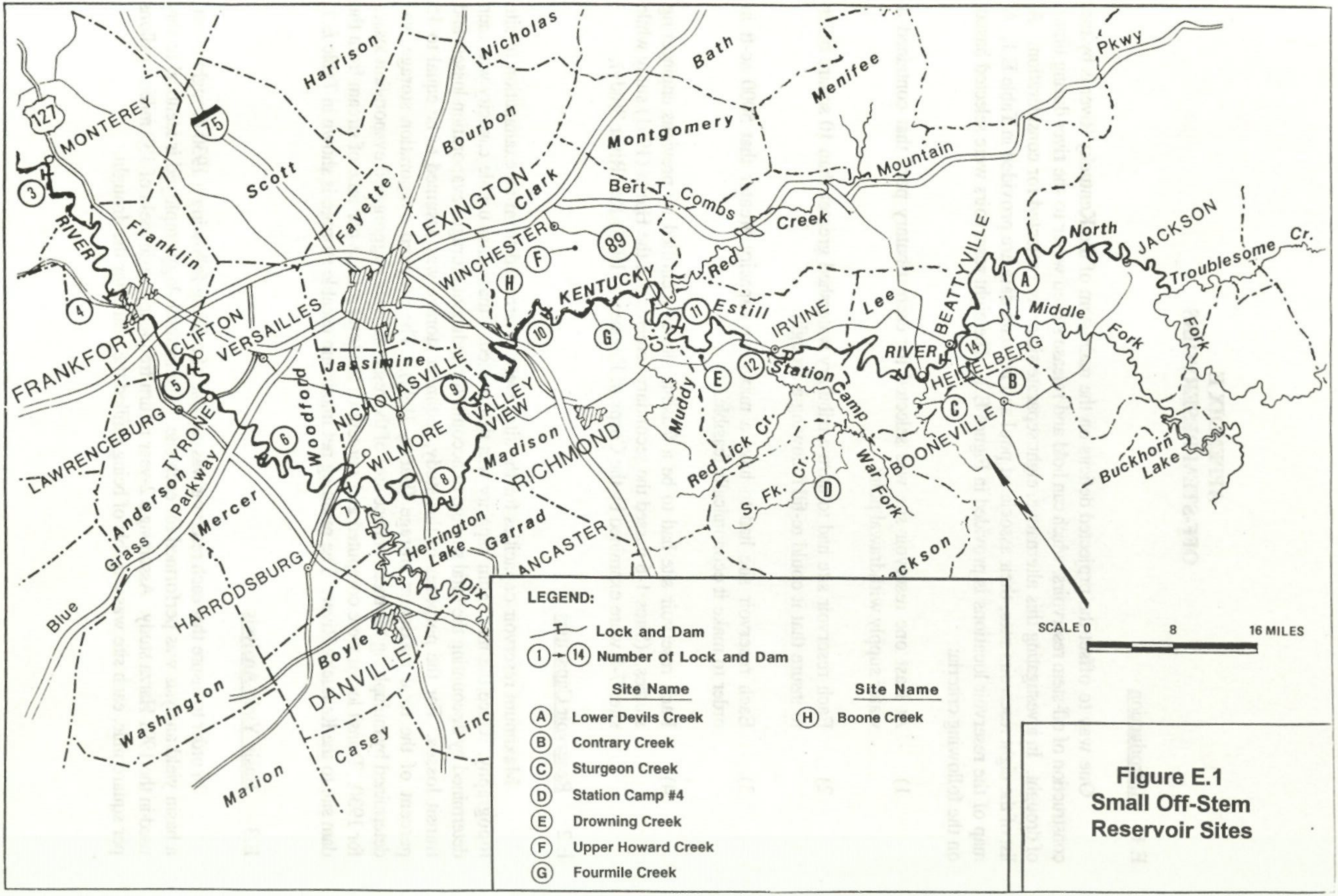

Figure E.1
Small Off-Stem
Reservoir Sites

Table E.1 Reservoir Site Characteristics

Reservoir Site	Associated Pool	Drainage Area (mi^2)	Dist. From Mainstem (mi)	Maximum Capacity (BG)	Net Useable Capacity (BG)
Lower Devils Creek	14	13	0	2.6	2.0
Contrary Creek	14	17	0	2.0	1.6
Sturgeon Creek	13	80	4	9.5	7.2
Station Camp #4	11	41	26	6.7	3.7
Drowning Creek	11	29	3	4.2	3.2
Upper Howard Creek	10	13	7	2.6	1.8
Fourmile Creek	10	25	0	3.3	2.6
Boone Creek	9	40	0	1.7	1.4

E.4 Environmental Assessment

Separate environmental assessments for each site were not performed as part of this study. Previous assessments for the different sites have been performed in the Corps of Engineers Red River Study (1978) and the more recent Harza Study (1991). As discussed previously, these assessments were used as one of the criteria for selecting the nine sites considered in this study.

E.5 Cost Functions

In order to examine the optimal combination of reservoirs that will satisfy an associated deficit stream, individual cost functions were developed for each reservoir site. Cost functions for the six Harza sites were obtained by updating the original cost data from the Harza (1991) report. Cost functions for the remaining three reservoirs were obtained using site data from the previous Red River Report (USCE, 1978) and updating the costs to the present. Each cost function may be expressed in terms of a fixed cost and a variable cost as shown in Eq (1).

$$\text{Cost (\$)} = \text{Fixed Cost} + \text{Variable Cost} * \text{Required Volume} \qquad \text{(E.1)}$$

The individual cost equations for each site are provided in Table E.2. The accompanying baseline costs used to construct the equations are provided in Exhibits E.1-E.8.

Table E.2 Reservoir Cost Functions (In Million Dollars)

