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Task I Report: Summary and Evaluation of Previous Water Supply Studies for the Kentucky River Basin

Kentucky Water Resources Research Institute

KENTUCKY RIVER BASIN
WATER SUPPLY ASSESSMENT STUDY

TASK 1 REPORT: SUMMARY AND EVALUATION OF PREVIOUS WATER SUPPLY STUDIES FOR THE KENTUCKY RIVER BASIN

PREPARED FOR

THE KENTUCKY RIVER AUTHORITY

PREPARED BY

THE KENTUCKY WATER RESOURCES RESEARCH INSTITUTE
UNIVERSITY OF KENTUCKY
LEXINGTON, KENTUCKY

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CHAPTER 1

INTRODUCTION

Overview

This report summarizes the results of Task I of the KWRRI Kentucky River Basin Water Supply Assessment Study. The KWRRI study was requested by the Kentucky River Authority in order to provide a basis for management decisions for the Kentucky River Basin. This study was necessitated as a result of unexamined or changing conditions that could significantly impact the conclusions and recommendations of the previous HARZA studies (Harza, et al, 1990; Harza, et al, 1991).

Among the unexamined or changed conditions are the following:

1. New population forecasts.
2. Impacts of water rates on consumption
3. Impacts of demand curtailment and reduction
4. Impacts of migration of off-stem users to the Kentucky River
5. Variance of the minimum flow requirement for Pool Nine
6. Possible installation of low-flow release valves in locks 9-14
7. Consideration of temporary crest gates for pools 9-14.

The KWRRI study was carried out in accordance with the Scope of Services that is part of the contractual agreement dated April 1, 1995 between the Kentucky Water Resources Research Institute and the Kentucky River Authority. The final scope of work was divided into five separate tasks. The purpose of Task I was to review and evaluate previous water-supply studies for the Kentucky River Basin with the goal of developing a finalized scope of work for the study. A copy of the finalized scope of work is provided in Appendix 1.

Summary of Previous Studies

Over the last several decades, several water-supply studies have been completed with regard to the entire Kentucky River Basin or an associated sub-basin. These studies have varied in both complexity and duration. Table 1 provides a summary of the major studies along with a listing of the associated reports. A brief synopsis of the two most recent HARZA studies is provided in the following sections.

Table 1
Kentucky River Basin Water Supply Studies

1. Kentucky River Authority Study

   a. Kentucky River Authority, 1995, *Station Camp Creek Preliminary Jackson County Reservoir Site Analysis*

2. Kentucky-American Water Company Study

   a. Kentucky American Water Company, 1993, *Kentucky River Aquatic Study*
   b. HARZA Engineering Company, 1992, *Source of Supply/Safe Yield Study*

3. Kentucky River Basin Steering Committee Study

   a. HARZA Engineering Company, 1991, *Development of a Long Range Water Supply Plan*

   b. HARZA Engineering, GRW Engineers, Inc., and Construction Dynamics Group, 1990, *Water Demands and Water Supply Yield and Deficit*

   c. U.S. Army Corps of Engineers, Louisville District. Kentucky River, *Reconnaissance Level Cost Estimate Data*, 1990,

4. KGS Study

   a. Carey, D., 1990, *Water Availability Modeling and Analysis of the Kentucky River*

5. Regional Water Supply Planning Meeting Report

   a. Rebmann, J. And Hassell, D., 1988, *The Kentucky River: An Outline of Issues for Water Supply Planning*

6. Station Camp Creek Study

   a. U.S. Army Corps of Engineers, 1988, *Interim Report: Kentucky River and Tributaries Station Camp Creek Kentucky*

7. Lexington-Fayette Urban County Government Study

   a. Rebmann, J. R., 1987, *A Multi-Purpose Surface Impoundment Proposal for the Kentucky River*

8. Kentucky Natural Resources and Environmental Protection Cabinet Study

   a. Daugherty & Trautwein, Inc., 1985, *Kentucky River Survey, Rehabilitation Study for Locks and Dams 5 through 14.*

9. Red River Alternatives Study

   a. U.S. Army Corps of Engineers, *1978, Special Report: Water Supply Alternatives to Red River Lake*

Kentucky-American Water Company Study (1992)

This study was performed for the Kentucky-American Water Company by HARZA Engineering Company and resulted in a report entitled "Source of Supply/Safe Yield Study." The purpose of the study was to evaluate the safe yield of the Kentucky River for the Kentucky American-Water Company intakes in Pool 9 of the Kentucky River. The safe yield was determined by simulating the operation of the Kentucky River system for the 1930 drought as adjusted for current conditions in the basin. The safe yield was defined as the maximum flow rate that could be sustained during the period when projected demands for the year 2020 could not be met. In computing the safe yield the leakage through all locks and dams was assumed to be 50 cfs. In addition, it was assumed that the water stored in the pools was available for use and that minimum release requirements would not be met whenever pool water levels were below the crest levels. However, demands for Kentucky-American were reduced to the safe yield level during the time period the projected demands could not be met. Under these conditions and assuming the 7Q10 requirement at pool 9 to be 120 cfs, a safe yield of 35 MGD was determined.

Kentucky River Basin Steering Committee Study (1990-1991)

This study was performed for the Kentucky River Basin Steering Committee by a engineering team led by HARZA Engineering Company. The study resulted in two separate reports entitled "Phase I Report: Water Demands and Water Supply Yield and Deficit" and "Phase II Report: Development of a Long Range Water Supply Plan" The purpose of the Phase I study was to develop a recommended design drought and design deficit for use in evaluating supply alternatives in the Phase II study. A brief summary of the results of both studies as taken from the original reports is provided in the following sections.

Phase I Study

The first phase of the Harza study resulted in a report entitled "Water Demands and Water Supply Yield and Deficit". This report identified expected future demands in the region as well as the resulting deficit for a range of hydrologic conditions including both the 1930 drought of record and the 1953 and 1988 droughts.

Daily Steamflows Daily streamflows in the historical drought periods were computed using flows recorded by the U.S. Geological Survey (USGS) at Kentucky River Locks and Dams Nos 4, 6, 10 and 14. The Harza analysis of historical droughts confirmed that the 1930 drought is the most severe of record with a return period greater than 100 years at all the USGS recording stations within the study area. The 1953 drought is the second most severe with a return period of approximately 100 years at Locks 10 and 14 and a return period of less than 50 years at Lock 6. The

1953 and 1930 droughts lasted for periods of 4 to 6 months. The 1988 drought, although severe, lasted for a relatively short period (2 months). Streamflows for the 1930 historical drought were adjusted for the effects of Carr Forks and Buckhorn Reservoirs and differing levels of municipal and industrial withdrawals and discharges so that consistent sequences of adjusted streamflows were used in the analysis.

