Water & Sewer Authority
of Cabarrus County

WSACC

Safe Yield Update and Regional Drought Operations Plan

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Prepared by:

BLACK & VEATCH

Black & Veatch International Company

Safe Yield Update and Regional Drought Operations

The water sources within Cabarrus and Rowan Counties which serve the entities in Cabarrus County include Lake Howell, Kannapolis Lake, Lake Concord, Lake Fisher, and Black Run Reservoir. The existing service areas of each entity and the location of the lakes are show in Figure 1.

1.0 Safe Yield Update

The severity of the recent drought has resulted in record low stream flows, low reservoir levels, emergency water supplies from sources outside Cabarrus County, and extended mandatory water restrictions. Using the mass-balance model to simulate reservoir operations, it can be shown that the recent drought (1998-2002) was the most severe in the last 103 years of record with respect to reservoir yield and reliability. To quantify the effects of the recent drought, it was necessary to update the mass-balance models. The update includes the new drought of record for the four major water supply reservoirs serving Cabarrus County: Lake Howell, Kannapolis Lake, Lake Fisher, and Lake Concord. In addition, the collection of bathymetric information for these reservoirs coupled with a better representation of the inflows to the reservoirs needed to be incorporated into the safe yield calculations.

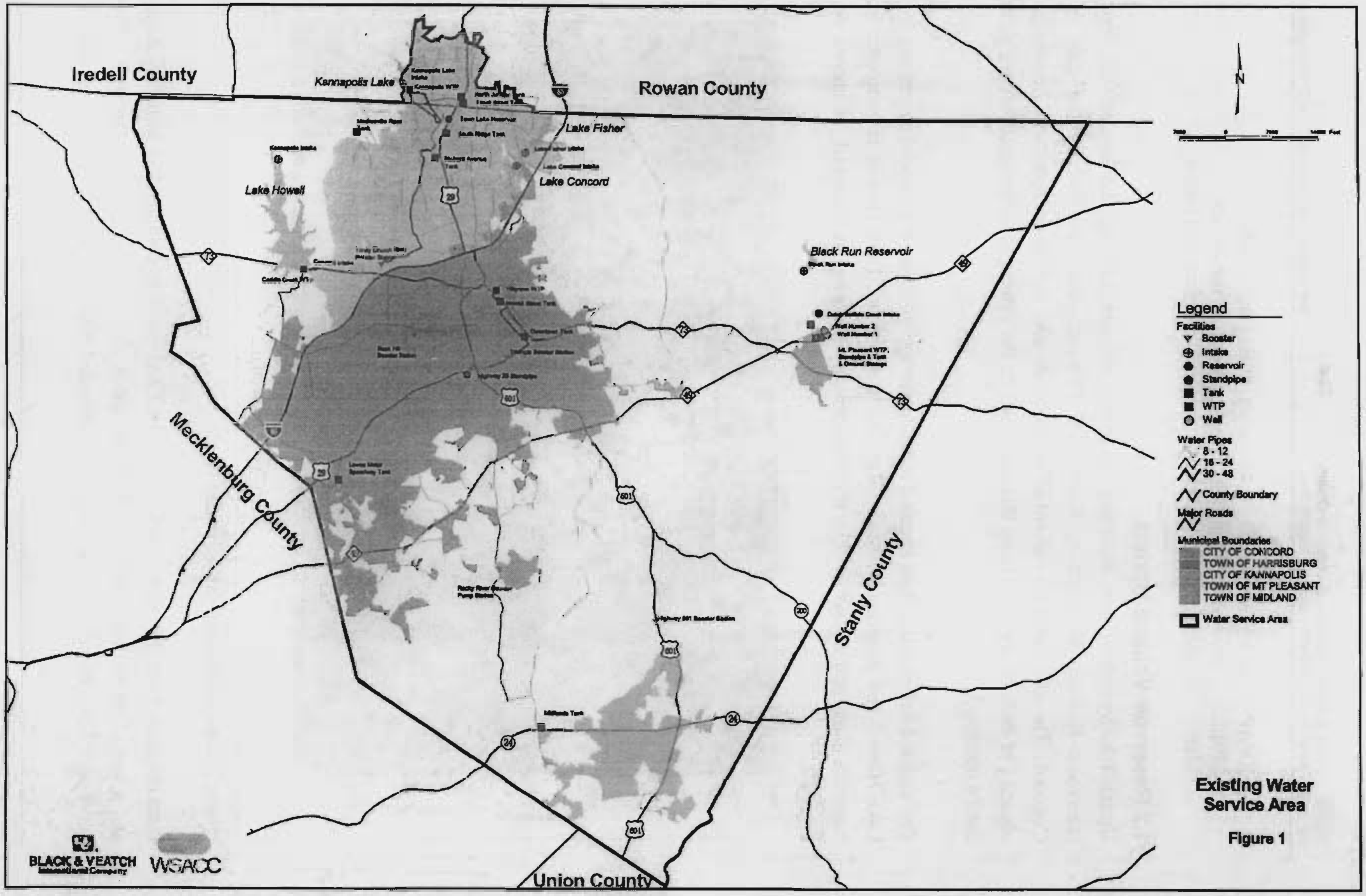
1.1 Mass-Balance Model Approach

The model used to analyze the reservoirs calculates the average annual yield for the reservoir based on constant demands imposed on simulated historical hydrologic data and current reservoir geometry. Yield is determined by solution of a water balance equation using an iterative approach. Solution of the water balance equation occurs when the difference in reservoir inflow and outflow equals the change in reservoir storage volume. Model inflows include precipitation and stream flow into the reservoir. Outflows include evaporation, user demands, spillway overflows, and downstream releases. The following water balance equation is used in the reservoir yield model:

$$VOL_1 = [VOL_0 + INFLOW + PRECIP] - [YIELD + EVAP + SPILL + MIF]$$

The variables in the equation are defined as:

VOL_1	= reservoir volume at the end of the month.
VOL_0	= reservoir volume at the beginning of the month.
INFLOW	= volume of inflow during the month.
PRECIP	= volume of precipitation on reservoir during the month.
YIELD	= average volume of yield during the month.



Existing Water Service Area

Figure 1

EVAP = volume of lake evaporation during the month.
SPILL = volume of spillway overflows during the month.
MIF = minimum release downstream of the dam and intake

1.2 Reservoir Volume Update

Updated bathymetric data including elevation, storage and surface area of the four reservoirs--Howell, Kannapolis, Fisher and Concord--was provided by the City of Concord. The data provides current information on lake bottom contours and the storage capacity of each reservoir. Using this information, the effects of sedimentation over time can be observed.

The updated bathymetric data showed reduced storage volumes at full-pool elevations for Lake Howell and Kannapolis Lake. The recent survey of Lake Howell is compared to historical data, and a loss of 734 million gallons of storage is observed, as shown on Figure 2.

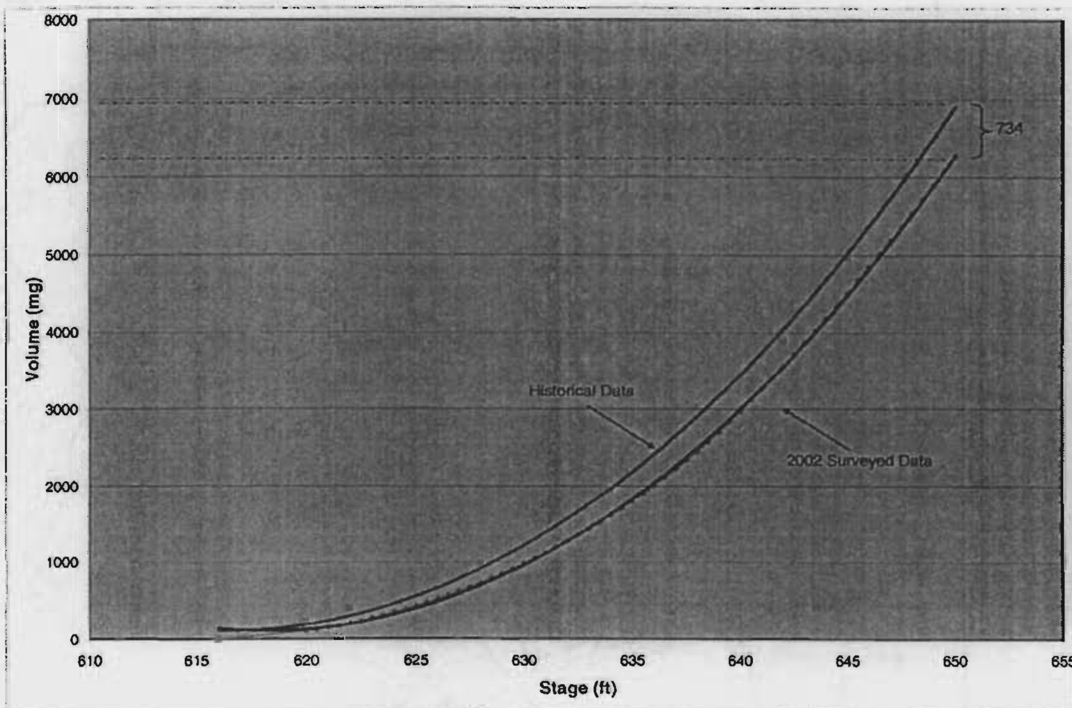


Figure 2. Lake Howell stage-storage volume update

Data obtained from the recent survey of Lake Kannapolis is compared to historical data, and a loss of 94 million gallons of total storage is observed, as shown in Figure 3. The surveys of Lake Fisher and Lake Concord provided information that was not previously available. The current relationship between water surface elevation (stage) and storage is shown for Lakes Fisher and Concord in Figures 4 and 5, respectively.