Reservoir Site	Fixed Cost (M$)	Variable Cost (M$/BG)
Lower Devils Creek	4.0	3.5
Contrary Creek	3.8	7.6
Sturgeon Creek	4.1	2.2
Station Camp #4	3.5	2.9
Drowning Creek	3.6	2.1
Upper Howard Creek	3.6	4.5
Fourmile Creek	3.6	4.1
Boone Creek	3.5	5.1

E.6 Detailed Results

Two separate capacity solutions were developed for each of the seven design deficits. Each solution involved a combination of one or more reservoirs. The first solution associated with each deficit corresponds to the solution resulting from a consideration of all possible sites. The second solution is obtained by eliminating the largest supply element from the first solution and then re-running the associated analysis. This analysis provides a sensitivity analysis for each solution so as to provide some insight as to the next best solution in the event the main supply element is eliminated from consideration due to secondary (environmental, political, etc) considerations.

In order to obtain the optimal mix of reservoirs, the aggregate deficit problem was formulated as a mixed-integer programming problem and solved using a linear programming optimizer coupled with a monthly mass-balance spreadsheet of the river system. Based on a forecasted monthly deficit trace for each pool, the algorithm determines the least-cost combination of reservoirs that would eliminate the total deficit. Along with the combination and maximum capacity of the reservoirs, the algorithm also determines their average monthly releases. Utilization of such an approach provides an efficient way to evaluate a multitude of potential reservoir combinations while providing for the least-cost solution. Application of this approach to the design deficits resulted in separate solutions for each deficit. Detailed results of the analysis are provided in Table E.3.