Water Demands Water demands were forecasted on a monthly average basis for each of the major municipalities and industries in the study area and combined into the total demand for each pool. A summary of the observed 1990 and forecasted 2050 net demands (withdrawals - return flows) for the month of August is provided in Table 2.

Table 2
Observed and Forecasted August Monthly Demands

Pool	1990 Demands	2050 Demands (Without Conservation)	2050 Demands (With Conservation)
4	8.0	6.7	5.7
5	3.3	3.9	3.3
6	0.8	0.9	0.9
7	-11.7	-12.7	-12.9
8	6.0	6.7	6.0
9	44.8	48.8	42.8
10	2.5	2.6	1.9
11	11.1	11.0	10.2
12	3.2	3.2	3.2
13	0.0	0.0	0.0
14	1.1	1.2	1.1

Water-Supply Deficits 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 "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 is less than demand. In calculating the deficit, Harza included irrigation as one of the major demand types. Table 3, below provides the computed total deficits for Kentucky River Pools 4 through 14 for historical droughts for 1990, and 2050 projected demands.

Table 3
Simulated Demand Deficits - (Billion Gallons)

Drought	Conservation	1990	2050
1930	No	8.1	8.7
1953	No	6.4	7.0
1988	No	1.3	1.2
1930	Yes[1]	5.9	6.5
1988	Yes[1]	1.0	1.2

[1]Assumes a water-shortage response program reduces demand during droughts similar to the demand reductions during the 1988 drought. Water-shortage response measures are assumed to be in effect for all water users in the basin.

Recommendations Based on the results of the study, the report recommended that the 1930 year drought be used as the design drought and that 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.

Phase II 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." 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.

Alternative Plans Twenty-seven alternative water-supply plans were developed and evaluated for the study. All of the plans would provide for the entire projected 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 elements included new dams at existing sites of Locks and Dams and at new sites. Raising of pool-water levels by up to 15 feet and lowering of existing water-supply intakes were considered. Small Upstream Reservoir plan elements included dams of 50 feet to 150 feet in height 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 having 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 combining smaller elements.

<u>Evaluation Criteria</u> 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; and potential recreational and tourism benefits. The evaluation was carried out using a 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 evaluate the diverse objective and subjective criteria. Coefficients were assigned to each of the ten criteria, reflecting their relative importance. The alternatives' performance was scored for each of the criteria. The products of the scores and the importance coefficients were then summed and ranked.

<u>Comparison of Alternatives.</u> Long-range water-supply plans utilizing dams at the existing or proposed new sites on the Kentucky River scored consistently higher than 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 dam at a site between existing Locks and Dams 10 and 11 and a new dam at Lock and Dam 12.

Table 4 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 4

Summary Comparison of Present Value Construction and Operation and Maintenance Costs (Costs in Million Dollars)

	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

KWRRI Study

Since the 1990 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 this 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 Authority has recently initiated several capital construction projects that will have an impact on the available water supply. Because the need for 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. Task 1 of the KWRRI study involved a review of previous water-supply studies for the Kentucky River Basin along with an evaluation of the modeling assumptions inherent in the HARZA Phase 1 study.

CHAPTER II

HARZA Deficit Forecast Assumptions

Introduction

In order to predict the water supply deficits that would result from various historic hydrologic streamflow sequences and forecasted demands, the Harza study employed the River/Reservoir Basin Yield Model (RRBY). This model is designed to be applicable to different river systems and operating constraints. The model begins by simulating the operation of the upstream-most reservoir in the system, the pool behind Lock and Dam 14, using a daily streamflow sequence for a particular drought, monthly average withdrawal and discharge rates, a constant minimum release rate and leakage. Daily outflow from this upstream-most pool plus the intervening natural flow becomes the inflow to the next pool downstream. This process is continued successively downstream until all of the lock and dam pools have been simulated.

Model Input Data

The basic input data for the RRBY model includes synthetic or historical intervening flows, reservoir elevation-area-volume characteristics, spillway discharge capacity versus elevation, seepage loss rates, demand rates, minimum release requirements, leakage rates and maximum and minimum pool elevations. The sources and assumptions used for each of these data types are outlined below.

Historical Streamflow Generation

Inflow into a pool was considered as originating from two sources: (1) water flowing over the weir of the immediately upstream lock & dam, and (2) lateral inflows from the pool's watershed. Daily steamflows into Pool 14 for 1930 and 1953 were obtained from USGS records. No storage above the crest of a pool was assumed to carryover to the next day (i.e., all water above the dam crest remaining after all demands were subtracted was passed over to satisfy downstream demands).

Lateral inflows were computed by first generating historical streamflows at all of the locks & dams. Streamflows gaging records at Locks 4, 6, 10, and 14 exist for 1930 and 1953. Streamflows at these locations were taken directly from the historical records. Streamflows at the intermediate locks were interpolated from the adjacent gaged locks by one of two methods. If the difference in the streamflows between gaged locks was positive, indicating an increase in streamflow at the downstream lock, then the streamflow at intermediate locks was interpolated by a ratio of the drainage areas. If the difference in the streamflows between gaged locks was negative, indicating a decrease at the downstream lock, then the streamflow at intermediate locks interpolated by a ratio of each lengths. Lateral inflows for each pool were then calculated by subtracting flows between adjacent locks.

To construct true "natural" streamflows, one must correct for historic demands. The 1930 streamflows were not corrected for historical demands, primarily because of the lack of available data and the relatively small magnitude of 1930 demands (Ky-American, the largest single demand on the river, did not begin withdrawing water from the river until 1931). 1953 historical streamflows were corrected for historic demands. Historic demand records were provided by Ky-American and KDOW. It appears that streamflows were corrected for municipal demands only.

