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WHITE OAK CREEK
HYDROLOGIC AND SPILLWAY ADEQUACY ANALYSIS

Submitted to:

Martin Marietta Systems, Inc.
DOE Contract No. DE-AC05-840R21400

Submitted by:

Dr. B.A. Tschantz, P.E.
Professor of Civil Engineering
The University of Tennessee
Knoxville, Tennessee

August 15, 1987

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August 15, 1987

Mr. Anthony N. Wylie
P.O. Box P, K155OE
Mail Stop 233
Oak Ridge, TN 37831

RE: Spillway Evaluation Study for White Oak Dam, Oak Ridge, Tennessee

Dear Mr. Wylie:

This engineering report summarizes the findings from a hydrologic study, which you requested, to evaluate the spillway capacity for White oak Dam, located on White Oak Creek, just upstream from its confluence with the Clinch River at Mile 20.83 on Watts Bar Reservoir, below Melton Hill Dam. The required spillway capacity is based on the hazard rating evaluation recommendation from a previous study (1). For this dam and reservoir size, White Oak Dam is classified in the "small" category, using either the U.S. Army Corps of Engineers or State of Tennessee size classification criteria. The location of the dam relative to potential loss of lives or property in event of failure, places the dam rating in the "significant" Hazard Potential classification. Given the "small size-significant Hazard Potential" rating for this dam, the spillway flood capacity should fall within the recommended Corps' range of 100-year flood to one-half Probable Maximum Flood (1/2 PMF). A Tennessee "Category 2" rating requires a spillway capacity based on 1/3 Probable Maximum Precipitation (1/3 PMP), which falls within the recommended Corps range.

The study findings are as follows:

A. Watershed Characteristics

White Oak Creek Watershed above White Oak Dam is approximately rectangular as shown in Figure 1 and contains 6.01 square miles of drainage area (1). White Oak Creek is fed from the southeast sector of the total watershed by one major tributary, Melton Branch. Melton Branch represents 1.48 square miles of drainage area, or about a quarter of the White Oak Creek Watershed. Most of the watershed is in Roane County, but a small corner in the northeast near Chestnut Ridge is in Anderson County. Figure 1 shows the White Oak Creek Watershed and the Melton Branch sub-basin.

Analysis of the Roane and Anderson County soil survey maps indicates approximately forty different soil groups in the White Oak Creek Watershed (24, 25). Most of these soils are a silty or very fine sandy loam texture, as shown in Table 1. The forty soils fall into three major hydrologic soil groups (HSG): B, C, and D, and range from moderate, slow to very slow infiltration rates, respectively.

The three soil groups are generally clustered into six broad east-west bands as shown in Figure 2 and are distributed in the total watershed as follows:

HSG	% of Watershed Area
B	54.1
C	20.0
D	25.9

Thus, the natural soils of the watershed tend to have relatively slow infiltration rates, and tend to produce relatively high runoff yields.

Planimetric analysis of topographic map and aerial photographic data and field inspection of the watershed indicate four broad land use categories and distribution as follows (4, 26):

