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Kentucky River Modeling and Monitoring Needs Assessment

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The Kentucky River Authority

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TABLE OF CONTENTS

List of Figures

List of Tables

responsibilities of the River Authority may be catalogued based on their associated function. These include water supply planning, water quality assessment/management, and operations. Normally, water supply planning activities will require long-term data; management and assessment, short-term data; and operational decisions, real-time data. Environmental monitoring activities can provide data serving several functions. Ongoing and proposed new monitoring efforts should be strategically coordinated to address a variety of assessment needs.

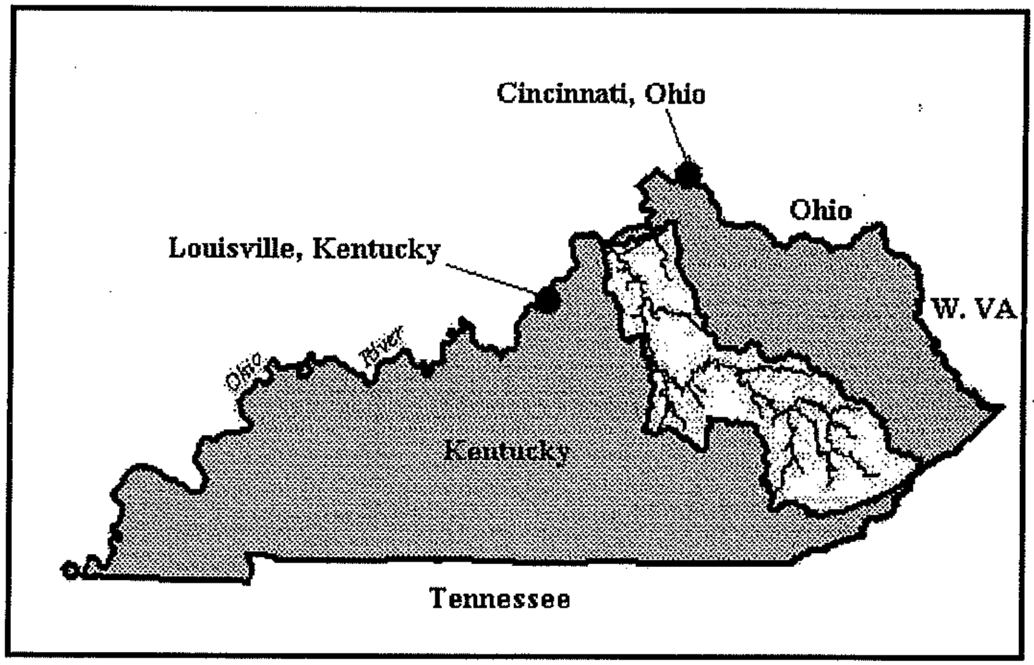

Figure 1. The Kentucky River Basin

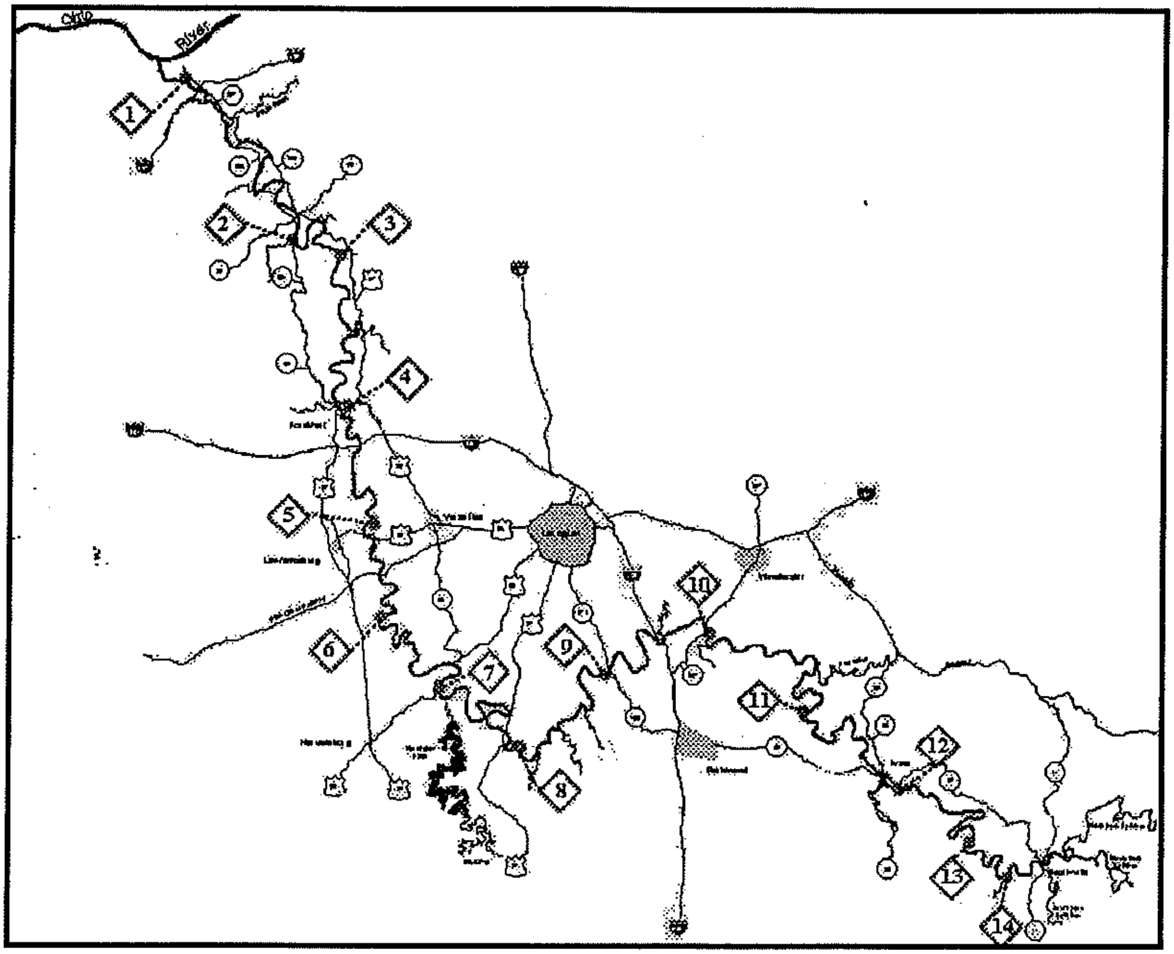

Figure 2. Locks and Dams on the Kentucky River
(http://www.state.ky.us/agencies/nrepc/kra/page1.htm)