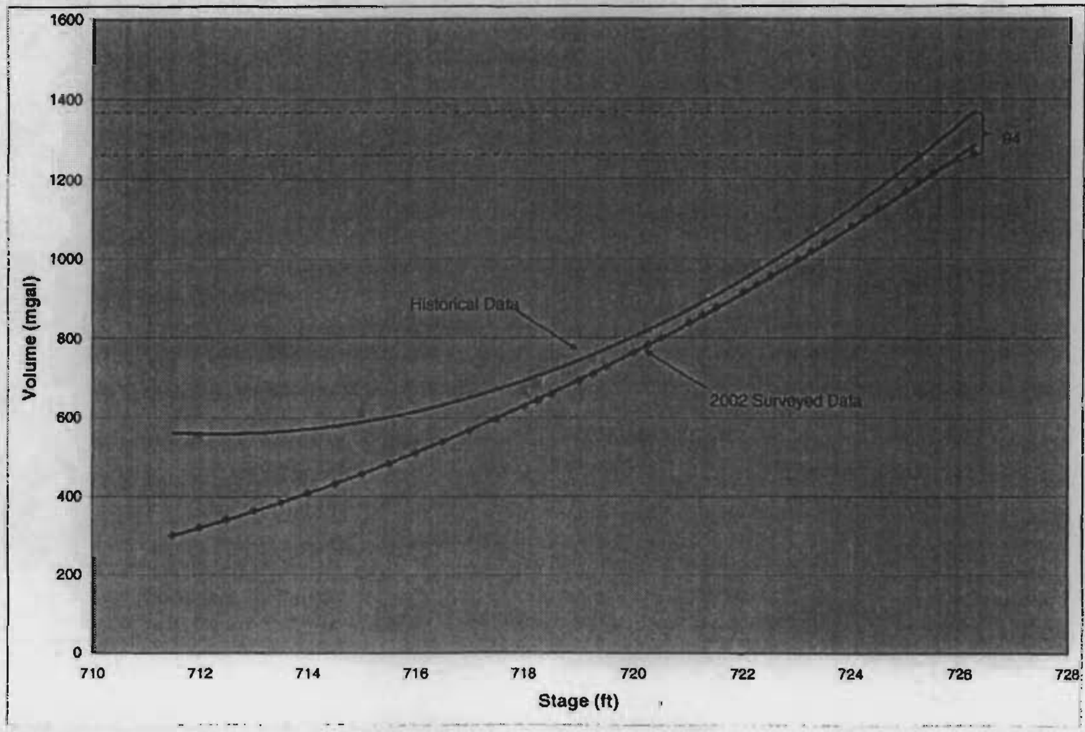


Figure 3. Kannapolis Lake stage-storage volume update

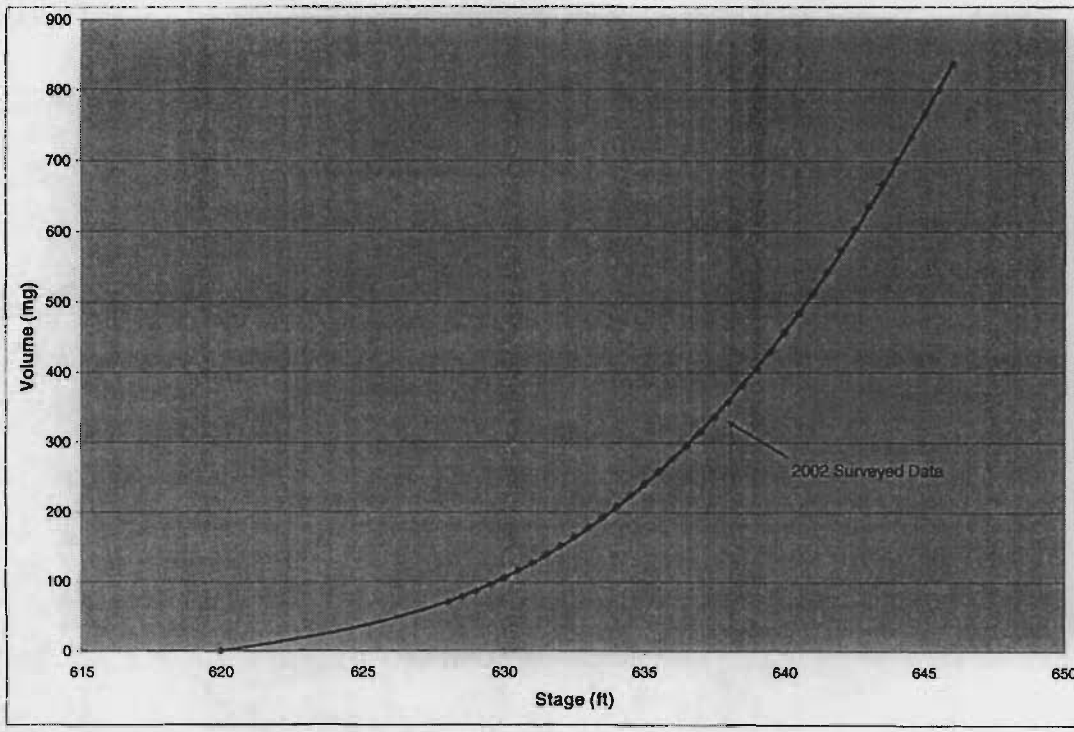


Figure 4. Lake Fisher stage-storage relationship

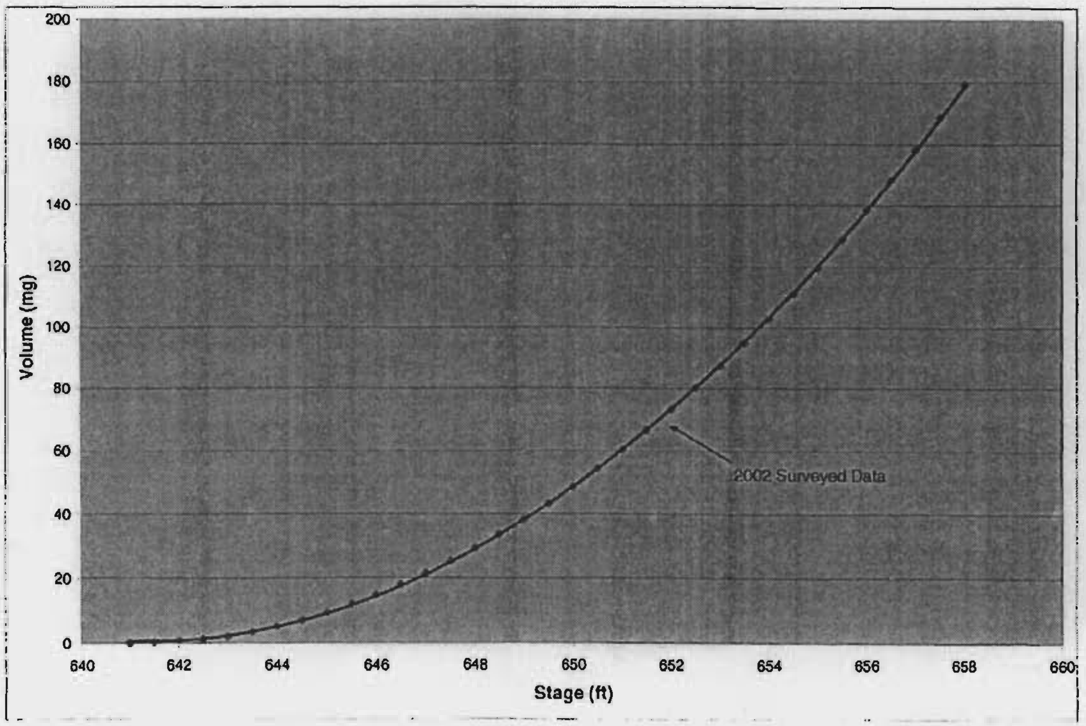


Figure 5. Lake Concord stage-storage relationship

1.3 Stream Flow Evaluation

The simulated stream flow record was extended to incorporate flow data through February 28, 2003. Some of the lowest stream flows of record were observed in August and September of 2002. Therefore, the gage weighting factors used to simulate the stream flow record were recalculated to account for the new data.

To evaluate the level of accuracy of the simulated flow record for Lake Howell, it was compared to USGS flow measurements collected over the last two years in the three streams feeding Lake Howell. The gage weighting factors used to simulate the stream flow record are heavily weighted toward Second Creek values. Therefore, the stream flow record for Second Creek (adjusted to size) was compared to the USGS field-measured data to assess its accuracy of stream flow prediction.

The USGS field data was collected over the period from January 2001 to September 2002. The sum of the three stream flow values from the tributaries provided the value used to represent total inflow into Lake Howell.

A common flow basis is needed for determination of flow accuracy. Accordingly, Second Creek gauged values were adjusted, based on drainage area ratio, for direct comparison to Lake Howell inflows. For the days on which the USGS collected Lake Howell inflow data, the actual measurements were compared to adjusted Second Creek flows, and to the synthesized flow record previously used in the safe yield model (also called Weighted Average). The numerical data are presented in Table 1, and the data are shown graphically on Figure 6.

Table 1

Comparison of Inflows into Lake Howell (cfs)

Date	USGS at Howell	Second Creek Adj.	Weighted Average
1/24/2001	9.27	12.35	16.57
7/12/2001	3.43	2.79	7.56
9/18/2001	2.11	1.79	3.41
11/7/2001	3.40	4.38	6.09
1/8/2002	8.01	8.36	16.64
2/12/2002	15.40	16.33	24.42
3/29/2002	13.28	17.13	22.85
4/8/2002	10.89	14.34	16.15
5/25/2002	4.51	3.31	6.50
7/23/2002	1.08	1.23	2.46
8/20/2002	0.16	0.80	3.07
9/26/2002	3.47	1.67	7.03

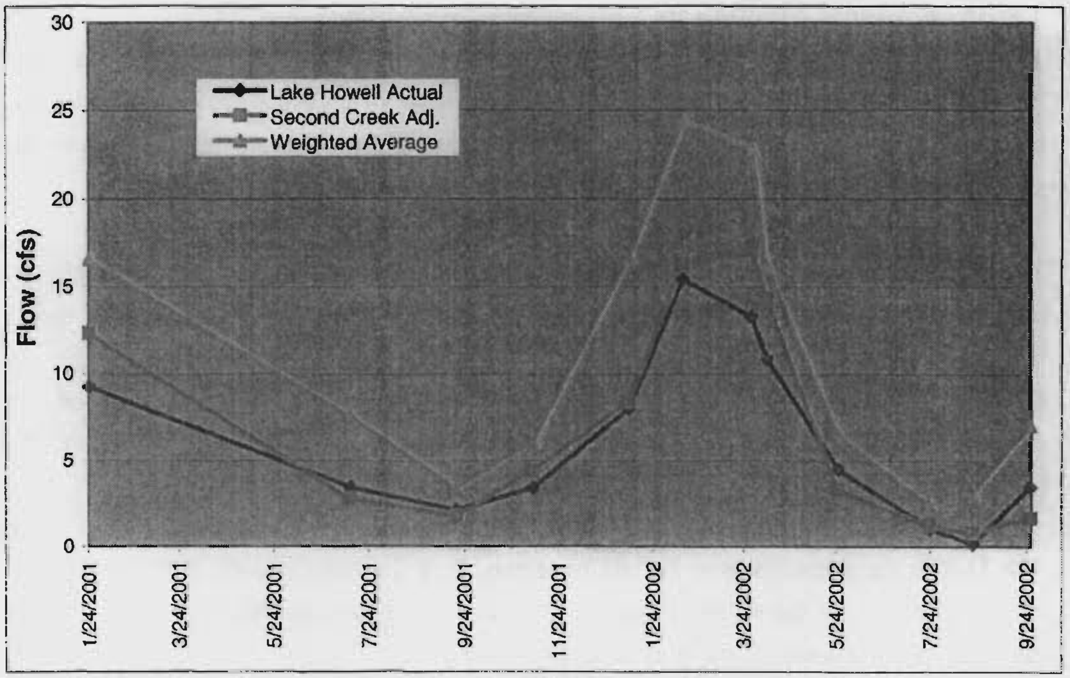


Figure 6. Comparison between simulated records and USGS stream flows at Lake Howell

The comparison of flows showed that the Weighted Average record overestimated the low flows observed at Lake Howell. The Second Creek values, adjusted to a comparable drainage area, are much closer to the actual Lake Howell inflows. Overall, they overestimated flows slightly over the period analyzed.

Additionally, a correlation analysis was performed on the three sources of data to provide a statistical determination of the accuracy of flow prediction. The correlation coefficient (R) is an index of the degree of association between two values. The correlation coefficient measures the degree to which the measured and predicted values agree, and is used as a measure of the accuracy of future predictions. A correlation coefficient greater than 0.7 indicates a significant degree of association between the measured and predicted values. The results of the correlation analysis show that both the weighted average-generated flows and Second Creek values associate extremely well to field-measured data for Lake Howell.

- Correlation between USGS measurements and Second Creek flows, $R = 0.98$
- Correlation between USGS measurements and weighted average flows, $R = 0.98$
- Correlation between Second Creek and weighted average flows, $R = 0.96$

Based on these results, a common (cfs/mi^2) simulated stream flow record (Jan. 1900 – Nov. 2002) based on USGS stream flow gages was generated for all reservoirs. When Second Creek gage data was available, this gage was used without other gage data. For all other periods, a weighted average approach was taken for the previously selected gages. Reservoir inflows were obtained by multiplying the common (cfs/mi^2) record by the corresponding reservoir's drainage area.

1.4 Reservoir Operating Assumptions

For the purpose of updating the mass-balance model and safe yield values for Lake Howell, Kannapolis Lake, Lake Fisher, and Lake Concord, operating constraints were re-evaluated in light of the extreme drought. Table 2 summarizes the operating assumptions used in the updated safe yield models for the four reservoirs.

Table 2
Reservoir Operating Constraints

Water Source	Total Volume (mg)	Usable Volume (mg)	Normal Elev. (ft)	Minimum Elev. (ft)	Basis	Minimum Release (cfs)
Lake Howell	6270.9	5296.3	650	630	Gravity flow to WTP	6.0
Kannapolis Lake	1262.2	941.1	726	712	Invert Intake Elev.	0.0
Lake Fisher	836.0	749.6	646	629	Elev. Sluice Gate #5	0.0
Lake Concord	179.2	179.2	658	641	Bottom of Reservoir	0.0

1.5 Safe Yield Conclusions

The safe yield of a water source is a measure of the capacity of the source and is defined as the allowable draft rate at which water can be continuously withdrawn during a low flow or drought event. It is a function of the stream flow, topographic conditions of the watershed, climatological conditions affecting evaporation from the reservoir, watershed development conditions affecting sedimentation of the stream, reservoir seepage, and usable storage capacity in the reservoir.