Historic streamflows were adjusted for the regulatory effects of Buckhorn and Carr Fork reservoirs. The apparent lack of good historical streamflow records in the area precluded Harza from routing actual historic inflows through the reservoirs. Instead, historic inflows were synthetically generated. Known streamflows on the Middle Fork of the Ky River during drought periods and after the installation of Buckhorn Reservoir (post 1960) were compared with calculated unregulated streamflows for the reach. The artificial unregulated streamflows were computed based on prorating recorded flows on the South Fork, which is unregulated, to the reservoir-affected site. The difference between the known actual streamflow and the "expected" flow on the Middle Fork was considered the effects of Buckhorn Reservoir. This amount was then subtracted from historical streamflows to generate historical inflows into Buckhorn. These inflows were then routed through the reservoir using an Army Corps of Engineers-provided rule curve. The lack of historical streamflow gages in the vicinity of Carr Fork Reservoir precluded the use of the above procedure to generate its inflows. Instead, Carr Fork releases were considered to be 1/7 of Buckhorn releases. One-seventh was chosen as an appropriate factor because it represented the ratio of average annual inflows and the ratio of the respective drainage areas of Buckhorn and Carr Fork.

Leakage

Leakage for all locks and dams was considered to be a constant value of 50 cfs; the same assumption made by the U.S. Army Corps of Engineers (1978) in their report, *"Water Supply Alternatives to Red River Lake"*. In each case the leakage estimate was considered to be independent of the water level in the pool. Because of the critical impact of leakage on the resulting deficit estimates, it is recommended that an effort to obtain more reliable estimates be undertaken.

Transmission Losses

No transmission losses were subtracted from Buckhorn or Carr Fork releases. Transmission losses, evaporation, etc. in the main stem of the river are implicit in the computed lateral inflows for the pools.

Dix Dam Effects

Dix Dam releases and leakage were not considered in the HARZA drought analysis runs. Furthermore, no releases or leakage from Dix Dam was assumed in their generation of historical flows for the Ky River.

Irrigation Demands

Actual potential irrigation areas for each pool were determined from information compiled from an aerial survey conducted during the 1988 drought by KDOW. Irrigation rates were calculated for each pool based on withdrawing 900 gallons per minute for 12 hours a day from May through October.

Critique of Modeling Assumptions

A review of the basic modeling assumptions of the Harza deficit analysis reveals several issues that could have an impact on the resulting deficit projections. Each of these issues is summarized in the sections:

Mass Balance Model

The RBBY model simulates basin behavior on a daily time interval by performing a series of mass balance computations on the Kentucky River main stream pools. A mass balance of inflows and outflows for each pool is conducted to compute daily water-supply shortages. Inflows into a pool included upstream flows, WWTP discharges, and lateral inflows from the incremental watershed. Outflows from a pool included lock and dam leakage, major municipal and industrial demands, irrigation demands, and flow over the dam crest. Water supply shortages were observed whenever net inflow into a pool was insufficient to satisfy the daily projected net demands. Net inflow was calculated as inflow remaining in a pool after dam leakage and minimum flow requirements were met. Net demands on a pool were defined as the sum of the municipal, industrial, and irrigation demands less any WWTP discharges into the pool. During a simulation, calculations were performed beginning with pool 14 and continued downstream on a pool by pool basis to pool 4. Any water remaining above the dam crest after demands were met was assumed to pass downstream to the next pool. Consequently, no storage above crest remained from the previous day for satisfying demands.

Return Flows

An analysis was conducted to evaluate the amount of consumptive loss (e.g., the percentage of demands that appears as return flow to the river from the WWTP) for the major users on the river, mainly utilities and other municipal withdrawers. Wastewater Treatment Plant (WWTP) discharges into the river were assumed to be a percentage of demands, not a percentage of the actual water withdrawn from the river to satisfy demands. Harza's assumption was that the demands existed, regardless if the river could sustain them or not, and that the demand would be satisfied from an outside water source. Hence the return flow from the WWTP should be a function of the demand.

Headwater Demands

During simulation of the river, historic inflows into pool 14 were not reduced for municipal or irrigation withdrawals from the three forks that constitute the headwater of the Kentucky River. Similarly, releases from Buckhorn & Carr Fork reservoirs were directly to pool 14 inflows; no reduction was made for headwater withdrawals.

Conclusions

Several weaknesses are apparent in the method and assumptions Harza used in simulating/modeling the Kentucky River. The most glaring is the use of a mass-balance model to simulate river hydraulics. The simplistic continuity equation that drives the RRBY model ignores the physical features of the river. Fourteen submerged dams line the 255 mile length of the main stem of the river. The size and shape of these dams dictate the quantity of water that can pass over them. The RRBY model ignores these features and assumes any water above a dam's crest remaining after all withdrawals is passed downstream, regardless if the dam can physically pass the water. This assumption "flushes" all water in the river above dam crests out of the system and presumes water levels in the main stem pools are at or below crest at the beginning of each day. It is unrealistic to assume storage above the dam crests is flushed out of the system daily. Aside from the obvious disagreement with physical observation-flushing the river daily would create excessive flows at the lower locks. Furthermore, the lack of a routing component permits water released from Buckhorn and Carr Fork reservoirs to empty into the Ohio River, over 400 miles away, in one day. From a deficit analysis viewpoint, this assumption is both conservative and liberal. It is conservative because on any one day excess water (water above crest after withdrawals) can be used to satisfy demands in downstream pools. However, it is intrinsically liberal because it ignores the in-channel storage of the river that is known to exist as water travels the length of the river.

Several potential criticisms can also be made with regard to the method in which Harza generated the historical river inflows used to characterize the 1930 & 1953 droughts. Recall historic lateral inflows into the river were generated by subtracting flow values at adjacent locks. The underlying assumption in this method is that water entering a pool (as both upstream and lateral inflow) is equal to its outflow. The fallacy of this assumption is in its oversight of changes in pool storage. Outflow from a pool is dictated by height of the water above the dam crests. A simple continuity check indicates that the difference between the inflow (from the upstream dam) and outflow rate must be attributable to changes in pool storage and lateral inflows from the watershed. Omission of the storage component yields incorrect lateral inflow values and raises suspicion as to the adequacy of lateral inflows generated in this manner as accurately characterizing the drought.

A second potential criticism in Harza's determination of historic river inflows is the exclusion of *any* releases from Dix Dam. Due to the severity of the drought it is likely that no controlled releases were made from the dam during the drought. However, the dam is known to have leaked during both droughts. Published records report the leakage for the dam to be on the order of 60-70 cfs in 1930. Leakage values between 40-55 were reported for 1953. Present leakage at the dam is reported to be on the order of 10-20 cfs. Leakage from Dix Dam flows into the Kentucky River at pool #7 and would be included in historical flow records. Harza reports no adjustment to historical records for Dix Dam leakage. By not removing the leakage bias from historical flows, lateral inflows derived from these records incorporate 1930/1953 dam leakage flows.