1.2 Water Supply Planning Responsibilities

In April 1995, the Authority executed a contract with the University of Kentucky Water Resources Research Institute (KWRRI) to perform a water supply study of the river basin. Results of that study indicate that in the absence of any conservation and/or drought management plans, a water supply deficit of approximately 9.7 billion gallons could be expected to occur in 2020 if the 1930 drought of record were to re-occur under existing conditions. Of this amount approximately 60% of the deficit can be attributable to satisfying current Division of Water low flow requirements. When minimum flow requirements are not being met, fish will die from lack of oxygen, and health and odor problems will occur, because there will not be enough dilution and dispersal of impurities. The regulatory standard for maintaining low flow is based on a statistical calculation of the lowest recorded flow in the river for seven straight days in any 10-year period (i.e., the 7Q10). When permitted withdrawals and the water in the river together do not add up to the 7Q10, the Division of Water is empowered to begin cutting back on the withdrawal permit limits. It should be recognized that the 7Q10 value represents a regulatory numerical standard that is not based on the point at which dissolved oxygen and waste dispersal actually become a problem. Actual minimum flow requirements can be estimated for a site-specific area that may in fact be either higher or lower than the current 7Q10 value.

As a result of the 1995 Water Supply Study, it was determined that a majority of the projected deficits (i.e., 6.7 billion gallons) could be eliminated through the installation of low-level release valves in dams 4-14. Installation of such valves allows for the 7Q10 requirement to be met even when flows over the in-river dams drop below the associated minimum flow requirement, thereby allowing withdrawals from the upstream pools for water supply purposes.

Four primary water supply alternatives were evaluated for satisfying the remaining 3.0 billion-gallon deficit that occurred in pool 9. These included: 1) Installation of temporary crest gates on dams 9-14; 2) construction of a large dam on the Kentucky River, 3) construction of a smaller dam on a tributary to the Kentucky River, and 4) construction of a treated-water pipeline from Louisville to Lexington. Of the alternatives that were directly under its control, the Kentucky River Authority decided to pursue the temporary crest gate solution as the most viable and economically feasible alternative for augmenting water supply during a severe drought.

As a result of the potential construction of release valves and/or crest gates on pools 9-14, the Kentucky River Authority will have the capability to control releases on the river and thus in essence regulate the minimum low flows. To effectively manage such a system, it is imperative that the authority have some method to predict the associated water quality impacts. The Kentucky Division of Water currently collects both ambient and compliance-based water quality data in the basin that provides some information for management purposes. In addition, the Kentucky River basin was a pilot study site for the USGS National Water Quality Assessment (NAWQA) program (1986), and some initial baseline information has been developed and documented. Unfortunately, such information is generally insufficient to provide a basis for evaluating the impacts of short-term or real-time management decisions. One way to circumvent this data deficiency is through mathematical modeling.

To provide an initial assessment of the water quality impacts of potential operational policies for the Kentucky River, the Kentucky Water Resources Research Institute (1996) was contracted to develop a water quality model for the Kentucky River and perform an associated water quality study for the river basin. The developed computer model, KYQUAL (Ormsbee, et al., 1998) includes an EXCEL spreadsheet interface that is linked with the CE-QUAL-W2 water quality model. The purpose of the study was to assess the potential water quality impacts of various management strategies (e.g., valve operations) for the 1930 drought of record for projected water demands for the year 2020. Using valves in the 1930 simulation, water consumption from the pools is allowed to continue to levels below dam crest. This inherently effects the water quality of the pools. To predict the water quality impact associated with such operations, a mathematical model of the river was developed. Prior to an evaluation of the impacts of the management strategies, the developed model was first calibrated using data associated with the 1988 drought. Once the model was calibrated, it was used to evaluate the potential water quality impacts associated with augmenting 1930/2020 deficits through the use of low-level release valves. The results of this study indicate that the proposed valves can be used to draw down the individual pools on the Kentucky River a maximum of four feet without causing significant chronic or acute impacts to the biota of the river.

1.2.1 Planning Data

Data requirements for water supply planning include historical streamflow series, water demand records and associated forecasts, water quality data and operational guidelines. Much of this data has been previously collected and reported in the series of reports associated with the KWRRI water supply study (Ormsbee and Herman, 1996) and the water quality study (Ormsbee, et al., 1998). These data have been compiled and tabulated in various spreadsheets contained within the KYBASIN and KYQUAL computer models. Data for future planning can be readily obtained from the various sources identified in the models.

Additional data for long-term water quality assessments are available from historical assessment studies or from regulatory activities. These sources include the bi-annual Kentucky Rivers Assessment Reports (available from the Kentucky Division of Water), various assessment reports from the US Geological Survey, and the USGS National Water Quality Assessment (NAWQA) study. In the future, additional data will be available through various reports associated with the Kentucky Watershed Framework Initiative (DOW, 1997).

1.2.2 Planning Models

As discussed in the previous section, various computer models have been developed for use by the Kentucky River Authority in satisfying its planning responsibilities. These include KYBASIN and KYQUAL, which were both developed by the KWRRI. KYBASIN (Herman and Ormsbee, 1996) was developed for water supply planning and has been used by the River Authority to develop a proposed valve operational plan for the river (Grier, 1998). KYQUAL (Ormsbee, et al., 1998) was developed for water quality assessment and has been used to evaluate the water quality impacts associated with valve operations for the 1930 design drought. While these models have provided the River Authority with a basis for evaluating general operational plans, they do not provide the River Authority with the capability to evaluate watershed management strategies, nor do they provide the River Authority with the capability to evaluate real-time impacts associated with the operation of the low-level release valves and/or temporary crest gates. To satisfy these objectives, additional models are needed.

1.3 Operation Responsibilities

Currently, low-level release valves are installed in dams 11-14. Flows through dam 10 and dams 8-4 can be regulated using existing gate valves in the associated locks. To transfer flows past dam 9, a pump is needed. As a result, the Kentucky River Authority now has the capacity to maintain the 7Q10 flows on the river through the operation of these valves and associated hydraulic structures. In addition, the Authority has considered the installation of temporary crest gates on dams 9 and/or 10. The optimal operation of these facilities will depend on the ability of the KRA to monitor and predict low flows on the river as well as to predict potential water quantity and water quality impacts. In addition to potential impacts on the river biota, the water quality can also directly impact the operational cost and efficiency of those water treatment facilities that use the Kentucky River as a water supply source.