1.5.1 Significant Water Supply Droughts. The updated mass-balance models were used to simulate an approximately 100-year period of hypothetical operations for each reservoir (1900-2002). The most significant 8 to 10 periods of drought were identified for each reservoir, and a yield was computed for each separate drought. The droughts are ranked based on the safe yield results. The lowest safe yields correspond to the most severe droughts for each source. The recent drought ranks as the drought-of-record for all reservoirs.

For each lake, the month and year that resulted in the lowest lake elevation is also identified. The results are shown in Table 3.

Table 3
Significant Water Supply Droughts (1900-2002)

Lake	Rank	Year	Month	Safe Yield (mgd)
Lake Howell	1	2002	October	7.05
	2	1956	November	16.20
	3	1927	November	16.30
	4	1970	July	18.00
	5	1942	November	18.30
	6	1986	December	18.50
	7	1981	November	18.80
	8	1932	September	19.05
	9	1914	November	20.25
	10	1994	December	21.00

Lake	Rank	Year	Month	Safe Yield (mgd)
Kannapolis Lake	1	2002	September	5.70
	2	1956	November	8.50
	3	1927	November	8.60
	4	1986	November	8.65
	5	1981	November	8.95
	6	1967	November	9.00
	7	1942	January	9.00
	8	1931	November	9.20

Lake	Rank	Year	Month	Safe Yield (mgd)
Lake Concord	1	2002	October	0.70
	2	1986	November	1.20
	3	1956	January	1.55
	4	1925	December	1.60
	5	1981	December	1.65
	6	1993	November	1.70
	7	1967	November	1.70
	8	1930	November	1.75

Lake	Rank	Year	Month	Safe Yield (mgd)
Lake Fisher	1	2002	October	3.00
	2	1986	November	5.15
	3	1956	January	6.35
	4	1926	October	6.55
	5	1981	November	6.65
	6	1967	November	6.90
	7	1993	December	7.00
	8	1931	November	7.10
	9	1983	November	7.35

1.5.2 Fifty-Year Safe Yield. The 50-year safe yield is computed for each reservoir to meet the North Carolina Department of Environment, Health, and Natural Resources guidelines. The guidelines base the safe yield of an impounded surface water source serving more than 50,000 people on a 50-year drought. Each of the four reservoirs was evaluated to determine its safe yield, using a 50-year drought recurrence interval.

Since approximately 100 years of reservoir operations are simulated, the most detrimental drought event of the period is determined to have a 100-year recurrence, and the second most significant drought is determined to have a 50-year recurrence. A summary and comparison of these safe yield values to previously published values is in Table 4.

Table 4
Reservoir Yield Estimates (mgd)

Water Source	1999 Report[1]	2002 Master Plan		2003 Update	
	20-yr	20-yr	50-yr	50-yr	100-yr
Lake Howell	23.80	21.60	17.60	16.20	7.05
Kannapolis Lake	-----	-----	8.60	8.50	5.70
Lake Fisher	7.10	6.30	6.30	5.15	3.00
Lake Concord	1.90	1.70	1.70	1.20	0.70

[1] *Water Supply Draft Rates*, Woolpert, for City of Concord, December 1999.

Reservoir safe yield numbers appropriate for operation and management of the water supplies, in accordance with North Carolina guidelines follow:

- Lake Howell = 16.2 mgd.
- Kannapolis Lake = 8.5 mgd.
- Lake Fisher = 5.15 mgd.
- Lake Concord = 1.2 mgd.

Results of the simulation of each reservoir, setting the fixed withdrawal rate equal to these 50-year safe yields, are shown in Figures 7, 8, 9, and 10.

It is significant to note that during the recent drought, withdrawals equal to the 50-year safe yield values could not have been sustained. The total safe yield from the four lakes equals 31.05 mgd, considering a 50-year recurrence, and reduces to 16.45 mgd, considering a 100-year recurrence. A drought management strategy is needed to manage the sources, in conjunction with water use reductions and purchase of additional supplies, to ensure safe and reliable operations. Drought management considerations and a recommended approach are discussed in the following sections.

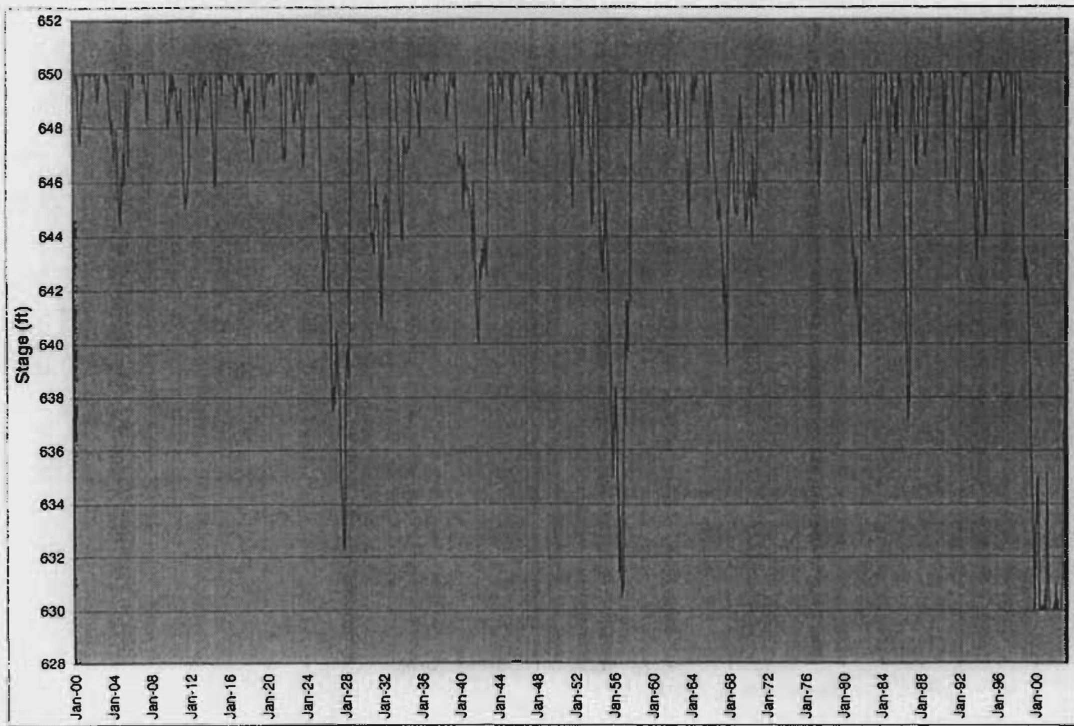


Figure 7. Lake Howell stage during the 103 years of simulated record at the 50-yr safe yield (16.2 mgd)

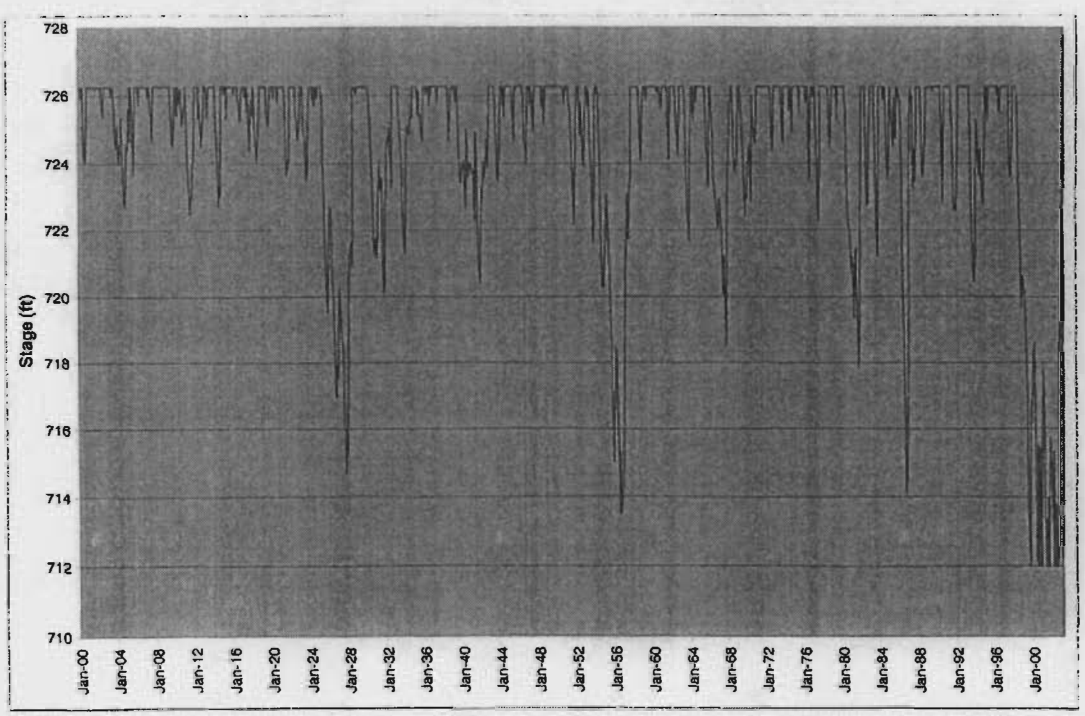


Figure 8. Kannapolis Lake stage during the 103 years of simulated record at the 50-yr safe yield (8.5 mgd)

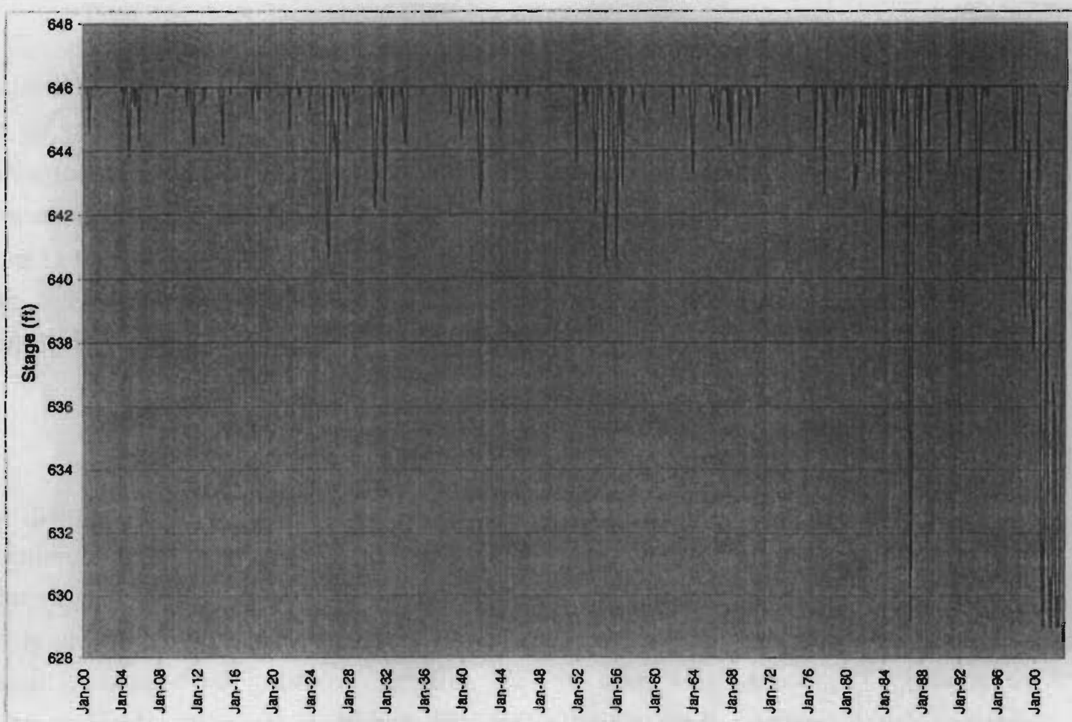


Figure 9. Lake Fisher stage during the 103 years of simulated record at the 50-yr safe yield (5.15 mgd)