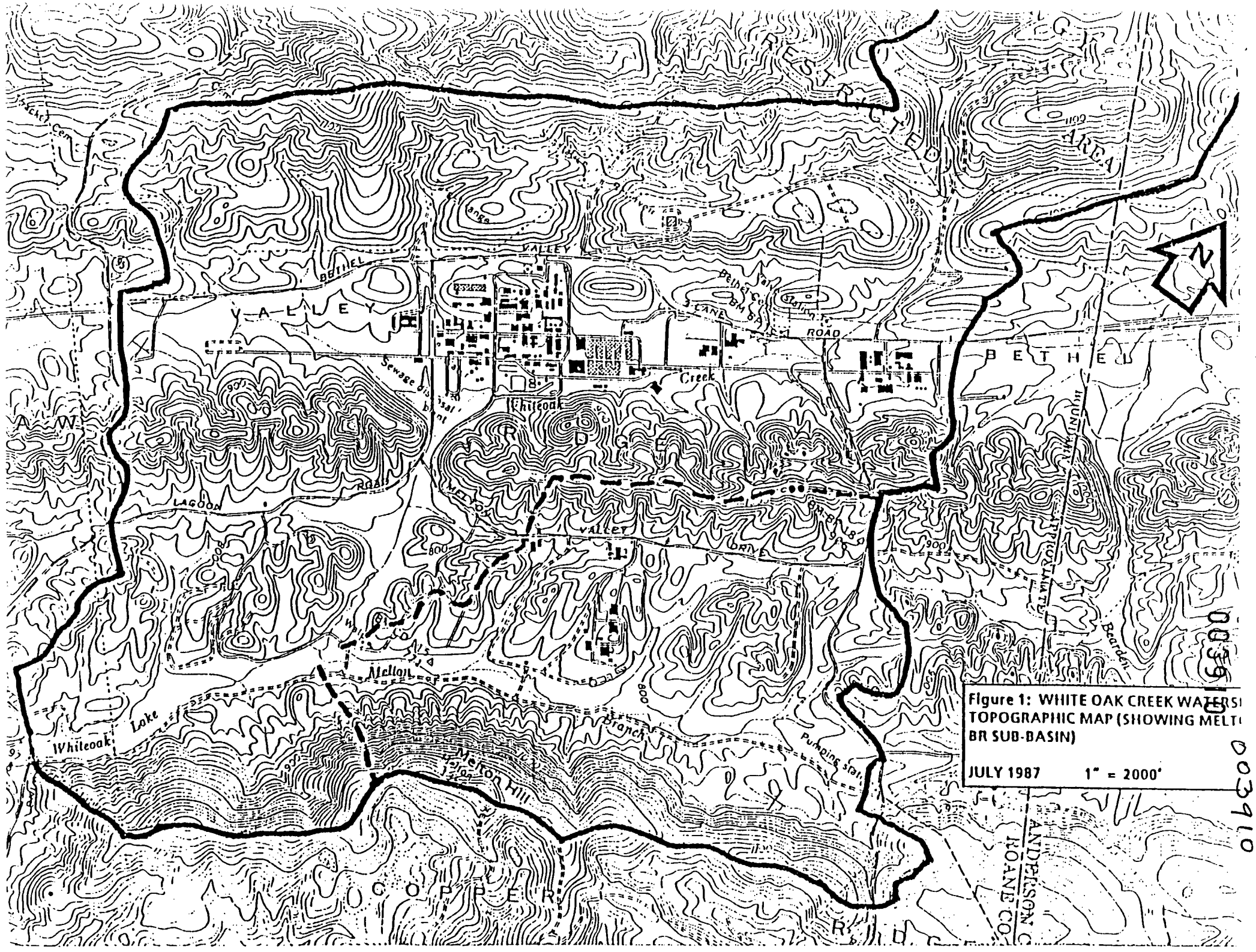

Figure 1: WHITE OAK CREEK WATERSI
TOPOGRAPHIC MAP (SHOWING MELT
BR SUB-BASIN)

JULY 1987 1" = 2000'

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Table 1. White Oak Watershed Hydrologic Soil Groups

County	Symbol	Soil Group Description	HSG
Roane	As	Armuchee silt loam	D
	Pv	Pope v.f. sandy loam	B
	Ps	Philo v.f. sandy loam	B
	Cs	Colbert silty clay loam	D
	Avk	Apison v.f. sandy loam	B
	Pg	Pope grav f. sandy loam	B
	Ls	Lehew stony f. sandy lm.	C
	RgA	Gullied land-Apison soil	B
	Cl	Colbert silt loam	D
	Cc	Clarksville chrty slt lm	B
	Fc	Fullerton cherty silt lm	B
	Fcl	Fullerton cherty silt lm	B
	Fcz	Fullerton cherty silt lm	B
	Us	Upshur silty clay loam	C
	Rsc	Stony land-Colbert/Talbot	D/C
	Ts	Talbott silty clay loam	C
	Ccz	Clarksville cherty slt lm	B
	Ccl	Clarksville cherty slt lm	B
	Avr	Apison v.f. sandy loam	B
	Ll	Lindside silt loam	C
	Clx	Colbert silt loam	D
	Fcr	Fullerton cherty silt lm	B
	Ml	Melvin silt loam	D
	Fct	Fullerton cherty silt lm	B
	Tsl	Talbott silty clay loam	C
	Rst	Talbott stony material	C
	Rgf	Fullerton-rough gullied	B
	Rg	Roane gravelly loam	B
	Dsl	Dewey silty clay loam	B
	Dm	Dewey silt loam	B
	Ds	Dewey silty clay loam	B
	Fck	Fullerton cherty silt lm	B
	Dsz	Dewey silty clay loam	B
Anderson	Fud	Fullerton cherty silt lm	B
	McC	Minvale cherty silt loam	B
	BoD	Bodine cherty silt loam	B
	Fue	Fullerton cherty silt lm	B
	Geb	Greendale silt loam	B
	Fuc	Fullerton cherty silt lm	B