Several of the criticisms of the Harza study involve the omission of factors influencing river behavior/flows. First, municipal, industrial, and irrigation demand withdrawals in the headwaters were ignored; no reduction to natural flows or reservoir releases was made to reflect these demands on the river. Additionally, no adjustment to the historic lateral-pool inflows was made to reflect the reduction caused by the numerous permitted withdrawals in the tributaries to the main stem pools. Secondly, while the water supply during the drought was characterized with historic river inflows, no adjustment to current demands, was made to reflect the increases in water usage that would result from the historic weather (i.e. temperature and rainfall) conditions of the drought. Thirdly, no reduction in return flows were made for demand reductions; return flows were a function of demand not water actually supplied. During periods where deficits were recorded return flows were still added into the system. Furthermore, demands on a pool were automatically reduced by estimated return flow percentages. In other words, return flows could be used to satisfy demands, even if water levels were below crest or intake elevations. Lastly, the assumption of a constant lock leakage is unrealistic. It is known that leakage values are a function of the water level in the pool. As water levels drop, the head on the leakage orifice is reduced.

In addition, some orifices may become exposed at lower levels.

A final potential criticism of the modeling technique employed in the Harza study lies in the definition of the deficit. Harza defined a deficit as unsatisfied municipal and irrigation demand. At times when flows are insufficient to satisfy minimum flow requirements and demands were prohibited, deficits were recorded. Irrigation demands are not regulated by the DOW and it is unrealistic to assume these withdrawals would adhere to permitted withdrawal regulations. It is likely irrigation demands would continue as long as water was available.

CHAPTER III

HARZA Demand Forecast Assumptions

Introduction

Water deficits, also known as shortages, and surpluses depend on both how much water is readily available and accessible for use in an area (supply) and how much water is used by residents, and other users, in that area (demand). To determine the likelihood of water deficits, the costs of these deficits, and efficient means of reducing the likelihood and the impact of water deficits, an understanding of the determinants of the demand for water in the Kentucky River Basin is fundamental. It is as important as understanding the determinants of supply.

This section provides a critique of the demand projections of the Harza Engineering Company report titled "Preliminary Long Range Water Supply Planning Study of the Kentucky River Basin, Phase I, Water Demands Water Supply, Yield and Deficit" (henceforth, Harza (1990)). While the critique will suggest some of the shortcomings of the Harza report, perhaps more importantly it will also suggest some potential means of modifying and improving future projections of water usage in the Kentucky River Basin.

Harza (1990), a study on water deficits in the Kentucky River Basin, primarily focuses on the supply of water. Minimal attention was focused on the determinants of the demand for water and how water usage might be altered in the future. The report did not thoroughly evaluate drought responses that focus on the usage of water. Alternative pricing schemes and conservation measures were considered, but not nearly as carefully as supply options.

The absence of attention in Harza (1990) of extensive demand analysis and serious consideration of the factors other than population that influence the demand for water, might lead readers of the report to the conclusion that water deficits can only be remedied by increases in the supply -- though this is not a position endorsed by Harza (1990). Our review of other studies that analyzed the demand for water suggests that the demand for water is not strictly a function of population, as assumed by Harza (1990). That water demand may be influenced by price and conservation practices suggests that deficit situations can be alleviated by changes in prices and conservation practices as well as short-run supply management and long-run increase in capacity. To evaluate the merits of the policies, the analysis of demand for water must attempt to determine the influence of these policies -- something not done in Harza (1990).

A Brief Review of Demand Projections in Harza (1990)

To estimate the future demand for water in the lower Kentucky River Basin, Harza made the assumption of constant per capita water demand through the relevant period of analysis, 2050. Using this as a starting point, Harza considered three alternative demand scenarios: 1) no additional conservation and no increase in intensity (therefore, constant per capita usage); 2) a 1% reduction in per capita use every five years due to unspecified factors; and 3) water usage similar to that observed during the shortage response plan of 1988.

For each demand scenario, Harza forecasted future demand based solely on population projections obtained from the University of Louisville Urban Studies Center based on U.S. Census data. Under each of the three scenarios the sole determinant of increases in water use is population growth.

An Overview of Demand Analysis

While population is certainly an important determinant of the demand for water in area, just as it is an important determinant of the demand for any commodity, it is by no means the only determinant. To understand some of the shortcomings in using only population as a predictor of the demand for water in the Kentucky River Basin, a brief discussion of the general approach to estimating and forecasting demand, as done by economists, may be beneficial.

In addition to population, economists believe a number of other factors will influence the demand for a product. Probably first among these determinants is the price of the product. Demand curves are "downward" sloping, meaning that as the price of product increases the demand for it will decrease. For countless products and commodities (including water), economists have found a strong link between price and use. If the price of water is likely to change, or if changes in water pricing are considered in water conservation plans, the impact of price on demand should be explicitly incorporated into any forecasts of future demand.

Other factors that generally affect demand for most products, and are likely to affect the demand for water, include income in the area and other socio-demographic characteristics of the households in the area. Generally, but not for all products, we expect demand for a product to increase with family income and household size. Additionally, demand for products, particularly utilities and energy, will change over time independently of price or income. Part of the explanation for these changes is undoubtedly technological innovations in the use of product. The rate of increase in gasoline consumption, for example, slowed in part due to the increased use of more fuel efficient automobiles.

If the demand for a product depends on more than a single factor, then approaches such as used in the Harza study are not entirely appropriate. When the demand for a product depends on a number of factors -- price, population, income, and time of year, for example -- that do not change in unison, then quantitatively determining the relationship between the demand for a product and these factors and then using this relationship to forecast future demand becomes more complicated. To estimate the demand relationship requires data for a number of years (or other period of time) on past use (demand) and the factors believed to influence demand. These data are then used to estimate a demand relationship using the statistical technique of multiple regression or a similar technique. Once this relationship is estimated, forecasting of future use requires predictions of the future values of all the factors affecting demand not simply one such as population.

Past Studies of the Demand for Water

Bearing in mind the wide range of factors that generally influence the demand for products, it is useful to briefly review the findings of studies that have focused on the demand for water, in particular the demand for water for residential use. Review of these studies will make some of the shortcomings of the demand analysis in Harza (1990) apparent and suggest how future studies may improve upon the analysis found in Harza.