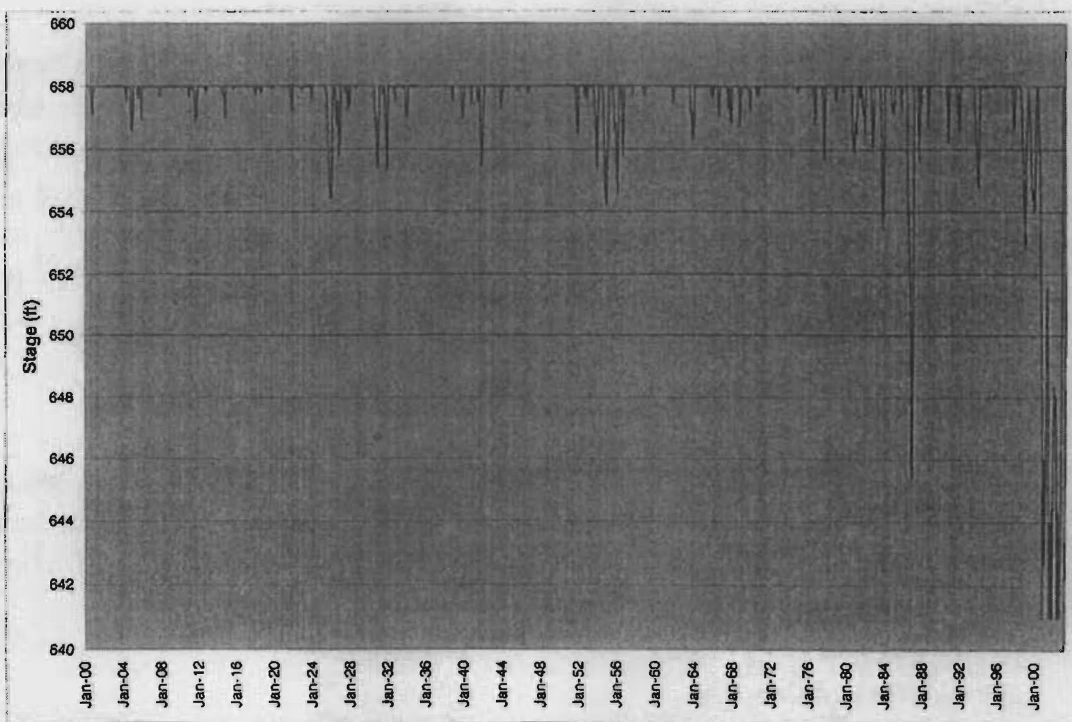


Figure 10. Lake Concord stage during the 103 years of simulated record at the 50-yr safe yield (1.2 mgd)

2.0 Regional Drought Operations

The occurrence of the recent, exceptional drought and the resulting record low levels in the water supply lakes provides great incentive to examine the benefits of managing and operating the water supplies of Cabarrus County in a coordinated manner. The objective of the evaluation of coordinated regional operations is to determine a sequence of operations that best extends the availability of the region's water supply storage in times of drought. A number of local, state, and river-based drought programs were investigated to provide information on similar programs implemented by others. Summaries of these programs are included in Appendix A.

2.1 Staged Water Use Restrictions

Water use restrictions are an integral component of any drought contingency plan, and these restrictions should become progressively more stringent as drought conditions increase in severity. Determining the onset and severity of drought conditions requires specific criterion that "trigger" the implementation of the appropriate drought mitigation techniques. These indicators must provide sufficient warning for adequate drought response, but not trigger these activities so prematurely or frequently that the public becomes complacent and non-responsive.

A four-staged approach to water use restrictions is preferred by WSACC and the member governments, for development of the operational plan. Voluntary Restrictions would occur in Stage 1; Mandatory Restrictions in Stages 2 and 3; and Emergency Restrictions in Stage 4. The mass-balance safe yield models developed for the four water supply reservoirs (Lake Howell, Kannapolis Lake, Lake Fisher, Lake Concord) provide the basis for developing the drought operating approach. The mass-balance model simulates hypothetical reservoir operations, including interactions with the other reservoirs in the system, using regional hydrologic information to develop a historical reservoir stage record.

A number of climatic indicators are available for monitoring drought conditions and triggering stages of drought response. Possible indicators include precipitation, stream flow, groundwater levels, and reservoir storage levels. A discussion of the most meaningful indicators of the water supplies of Cabarrus County follows.

2.2 Indicators of Drought

Drought indicators are used to identify the onset of deteriorating water supply conditions and provide a warning for appropriate stages of drought response. Initial triggers prompt early response actions such as voluntary conservation. Subsequent triggers indicate an imminent water shortage, and eventually the need for strict water rationing. These triggers must provide sufficient warning for drought response by the region's water customers. Similarly, indicators are useful for determining the appropriate timing for lessening or discontinuing staged water use restrictions

Since the bulk of the raw water supplies in Cabarrus County are surface water storage reservoirs, the parameters evaluated are precipitation, stream flow, and reservoir volume. These parameters directly influence surface water sources, and they are easy to monitor.

The mass-balance models, developed for computation of safe yield, provided the tool to evaluate the effectiveness of drought indicators. The safe yield model simulates hypothetical reservoir operations, considering stream flow, precipitation, releases, and withdrawal rates to develop historical reservoir stage records.

2.2.1 Precipitation. Precipitation is the parameter used to determine meteorological drought, considering seasonal rainfall patterns, degree of dryness, and duration of the dry period. In agricultural applications, differences between actual and expected evapo-transpiration and topsoil moisture can define a drought. Sustained periods of departures from expected precipitation will eventually affect the groundwater and surface water base flows. Although the concept of accumulated precipitation deficit is a simple concept to grasp, it is not as effective as an indicator or predictor of water supply drought.

2.2.2 Stream Flow. The annual cycle of reservoir inflow generally peaks in the spring, and then slowly declines through the summer months with minimum flows typically observed in the fall. Conversely, the annual pattern for water demand peaks during the summer months with more modest demands in the spring and fall, and the lowest demands (reflecting minimum outdoor water use) in the winter. Winter and spring are typically the "refill" periods where inflow exceeds the moderate demand.

Hydrological drought occurs when a precipitation deficiency affects the surface or subsurface water supplies. It takes varying periods of time for precipitation deficiencies to affect the different parts of the hydrologic system, such as soil moisture, stream flow, groundwater, and reservoir levels. A few months of below-normal rainfall are not likely to affect the volume of water stored in the reservoirs; however, each reservoir will behave differently, based on its unique combination of drainage area, storage volume, and inflow factors.

Stream flow can serve as a reasonable predictor of water supply drought; particularly if it is compared to expected monthly values. For Lake Howell, a table of expected inflow by month was prepared for use in monitoring actual inflows (Table 5).

Table 5
Mean Monthly Inflow to Lake Howell (cfs)

Month	Mean Flow	75% Mean	50% Mean	25% Mean	10% Mean
January	51.8	38.9	25.9	13.0	5.2
February	58.5	43.9	29.3	14.6	5.9
March	63.5	47.6	31.7	15.9	6.3
April	51.9	38.9	25.9	13.0	5.2
May	38.3	28.7	19.2	9.6	3.8
June	35.0	26.3	17.5	8.8	3.5
July	29.9	22.4	15.0	7.5	3.0
August	31.0	23.3	15.5	7.7	3.1
September	26.6	20.0	13.3	6.7	2.7
October	31.8	23.9	15.9	7.9	3.2
November	30.3	22.7	15.1	7.6	3.0
December	39.7	29.8	19.9	9.9	4.0
Annual Average	40.7	30.5	20.3	10.2	4.1

For example, the twelve USGS field measurements of inflow to Lake Howell (refer to Table 1) show that flows in 2001 and 2002 were only 10 to 25 percent of the flow expected in those months. Over the period from May 1998 to November 2002, average inflow was between 25 and 50 percent of the expected annual average flow. Mean inflow to each of the four reservoirs during three severe droughts is shown in Table 6

Table 6
Mean Inflow (cfs) during Severe Droughts

Water Source	Drought Period			Drainage Area (mi^2)
	4/54 – 6/58	3/86 – 2/87	5/98 – 11/02	
Lake Howell	35.2	21.3	15.3	47.0
Kannapolis Lake[1]	14.6	11.3	9.5	66.2
Lake Fisher	14.0	8.5	6.1	18.7
Lake Concord	3.5	2.1	1.5	4.7

[1] Includes drainage area (55.6 sq.mi.) and inflows from Second Creek Pumping Station.

Stream flow can be most effective as a supplementary drought indicator, when it is used with monitoring reservoir storage.

2.2.3 Reservoir Volume. Each reservoir was analyzed independently and then in the context of the whole system to assess the reservoir's value as an indicator of the total available volume of the system. Plots of usable volume versus percentage of volume remaining for each reservoir and the combined system storage are shown on Figure 11. Lake Howell contains approximately 74% of the usable volume of the system; Kannapolis Lake and Lake Fisher contain approximately 13% and 11%, respectively; and Lake Concord contains about 2% of the usable volume of the system.

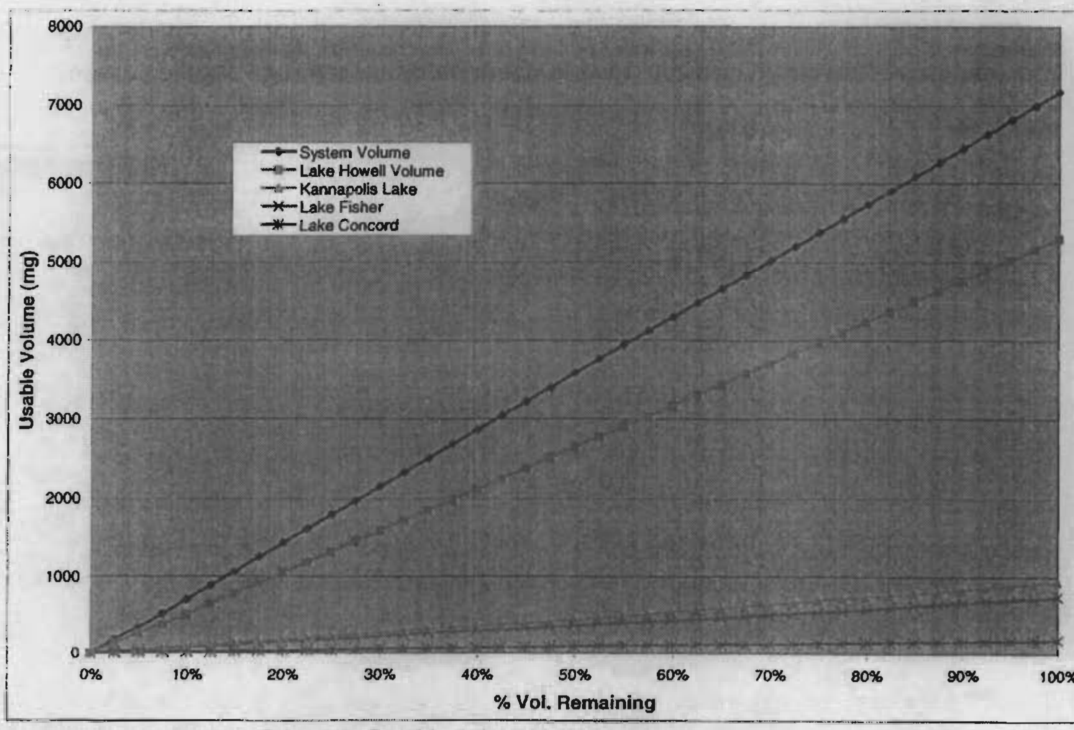


Figure 11. Distribution of storage of usable volume for the system

Because of its dominating share of the total system storage, only Lake Howell can reasonably represent the condition of the total system storage. Drought operating curves that correspond to usable volume will use the storage contained in Lake Howell as the primary drought stage indicator.

2.3 Evaluation of Reservoirs during Drought Conditions

The purpose of simulating and evaluating the operations of each of the four reservoirs is to determine the preferred manner of managing the raw water sources of Cabarrus County during periods of drought. In the analysis, each reservoir is analyzed independently and as part of the system. Three specific drought periods were considered (1950s, 1980s, and 1998-2002) to evaluate reservoir response to droughts with different characteristics.