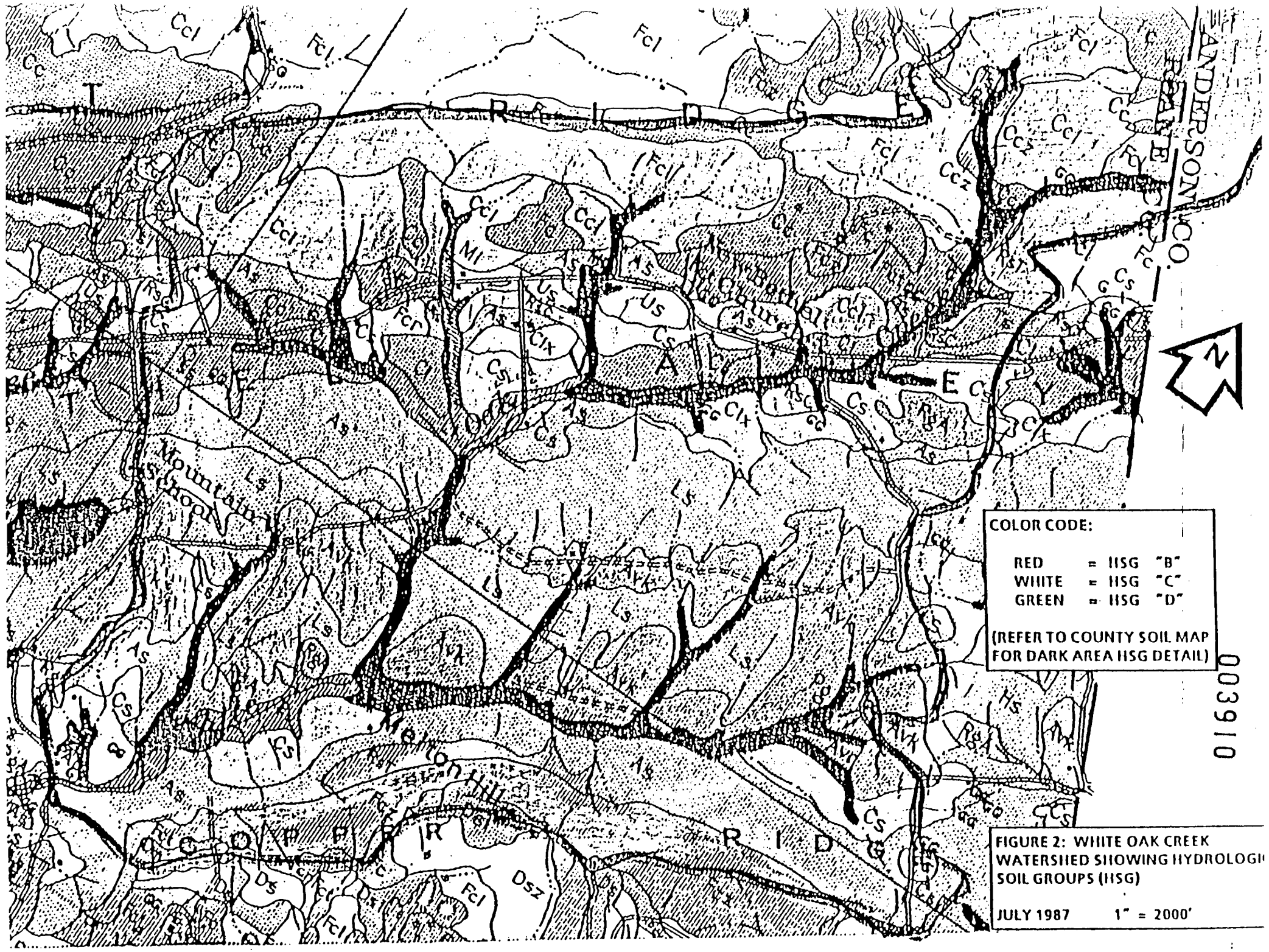

FIGURE 2: WHITE OAK CREEK WATERSHED SHOWING HYDROLOGIC SOIL GROUPS (HSG)

JULY 1987 1" = 2000'

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Land Use	% of Watershed Area
Forest (good cover)	84.7
Meadow/field (good cover)	6.7
Grass (good condition)	2.4
Indust./Dense Bldgs./Imperv. Areas	6.2

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The hydrologic soil group (soil) and land use (cover) in the watershed may be combined into a single weighted hydrologic soil-cover complex, which is defined by the U.S. Soil Conservation Service as a "Curve Number", or CN. The weighted CN for the soil-landuse matrix combinations and for an average antecedent soil moisture condition (AMC II) is 65 for White Oak Creek Watershed.

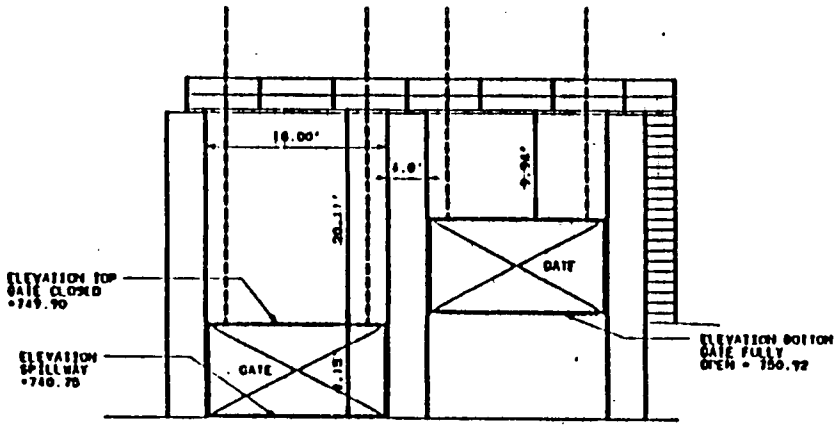
Although the watershed land slope ranges from steep (58%) to flat (0%), the average basin slope is moderately steep (13%). The longest flow path, or hydraulic length, for the watershed is 24,500 ft, measured from the northeast rim on Chestnut Ridge near the Roane-Anderson County Line to the dam in the southeast. The watershed ranges in elevation from 1356 ft (MSL) on Melton Hill along the southern rim of the watershed, to the pool level of White Oak Reservoir (normally about 744 ft). 744.9

The time of concentration for the watershed is computed by both SCS-Curve Number method and Time of Travel method to be 2.90 hrs (14). Basin lag time is estimated to be 1.74 hrs.