Table E.3 Primary and Secondary Optimal Reservoir Solutions for All Demand Forecasts

Demand Forecast	Reservoir	Net Capacity (BG)	Required Capacity (BG)	Total Cost (Million $)
1994				
Primary	Drowning Creek	0.271	0.692	12.3
Secondary	Sturgeon Creek	0.271	0.934	12.8
2000 M				
Primary	Drowning Creek	0.458	0.921	12.7
Secondary	Sturgeon Creek	0.458	1.164	13.3
2000 H				
Primary	Drowning Creek	0.968	1.546	14.1
Secondary	Sturgeon Creek	0.968	1.794	14.7
2010 M				
Primary	Drowning Creek	0.891	1.452	13.9
Secondary	Sturgeon Creek	0.891	1.699	14.5
2010 H				
Primary	Drowning Creek	2.091	2.920	17.0
Secondary	Sturgeon Creek	2.091	3.181	17.7
2020 M				
Primary	Drowning Creek	1.143	1.759	14.5
Secondary	Sturgeon Creek	1.143	2.009	15.1
2020 H				
Primary	Drowning Creek	3.038	4.079	19.5
Secondary	Sturgeon Creek	3.038	4.349	20.2

Kentucky River Basin Study
Off-Stem Reservoir Alternative
Construction Cost Estimate
Lower Devils Creek
Maximum Capacity - 2.6 Billion Gallons

EXHIBIT E-1

Item	Unit	Unit Cost	Quantity	Total
Acquisition Costs				
Land Acquisition	Acre	$1,000	176	176,000
Legal	Lump Sum	$1,000,000	1	1,000,000
Total Acquisition Costs				1,176,000
Construction Costs				
Mobilization	Each	$250,000	1	250,000
Construction Access Road	Mile	$50,000	10	500,000
Dam Site Preparation	Acre	$20,000	5	100,000
Reservoir Area Cleaning	Acre	$5,000	160	800,000
Random Fill	Cubic Yard	$5	386,000	1,930,000
Select Fill	Cubic Yard	$10	85,000	850,000
Principal Spillway	Linear Ft	$500	380	190,000
Emergency Spillway	Cubic Yard	$50	3,900	195,000
Subtotal Direct Costs				4,815,000
Contingencies (20%)				963,000
Total Direct Costs				5,778,000
Engineering /Administration (15%)				866,700
Total Construction Cost				6,644,700
Operation Cost	Year	$100,000	50	2,148,220
Total Project Cost				9,968,920

Kentucky River Basin Study
Off-Stem Reservoir Alternative
Construction Cost Estimate
Contrary Creek
Maximum Capacity - 2.0 Billion Gallons

EXHIBIT E-2

Item	Unit	Unit Cost	Quantity	Total
Acquisition Costs				
Land Acquisition	Acre	$1,000	165	165,000
Legal	Lump Sum	$1,000,000	1	1,000,000
Total Acquisition Costs				1165,000
Construction Costs				
Mobilization	Each	$250,000	1	250,000
Construction Access Road	Mile	$50,000	4	200,000
Dam Site Preparation	Acre	$20,000	8	160,000
Reservoir Area Cleaning	Acre	$5,000	150	750,000
Random Fill	Cubic Yard	$5	956,000	4,780,000
Select Fill	Cubic Yard	$10	210,000	2,100,000
Principal Spillway	Linear Ft	$500	558	279,000
Emergency Spillway	Cubic Yard	$50	6,000	300,000
Subtotal Direct Costs				8,819,000
Contingencies (20%)				1,763,800
Total Direct Costs				10,582,800
Engineering /Administration (15%)				1,587,420
Total Construction Cost				12,170,220
Operation Cost	Year	$100,000	50	2,148,220
Total Project Cost				15,483,440

Kentucky River Basin Study
Off-Stem Reservoir Alternative
Construction Cost Estimate
Sturgeon Creek
Maximum Capacity - 9.5 Billion Gallons