Operation of the reservoirs was analyzed over the recent, record drought. Each reservoir was simulated to operate at a flow equal to the safe yield values computed for the drought-of record (Table 4). Remaining volume in each reservoir and total system volume is plotted over time in Figure 12. The figure shows the strong relationship between Lake Howell volume and total remaining volume available to the system

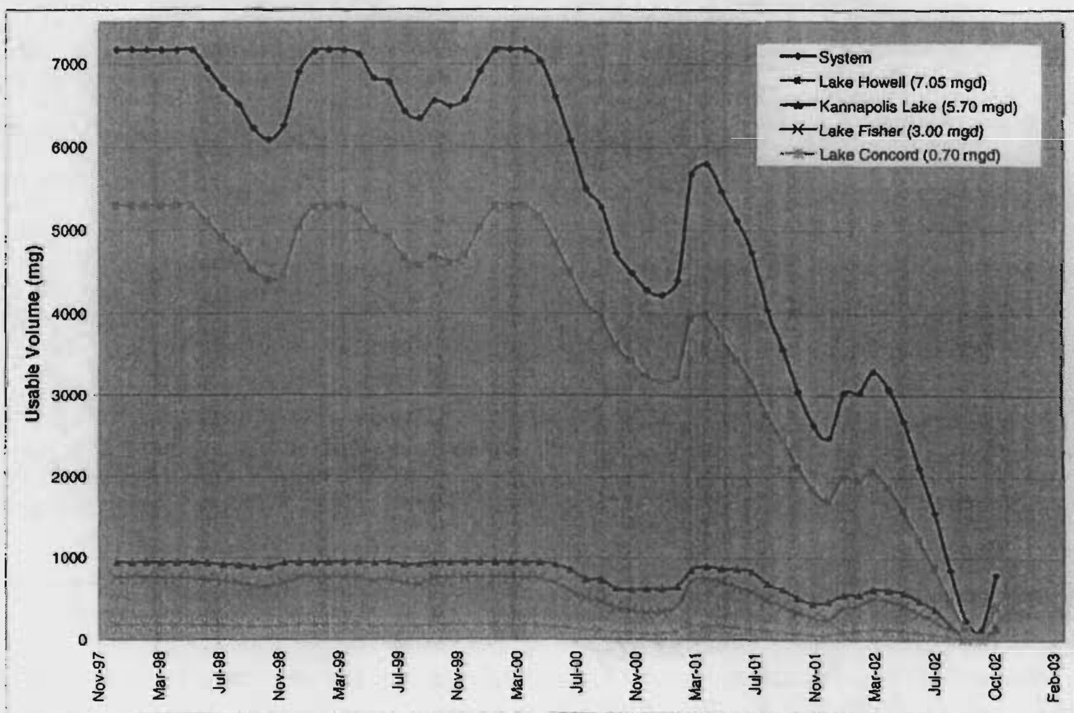


Figure 12. Reservoir simulation during drought of record, withdrawals at 100-yr safe yield

It is useful to refer back to Figures 7, 8, 9, and 10 to analyze reservoir behavior with withdrawals equal to the 50-year safe yield. Although the recent drought is the drought-of-record for all four reservoirs, the next most severe drought, the basis of the 50-year safe yield, is not the same for all reservoirs. The 50-year safe yield of Lake Howell and

Kannapolis is determined by the 1950's drought. For Lakes Fisher and Concord, the drought of the late 1980's defines the 50-year safe yield. Generally, Lake Howell and Kannapolis Lake are affected by similar droughts and Lakes Fisher and Concord are affected by similar droughts, as shown in Table 3.

The similarities are attributable to the ability to refill the lake based on drainage area or the lack of significant storage volume to capture the available inflow. These observations are described for each reservoir, and they provide information for development of the drought operations strategy.

2.3.1 Lake Howell. Lake Howell is affected by droughts of long duration and low to moderate inflow, similar to characteristics of the droughts of the 1920s and 1950s. Droughts of extremely low inflow, but shorter duration, like the 1980's drought, do not affect Lake Howell greatly because of the large volume stored. The most recent drought exhibited long duration, from 1998 through 2002, and very low inflows. The ratio of Lake Howell's usable volume to its drainage area ratio is 112.7 million gallons/square mile.

2.3.2 Lake Fisher and Lake Concord. Lake Fisher and Lake Concord hold much less storage, and they do not respond well to very low inflows, even of short duration. The drought of the 1980's exhibited these characteristics. Over a longer duration, small storms may occur that refill the smaller storage volume. They both respond well to longer duration droughts of low to moderate inflow, like the 1920's and 1950's droughts. Their refill capabilities are due to larger drainage areas, relative to their usable volumes. Their usable volume to drainage area ratios are similar. Lake Fisher holds 40.1 million gallons for each square mile of drainage area, and Lake Concord holds 38.1 million gallons for each square mile of drainage area.

2.3.3 Kannapolis Lake. Kannapolis Lake exhibits characteristics of both types of reservoir, due to its smaller volume, but greater refill capacity from Second Creek. Considering only the lake's watershed, Lake Kannapolis contains nearly 89 million gallons of usable volume per square mile of drainage area. If the Second Creek drainage area (55.6 mi^2) was considered, then the refill capability increases dramatically.

2.4 Drought Operating Curves

2.4.1 Seasonal Considerations. For reliable and safe reservoir operation, it is desirable for the reservoir to be nearly full in the Spring, prior to the onset of low flow, high evaporation, and high water demand months. Likewise, it is expected that the reservoir will drop to its lowest acceptable levels in the early Fall, following the same high water use months. These two empirical objectives are used to define the upper and lower bounds of usable volume, for each stage of drought, when seasonal effects are considered. The proposed drought operating curves reflect these complementary annual cycles.

2.4.2 Minimum Release from Lake Howell

In addition to stipulating water use reductions, each stage of drought restriction is proposed to coincide with a reduction in the minimum release from Lake Howell. The NCDENR Administrative Code provides consideration of reductions in specified minimum release from a dam. The language can be found in Title 15A, Subchapter 2K - Dam Safety, Section 0500, (http://www.dlr.enr.state.nc.us/Title15A_SubCh2K.html).

Preliminary conversations were held with representatives of the Instream Flow Unit of the Division of Water Resources and others with expertise in the water supply program and biological resources to discuss the development of a tiered release approach for the dam at Lake Howell. The protection of base flows in Coddle Creek downstream of the dam was identified as a principal objective to sustain biological habitat. Preliminary guidance was to devise a release schedule that would provide water supply relief earlier in the drought, to reduce the frequency of calling for severe stages of drought restrictions and dam release reductions later in the drought.

A number of options were modeled, and the following tiered release system was selected because Stage 4 drought restrictions would have occurred only once during the period of time simulated. Only during the severe drought experienced from 1998 to 2002 would the implementation of Stage 3 and 4 drought restrictions have been required.

For purposes of evaluating the proposed drought curves, the required minimum release from Lake Howell is reduced from 6 cfs in normal conditions to 3 cfs during Stage 1 drought restrictions; to 2 cfs during Stages 2, 3 and 4 restrictions. Water withdrawal reductions from Lake Howell of 10, 10, 20, and 25 percent are planned to coincide with

Drought Stages 1, 2, 3 and 4, respectively. Mean monthly inflow values are reported in Table 5.

2.4.3 Proposed Drought Operating Curves.

Percentage of usable volume, reservoir pool elevation, and frequency of drought restrictions were factors in the derivation of the drought curves. An evaluation of several combinations resulted in the following criteria used for the Stage 1, Stage 2, Stage 3 and Stage 4 drought curves, as presented on Figures 13 and 14. The curves are based on the percentage of usable volume in Lake Howell and consider seasonal variations in storage in Stages 3 and 4. The basis of and actions planned for each stage of drought follow:

- Normal: over 70 percent of the usable volume remaining in Lake Howell and reservoir inflow is above 75 percent of the historical mean monthly flow for the corresponding month (see Table 5); minimum release = 6 cfs; water withdrawal reduction from Lake Howell = 0 percent.
- Stage 1: over 70 percent of the usable volume remaining in Lake Howell, but reservoir inflow is below 75 percent of the historical mean monthly flow for the corresponding month (see Table 5); minimum release = 3 cfs; water withdrawal reduction from Lake Howell = 10 percent.
- Stage 2: 70 percent of the usable volume remaining in Lake Howell; minimum release = 2 cfs; water withdrawal reduction from Lake Howell = 10 percent.
- Stage 3: 60 percent to 40 percent of the usable volume remaining, depending on month; minimum release = 2 cfs; water withdrawal reduction from Lake Howell = 20 percent.
- Stage 4: 50 percent to 30 percent of the usable volume remaining, depending on month; minimum release = 2 cfs; water withdrawal reduction from Lake Howell = 25 percent.

A summary of storage volume and reservoir pool elevation data used to develop the operating curves is in Table 7. As shown, the operating curve arrangement triggers the four drought stages, depending on the month of the year.

Washwater from the Coddle Creek Water Treatment Plant discharges continuously into Coddle Creek downstream of Lake Howell. In addition to the releases from Lake Howell indicated above, 1 cfs will credited for the discharge from the treatment plant. When additional raw or treated water is delivered to Cabarrus County to meet the long-term water supply needs of the entities of the county, the 1 cfs credit from the water treatment plant will be rescinded. Figure 15 shows the location of the Coddle Creek WTP in relation to Lake Howell.