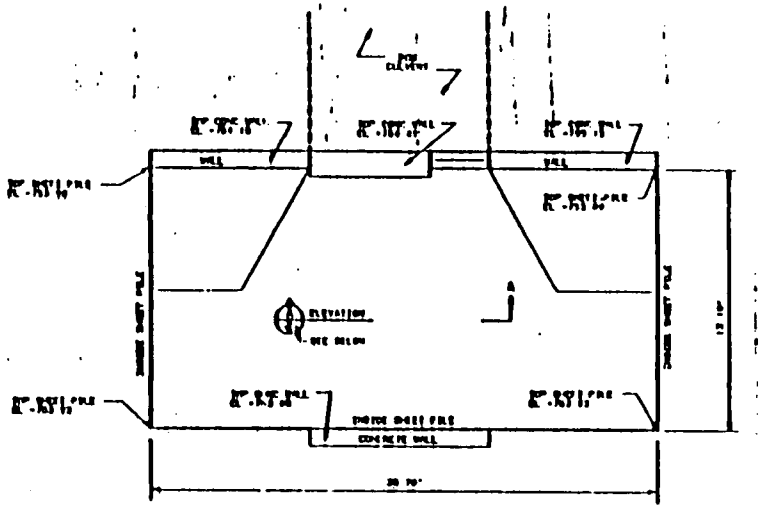
B. Spillway, Reservoir, and Dam Characteristics

White Oak Dam is an earthen structure, originally constructed as a roadway embankment over White Oak Creek. The crest of the dam supports Tennessee 95, a two-laned, 40 ft wide, paved highway. The dam is approximately 400-ft long and is about twenty feet high at its maximum section. The roadway pavement, which

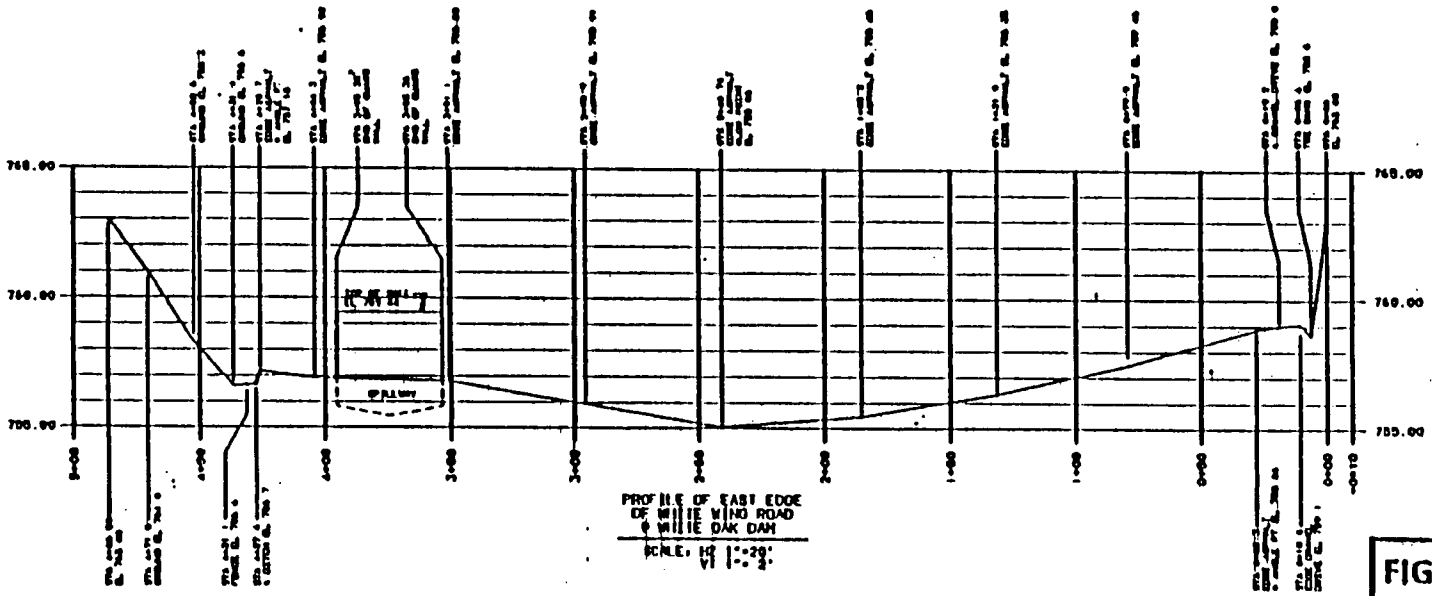
forms the crest of the dam, has a pronounced dip or "sag" elevation 755.05 ft (MSL) near the longitudinal center. This sag point is important in that the dam would overtop first at this point, should the spillway facilities be inadequate to accommodate the flood flow. The cross-section of the dam varies considerably in width, geometry and face cover. At its maximum cross-sectional height, the downstream face slope is 2.75H:IV and the downstream slope is a steep 1.88H:IV. The length of the dam includes two outlets. The oldest outlet, a 16-ft wide by 12-ft high concrete box culvert, was originally constructed in the early 1940's near the south end of the dam to convey White Oak Creek flow under the roadway. In 1943, a 36-ft by 13-ft sheet pile coffer dam was placed around the upstream culvert inlet to form a lake. Later, in 1959, the coffer dam was raised four feet, making the nominal elevation of the crest of the coffer dam 753.9 ft. Twin sluice gates at the base of the coffer dam on the lake side are welded shut and are not functional. An emergency spillway was constructed in 1982 on the north, or right end, of the dam, to provide accurate stream flow measurement capability and to increase the spillway capacity of the dam. The spillway consists of twin lift gates, each 18-ft wide and approximately 9-ft high, which are operated by motor from an elevated catwalk. The gates are used to control the flow out of the lake and the reservoir level. The bottom, or sill, of the gates is at elevation 740.75 and the top of the gates at fully-closed position is at elevation 749.90. When wide open, the gate bottoms are at 750.92 and tops at 760.07. When fully closed, the gates would begin to be overtopped when the reservoir water reaches elevation 749.90. Figure 3 shows the spillway and coffer dam details. The gates are separated by a 4-ft pier and together form a 40-ft wide spillway channel, which contains a series of two flow control weirs. The first weir is a triangular, broadcrested, concrete weir, whose crest is set at elevation 744.0 ft. The weir is located about 70 ft downstream from the spillway gates. Above this weir is a roadway bridge, which has an underclearance elevation