1.3.1 Operational Data Availability

Real-time data (both water quantity and water quality) are needed to support operational decisions associated with the operation of the proposed low-level release valves on the Kentucky River. Such data are needed to identify low-flow trigger events and to evaluate the associated water quality impacts. This objective may be accomplished directly using comprehensive monitoring data, or indirectly using limited monitoring data along with mathematical models. Additional real-time data will be necessary to coordinate the raising or lowering of potential temporary crest gates on either dam 9 or 10.

Real-time streamflow data are readily available from the USGS for selected stations in the Kentucky River Basin. This data may be currently accessed via the internet through the Kentucky River Authority's Web page: http://www.state.ky.us/agencies/nrepc/kra/page1.htm. A list of the available stations is provided in Table 1, while the location of the various stations is shown in Figure 3. Real-time rainfall data are also readily available from NOAA for selected stations within the Kentucky River Basin. This data may also be accessed from the KRA Web page. This data is associated with the NOAA Automated Flood Warning System (AFWS), which is concentrated in counties in eastern Kentucky. A list of the stations is provided in Table 2, while the locations of the various rainfall stations are shown in Figure 4. Additional hourly rainfall data and meteorological data (e.g., cloud cover, dewpoint temperature, solar radiation, wind speed, and wind direction) for use in calibrating any sophisticated water quality model (i.e., HSPF) can be obtained from the several regional National Weather Service meteorological stations located within or adjacent to the basin (see Table 3 and Figure 4 and web address: http://wwwagwx.ca.uky.edu/). Both types of data will be needed to run any real-time operations model associated with the Kentucky River.

Table 2. List of NOAA Real – Time Rainfall Stations

County	AFWS Gaging Station #	County	AFWS Gaging Station #
Breathitt	3135	Knox	3155
	3137	Letcher	3165
	3138		3163
	3139		3164
	3134		3162
	3132	Owsley	3166
Clay	3187		3052
	3186		3053
Estill	3010		3054
Franklin	3092	Perry	3167
Harlan	3141		3176
Jackson	3021		3168
Lee	3023		3169
	3024	Powell	3056
	3025		3057
	3026		3059
Leslie	3184		3055
	3185	Wolfe	3068
	3181		3069
	3182		3070
	3183		3067

Table 3. List of Meteorological Stations

Location
Greater Cincinnati Airport
Lexington Bluegrass Airport
Morehead State University
Jackson Airport

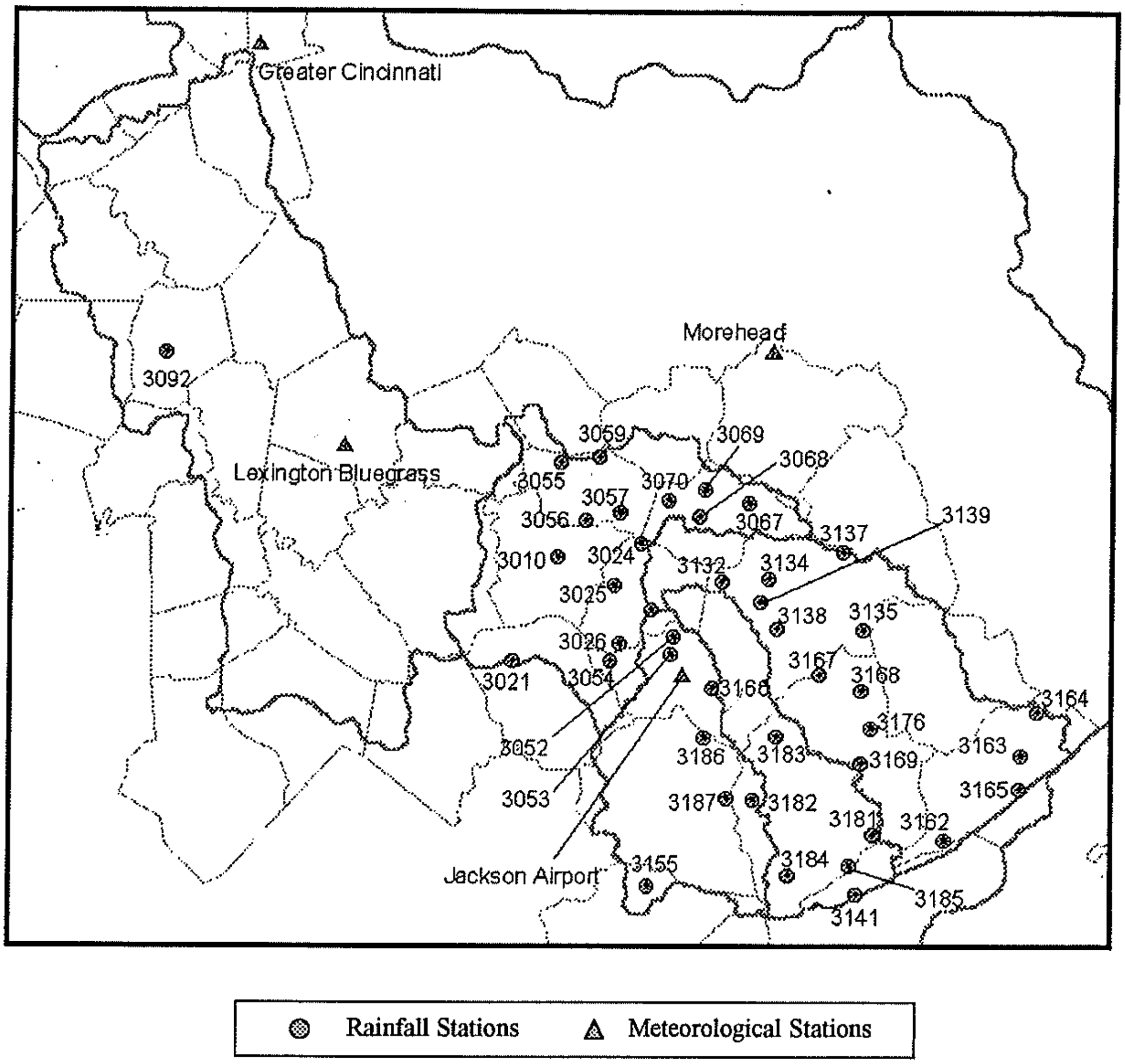

Figure 4. Location of NOAA Stations

1.3.2 Operational Models

To evaluate the impacts of real-time operational decisions on the Kentucky River, some type of real-time operational model is needed. Although KYBASIN and KYQUAL were primarily developed for use in planning studies and for developing general operational guidelines, components of both models can be combined to provide a real-time model. Flow and water quality boundary conditions for such a model would require an extensive real-time monitoring network. Part of the flow data can be readily obtained using the existing USGS streamflow network. Unfortunately, the reliability of this data significantly decreases as the flows approach those values associated with drought events. As a result, additional hardware will be needed at these sites to provide reliable low-flow estimates needed to evaluate drought management policies.