Several studies including Hewitt and Hanemann (1995), Nieswiadomy (1992), Lyman (1992), Martin and Thomas (1986), Danielson (1979), Foster and Beattie (1979), and Danielson (1972), have considered the influence of factors other than and in addition to population on the residential demand for water. Factors found to influence the demand for water in these studies include climate variables such as average rainfall and temperature, income, the pricing of water and the structure of the pricing scheme, and the number of persons in the household.

One finding of particular interest to a critique of Harza (1990) is the relationship between residential demand for water and climate/weather variables. For example Foster and Beattie (1979) among others find residential water demand increases when rainfall decreases and temperature increase -- drought conditions. This result is not surprising as the use of water for watering of lawns and recreational purposes (pools) increases during these times. Harza (1990), because it based its demand projections strictly on population, does not incorporate the **increase** in water usage during a drought into its projections if no special action is taken to limit demand. Instead, assuming that summer (August?) water usage depends only on the current population. Thus the projected water deficits found in Harza (1990) are likely to be underestimates of the actual deficits in the absence of any changes in water pricing, conservation practices, or supply changes. Future studies of water demand and deficit analysis in the Kentucky River Basin should incorporate the influence of climate/weather conditions and the subsequent increase in residential water use into demand and deficit projections.

The Relationship Between Population and Water Use

Harza (1990) explicitly assumed that per capita water use in the future (through 2050) would remain at the same level as per capita water use in 1990. While this may be viewed as an approximate projection for the purposes of forecasting future use, the obvious question for an analysts is whether this is the best projection given the information we have. In particular, has per capita water remained constant over time in the past? If not, we should be wary of predicting future use to remain at the same levels.

We plan to study water use for any trend in per capita water use with data from KAWC. We suspect per capita water use has not remained constant during past years. Statistical analysis of the trend in per capita water use might suggest that a more appropriate assumption than constant per capita use is an assumption that water consumption is changing. If per capita water use in the future increases at the rates it has (if it has) in the past fifteen years then the increase in demand and therefore the projected deficits, in the future will be much larger than projected in Harza (1990).

In contrasting our projections of per capita water use with those in Harza (1990) we will provide two cautionary notes: 1) projections of future demand based on past demand are often very inaccurate in part due to unanticipated changes in technology, prices, or substitute goods and products; 2) estimating how per capita consumption has changed over a period of time does not explain why per capita consumption has changed. During the period [whatever period we have data on] per capita consumption may have changed for several reasons. During this period real incomes (inflation adjusted) in the area may have changed, and the real price of water may have changed. In addition the mix of resident, commercial, and industrial users may have changed dramatically. This is a point we shall discuss later in more detail. Finally, the uses and taste for water may have changed during the period because of technological changes.

Rather than simply find a simple relationship between per capita water usage and time as has been done here, a more thorough study of water demand should relate the changes in per capita water use to other factors that have changed over time such as incomes and rates using the multiple regression analysis or similar statistical analysis. However, even when these factors are considered, there may be some changes in water use over time not explained by changes in these factors so that a time trend needs to be included in the analysis, presumably as a proxy for unquantifiable technological or taste changes. This time trend in water use, while necessary, should be only one of the factors in the demand analysis. Inclusion of both a time trend and other factors (income, for example) whose future values can be projected when estimating a demand relationship should provide for better projections of future demand for water than Harza's (1990) three projections.

The Demand for Water and the Type of User

Harza (1990) made no attempt to distinguish among the variety of types of users of water, in particular, the distinction between residential, commercial, and industrial users. Instead Harza (1990) simply focuses on population as a determinant of water use. This assumption, while a good starting point, is not likely to explain much of the changes in water use over time in the Kentucky River Basin. Currently, some water is used by nonresidential users with commercial and agricultural users comprising the remainder of the market. The demand for water is not simply determined by the population of the Kentucky River Basin but also by the employment and commercial base of the basin. More attention must be paid to understanding the relationship between the types of business and commercial enterprises in the basin and water usage. The residential-commercial mix is particularly important, if the nature of commercial and business activity in the Basin changes over time. If industrial and commercial water usage continues to become a greater share of the total use of water in the Basin, then the projections made by Harza (1990) of constant or decreasing per capita water demand is not likely to be very accurate.

In addition to increasing the accuracy of projections of future water use, disaggregating water use by type of user may also provide more information about the impacts of rates and conservation policies. Currently, commercial and industrial users receive lower rates than residential users. What impact would changes in commercial and industrial rates have on their water usage? What would the impact of rate changes have on commercial and industrial activity, economic development, in the Basin. These are important issues that the methodology for projecting demand in Harza (1990) can not address but could potentially be addressed if the demand for water is disaggregating by type of user with the demand for water by each type of user analyzed separately.

The Price Elasticity of Water

The price elasticity of a good measures the response in demand of that good to changes in the price of a good. For example, if the price elasticity of a good is -2 then a 10% increase in price would decrease water demand by 20% and a 15% decrease in price would increase water demand by 30%. Price elasticities are derived from the estimation of demand relationships as discussed earlier. Harza (1990) assumes a price elasticity of water of -0.92, meaning, for example, a 10% increase in water rates would decrease the demand for water by 9.2%.

Danielson (1979) reports a price elasticity of demand for water by residential users that is much lower, -0.27. In a summary of other studies Danielson reports elasticities in the range of -0.02 to -1.10. If Danielson is right, the lower estimates imply that consumers are much less responsive to price than Harza (1990) assumes. However, the responsiveness of the demand for water to rate changes depends on the use of the water. Danielson (1992) finds that while residential demand for water is not very responsive to rate changes (-0.31), sprinkling demand is highly sensitive (-1.38). The implication of this finding suggests that rate increases for residential users will primarily affect the use of water for care and maintenance of the lawn and not use within the home.

Perhaps a greater shortcoming in Harza (1990) than its assumption about the elasticity is the failure of the elasticity to be integrated into the demand analysis undertaken in Harza (1990). The primary purpose of obtaining price elasticities is to estimate the impacts of price changes on consumption. Harza (1990) made no attempts to estimate how changes in water rates might affect water usage unless increases in prices are the reason for the 1% decrease in per capita water use every five years. While Harza (1990) recommended reforming the pricing structure of water, it failed to use price elasticities to project the impact of these changes in pricing structure on water usage.

Conservation Plans and the 1988 Water Shortage Plan Scenario

In addition to the scenario of constant per capita water use, Harza (1990) also undertakes projections assuming that: 1) per capita water use decreases by 1% every five years; and 2) per capita water use is the same as under the 1988 water shortage plan.