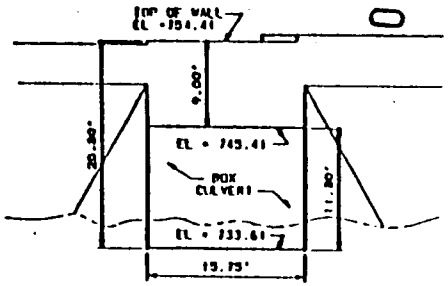
SPILLWAY
NOT TO SCALE



PLAN - COFFER DAM
& BOX CULVERT
NOT TO SCALE



PROFILE OF EAST EDGE
OF WHITE WING ROAD
& WHITE OAK DAM
SCALE: HZ 1"=20'
VT 1"=2'



ELEVATION A-A
NOT TO SCALE

FIGURE 3: WHITE OAK DAM COFFERDA SPILLWAY GATES, AND CREST PROFILE DETAILS

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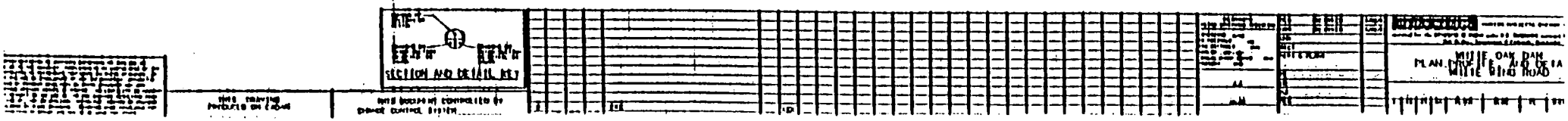


of 754.0. Water flow having a surface elevation above 754.0 at the triangular weir would begin to be controlled as orifice flow through the bridge opening, and not as weir flow.

Approximately 170-ft downstream from the spillway gates is a second weir. This weir consists of a combination standard 3-ft, sharp-crested trapezoidal weir set into a 40-ft wide, concrete broadcrested, rectangular weir sill. The crest of the trapezoidal weir is elevation 743.50 and the rectangular sill crest is elevation 744.83.

Discharge - reservoir elevation rating curves were developed for the expected range in reservoir levels, between low flow and flood operating conditions, for the combined capacity of both coffer dam and emergency spillway outlets. Both fully-open and fully-closed twin spillway gate conditions were assumed in this study. Figure 4 presents the combined spillway rating curves for both gate conditions.

Reservoir elevation - surface area - volume rating curves for the expected minimum to maximum lake level range were developed from ORNL and Martin Marietta-furnished data and from topographic maps (1,3,4).