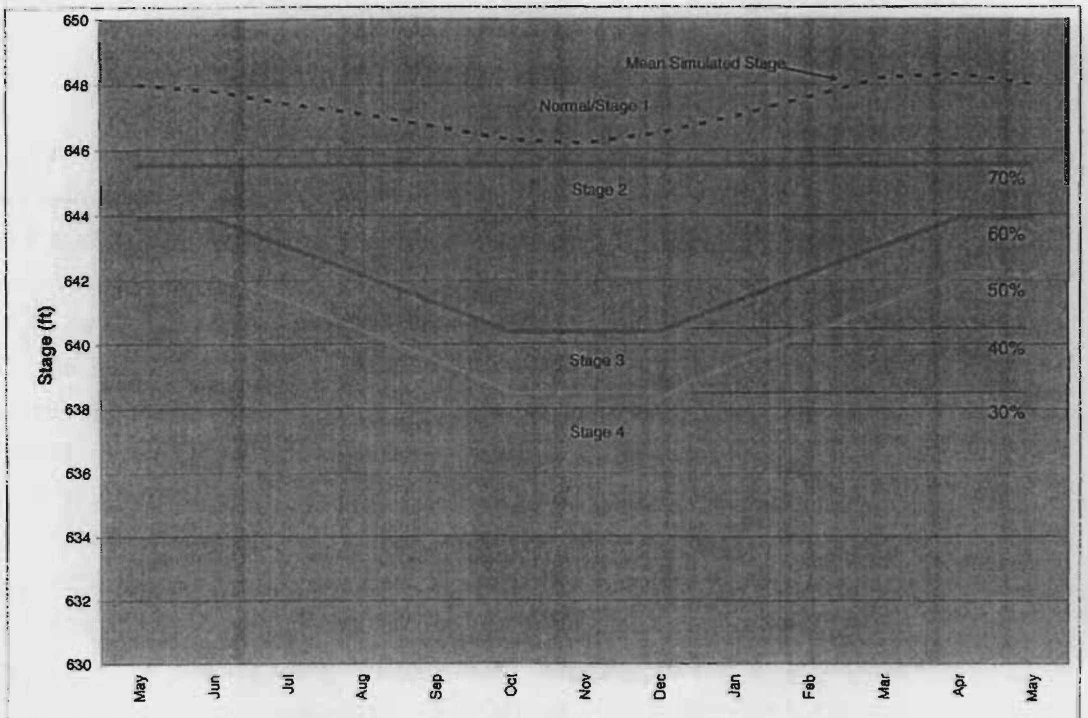


Figure 13. Lake Howell Stage – Seasonal Drought Curves

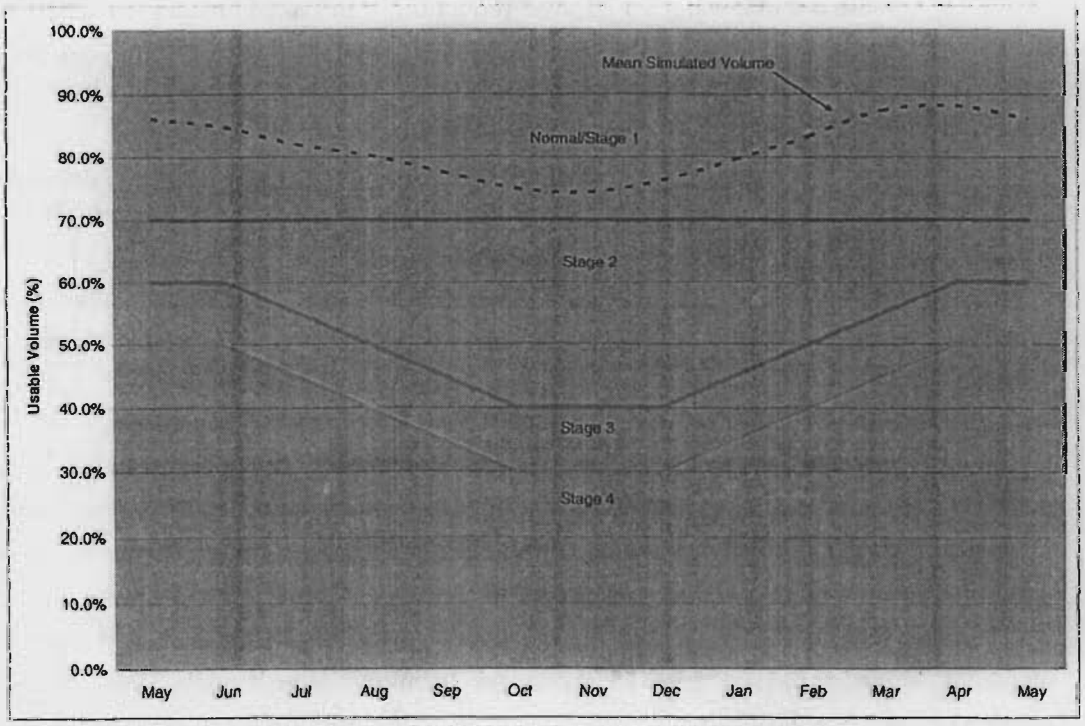


Figure 14. Lake Howell Percentage of Usable Volume – Seasonal Drought Curves

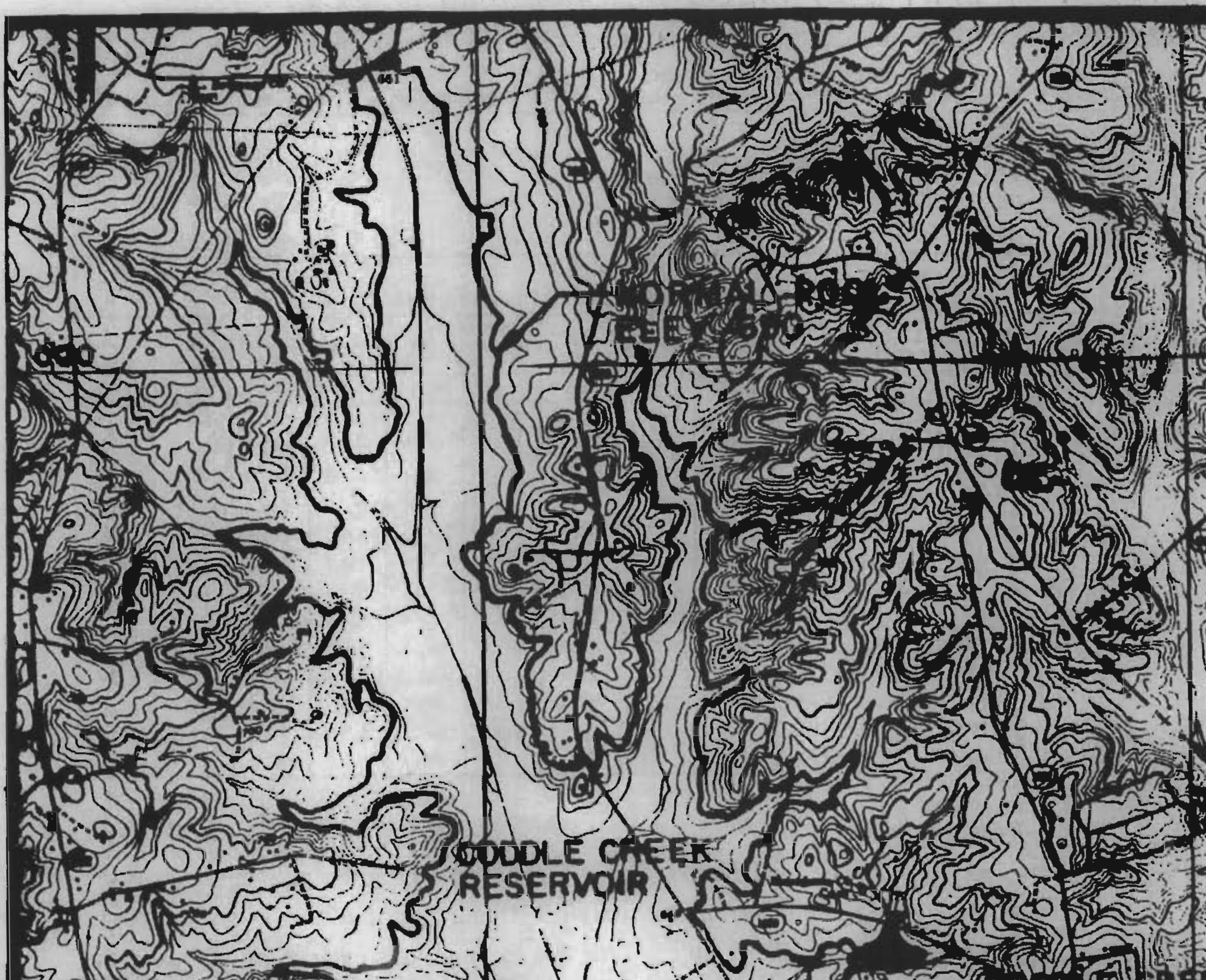


Figure 15

Table 7
Lake Howell, Seasonal Drought Operating Curve Data

Month	Crest Elevation = 650 feet with a usable volume of 5.3 billion gallons									Simulated Data		
	Percent of Usable Volume			Usable Volume [10^6 gal]			Reservoir Stage [ft]			Mean Stage	Mean Volume	Mean % Vol
	Stage 2	Stage 3	Stage 4	Stage 2	Stage 3	Stage 4	Stage 2	Stage 3	Stage 4			
May	70.0%	60.0%	50.0%	3707	3178	2648	645.5	643.9	642.2	647.7	4458	84.2%
Jun	70.0%	60.0%	50.0%	3707	3178	2648	645.5	643.9	642.2	647.5	4372	82.6%
Jul	70.0%	55.0%	45.0%	3707	2913	2383	645.5	643.1	641.3	647.0	4212	79.5%
Aug	70.0%	50.0%	40.0%	3707	2648	2119	645.5	642.2	640.4	646.7	4118	77.8%
Sep	70.0%	45.0%	35.0%	3707	2383	1854	645.5	641.3	639.5	646.3	3983	75.2%
Oct	70.0%	40.0%	30.0%	3707	2119	1589	645.5	640.4	638.4	645.9	3844	72.6%
Nov	70.0%	40.0%	30.0%	3707	2119	1589	645.5	640.4	638.4	645.7	3782	71.4%
Dec	70.0%	40.0%	30.0%	3707	2119	1589	645.5	640.4	638.4	646.3	3972	75.0%
Jan	70.0%	45.0%	35.0%	3707	2383	1854	645.5	641.3	639.5	646.7	4125	77.9%
Feb	70.0%	50.0%	40.0%	3707	2648	2119	645.5	642.2	640.4	647.4	4347	82.1%
Mar	70.0%	55.0%	45.0%	3707	2913	2383	645.5	643.1	641.3	647.9	4532	85.6%
Apr	70.0%	60.0%	50.0%	3707	3178	2648	645.5	643.9	642.2	648.0	4553	86.0%
May	70.0%	60.0%	50.0%	3707	3178	2648	645.5	643.9	642.2	647.7	4458	84.2%

2.4.4 Frequency Analysis.

As mentioned previously, an effective drought monitoring program must not trigger the need for water restrictions so prematurely or frequently that the overall drought contingency plan becomes ineffective. With this in mind, this evaluation examined the frequency of drought stage triggering over the entire simulated record. Conservation measures resulting in reduced demand, and reduced downstream releases are simulated, corresponding to drought stage. The resulting simulation of Lake Howell pool elevation is shown on Figure 16. Under these conditions, a Stage 2 drought condition would be called in 3 droughts over the 103 year record, or a frequency of once every 33 years (Table 8). Stage 3 and 4 restrictions would be implemented in only one drought over the 103-year record. That drought event is the 1998-2002 occurrence.

Table 8
Frequency of Entering Drought Stage By Events (103-yr)

Normal	Stage 1	Stage 2	Stage 3	Stage 4
-----	-----	3	0	1

Another consideration is the cumulative amount of time that the water customers would experience the various stages of drought restrictions. These are expressed in two different ways in Table 9. First, the percentage of months of the entire period (103 years) of simulation is shown. Then the number of months that each Stage would be expected to occur in a 10-year period is expressed. For example, based on the previous criteria, Lake Howell is considered to be in a "normal" condition in 57.8 percent of the record. Expressed differently, this is 69 months in a 10-year period. Stage 1 drought conditions occur 38.0 percent of the simulated time. This is equivalent to 46 months in a 10-year period. Drought events resulting in Drought Stage 2, 3, or 4 conditions occur only 4.2 percent of the simulated time, or for a total of 5 months in a 10-year period.

Table 9
Duration of Time in Drought Stage

Drought Stage	Frequency (%)	Months in 10-years
Normal	57.8	69
Stage 1	38.0	46
Stage 2	1.7	2
Stage 3	0.6	1
Stage 4	1.9	2

During periods of severe extended drought, conservation measures alone may not be adequate to provide reliable water supply to the communities. Additional water supplies may need to be imported to achieve the desired level of supply reliability.

2.5 Summary

The proposed drought curves use Lake Howell reservoir stage as the primary drought indicator. The analysis of safe yield shows that Lake Howell is limited in its ability to recharge, once its volume and elevation have dropped. Therefore, preserving the volume of water in Lake Howell becomes a priority, once Stage 1 restrictions are implemented. Water use restrictions in concert with reductions in reservoir release are recommended to ensure reliability of the water supply during drought.