A real-time water quality network does not exist for the Kentucky River. Although existing deficiencies in both water quantity and water quality boundary condition data can be supplemented using estimated values through model simulation, (e.g., HSPF) such an approach will require additional real-time weather data (e.g., rainfall, air temperature, cloud cover, dewpoint temperature, solar radiation, and wind speed and direction) as well as general watershed data (e.g., soil, land use). Fortunately, much of this data is readily available for the basin.

1.4 Management Responsibilities

As a partner in the Kentucky Watershed Framework Initiative and as the lead agency in the Kentucky River Basin, the Kentucky River Authority has accepted the responsibility to help coordinate watershed management activities within the basin. The ultimate objective of this process is to improve and protect the water quantity/quality resources of the basin through the development and implementation of site-specific management plans tailored to local stakeholder interests, resources and needs. Specific activities include data scoping and collection, assessment, prioritization and targeting, watershed plan development and implementation. To successfully fulfill this responsibility, it is important that the River Authority have adequate assessment tools for use in identifying environmental trends and making responsible management decisions. One way to augment such data is using a watershed management model.

1.4.1 Management Models

To develop and evaluate various watershed management plans within the Kentucky River Basin, some type of continuous watershed simulation model is needed. Various watershed models have been developed for use in watershed management. In a 1989 study, El-Kai (1989) evaluated over 30 such watershed models for use in such applications. Of these models, four have the potential for use in comprehensive watershed modeling. These include the Agricultural Non-Point Source Model (AGNPS), the Hydrologic Simulation Program - FORTRAN (HSPF), the Soil and Water Assessment Tool (SWAT), and Better Assessment Science Integrating Point and Nonpoint Sources (BASINS). AGNPS was developed by the Agricultural Research Service (Young, et al., 1989) and has the capability to simulate soil erosion, nutrient (nitrogen and phosphorus) transport, and chemical oxygen demand in an agricultural watershed. The main drawback of the model for the proposed application is that is limited to event-based applications. SWAT was also developed by the ARS (Arnold, et al., 1996) and is a vector-based, continuous simulation model that operates on a daily time step. The model was originally designed to model the water management, sediment, and agricultural chemical yields in large ungaged watersheds. HSPF is a continuous watershed model, with the ability to simulated water quantity and water quality aspects (Bicknell, et al., 1993). A comparison of both SWAT and HSPF for use in modeling the Kentucky River Basin (Bishoff, et al., 1997) concluded that SWAT was much easier to apply, although HSPF was more robust and provided greater modeling capabilities, especially for the types of watersheds encountered in the Kentucky River Basin.

Recently, the applicability of the HSPF model was greatly enhanced through the development of the BASINS modeling environment. BASINS was recently released by the Environmental Protection Agency (1998), which has made a commitment to support the use of the model for national applications in watershed management and TMDL development. BASINS runs through an Arcview3 model interface, which allows BASINS to use various GIS coverages for data file construction and subsequent model parameter selection. The environment greatly enhances the capabilities of the underlying watershed model (i.e., HSPF) and allows for inclusion of point source impacts. BASINS is highly recommended for use by the Kentucky River Authority in fulfilling its watershed management responsibilities.

1.4.2 Management Data Availability

Short-term water quantity data (both rainfall and streamflow) are available from selected stations from both the NWS and the USGS through their annual publications. Additional meteorological data (e.g., cloud cover, dewpoint temperature, solar radiation, wind speed, and wind direction) for use in calibrating any sophisticated water quality model (i.e., HSPF) can be obtained from the National Weather Service (via the National Oceanic and Atmospheric Association). Short-term water quality data (both chemical and biological) are available from ongoing ambient and compliance monitoring activities associated with the Kentucky Division of Water and other state and Federal agencies (e.g., US Fish and Wildlife Service). A list of the Division of Water ambient water quality stations is provided in Table 4 and illustrated in Figure 5 (website: http://nrweb1.nr.state.ky.us/nrgis/kyrivbase2.html). In addition, as part of the Kentucky Watershed Framework Initiative, the state has agreed to place two additional water quality monitoring stations on the mainstem of the Kentucky River. Such data are useful for making short-term assessments, identifying specific problem areas and for use in calibrating and applying hydrologic/water quality models (e.g., HSPF) for use in evaluating possible management strategies.

Table 4. List of Existing Water Quality Stations

NAME	SAMPLER	MAP NUMBER
KY Riv, Benson -Eagle	DOW	1
KY Riv, Benson-Lock 8	DOW	2
Silver Cr	DOW	3
Elkhorn Cr	DOW	4
Dix Riv 9	DOW	5
Red River 3	DOW	6
Red River 9	DOW	7
Troublesome Cr 3	DOW	8
N Fk KY Riv	DOW	9
Middle Fk KY Riv	DOW	10
S Fk KY Riv	DOW	11
Red Bird Riv	DOW	12
Goose Cr	DOW	13
Middle Fk KY Riv	DOW	14
Rockhouse Cr	DOW	15
Leatherwood Cr	DOW	16
Maces Cr	DOW	17
Quicksand Cr	DOW	18
Red River 8	DOW	19
Sturgeon Cr	DOW	20
Middle Fk KY Riv	DOW	21
Millers Cr	DOW	22
Hardwick Cr	DOW	23

streamflow gaging network is sufficient to provide a general characterization of flows in the basin, it is not adequate to provide a highly reliable basis on which to base operational decisions associated with each pool. Additional reliability will be achieved through the addition of more stations. A list of the potential stations listed in order of importance is provided in Table 5 and illustrated in Figure 6.