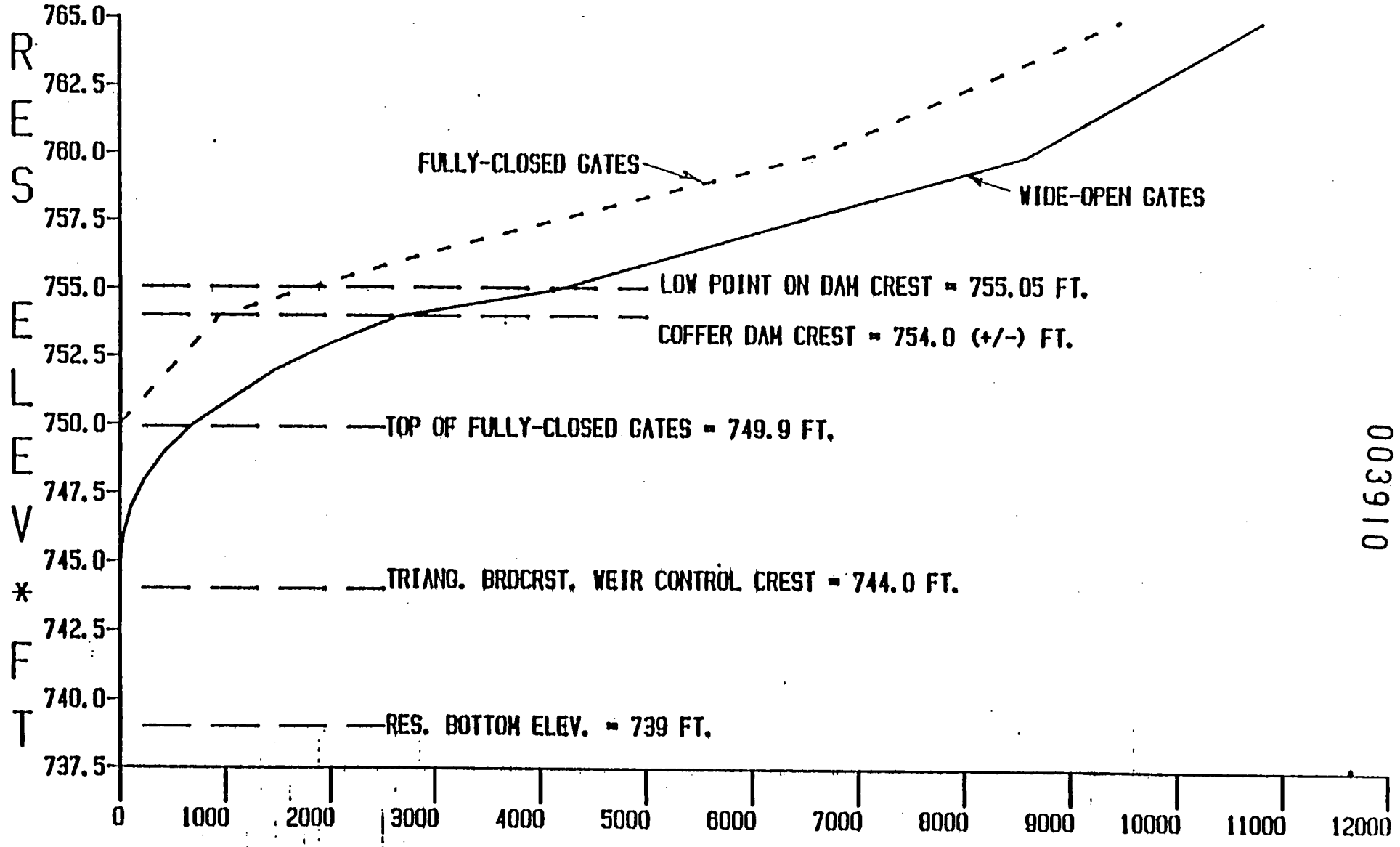
C. Derivation of Spillway Design Storms and Floods

From an earlier hazard rating study, White Oak Dam should be capable of accommodating a 100-year to one-half Probable Maximum Flood (1/2 PMF).

A 100-year flood is derived from a 100-year frequency, 24-hour duration precipitation depth of 6.5 inches (5). The precipitation distribution is assumed to follow the standard SCS 24-hour, Type II, Eastern U..S. storm distribution.

Since the recommended spillway capacity covers a range of flood flow to 1/2 PMF, the full PMF must first be determined, in order for discrete fractions of the PMF to be calculated. In this study, the following inflow design floods (IDF) are computed for comparison purposes:

SPILLWAY RATING CURVES FOR WHITE OAK DAM



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100 -yr	.50 PMF
.1 PMF	.75 PMF
.25 PMF	1.00 PMF
.33 PMF	.33 PMP (Tennessee Criteria)

The PMF (and fractions) is based on the Probable Maximum Storm (PMS), which is derived from the "all-season" Probable Maximum Precipitation (PMP), according to procedures developed by the National Oceanic and Atmospheric Administration (NOAA) and the U.S. Corps of Engineers (COE). The procedure for deriving the PMP is specified in NOAA Hydrometeorological Report No. 51 (HMR51), the PMS procedure is outlined in NOAA HMR52, and the PMF procedure is contained in HMR52 (6,7,8). In this study, both the PMS and PMF are developed from IBM PC/XT microcomputer programs (9,10).

The PMP, PMS, and PMF analyses for this study are summarized as follows:

PMP: HMR51 indicates that the following PMP input should be used for the 6 square mile White Oak Creek Watershed:

Storm Duration (hrs)	PMP Depth (inches)
6	29.5
12	35.0
24	38.5
48	42.5
72	44.0

PMS: HMR52 develops the temporal and geographical distribution of the PMP over the watershed for the first 72 hours. The HMR52 computer program optimally locates and orients the PMS over the watershed centroid according to watershed shape and regional storm patterns, respectively.