EXHIBIT E-3

Item	Unit	Unit Cost	Quantity	Total
Acquisition Costs				
Land Acquisition	Acre	$1,000	770	770,000
Legal	Lump Sum	$1,000,000	1	1,000,000
Total Acquisition Costs				1,770,000
Construction Costs				
Mobilization	Each	$250,000	1	250,000
Construction Access Road	Mile	$50,000	10	500,000
Dam Site Preparation	Acre	$20,000	10	200,000
Reservoir Area Cleaning	Acre	$5,000	700	3,500,000
Random Fill	Cubic Yard	$5	922,000	4,610,000
Select Fill	Cubic Yard	$10	203,000	2,030,000
Principal Spillway	Linear Ft	$500	474	237,000
Emergency Spillway	Cubic Yard	$50	7,400	370,000
Subtotal Direct Costs				11,697,000
Contingencies (20%)				2,339,400
Total Direct Costs				14,036,400
Engineering /Administration (15%)				2,105,460
Total Construction Cost				16,141,860
Operation Cost	Year	$100,000	50	2,148,220
Total Project Cost				20,060,080

Kentucky River Basin Study
Off-Stem Reservoir Alternative
Construction Cost Estimate
Station Camp #4
Maximum Capacity -6.7Billion Gallons

EXHIBIT E-4

Item	Unit	Unit Cost	Quantity	Total
Acquisition Costs				
Land Acquisition	Acre	$1,000	429	429,000
Legal	Lump Sum	$1,000,000	1	1,000,000
Total Acquisition Costs				1,429,000
Construction Costs				
Mobilization	Each	$250,000	1	250,000
Construction Access Road	Mile	$50,000	0	0
Dam Site Preparation	Acre	$20,000	6	120,000
Reservoir Area Cleaning	Acre	$5,000	390	1,950,000
Random Fill	Cubic Yard	$5	595,000	2,975,000
Select Fill	Cubic Yard	$10	131,000	1,310,000
Principal Spillway	Linear Ft	$500	478	239,000
Emergency Spillway	Cubic Yard	$50	6,400	320,000
Subtotal Direct Costs				7,164,000
Contingencies (20%)				1,432,800
Total Direct Costs				8,596,800
Engineering /Administration (15%)				1,289,520
Total Construction Cost				9,886,320
Operation Cost	Year	$100,000	50	2,148,220
Total Project Cost				13,463,540

Kentucky River Basin Study
Off-Stem Reservoir Alternative
Construction Cost Estimate
Drowning Creek
Maximum Capacity - 4.2 Billion Gallons

EXHIBIT E-5

Item	Unit	Unit Cost	Quantity	Total
Acquisition Costs				
Land Acquisition	Acre	$1,000	468	468,000
Legal	Lump Sum	$1,000,000	1	1,000,000
Total Acquisition Costs				1,468,000
Construction Costs				
Mobilization	Each	$250,000	1	250,000
Construction Access Road	Mile	$50,000	0.5	25,000
Dam Site Preparation	Acre	$20,000	7	140,000
Reservoir Area Cleaning	Acre	$5,000	425	2,125,000
Random Fill	Cubic Yard	$5	494,000	2,470,000
Select Fill	Cubic Yard	$10	109,000	1,090,000
Principal Spillway	Linear Ft	$500	390	195,000
Emergency Spillway	Cubic Yard	$50	4,500	225,000
Subtotal Direct Costs				6,520,000
Contingencies (20%)				1,304,000
Total Direct Costs				7,824,000
Engineering /Administration (15%)				1,173,600
Total Construction Cost				8,997,600
Operation Cost	Year	$100,000	50	2,148,220
Total Project Cost				12,613,820

Kentucky River Basin Study
Off-Stem Reservoir Alternative
Construction Cost Estimate
Upper Howard Creek
Maximum Capacity - 2.6 Billion Gallons

EXHIBIT E-6

Item	Unit	Unit Cost	Quantity	Total
Acquisition Costs				
Land Acquisition	Acre	$1,000	440	440,000
Legal	Lump Sum	$1,000,000	1	1,000,000
Total Acquisition Costs				1,440,000
Construction Costs				
Mobilization	Each	$250,000	1	250,000
Construction Access Road	Mile	$50,000	2	100,000
Dam Site Preparation	Acre	$20,000	6	120,000
Reservoir Area Cleaning	Acre	$5,000	400	2,000,000
Random Fill	Cubic Yard	$5	274,000	1,370,000
Select Fill	Cubic Yard	$10	61,000	610,000
Principal Spillway	Linear Ft	$500	262	131,000
Emergency Spillway	Cubic Yard	$50	2,700	135,000
Subtotal Direct Costs				4,716,000
Contingencies (20%)				943,200
Total Direct Costs				5,659,200
Engineering /Administration (15%)				848,880
Total Construction Cost				6,508,080
Operation Cost	Year	$100,000	50	2,148,220
Total Project Cost				10,096,300