Currently, there exist no real-time water quality stations within the Kentucky River Basin. To evaluate the real-time impacts of operational decisions some kind of real-time monitoring network is needed for the main-stem of the Kentucky River. A list of the potential stations listed in order of importance is provided in Table 6 and illustrated in Figure 7. To permit an adequate water quality characterization, it is recommended that continuous water quality recorders be used instead of coordinated grab samples.

As an alternative to additional real-time streamflow gaging stations, real-time streamflows and associated water quality loadings and impacts can be approximated using a calibrated watershed model (e.g., HSPF) along with real-time rainfall data. Precipitation is the driving force behind most hydrologic processes occurring in a watershed, such as runoff production, flooding, erosion, pollutant transport, etc. (Bras and Rodriguez-Iturbe, 1993; Dunne and Black, 1970). This information is best collected at hourly intervals or less (Chew, et al., 1991). In urban areas, it is critical to have 5 to 15 minute rainfall data when modeling rainfall-runoff in smaller basins (Jarrett, 1998). Real-time data associated with the current NWS AFWS rainfall network (see Figure 4) should provided sufficient rainfall gage coverage for those subbasins located in the headwaters of the Kentucky River. To forecast hydrologic conditions in the central and lower basin, additional stations would be highly desired. A list of potential stations listed in order of importance is provided in Table 7 and illustrated in Figure 8.

1.5.2 Management Model Needs

Successful watershed management requires both long-term ambient monitoring and short-term intensive monitoring. Long-term ambient monitoring will be required at strategically located sites for documenting trends, identifying problems, providing inputs for modeling efforts, and evaluating effectiveness of management controls on water quality and quantity. Intensive short-term monitoring can be used to locate and quantify pollutant sources, measure the effect and fate of pollutants, and characterize the extent of environmental contamination in relation to specific activities or particular land use. Although long-term and short-term water quality monitoring are useful for assessment purposes, they cannot be readily used to predict the impacts of associated management strategies. For that task, some type of watershed management model is required.

Data requirements for development of a watershed management model for the Kentucky River include hourly rainfall data from distributed gaging stations located across the basin, continuous streamflow records at selected stations, and associated water quality data. The current distributions of rainfall stations associated with the NWS

AFWS system along with additional NWS hourly stations (see Figure 4 and 8) should be sufficient to allow for adequate model calibration for the 11-digit HUC basins located within the Kentucky River Basin. Continuous streamflow at selected stations is necessary for both operation and management. River and river basin management models capable of predicting the effects of changing flow volumes and the influence of pollutant inputs to the watershed and river system must function in near continuous time (James, 1994). To do this these models must make some basic assumptions regarding how water and pollutants move and change within the river/river basin system. The only way to successfully adjust and test these assumptions (calibration and confirmation) is to match the model output (predictions), usually in hourly or daily time-steps, with continuously observed information (monitoring data) (James and Burges, 1982; and James, 1994). The existing USGS streamflow station network within the basin is sufficient to calibrate HSPF for 8-digit basins. The network is insufficient to accurately calibrate the model for each 11-digit HUC basin. Although, some parameter values from the 8-digit basin calibrations may be transferable to the smaller basins many will not be and many basin types are not characterized by the present network. For example, the Jefferson County Metropolitan Sewer District (MSD) has decided that eight streamflow stations is inadequate to characterize the flow in the 11-digit HUC basins in that county (Jarrett, et al., 1998). Consequently, they augmented that network to include 20 streamflow gauges. Ideally, the existing streamflow network in the Kentucky River Basin should be augmented with additional stations. A list of potential streamflow stations listed in the order of importance is provided in Table 5 and illustrated in Figure 6. In addition to these stations, an additional gaging station on Eagle Creek would also be highly desirable.

Although much water quality data exists for the Kentucky River Basin, the majority of the data is based on point or synoptic samples that do not reflect continuous fluctuations over time or temporal variations associated with a particular storm/flood event. A list of the major ambient water quality stations located within the basin has been provided in Table 4 and illustrated in Figure 5. While some level of water quality calibration can be achieved with such data, data from continuous recorders is much more useful for developing accurately calibrated models. In addition to the water quality stations proposed for the main-stem of the Kentucky River, additional monitoring stations are proposed for selected tributaries of the river. Such stations are needed to develop more accurate loading functions for the operational model as well as providing a basis for calibrating watershed management models. In addition, such models can be used to assess the impacts of proposed watershed management strategies. A list of desirable stations listed in the order of importance is provided in Table 8 and illustrated in Figure 9.

A successful watershed management strategy must consider the complex interactions of landuse, meteorology, geology, soils, vegetation, and groundwater as well as instream processes and characteristics (Eagleson, 1978; Jakeman, et al., 1992). Hydrologic data requirements for a watershed management model of the Kentucky River include spatially distributed information on all of the above attributes (Bhaskar, et al., 1992). Characteristics such as geology, soils, vegetation, and deep groundwater usually vary slowly through time and thus the time intervals for data collection can be months years or decades. Other characteristics such as precipitation, streamflow, and many aspects of water quality vary continuously (Chapra, 1997; Brezonik, 1994; Leopold, 1973). Consequently, data collection should be at an interval adequate to assess the salient features of the particular characteristic (Loftis and Ward, 1980; Ward, et al., 1979).

1.6 Conclusions and Recommendations

This report has identified three basic responsibilities of the Kentucky River Authority as they relate to specific monitoring needs. These responsibilities are planning, operations, and management. With regard to each responsibility, the report has characterized all data currently available for use in supporting these functions. Such data have included streamflow data, rainfall data, and water quality data. Based on an inventory of existing data, an attempt has been made to identify additional data needs in support of these functions. As a final guide for use in satisfying these needs, a composite prioritization of the proposed monitoring stations for both operations and management purposes is provided in Table 9 and 10 and Figures 10 and 11. These tables provide potential roadmaps for use in implementing a comprehensive monitoring network for the Kentucky River Basin. By developing and implementing such a network, additional data can be collected on a continuing basis so as to provide a framework from which the Kentucky River Authority can make informed and scientifically-based management decisions.