Computer results show that the optimum PMS is elliptically shaped, the major axis of the storm ellipse is oriented at 220° (N40°E), and produces incremental 6-hr average rainfall depths over the watershed as follows:

Time from Beginning of PMS Storm (Hrs)	Cumulative PMP Depth (Inches)
6	0.41
12	0.90
18	1.55
24	2.45
30	3.98
36	9.31
42	38.44
48	40.79
54	41.93
60	42.68
66	43.24
72	43.68

PMF (and Fractions of PMF): Once the PMS design storm is defined, the depth-time data can be entered as precipitation data input to the Corps of Engineers HEC-1 Flood Hydrograph computer program, to generate any fraction of the PMP or PMF, including the full PMF, for given or assumed hydrological conditions of the watershed.

In the same manner the 100-yr precipitation depth distribution can be entered into HEC-1 to produce the 100-yr flood.

In this study, the hydrological conditions, defined in terms of the watershed size (6.01 sq mi); landuse soil complex or SCS curve number (65); antecedent moisture

condition (average or AMC II); and time of concentration (2.90 hrs) or basin lag (1.74 hrs), are entered into HEC-1 for each of the specified storms to generate the inflow hydrograph to White Oak Reservoir. HEC-1 produces the following peak flows for the specified storms, using the SCS dimensionless, curvilinear, unit hydrograph method option:

Level of Flood	Peak Inflow to Reservoir (CFS)
100 -yr	2,453
.10 PMF	2,669
.25 PMF	6,672
.33 PMF	8,887
.50 PMF	13,343
.75 PMF	20,015
1.00 PMF	26,686
.33 PMP	7,402

Results indicate that the .10 PMF is approximately 10 percent greater than the computed 100-yr flood. The reader is cautioned about comparing the 100-yr flood peak of 2,453 cfs computed here with the 100-yr flood peak (1872 cfs) obtained by applying the USGS regional flood peak regression formula for Tennessee Area 1 (11). First, the USGS regression equation for the 100-yr flood has a standard error of estimate of 50 percent. Second, the USGS regression equation is based on watershed size only, and does not completely reflect the site specific conditions (here, relatively "tight" soils) of White Oak Watershed.

The author feels that the HEC-1 generated peak flow results are reasonable for evaluating the adequacy of the spillway facilities at White Oak Dam.

D. Spillway Adequacy Evaluation

The adequacy of the White Oak Dam spillway system to pass the recommended flood flow range (i.e., 100-yr to 1/2 PMF) was determined by applying each of the above floods to the given White Oak Reservoir, dam, and spillway conditions and using the HEC-1 modified Puls storage routing option for analyzing the flood hydrographs, as they pass through the reservoir, ultimately flow over the spillway and cofferdam, and possibly overtop the dam.

For this spillway analysis study, the starting reservoir level just prior to an incoming flood was assumed to be the same as the control crest of the triangular broadcrested weir, or elevation 744.0. This elevation corresponds closely to a "normal pool" level, which is commonly assumed as an initial condition prior to an incoming flood. In addition, for a fully-closed gate condition only, spillway analysis was performed for a starting reservoir elevation corresponding to the top of the coffer dam (753.9) for all incoming flood flows. The tailwater elevation in White Oak Creek just below the dam spillway, and cofferdam, was assumed to be at TVA's Watts Bar Normal Maximum Pool level of 741.0 (12).

Results of the HEC-1 flood routing and spillway analysis for each of the flood conditions are summarized and compared in the following section.

E. Summary of Study Findings

The hydrological analysis of White Oak Watershed and Subsequent spillway analysis at the dam are summarized in Tables 2 and 3. Table 2 gives the results for a

Table 2. Summary Results of White Oak Dam Spillway Analysis (Twin Spillway Gates Wide Open)

Level of Flood	Inflow Peak (cfs)	Max. Res. Elev. (ft.)	Max. Dam Overtopping Depth (ft)	Duration of Dam Overtopping (hrs)	Maximum Total Outflow (cfs)	Time of Max. Outflow After Start of Storm (hrs)
10 -yr	1,290	749.83	-	0	645	15.75 (24-hr storn
* 100 -yr	2,453	751.81	-	0	1,574	15.00 (24-hr storn
* .10 PMF	2,669	752.85	-	0	2,083	42.00 (72-hr storn
* .25 PMF	6,672	756.62	1.57	3.0	6,208	42.00 (72-hr storn
* .33 PMF	8,887	757.69	2.64	4.0	8,703	42.00 (72-hr storn
* .50 PMF	13,343	758.98	3.93	5.0	13,102	42.00 (72-hr storn
.75 PMF	20,015	760.40	5.45	7.0	19,432	42.00 (72-hr storn
Full PMF	26,686	761.63	6.58	8.0	25,893	42.00 (72-hr storn
.33 PMP	7,402	757.02	1.97	3.0	6,996	42.00 (72-hr storn

Notes:

1. Starting Reservoir Elevation Prior to Flood = 744.0
2. Top of Dam Elevation = 755.05
3. Assumed Dam Tailwater Elevation = 741.0 for Spillway/Coffer Dam Outflow
4. Top of Coffer Dam Elevation = 753.9
5. Elevation of Spillway Bridge Underclearance = 754.0
6. *Recommended spillway capacity range for "Small Size-significant Hazard Potential" classification is 100-yr to 1 (U.S. Army Corps) and 1/3 PMP (State of Tennessee).