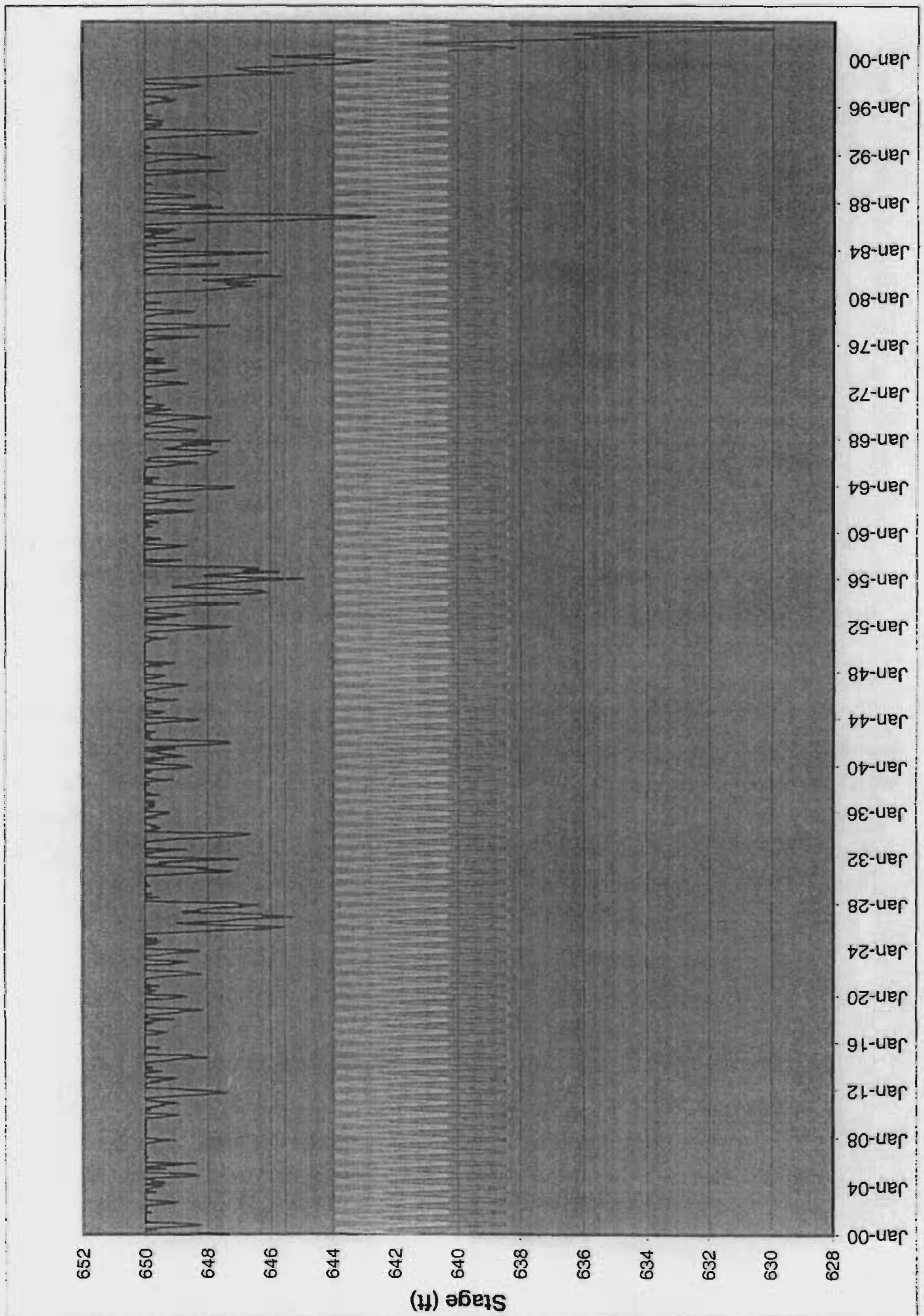

Stage (ft)
652
650
648
646
644
642
640
638
636
634
632
630
628
Jan-00
Jan-04
Jan-08
Jan-12
Jan-16
Jan-20
Jan-24
Jan-28
Jan-32
Jan-36
Jan-40
Jan-44
Jan-48
Jan-52
Jan-56
Jan-60
Jan-64
Jan-68
Jan-72
Jan-76
Jan-80
Jan-84
Jan-88
Jan-92
Jan-96
Jan-00

Figure 16

Appendix A

Drought Program Summaries:

Charlotte-Mecklenburg, NC
Delaware River Basin
Durham, NC
Greensboro, NC
Newport News, VA
Orange County Water and Sewer Authority, NC
Potomac River Basin
State of Maryland
State of Pennsylvania

Location: Charlotte-Mecklenburg, North Carolina

Management Agency: Charlotte-Mecklenburg Utilities

Drought Indicator(s):
- [x] Reservoir Water Levels
- [ ] Stream Flows
- [x] Water Production and Distribution Capabilities
- [ ] Drawdown Rates
- [ ] Precipitation Outlook
- [ ] Daily Water Use Patterns
- [ ] Seasonal and Long-Term Weather Patterns
- [ ] Availability of Water from Other Sources
- [ ] Other:

Additional Information:
Water Watch Index www.charmeck.org/apps/cmuforms/waterwatch.cfm
Water Smart Program - (704)399-2221

Program Summary

The program was completely rewritten and will be available to the public in Spring 2003.

Location: Delaware River Basin

Management Agency: Delaware River Basin Commission (DRBC)

Drought Indicator(s):
- [x] Reservoir Water Levels
- [ ] Stream Flows
- [ ] Water Production and Distribution Capabilities
- [ ] Drawdown Rates
- [ ] Precipitation Outlook
- [ ] Daily Water Use Patterns
- [ ] Seasonal and Long-Term Weather Patterns
- [ ] Availability of Water from Other Sources
- [ ] Other:

Additional Information:
"Delaware River Basin Commission's Homepage"
http://www.state.nj.us/drbc/drbc.htm/
Delaware River Basin Commission (2003)

Program Summary

The Delaware River Basin drains portions of four states: Pennsylvania, New Jersey, New York, and Delaware. In 1961, the governors of these states and the federal government created the Delaware River Basin Commission (DRBC) to manage water resources throughout the basin without regard to political boundaries.

The DRBC monitors regional drought conditions using storage-based reservoir operating curves for the New York City – Delaware River Basin Reservoirs (Cannonsville, Pepacton, and Neversink), which are located in the river's headwaters in the Catskill Mountains. The drought operating (rule) curves are based on the combined storage of the three reservoirs (271 billion gallons). These curves establish minimum storage levels that reflect annual reservoir inflow variations and seasonal demand patterns. During drought periods, the DRBC uses the operating curves to allocate water diversions to New York City and New Jersey while providing minimum flow targets at selected river locations for salinity control in the Delaware Estuary. The DRBC also monitors storage in the Blue Marsh and Beltzville Reservoirs, which are located in the Lower Delaware River Basin, in an effort to address varying hydrologic conditions within the watershed.

The drought operating curves define three drought operating status "zones" that outline a phased water diversion reduction schedule and accompanying releases for salinity control. When the combined reservoir storage drops below the drought watch curve for five consecutive days, allocations and flow targets are reduced according to the phased reduction schedule. Additional reductions are implemented on the first day that the combined reservoir storage drops into the drought warning zone. If the combined reservoir storage enters the drought zone and remains there for five consecutive days, the DRBC further reduces allocations and flow targets and may declare a drought emergency for the region. Note that a drought declaration requires a unanimous vote among the Commission's members.

Location: Durham, North Carolina

Management Agency: City Manager and the Conservation Program

Drought Indicator(s):
- ☒ Reservoir Water Levels
- ☒ Stream Flows
- ☒ Water Production and Distribution Capabilities
- ☒ Drawdown Rates
- ☒ Precipitation Outlook
- ☒ Daily Water Use Patterns
- ☒ Seasonal and Long-Term Weather Patterns
- ☐ Availability of Water from Other Sources
- ☐ Other:

Additional Information:
The Water Conservation Ordinance of Durham:
www.ci.durham.nc.us/departments/environ/ordinance.asp

Program Summary

The city of Durham uses a Risk-Based Simulation Model for drought management. It is based on historical data. The model was developed in 1999, before the most recent drought, so a few minor changes to the plan were made to account for the severity of the drought in 2001-2002. The changes simply consist of stricter water use requirements during different stages of drought.

Stage I - Continuing Voluntary Conservation Practices
No changes made as a result of the 2001-2002 drought.

Stage II – Voluntary Conservation
No changes made as a result of the 2001-2002 drought.

Stage III – Moderate Mandatory Conservation
2002 changes include the mandatory 30% reduction in industrial, manufacturing, and commercial water use. Car washing is limited to private wells or where 50% or more of the water is recycled or where it can be demonstrated that 30 gallons of water or less are used to wash the vehicle.

Stage IV – Severe Mandatory Conservation
2002 changes include the mandatory 50% reduction in industrial, manufacturing, and commercial water use

Stage V – Stringent Mandatory Conservation

Stage VI - Rationing

Location: Greensboro, North Carolina

Management Agency: Department of Water Resources, Director of Water Resources, City Manager, Mayer, and City Council

Drought Indicator(s):
- ☒ Reservoir Water Levels
- ☒ Stream Flows
- ☒ Water Production and Distribution Capabilities
- ☒ Drawdown Rates
- ☒ Precipitation Outlook
- ☒ Daily Water Use Patterns
- ☒ Seasonal and Long-Term Weather Patterns
- ☒ Availability of Water from Other Sources
- ☐ Other:

Additional Information:
Emergency Water Conservation and Restriction Plan
http://www.ci.greensboro.nc.us/wateres/Conservation/CHAPTER%2029.pdf

Program Summary

All of Greensboro's water comes form surface water sources: Lake Higgins, Lake Brandt, and Lake Townsend Reservoirs. The criteria used to determine a water shortage are listed above. However, the severity of the shortage is determined primarily by the levels of Lakes Brandt and Lake Townsend.

a) **Stage I** – Water Restrictions Alert
These *voluntary* restrictions are enacted when the levels of the lakes do not conform to seasonal expectations or the daily water demand is approaching ninety five percent of the system capacity.

b) **Stage IIA*** – Water Shortage Level I Warning
These mandatory restrictions are imposed when it is determined that there are no more than 150 days' of supply water available.

c) **Stage IIB** * – Water Shortage Level II Warning
This stage occurs upon the determination that no more than 125 days' of supply water is available.

d) **Stage III** * – Water Shortage Danger
These restrictions are enacted when the supply of water is determined to be less than 100 days of supply available.

e) **Stage IV** *– Water Shortage Emergency
The restrictions of Stage IV are imposed upon the determination of less than 75 days of water supply available.

f) **Stage V*** – Water Shortage Crisis
Stage V is in effect when it is determined that the available water supply is less than 50 days.

Location: Newport News, Virginia

Management Agency: Newport News Department of Public Utilities

Drought Indicator(s):
☒Reservoir Water Levels
☒Stream Flows
☒Water Production and Distribution Capabilities
☒Drawdown Rates
☒Precipitation Outlook
☒Daily Water Use Patterns
☒Seasonal and Long-Term Weather Patterns
☐Availability of Water from Other Sources
☒Other:Estimates of Min. Essential Supplies to Preserve Public Health and Safety

Additional Information:
The King William Reservoir Project- Additional Future Water Supply
http://www.kwreservoir.com/

Newport News Waterworks
http://www.newport-news.va.us/wwdept/index.shtml

Program Summary

The primary sources of raw water are the Chickahominy River and the Diascund Reservoir with lesser contributions from Skiffes Creek, Lee Hall and Harwood's Mill reservoirs. Little Creek Reservoir is an insignificant source of water because of its small watershed area, however, its large volume helps to supply water during dry periods when there is relatively little natural flow. In addition, a project is underway (The King William Reservoir Project) to help ensure reliable future water supply.

Should any one tier fail to conserve sufficient amounts of water supply, the next tier may be implemented.

The drought plan does not define specific triggering criteria. However, consideration of these various climatic parameters and the other considerations listed above provide a basis for initiating drought response efforts.

a) Tier 1, Voluntary Conservation, economic incentives
b) Tier 2, Mandatory Restrictions, fees used to encourage compliance
c) Tier 3, Water Rationing, violators incur charges of a Class 4 misdemeanor and a fine

Location: Orange County, North Carolina

Management Agency: Orange Water and Sewer Authority

Drought Indicator(s):
- ☒ Reservoir Water Levels
- ☒ Stream Flows
- ☐ Water Production and Distribution Capabilities
- ☒ Drawdown Rates
- ☐ Precipitation Outlook
- ☒ Daily Water Use Patterns
- ☐ Seasonal and Long-Term Weather Patterns
- ☒ Availability of Water from Other Sources
- ☐ Other:

Additional Information:
www.owasa.org/pages/2003consord.asp

Program Summary

The determination of drought shortage conditions shall be guided by periodic extimates of the risk (i.e., probability) that water stored in OWASA's reservoir system will decline to unacceptably low levels within the foreseeable future. Until improved or alternative criteria are developed, such guidance shall be based on a five percent or greater risk that total reservoir storage will decline to 20 percent or less of total storage capacity within an 18 month period. In the event of a water supply shortage, OWASA shall, using its best professional judgment, determine which of the following stages is the most appropriate response to the estimated level of risk.

A. Water Supply Advisory

B. Stage One (1) Water Shortage
Actions shall be taken with the goal of reducing the overall water demand by 10%.

C. Stage Two (2) Water Shortage
Actions shall be taken with the goal of reducing the overall water demand by 15%.

D. Stage Three (3) Water Shortage
Actions shall be taken with the goal of reducing the overall water demand by 20%.

E. Water Supply Emergency
In addition to the previous measures the following actions shall be taken.

1. No OWASA-supplied potable water may be used for any outdoor purposes other than emergency fire or other safety issues.
2. Water used for heating or cooling shall be reduced to all but essential facilities.
3. Water may be discontinued in portions of the service area to preserve the availability of water for essential public health.