One criticism of the assumption of a 1% decrease in water consumption per capita every five years is how is this decrease obtained? Where is the analysis that shows it. Such analysis may suggest per capita consumption is increasing, not decreasing, so presumably to change this trend, rate increases or conservation measures must be undertaken. But Harza (1990) has not offered any explanation of how, or what might be the most effective way, of obtaining this reduction in consumption.

While water consumption per capita did decrease under the 1988 Water Shortage Plan, our hunch is long-term per capita water demand is not significantly effected by conservation plans. Thus the scenario given under the 1988 Water Shortage Plan might be underestimate long-term water use.

Conclusions

To understand and forecast water deficits, an understanding of the determinants of both the supply of and demand for water are needed. The probability and severity of water deficits can be reduced by either increases in the supply of water or decreases in the demand for water. In many cases it may be both easier to implement measures to reduce the demand for water and more cost effective.

The focus of Harza (1990) is clearly on the supply of water. The demand projections of Harza (1990) are based on the assumptions of 1) constant per capita water use or 2) a gradual (1% every five years) reduction in per capita water use. The critical (and only) determinant of projected water use in Harza (1990) is the projected growth in population.

While population growth is an important determinant of water demand, it is not, as many studies have found, the only determinant of water demand. Here we have suggested that future studies of water usage in the Basin consider other factors that affect the demand for water such as income, the type of users (commercial, industrial and residential), climatic conditions, conservation measures, and the pricing practices of water. Basing projections of water usage on these factors in addition to population should improve the reliability of these projections. As discussed, determining the simultaneous influence of these numerous factors on water demand is possible using the statistical technique of multiple regression.

In addition to improving the reliability of projections of future water use, demand analysis that incorporates factors such as water pricing and conservation plans makes it possible to analyze the impacts of changes in water pricing and the implementation of conservation plans on the demand for water. As these policies are alternatives to often expensive policies designed to increase the supply of water, the effectiveness of these policies needs to be evaluated. While Harza (1990) recommends changes in pricing practices and the adoption of conservation plans, the demand analysis done in Harza (1990) does not provided the basis for the analysis of these policies.

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APPENDIX I

KENTUCKY RIVER BASIN WATER SUPPLY ASSESSMENT

Final Draft Study Plan For The
Kentucky River Authority
August, 1995

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

Background

The management of a major river basin is a complex process and should be approached with all of the modern tools available and in cooperation with the people and legal entities within the basin. To achieve the full benefits of such a large and complex natural resource, information on the natural systems is required, the demographic trends must be studied, the economic framework and trends analyzed, and the wishes of the people of the basin determined.

The Harza study (1990) evaluated water supply deficit along the mainstem Kentucky River for 50-year, 100-year, 1953 and 1930 droughts. They found that 7 billion gallons (BG) of storage would be required, with conservation, if 7Q10 low-flow requirements were maintained. The study also found that if the pools could be mined, and if the low-flow requirements were reduced 50%, then the deficit would be 0.4 BG, occurring entirely in pool #9. After the Harza report, Kentucky-American conducted a study of the impacts of low-flows on aquatic life. Based on this study, KYDOW has determined that the mandates of the state's water law could be achieved at somewhat lower levels of flow. Therefore, Kentucky-American's water withdrawal permit was amended to include a schedule of allowable withdrawals at low flows.

The Harza study also recommended a Conservation program which included:

1. Development of a Water Shortage Response Plan
2. Public Education and Information Program
3. Citizen's Advisory Committee
4. Plumbing device retrofit program
5. Plumbing device change out
6. Leak Detection Program
7. Pricing policies, replacement of declining block pricing, establishment of drought emergency rate structure

The Kentucky River Authority (KRA) has put into practice several of the recommendations such as the installation of release valves in Locks and Dams 11 through 14 for the purpose of mining the pools during droughts. Consideration is being given for the placement of release valves in other locks and dams.

Policy issues under consideration by the KRA relate to water supply planning that would ensure that low-flow requirements will be maintained and a determination on how much and how long reduction in water use can be extended during a severe drought without significant social, economic and political losses.

The previous work has been criticized on several fronts that must be addressed by the proposed study. The major criticisms can be summarized as follows:

1. Benefits of conservation are thought to be too low. A more detailed look at conservation and drought management is needed.

2. Projections of population growth are thought to be too low. Insufficient consideration was given to development growth.

3. There may still be lingering concern that ground-water sources were not given ample consideration.

Scope of Work

Water supply planning is not an exact science. Levels of conservation and demand reduction versus levels of capital construction for assured water supply are social choices. Estimates of water supplies needed for economic development are matters of opinion and choice. The key to the success of the Water Supply Assessment will be the assurance that the viewpoints of all interested parties shall be incorporated. This does not mean that such viewpoints will be adopted, but rather that they will be reflected in the range of choices which will be developed. To this end it would be appropriate that the study be conducted in consultation with an advisory group consisting of representatives from: development groups, conservationist/environmental groups, Kentucky-American, business, state and local governments, state agencies such as DOW, members of the KRA Advisory Board, and others.

TASK I - Assessment of Previous Deficit Reports (Months 0-4)

A. Evaluate deficit analyses in Harza report in light of criticisms and changed conditions including:

1. Minimum flow requirements
2. Potential impact of capital construction projects
3. Management measures
4. Conservation measures
5. Impact of alternative economic growth assumptions

In consultation with the advisory group, determine those areas in the Harza report which need to be explored in more detail. For example, DOW could provide input into what could, and should, be done with regard to variances on low-flow requirements. Conservationists may feel that the effectiveness of conservation and management measures were underestimated, while economic development groups may feel that demand projections are too small. The impact of these viewpoints on the water demands can be examined once the viewpoints are established.

B. Identify Data Needs

Get data and analytical tools used in Harza report for use in this study. This would include a review of the computer model, computer model input data, etc. Identify additional data which will be needed to evaluate alternatives suggested by advisory board. Also, identify a computer model that can be utilized by the Kentucky River Authority in the future.

C. Draft Study Plan (Presented at the end of month 4)

A draft study plan will be developed and presented to the Advisory Board and the Authority for comments before proceeding. Comments and suggestions will be taken under advisement and a final study plan developed.

TASK II - Water Supplies in the Upper Forks and Other Areas not Served by the Main Stem (Months 4-12)

Water supply needs in the headwaters of the Kentucky River-North Fork, South Fork, and Middle Fork basins - will be assessed using information from the Kentucky Division of Water, Area Development Districts (KRADD, BGADD, NKADD, CVADD, KIPDA), the Rural Water Association, the Cabinet for Human Resources, city and county officials and engineers, the Department of Abandoned Mine Lands, water companies, and others. The information will be used to:

1) Characterize the surface and ground water supply systems, both public and private.