Kentucky River Basin Study
Off-Stem Reservoir Alternative
Construction Cost Estimate
Fourmile Creek
Maximum Capacity - 3.3 Billion Gallons

EXHIBIT E-7

Item	Unit	Unit Cost	Quantity	Total
Acquisition Costs				
Land Acquisition	Acre	$1,000	220	220,000
Legal	Lump Sum	$1,000,000	1	1,000,000
Total Acquisition Costs				1,220,000
Construction Costs				
Mobilization	Each	$250,000	1	250,000
Construction Access Road	Mile	$50,000	0	0
Dam Site Preparation	Acre	$20,000	10	200,000
Reservoir Area Cleaning	Acre	$5,000	200	1,000,000
Random Fill	Cubic Yard	$5	857,000	4,285,000
Select Fill	Cubic Yard	$10	188,000	1,880,000
Principal Spillway	Linear Ft	$500	450	225,000
Emergency Spillway	Cubic Yard	$50	5,400	270,000
Subtotal Direct Costs				8,110,000
Contingencies (20%)				1,622,000
Total Direct Costs				9,732,000
Engineering /Administration (15%)				1,459,800
Total Construction Cost				11,191,800
Operation Cost	Year	$100,000	50	2,148,220
Total Project Cost				14,560,020

Kentucky River Basin Study EXHIBIT E-8
Off-Stem Reservoir Alternative
Construction Cost Estimate
Boone Creek
Maximum Capacity -1.7 Billion Gallons

Item	Unit	Unit Cost	Quantity	Total
Acquisition Costs				
Land Acquisition	Acre	$1,000	162	162,000
Legal	Lump Sum	$1,000,000	1	1,000,000
Total Acquisition Costs				1,162,000
Construction Costs				
Mobilization	Each	$250,000	1	250,000
Construction Access Road	Mile	$50,000	0	0
Dam Site Preparation	Acre	$20,000	6	120,000
Reservoir Area Cleaning	Acre	$5,000	147	735,000
Random Fill	Cubic Yard	$5	665,000	3,325,000
Select Fill	Cubic Yard	$10	146,000	1,460,000
Principal Spillway	Linear Ft	$500	574	287,000
Emergency Spillway	Cubic Yard	$50	7,500	375,000
Subtotal Direct Costs				6,552,000
Contingencies (20%)				1,310,400
Total Direct Costs				7,862,400
Engineering /Administration (15%)				1,179,360
Total Construction Cost				9,041,760
Operation Cost	Year	$100,000	50	2,148,220
Total Project Cost				12,351,980

APPENDIX F

KYBASIN Detailed Results for Valve and Pipeline Alternative

This appendix contains the predicted demand deficits in Ky. River mainstem pools resulting from simulation of the Ky. River Basin with the KYBASIN model under the valve and pipeline alternative for demand forecasts for 1994, 2000, 2010, and 2020. Two deficit traces are provided for each of the projected demand years (e.g. 2000, 2010, and 2020) to reflect two different population growth projections: *moderate* and *high*. Deficits reflect simulation of the present supply system, with the addition of a treated water pipeline from Louisville and low-level valves in locks and dams #9 - #14, under the effects of historic 1930 drought conditions.

The valves are assumed to allow depletion of pool storage below crest as long as the DOW minimum flow requirement policy is heeded. In addition, valves are permitted to transfer unused/surplus storage in upstream pools to downstream locations. In either case, pool depletion was prohibited at water levels more than 4 feet below the dam crest.