Table 5. List of Potential Real-Time Streamflow Stations

Gaging Station Location	Priority
Dam 9	1
Dam 8	2
Dam 11	3
Dam 12	4
Dam 13	5
Dam 5	6
Dam 3	7

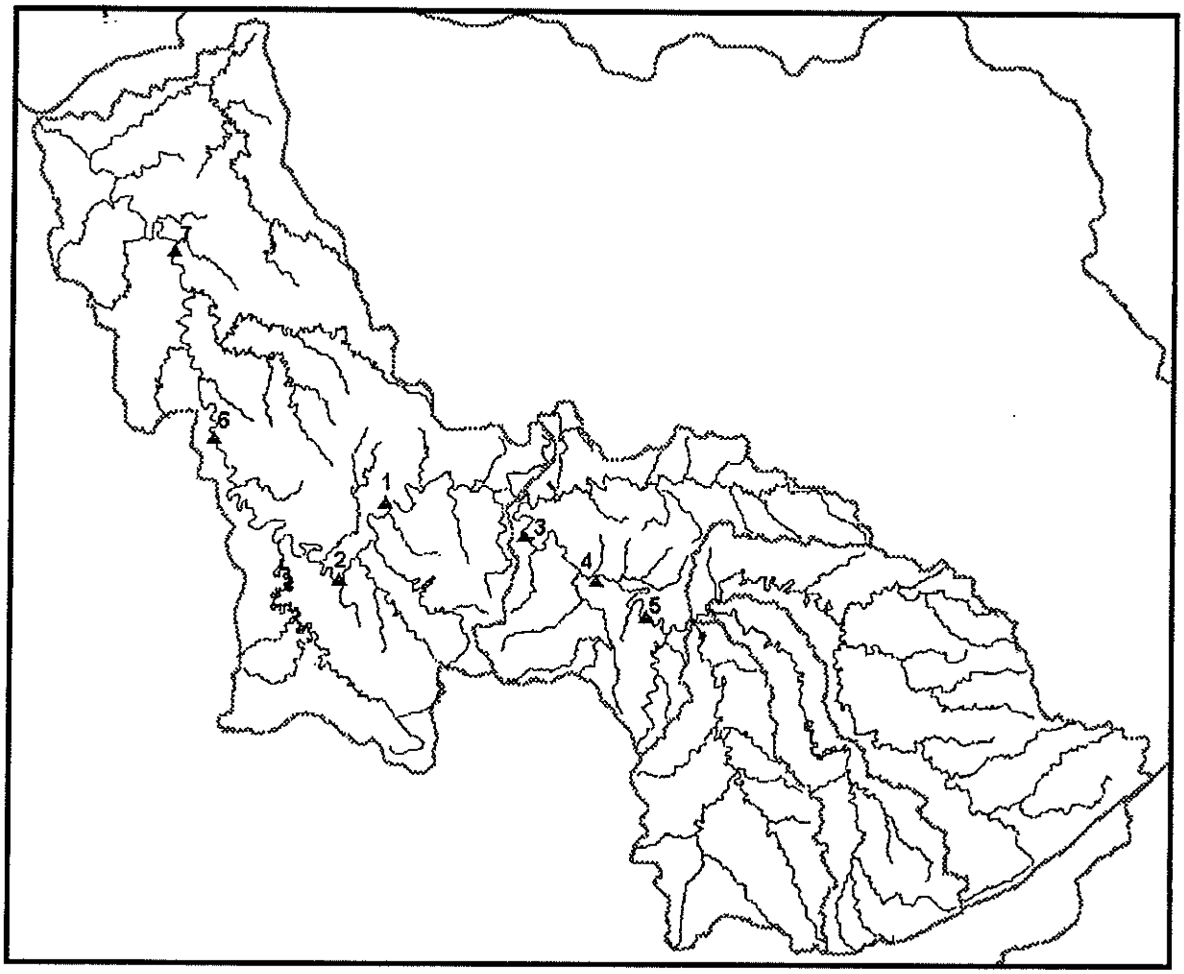

Figure 6. Location of Potential Real-Time Streamflow Stations

Table 6. List of Potential Real-Time Water Quality Stations

Location	Priority
Pool 9	1
Pool 8	2
Pool 4	3
Pool 14	4
Pool 10	5
Pool 11	6
Pool 3	7