2) Assess the water quality, reliability, and extent of domestic ground water supplies.

3) Create, or recommend, programs and methods for the protection and improvement of ground water supply systems.

4) Assess the water quality, reliability, extent, and efficiency of surface water supplies.

5) Recommend system supply improvements and priorities.

6) Evaluate drought response planning and make recommendations.

The results of this assessment will be incorporated into the Long Range Water Supply Plan, Task V. Specific products that will be developed will include maps of various water use attributes and physical aspects of the basin, compilation of water demand data, water supply information, reservoir data and planned surface storage facilities, and other data that will assist in the assessment of water supply and demand for the Upper Forks region.

TASK III - Water Supply and Demand Evaluation (Months 4-12)

A. Data Collection

Collect, or generate, data necessary for the analysis of the balance between supply and demand based on alternative assumptions. Required data are expected to include:

1. Spatial Data
   a. Topographic data for river
   b. Withdrawal locations and capacities.
   c. Discharge locations and estimates.

2. Physical data for the Kentucky River.
   a. Stage/Storage data for pools.
   b. Stage/Discharge relationships for dams.
   c. Physical Data for Carr Fork Reservoir.
   d. Physical Data for Buckhorn Reservoir.
   e. Physical Data for Dix Dam

3. Operational Data
   a. Minimum flow requirements for each pool.
   b. Operational policies for Carr Fork and Buckhorn.
   c. Evaporation/Leakage Data

4. Supply Data - Historic Streamflow Sequences (1930 and 1953)

5. Demand Data and Economic Data

There are three primary purposes of collecting data on demand (usage), conservation practices, and water pricing rates: (1) to determine the factors that have influenced demand or water usage in the past. (2), using this relationship between economic and demographic factors, to forecast future demand given projections of future economic and demographic characteristics of the basin and (3) to simulate the short term and long term impacts of conservation and pricing policies on demand. The data necessary to undertake estimation and forecasting of demand as well as the sensitivity of demand to policies include:

a. Water usage data (monthly baseline data)
    1) Residential usage
    2) Industrial and other heavy users
b. Population data and population projections
c. Measures of industrial and business activity and projections of industrial activity
d. Measures of drought severity (to use in demand forecasts)
e. Past conservation policies and their impacts
f. Water pricing rates

B. Data Evaluation

Once the necessary data have been collected, the data will be analyzed to determine adequacy for subsequent analysis.

C. Data Generation

Where the data are deemed to be insufficient additional data will be collected or generated (i.e. streamflow or demand sequences).

D. Model Development/Evaluation

A computer model of the Kentucky River will be used in order to analyze the impacts of different operational scenarios on the resulting balance of supply and demand for at least two different drought scenarios (1930-drought of record, and 1953-approximately a 50 year drought). The proposed model will be developed for use by the Authority and should provide the basis for drought management planning and for long-term water supply planning. The model will incorporate in-line and off-line storage, storage losses, demands, return flows, and evaporation losses. The model will evaluate the impacts of changing demand levels, conservation or demand reduction strategies, upstream regulation, and system losses on supply reliability. The model could also be used to evaluate alternative supply sources such as reservoir storage, interbasin transfers, withdrawal relocation, etc. Expect inputs will include:

1) Demands by location (with intake elev)
2) Return flow locations and volumes
3) Monthly and Peak Demand ratios (relative to average demands)
4) Historical or simulated streamflow at selected point(s).
5) Drainage areas at demand points and storage points.
6) Operating policies for regulation structures.
7) Stage-volume-surface area functions for storage facilities.
8) Storage loss functions (optional)
9) Monthly Average Evaporation (default values will be provided)

Outputs are expected to include the magnitude, duration and frequency of supply deficits at given demand points.

E. Scenario Development

Several different operational scenarios will be developed and then analyzed using the Kentucky River Model. The final set of scenarios to be analyzed will be determined after consultation with the planning committee. However, at a minimum, it is expected that the following scenarios will be included:

a. Existing Conditions
b. System Expansions
c. Leakage Reduction
d. Modification of Minimum Release Rule
e. Drainage/Mining of Pools
f. Drought Response Plan. Analyze the impact of response plans that use both drought conservation practices and conservation pricing for droughts.
g. Conservation pricing. Evaluation of long- and short- term changes in pricing on water usage and water deficits.
h. Demand Sensitivity. Consider the sensitivity of water usage and deficits to different demand scenarios other than the baseline case. Different scenarios might include differences in the growth rate of population, the mix of business activity in the basin, or the location of population and industry within the basin.

F. Scenario Evaluation

Once the various operational scenarios have been developed, each scenario will be analyzed for the 2 different drought simulations (1930, 1953) for different demand projections over time.

G. Matrix Construction

The results from the scenario evaluation will be summarized in a solution matrix that will illustrate the range of estimates of supply and demand as a function of the various drought scenarios. This matrix will provide the basis for a recommendation to the KRA with regard to water supply investment.

Specific products to be developed will include a Kentucky River Planning Model (along with associated documentation) and a Water Supply/Demand Report. The Summary Report will identify the expected supply deficits associated with different operational scenarios for both the 1930 and 1953 drought for different demand projections over time.

TASK IV - Drought Response Plan (Months 2-16)

The fourth task of the project will involve the development of a decision support system for use in drought management. As currently envisioned, the system could be used by either Kentucky River Authority personnel or Division of Water Personnel to investigate the impacts of forecasted weather conditions and alternative operational scenarios on regional water supplies. The proposed system could be used to develop general planning guidelines or used in a real time sense during an actual drought. It is anticipated that the system will incorporate existing drought management guidelines as developed by the Kentucky Division of Water along with a physical description of the Kentucky River System. The anticipated steps for development of the proposed system may be summarized as follows:

A. Develop an interactive mathematical model of the Kentucky River System.

B. Develop a database of historical streamflow traces.

C. Attempt to quantify the economic costs associated with different levels of drought and the impact of alternative conservation and pricing practices on the economic costs of droughts. This would necessitate developing an understanding of the responses in different types of water usage to drought situations.

D. Evaluate existing drought response rules as proposed by the state DOW. The existing rules will be examined in an attempt to develop an initial framework for an operation rule base for inclusion in the decision support system.