Location: Potomac River Basin

Management Agency: Section for Cooperative Water Supply Operations of the Interstate Commission on the Potomac River Basin (CO-OP)

Drought Indicator(s):
- ☒ Reservoir Water Levels
- ☐ Stream Flows
- ☐ Water Production and Distribution Capabilities
- ☐ Drawdown Rates
- ☐ Precipitation Outlook
- ☐ Daily Water Use Patterns
- ☐ Seasonal and Long-Term Weather Patterns
- ☐ Availability of Water from Other Sources
- ☒ Other:National Weather Service Drought Monitoring

Additional Information:
"Interstate Commission on the Potomac River Basin"
http://www.potomacriver.org/
Interstate Commission on the Potomac River Basin (2003)

Program Summary

The Potomac River Basin drains portions of four states (Virginia, Maryland, Pennsylvania, and West Virginia) and the District of Columbia. In 1940, these states, the District of Columbia, and the United States Congress created the Interstate Commission on the Potomac River Basin (ICPRB) to protect the basin's water resources.

Cooperative agreements among the ICPRB and the three major Washington metropolitan area water utilities – Fairfax County Water Authority (FCWA), Washington Suburban Sanitary Commission (WSSC), and the Washington Aqueduct Division (WAD) of the Corps of Engineers – govern water resource management in the Potomac River Basin. Under the 1978 Low Flow Allocation Agreement (LFAA) and the 1982 Water Supply Coordination Agreement (WSCA), deteriorating drought conditions defined by low river flows initiate coordinated water supply management operations, which include releases from regional reservoirs to meet municipal demands and minimum flow requirements. Additionally, the LFAA established a formula based on the utility's average daily "winter" use for determining water allocation during times of drought. The CO-OP suppliers share the cost of operating and maintaining the Potomac storage reservoirs along with the funding for cooperative committee operations and supporting studies, such as regular water supply-demand projection analysis updates.

In addition to the CO-OP agreements, the Metropolitan Washington Council of Governments (MWCOG) monitors regional drought conditions and maintains a drought awareness and response plan. This plan addresses the need for regional drought management for water sources outside of those governed by the LFAA and WSCA. For example, WSSC and FCWA each independently own and operate water supply reservoirs located on Potomac River tributaries. The plan outlines coordinated public drought response actions as follows: call for voluntary conservation under a drought watch, require voluntary water restrictions under a drought warning, and implement mandatory water restrictions under a drought emergency.

Location: State of Maryland

Management Agency: Maryland Department of the Environment

Drought Indicator(s):
- ☒ Reservoir Water Levels
- ☒ Stream Flows
- ☐ Water Production and Distribution Capabilities
- ☐ Drawdown Rates
- ☒ Precipitation Outlook
- ☐ Daily Water Use Patterns
- ☒ Seasonal and Long-Term Weather Patterns
- ☐ Availability of Water from Other Sources
- ☒ Other:Groundwater Levels

Additional Information:
"Maryland Drought Information"
www.mde.state.md.us/Water/Drought/home/index.asp
Maryland Department of the Environment (2002)

"Drought Monitoring and Response Plan"
www.mde.state.md.us/assets/document/drought/droughtreport.pdf
Maryland Department of the Environment (2000)

Program Summary

Nearly 90 percent of Maryland's population relies on public water supplies. However, the primary water source varies according to a region's geologic setting, topographic features, and weather patterns. Larger water suppliers, such as the Washington Suburban Sanitary Commission, operate large reservoirs, while rural systems rely on groundwater wells. Moreover, the state is divided into four specific regions based on climatological similarities and water sources. With this in mind, the Maryland Drought Monitoring and Response Plan includes a state-wide climate monitoring program and a staged drought response plan tailored to meet the state's diverse water management needs.

The drought monitoring program employs four regional drought indicators: precipitation deficits, stream flow, groundwater levels, and reservoir storage. Current precipitation amounts, expressed as a percentage of normal (30-year running average), are monitored to identify regional precipitation anomalies. Select streamgages and groundwater wells represent different regions and their primary water supply sources. Remaining available storage in ten reservoirs across the state provide an indication of impending water shortages, particularly in the summer months.

The drought response plan presents a staged approach to defining drought status. Stage 1 represents normal conditions. Stage 2 and Stage 3 represent a drought watch and drought warning, respectively, where voluntary water use reductions are encouraged through public outreach and education. Stage 4 represents a drought emergency where mandatory water use restrictions are enforced in an attempt to achieve a 15-20 percent reduction in water use. Prohibited activities include lawn watering, operation of ornamental fountains, and automobile washing among other non-essential uses.

Location: State of Pennsylvania

Management Agency: Pennsylvania Emergency Management Agency
Pennsylvania Department of Environmental Protection

Drought Indicator(s):
- ☒ Reservoir Water Levels
- ☒ Stream Flows
- ☐ Water Production and Distribution Capabilities
- ☐ Drawdown Rates
- ☒ Precipitation Outlook
- ☐ Daily Water Use Patterns
- ☒ Seasonal and Long-Term Weather Patterns
- ☐ Availability of Water from Other Sources
- ☒ Other:Groundwater Levels, Palmer Drought Severity Index

Additional Information:

"Drought Information Center (Pennsylvania)"
www.dep.state.pa.us/dep/subject/hotopics/drought/
Pennsylvania Department of Environmental Protection (2002)

Program Summary

The Pennsylvania Department of Environmental Protection (DEP) monitors state-wide drought conditions and provides recommendations for drought response to the Pennsylvania Emergency Management Agency (PEMA). The Pennsylvania Drought Management Plan includes a drought monitoring program, which is based on regional drought indicators, and a comprehensive drought response program that outlines conservation measures and water use restrictions to be implemented as appropriate.

The drought monitoring program employs five climatic parameters as drought indicators as shown above. Precipitation deficits, expressed as a percentage of normal (30-year running average), provide an early indication of impending drought conditions. DEP calculates 30-day average stream flows for 73 streamgages throughout the state and compares these values to exceedance probabilities. Similarly, groundwater wells (including at least one well in each county) are monitored to provide 30-day average depths to water and compared to representative exceedances. Remaining available storage in several reservoirs across the state provide an indication of impending water shortages. The PDSI represents long-term, abnormal climatic variations.

The drought response plan presents a staged approach to defining drought status. A drought watch status requires voluntary conservation targeting a five percent water use reduction. A drought warning requires additional voluntary conservation to achieve a 10-15 percent reduction. A drought emergency initiates increased coordination among the various agencies to ensure effective implementation of drought response measures, which may include mandatory non-essential water use restrictions or water rationing if needed.

In addition to the state-wide drought management plan, Pennsylvania requires all public water suppliers to submit individual drought contingency plans. These plans must identify a drought watch, warning, and emergency for each specific water system.

Appendix B: Black Run Reservoir Safe Yield

The Water and Sewer Authority of Cabarrus County owns and operates the Mount Pleasant water supply and treatment system. The system consists of a water treatment plant with an intake structure on the Dutch Buffalo Creek and an offline reservoir that impounds water from Black Run. The reservoir supplements the creek's stream flow during periods of low-flow conditions, as Black Run is a tributary of Dutch Buffalo Creek and is located upstream of the water treatment plant's intake structure. The figure below shows the stage-storage relationship at Black Run Reservoir, created from the recent bathymetric survey. A total storage volume of 177.4 million gallons is estimated, and because of the reservoir outlet configuration, all of that volume is assumed usable. A minimum of 0.2 cfs is required to be released from the reservoir on Black Run through an outlet pipe.

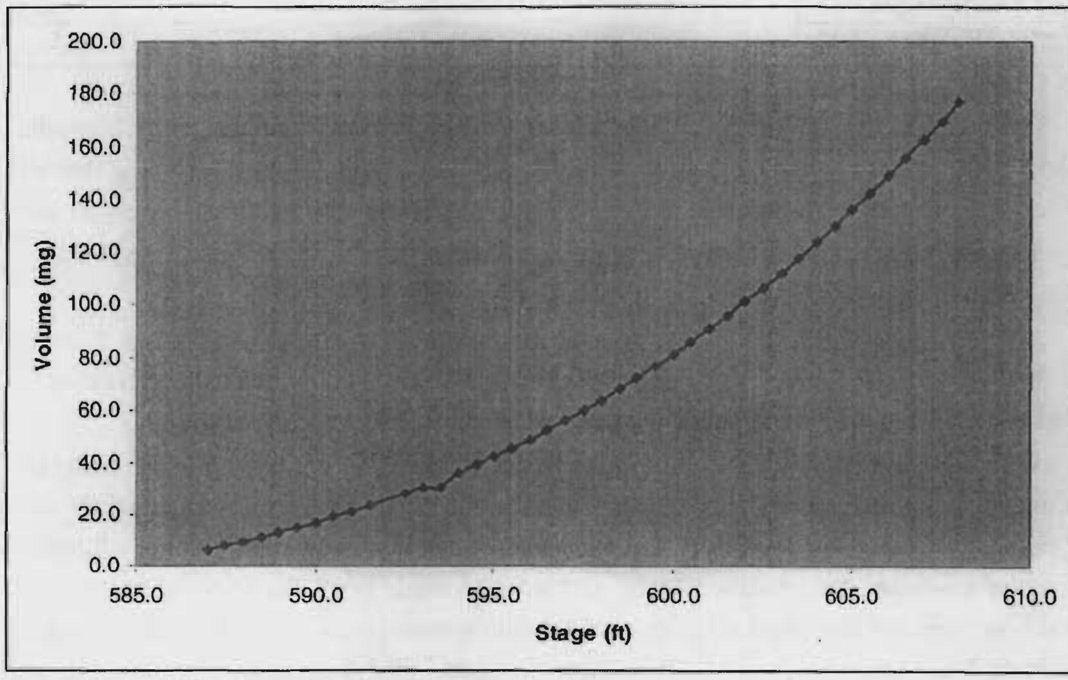


Figure B-1. Black Run Reservoir stage-storage relationship

The safe yield of Black Run is estimated based on a comparison with other reservoirs for which mass-balance models were developed. The following assumptions are used:

- The inflow characteristics of Black Run are similar to those of the tributaries to Lake Concord and Lake Fisher.

- The reservoir behaves similarly to Lakes Fisher and Concord during drought events, and the 50-yr safe yield is defined by the 1986-1987 drought event.
- Duration of the critical drought is related to storage volume.
- Stream flow, precipitation, and evaporation are not considered.

Table B-1
Comparison of Reservoir Parameters

	Black Run Res.	Lake Concord	Lake Fisher
Drainage Area	6.7 sq. mi.	4.7 sq. mi.	18.7 sq.mi
Volume	177.4 mgal	179.2 mgal	749.6 mgal
Duration of 50-yr Drought, days	Assume 365 days	365 days	396 days
Zero Inflow Yield (=Volume/Duration)	0.49 mgd	0.49 mgd	1.89 mgd
Mass-Balance Yield	--	1.2 mgd	5.15 mgd

Based on these assumptions, a "zero inflow" yield value was calculated by dividing the usable reservoir volume by the duration of the 50-year drought event, assuming that no inflow occurs. The duration of the event is defined from the time that the reservoir was full until it reaches its minimum elevation and then refills. At Lake Fisher the event lasted 396 days, and at Lake Concord, that event lasted 365 days.

The "zero inflow" value can be compared to the safe yield computed using the mass balance model. The mass balance models consider the effect of precipitation, evaporation and stream flow. It is apparent that not considering these effects results in underestimating the reservoir's yield. Following the methodology described above to compute the zero inflow yield at Lake Fisher resulted in a value of 1.89 mgd, while the use of a detailed mass-balance model yielded 5.15 mgd. For Lake Concord a "zero inflow" yield of 0.49 mgd was calculated, while a mass balance model yields 1.2 mgd.

Taking these relationships into consideration it is assumed that the Black Run Reservoir, similar to Lake Concord based on drainage are and storage volume, will respond to drought in a similar manner. Considering the 1.2 mgd safe yield computed using the mass balance model and subtracting the 0.2 cfs (0.13 mgd) minimum release requirement, it is reasonable to assume a safe yield of 1.0 mgd for the Black Run Reservoir, not considering additional flows from Dutch Buffalo Creek.