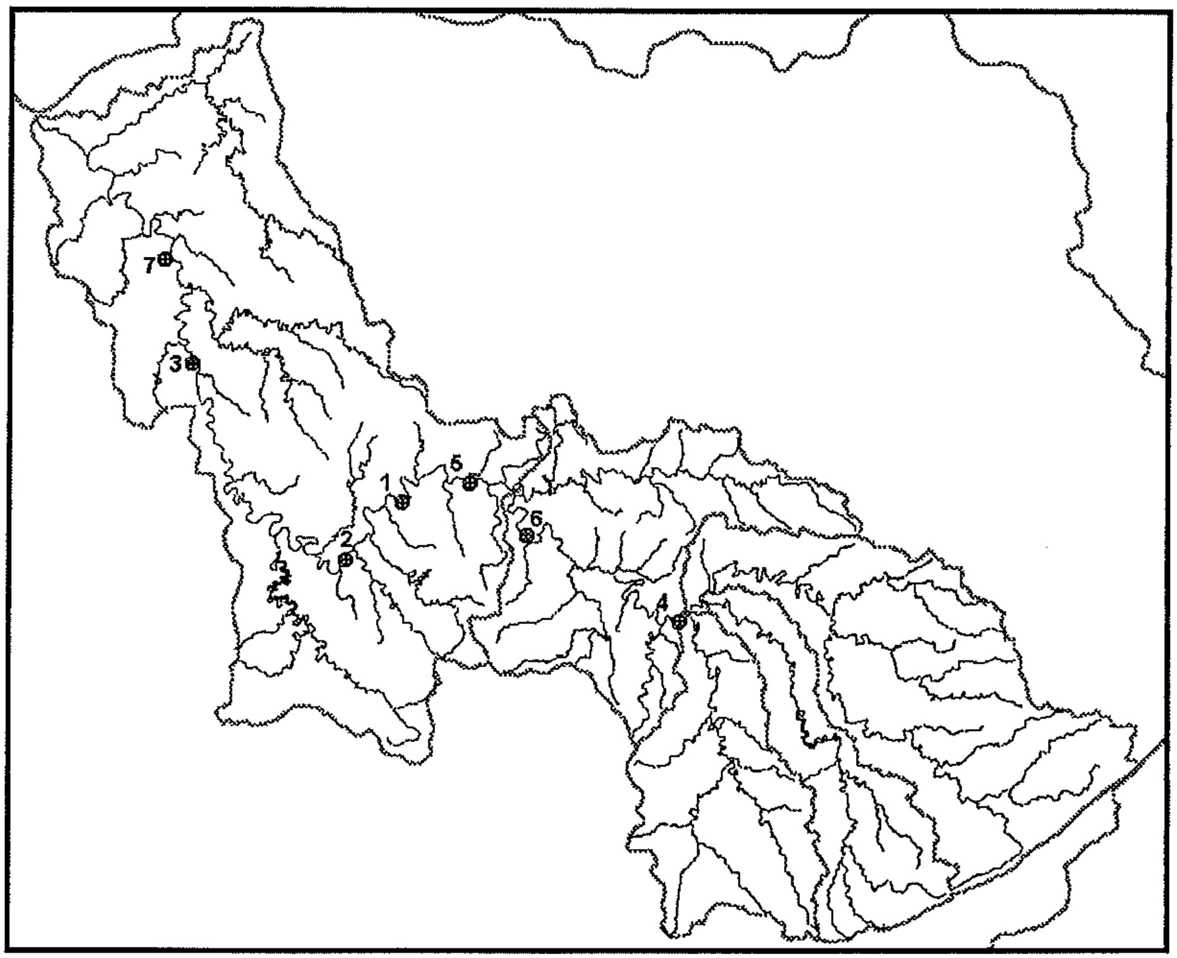

Figure 7. Location of Potential Real-Time Mainstem Water Quality Stations

Table 8. List of Potential Real-Time Tributary Water Quality Stations

Location	Priority
Red River @ Pool 10	1
North Fork KY River	2
Middle Fork KY River	3
South Fork KY River	4
Otter Cr @ Pool 10	5
Dix River @ Pool 7	6
Elk Horn Cr @ Pool 3	7
Eagle Cr @ Pool 2	8

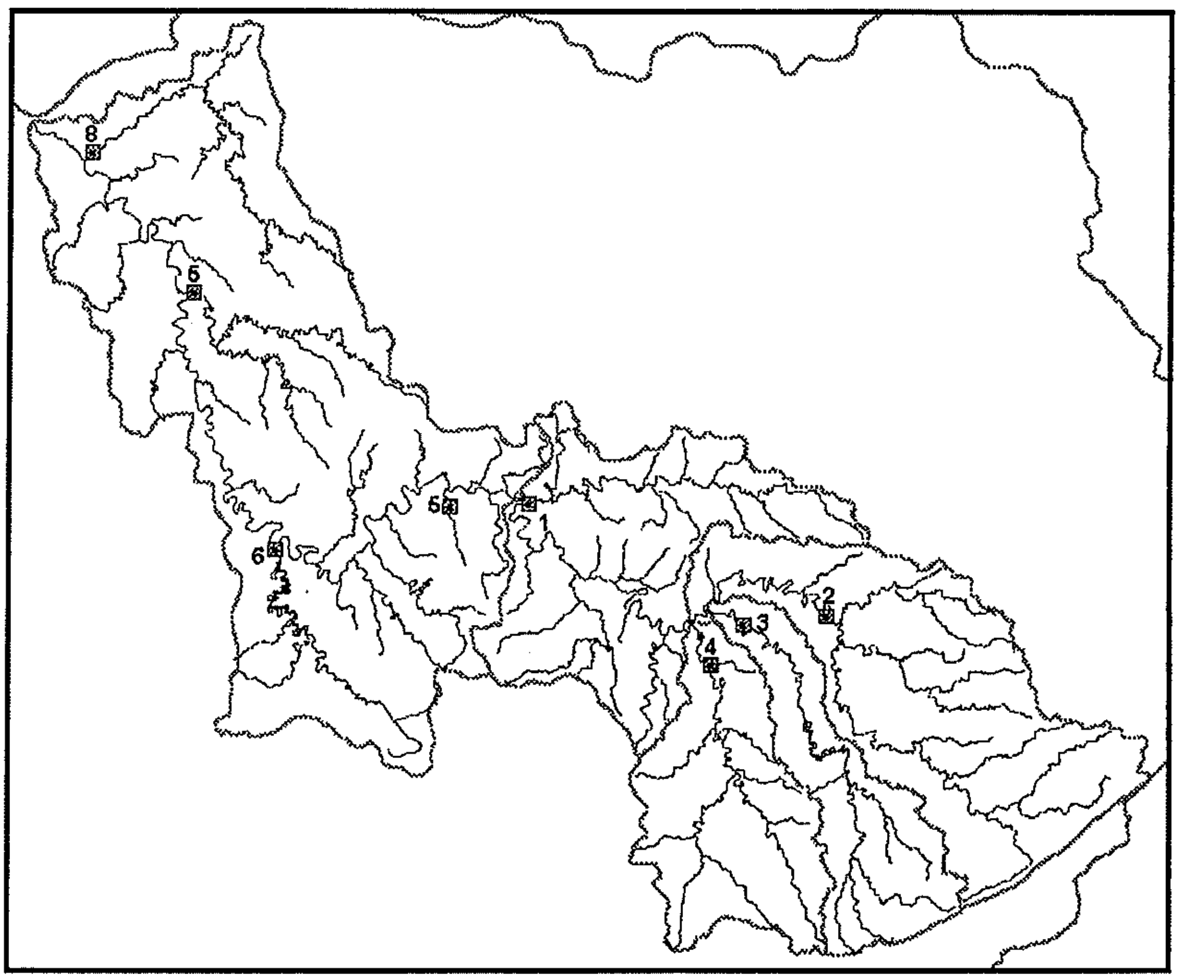

Figure 9. Location of Potential Real-Time Tributary Water Quality Stations

Table 9. List of Prioritized Monitoring Stations for Operations

Priority	Station Type	Station Name / Location	Primary Function
1	Flowrate	Dam 9	Operations
2	Water Quality	Pool 9	Operations
3	Flowrate	Dam 8	Operations
4	Water Quality	Pool 8	Operations
5	Water Quality	Pool 4	Operations
6	Water Quality	Pool 14	Operations
7	Flowrate	Dam 11	Operations
8	Flowrate	Dam 12	Operations
9	Flowrate	Dam 13	Operations
10	Water Quality	Pool 10	Operations
11	Water Quality	Pool 11	Operations
12	Flowrate	Dam 3	Operations
13	Water Quality	Pool 3	Operations
14	Flowrate	Dam 5	Operations