E. Consider both the impact of water supply and water pricing on industrial activity. Determine if the possibility of droughts and water deficits has a significant impact on industrial location and activity. Further try to examine the impact of alternative drought response actions on industrial activity.

F. Discuss some of the impacts of alternative drought response plans on environmental conditions and attempt to provide some analysis of the costs and benefits associated with the environmental impacts of the alternative response plans.

G. Develop a graphical user interface that can be used to set withdrawal and release limits for various points along the Kentucky River and visualize both the hydrologic and economic impacts.

Specific products are expected to include a Drought Management Model along with supporting documentation and a Drought Response Plan Report.

TASK V - Long Range Water Supply Plan (Months 12-18)

A. Alternative Solutions

The water supply model and the demand model will be brought together such that a matrix of many alternatives will be available for solution. This set of models will be provided to the Kentucky River Basin Authority as a major product of this study for their use in planning for the future as new ideas develop or as social and economic conditions change. The information developed in Tasks I - IV will be utilized to develop many alternative solutions. Several will be selected to demonstrate the range of application of the system. Even though a wide range of river system structural changes can be examined and many demand scenarios based on population and economic trends can be studied, an effort will be made to make sure that viewpoints of conservationists and developers will be kept in a proper perspective. We will try to :

1. Keep solutions to water supply problems along the Kentucky River within the basic structure of the existing dam system.

2. Try to solve water supply problems within the geographic area of the problem. There should be an equitable distribution of costs and benefits within the basin.

3. Marginal costs of providing drought storage should be identified. It is conceivable that the marginal costs of a project might be such that the project is relatively insensitive to varying assumptions about conservation or demand growth.

For example, for a given project it might cost relatively little more to provide for an additional 10-20% of water during a project.

B. Long Range Water Supply Plan

Alternative scenarios, together with the proposed methods for reducing or eliminating potential deficits, will be evaluated by the Authority and the Advisory Group. A plan which best reflects the interests of all will be developed as the Long Range Water Supply Plan.

Anticipated Products and Schedule

The products developed by the study will include;

1. Draft Study Plan (Month 4)
2. Water Supply/Demand Report (Month 12)
3. Drought Response Plan (Month 16)
4. Long Range Water Supply Plan (Month 18) including decision suppory

APPENDIX II

SUMMARY OF KENTUCKY RIVER DATUMS

During the review of the previous water supply studies for the Kentucky River Basin it was determined that several different river datum exist. In order to properly compare the data and results from one study to another it is important that these differences be identified and understood. The following paragraphs summarize the different datum as identified as part of this study. This information is the result of published information by Jim Smith (COE, Louisville District), Dennis McClain (USGS), and Bill Grier (KRA). The National Geodetic Vertical Datum of 1929 has been used as the reference datum in the KWRRI study.

The USGS publish daily streamflows at lock & dam 14, 10, 6, 4, and 2 in an annual document entitled ***Water Resources Data***. They maintain a database of stage-discharge information for these locks, compiled from measurements made at each lock site. (Measurements are made approximately every six weeks and 20-30 years of data exists for most of the locks). The water level at each lock is measured daily and converted to a streamflow using a rating table developed from the state-discharge database. Elevations for the rating table use the datum specified at each lock in ***Water Resources Data.*** The datum for each gaged lock is listed below.

Lock & Dam #14	Ohio River Datum
Lock & Dam # 10	Ohio River Datum
Lock & Dam # 6	Kentucky River Datum
Lock & Dam # 4	National Geodetic Vertical Datum of 1929
Lock & Dam # 2	National Geodetic Vertical Datum of 1929

The USGS could not provide a conversion between the Kentucky River Datum and the Ohio River Datum. They did note that the correction would be variable for each lock and dam, since the Kentucky River Datum is different at each location.

The Corps of Engineers has published drawings of each lock & dam on the Ky River, illustrating plan and cross section views of the lock & dam structures. The dam crest elevations on these drawings use the Kentucky River Datum (KRD). Conversion from KRD to the National Geodetic Vertical Datum (NGVD) is possible through the use of a correction. The magnitude of the correction is different for each lock & dam, as the KRD is different at each location. Below is a list of the dam crest elevations for each lock in both KRD and NGVD, as well as, the correction to convert between them. Note that the exact value of each correction is not known. The corrections indicated below are only *approximations* supplied by the Corps representing their "best guess".

Location	Dam Crest (KRD)	Correction[1]
Lock & Dam # 14	637.60'	3.20'
Lock & Dam # 13	620.60'	2.70'
Lock & Dam # 12	602.60'	2.50'
Lock & Dam # 11	585.60'	2.55'
Lock & Dam # 10	567.60'	1.90'
Lock & Dam # 9	550.60'	2.00'
Lock & Dam # 8	533.26'	2.00'
Lock & Dam # 7	514.60'	1.53'
Lock & Dam # 6	499.30'	2.10'
Lock & Dam # 5	485.35'	1.81'
Lock & Dam # 4	470.35'	1.80'
Lock & Dam # 3	457.13'	2.80'
Lock & Dam # 2	443.97'	2.97'
Lock & Dam # 1	430.03'	2.36'

[1]KRD - Correction = NGVD

Review of information provided by Harza Engineers Inc., reveals that several of the dam crest elevations used in their analysis for the Steering Committee do not match those values quoted the Corps. The crest elevations offered by the Corps and those used in Harza's analysis are summarized in the table below.

Location	Dam Crest[2] (COE)	Dam Crest[2] (HARZA)
Lock & Dam # 14	634.40'	634.40'
Lock & Dam # 13	617.90'	617.90'
Lock & Dam # 12	600.10'	600.10'
Lock & Dam # 11	**583.10'**	**583.00'**
Lock & Dam # 10	565.70'	565.70'
Lock & Dam # 9	548.60'	548.60'
Lock & Dam # 8	**531.26'**	**531.20'**
Lock & Dam # 7	513.10'	513.10'
Lock & Dam # 6	**497.20'**	**497.30'**
Lock & Dam # 5	**483.54'**	**483.50'**
Lock & Dam # 4	**468.55'**	**468.50'**
Lock & Dam # 3	454.33'	N/A
Lock & Dam # 2	441.00'	N/A
Lock & Dam # 1	427.67'	N/A

[2]Dam crest listed are based on the NGDV of 1929.

Note: The ORD, KRD, and NGVD of 1929 are not the only datums that have been used on the Kentucky River. Others exist but do not appear in any of the data we have collected at this time.

Task1.E17