The pipeline proposed by Ky-American Water Co. is used in this alternative and consists of a 15 mgd treated water pipeline to Louisville, Ky. The full 15 mgd capacity was assumed eligible for withdrawal in Lexington; withdrawals from intermediate connections on the proposed pipeline between Louisville and Lexington were not considered.

The water supply deficits for each demand forecast are given in the tables below. Deficits are identified by pool as the sum of all daily deficits (i.e. unmet demands) occurring in the pool over the 12-month simulation period. All deficits identified in the tables are given in billion gallons (BG).

The schedule of valve releases used to deplete unused upstream storage is referred to as the pool transfer strategy. The pool transfer strategy used in each simulation is provided below each deficit trace. The pool transfer strategy denotes the average daily release (through the valves) from a pool in each month. Pool transfers in the tables appear in units of million gallons per day (mgd). Blank values denote that no release is specified from the pool through the valves.

Note that for simulations involving pool transfers with low-level valves, deficit traces may be misleading. Pool transfer policies can result in a migration of basin deficits upstream if to much water is depleted from upper pools to satisfy downstream demands. In our analysis care was taken not to migrate deficits to upstream pools.

Table F.1: Deficits in main stem pools for the valve and pipeline alternative under 1930 drought conditions, no conservation, and 1994 demands

KY River Pool	Deficit (BG)
Pool #14	0
Pool #13	0
Pool #12	0
Pool #11	0
Pool #10	0
Pool #9	0
Pool #8	0.307
Pool #7	0.106
Pool #6	0.044
Pool #5	0.279
Pool #4	0.907
Pool #3	0.023
Pool #2	0
Total for Basin	***1.666***

Table F.2: Pool transfer strategy for the valve and pipeline alternative under 1930 drought conditions, no conservation, and 1994 demands

Pool	Jun	Jul	Aug	Sep	Oct	Nov	Dec
#14	25	10	5	5	5	10	10
#13	35	20	15	25	20	25	25
#12	45	35	30	45	40	50	50
#11	45	35	30	45	40	50	50
#10	55	45	40	55	50	55	55
#9							

Table F.3: Deficits in main stem pools for the valve and pipeline alternative under 1930 drought conditions, no conservation, and 2000 (moderate) demands

KY River Pool	Deficit (BG)
Pool #14	0
Pool #13	0
Pool #12	0
Pool #11	0
Pool #10	0
Pool #9	0
Pool #8	0.342
Pool #7	0.109
Pool #6	0.047
Pool #5	0.298
Pool #4	0.927
Pool #3	0.024
Pool #2	0
Total for Basin	***1.746***

Table F.4: Pool transfer strategy for the valve and pipeline alternative under 1930 drought conditions, no conservation, and 2000 (moderate) demands

Pool	Jun	Jul	Aug	Sep	Oct	Nov	Dec
#14	25	10	5	5	5	10	10
#13	35	20	15	25	20	25	25
#12	45	35	30	45	40	50	50
#11	45	35	30	45	40	50	50
#10	55	45	40	55	50	55	55
#9							

Table F.5: Deficits in main stem pools for the valve and pipeline alternative under 1930 drought conditions, no conservation, and 2000 (high) demands

KY River Pool	Deficit (BG)
Pool #14	0
Pool #13	0
Pool #12	0
Pool #11	0
Pool #10	0
Pool #9	0
Pool #8	0.426
Pool #7	0.110
Pool #6	0.054
Pool #5	0.322
Pool #4	1.011
Pool #3	0.025
Pool #2	0
Total for Basin	***1.948***

Table F.6: Pool transfer strategy for the valve and pipeline alternative under 1930 drought conditions, no conservation, and 2000 (high) demands

Pool	Jun	Jul	Aug	Sep	Oct	Nov	Dec
#14	25	10	5	5	5	10	10
#13	35	20	15	25	20	25	25
#12	45	35	30	45	40	50	50
#11	45	35	30	45	40	50	50
#10	55	45	40	55	50	55	55
#9							