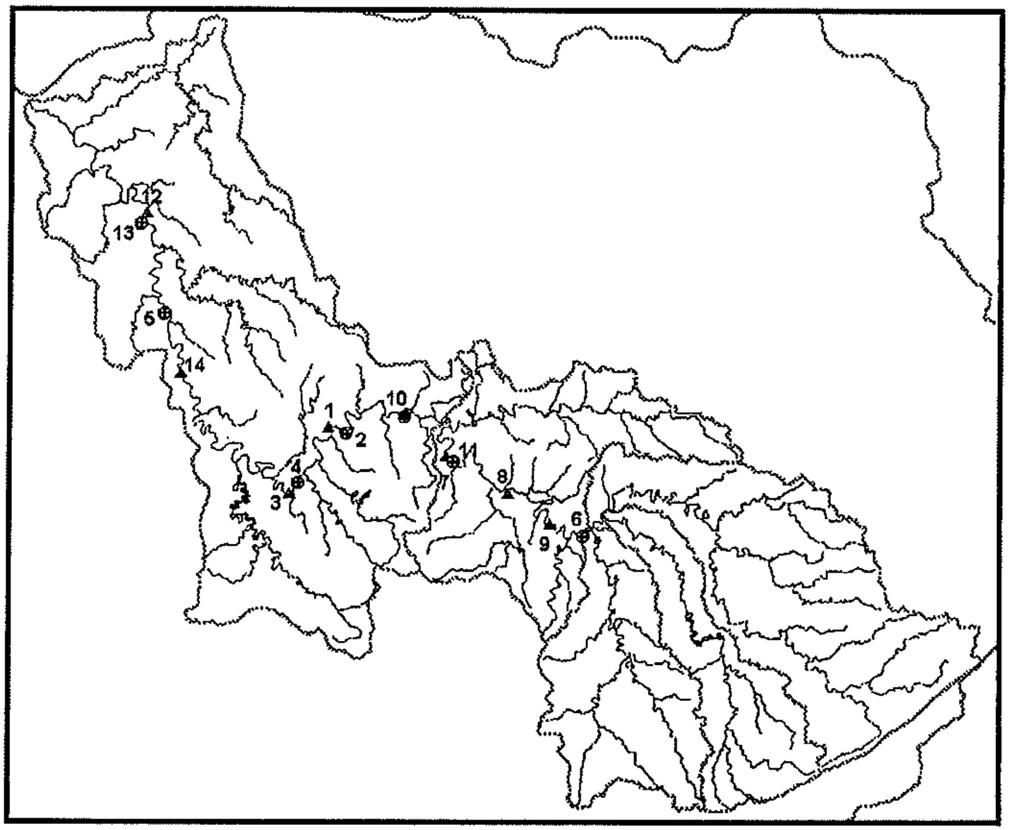

Figure 10. Location of Prioritized Monitoring Stations for Operations

Table 10. List of Prioritized Monitoring Stations for Management

Priority	Station Type	Station Name / Location	Primary Function
1	Rainfall	Richmond	Management
2	Water Quality	Red River	Management
3	Water Quality	North Fork	Management
4	Water Quality	Middle Fork	Management
5	Water Quality	South Fork	Management
6	Rainfall	Georgetown	Management
7	Water Quality	Otter Creek	Management
8	Water Quality	Dix River	Management
9	Water Quality	Elkhorn Creek	Management
10	Water Quality	Eagle Creek	Management
11	Rainfall	Owenton	Management

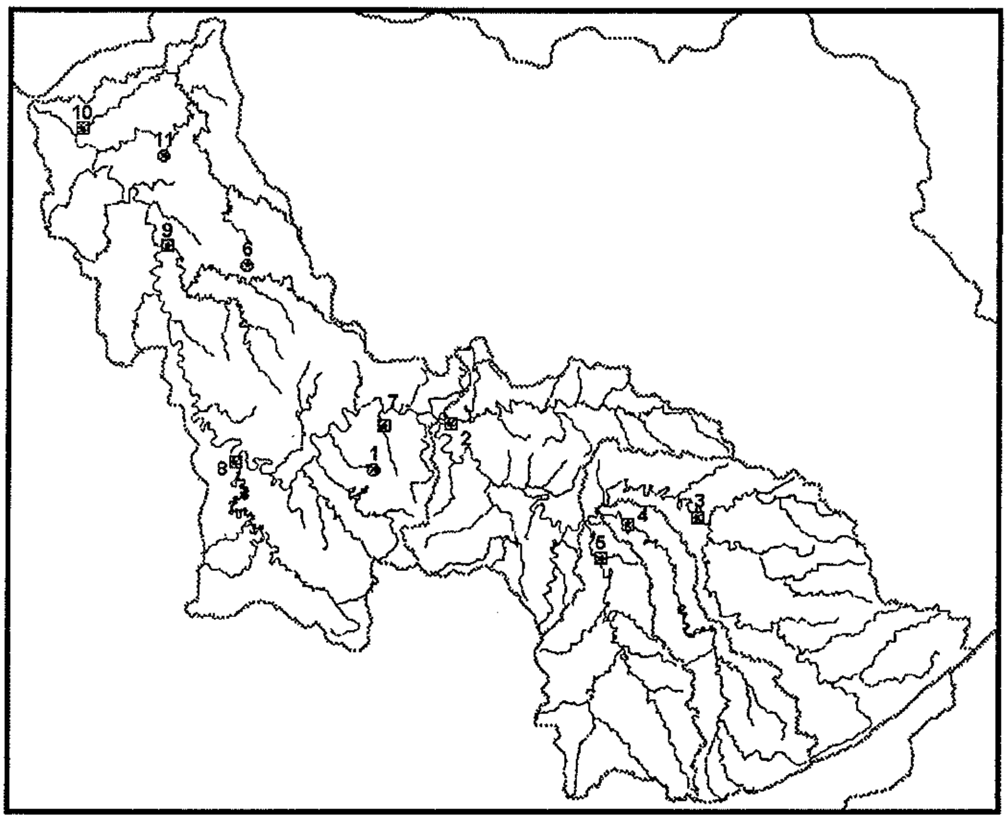

Figure 11. Location of Prioritized Monitoring Stations for Management

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