Table F.7: Deficits in main stem pools for the valve and pipeline alternative under 1930 drought conditions, no conservation, and 2010 (moderate) demands

KY River Pool	Deficit (BG)
Pool #14	0
Pool #13	0
Pool #12	0
Pool #11	0
Pool #10	0
Pool #9	0
Pool #8	0.428
Pool #7	0.112
Pool #6	0.056
Pool #5	0.336
Pool #4	0.996
Pool #3	0.025
Pool #2	0
Total for Basin	***1.954***

Table F.8: Pool transfer strategy for the valve and pipeline alternative under 1930 drought conditions, no conservation, and 2010 (moderate) demands

Pool	Jun	Jul	Aug	Sep	Oct	Nov	Dec
#14	25	10	5	5	5	10	10
#13	35	20	15	25	20	25	25
#12	45	35	30	45	40	50	50
#11	45	35	30	45	40	50	50
#10	55	45	40	55	50	55	55
#9							

Table F.9: Deficits in main stem pools for the valve and pipeline alternative under 1930 drought conditions, no conservation, and 2010 (high) demands

KY River Pool	Deficit (BG)
Pool #14	0
Pool #13	0
Pool #12	0
Pool #11	0
Pool #10	0
Pool #9	0.250
Pool #8	0.575
Pool #7	0.114
Pool #6	0.068
Pool #5	0.380
Pool #4	1.038
Pool #3	0.020
Pool #2	0
Total for Basin	***2.445***

Table F.10: Pool transfer strategy for the valve and pipeline alternative under 1930 drought conditions, no conservation, and 2010 (high) demands

Pool	Jun	Jul	Aug	Sep	Oct	Nov	Dec
#14	20	10	5			10	10
#13	30	20	15	25	20	25	25
#12	40	35	30	45	40	50	50
#11	40	35	30	45	40	50	50
#10	45	45	40	55	50	55	55
#9							

Table F.11: Deficits in main stem pools for the valve and pipeline alternative under 1930 drought conditions, no conservation, and 2020 (moderate) demands

KY River Pool	Deficit (BG)
Pool #14	0
Pool #13	0
Pool #12	0
Pool #11	0
Pool #10	0
Pool #9	0.012
Pool #8	0.468
Pool #7	0.115
Pool #6	0.063
Pool #5	0.365
Pool #4	1.004
Pool #3	0.025
Pool #2	0
Total for Basin	***2.052***

Table F.12: Pool transfer strategy for the valve and pipeline alternative under 1930 drought conditions, no conservation, and 2020 (moderate) demands

Pool	Jun	Jul	Aug	Sep	Oct	Nov	Dec
#14	20	10	10			10	10
#13	30	20	20	25	20	25	25
#12	40	35	35	45	40	50	50
#11	40	35	35	45	40	50	50
#10	45	45	50	55	50	55	55
#9							

Table F.13: Deficits in main stem pools for the valve and pipeline alternative under 1930 drought conditions, no conservation, and 2020 (high) demands

KY River Pool	Deficit (BG)
Pool #14	0
Pool #13	0
Pool #12	0
Pool #11	0
Pool #10	0
Pool #9	1.116
Pool #8	0.674
Pool #7	0.118
Pool #6	0.080
Pool #5	0.425
Pool #4	1.061
Pool #3	0.021
Pool #2	0
Total for Basin	***3.494***

Table F.14: Pool transfer strategy for the valve and pipeline alternative under 1930 drought conditions, no conservation, and 2020 (high) demands

Pool	Jun	Jul	Aug	Sep	Oct	Nov	Dec
#14	20	10	5			10	10
#13	30	20	15	25	20	25	25
#12	40	35	30	45	40	50	50
#11	40	35	30	45	40	50	50
#10	45	45	40	55	50	55	55
#9							