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Table 3. Summary Results of White Oak Dam Spillway Analysis (Twin Spillway Gates Fully Closed)

Level of Flood	Inflow Peak (cfs)	Max. Res. Elev. (ft.)	Max. Dam Overtopping Depth (ft)	Duration of Dam Overtopping (hrs)	Maximum Total Outflow (cfs)	Time of Max. Outflow After Start of Storm (hrs)
10 -yr	1,290	751.65	-	0	394	17.25 (24-hr storm)
* 100 -yr	2,453	754.08	-	0	999	16.00 (24-hr storm)
* .10 PMF	2,669	755.30	0.25	2.0	2,049	42.00 (72-hr storm)
* .25 PMF	6,672	752.72	2.67	6.0	6,553	42.00 (72-hr storm)
* .33 PMF	8,887	758.37	3.32	6.0	8,661	42.00 (72-hr storm)
* 50 PMF	13,343	759.45	4.40	8.0	12,973	42.00 (72-hr storm)
75 PMF	20,015	760.79	5.74	11.0	19,466	42.00 (72-hr storm)
Full PMF	26,686	761.94	6.89	13.0	25,943	42.00 (72-hr storm)
* 33 PMP	7,402	757.93	2.88	5.0	7,206	42.00 (72-hr storm)

Notes:

1. Starting Reservoir Elevation Prior to Flood = 744.0. A starting elevation of 753.9 corresponding to the crest of coffer dam, increases the overtopping depth for the .10 PMF by about 0.1 ft, but does not affect any of the hi flows.
2. Top of Dam Elevation = 755.05
3. Assumed Dam Tailwater Elevation = 741.0 for Spillway/Coffer Dam Outflow
4. Top of Coffer Dam Elevation = 753.9
5. Elevation of Spillway Bridge Underclearance = 754.0
6. *Recommended spillway capacity range for "Small Size-significant Hazard Potential" classification is 100-yr to 1/2 (U.S. Army Corps) and 1/3 PMP (State of Tennessee).

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wide-open twin spillway gate condition and Table 3 for fully-closed gate condition. The tables compare inflow flood peaks, maximum reservoir elevations, maximum dam overtopping depths, duration of dam overtopping, maximum combined spillway/coffer dam/overtopping outflow, and time of maximum outflow after start of storm for each specified flood level. The 10-yr flood, developed from a 4.8 inch, 24-hr storm, is incidentally included in the table for comparing hydraulic results with the 100-yr flood.

Results show that the combined spillway capacity is adequate to handle the low end (100-yr flood) of the recommended design flood range, adequate for .1 PMF if the spillway gates are wide open, and inadequate to 1/2 PMF, assuming that the spillway gates are wide open. The spillway analysis results were found to be insensitive to the difference between starting reservoir elevations of 744.0 and 753.9 ft prior to an incoming flood event for a fully closed gate condition.

Examination of Tables 2 and 3 indicates that the difference in overtopping depths between wide-open and fully-closed spillway gate positions is within a foot for all flood levels.

It is the opinion of the author that complete dam failure and release of reservoir contents by overtopping, for floods up to the 1/2 PMF, is highly unlikely in light of the wide (40-ft) and non-erodible paved roadway surface and because the downstream slope is protected with dumped rip rap. However, prolonged overtopping depths over a couple feet and high velocities associated with overtopping can be expected to produce significant, and possibly, irreparable erosion damage to the embankment structure (particularly along the downstream face in areas where the rip rap is weak) and to the unprotected berms of the roadway shoulders.

In summary, the conclusion to be drawn from this analysis is that the total spillway capacity of White Oak Dam is hydraulically "adequate" for the 100-yr

flood, regardless of the position of the gates; "adequate" for the .10 PMF flood if the gates are wide open; but "inadequate" for all other floods up to the 0.50 PMF, regardless of gate position, for the size and hazard potential classification of the dam. However, for this specific dam, the spillway inadequacy does not necessarily or automatically imply an "unsafe" dam. Instead, the safety of the dam should be regarded in terms of total failure risk from all possible causes and all consequential hazards to public safety.

I will maintain the various computer input files and detailed output print-outs resulting from this study for your inspection and use, as required by the contract. Please call me if you wish to discuss any questions or implications arising from my analysis or findings presented in this report.

Sincerely,

BRUCE A. TSCHANTZ
REGISTERED ENGINEER
AGRICULTURE
NO. 8129
STATE OF TENNESSEE

P.E.

Bruce A. Tschantz, P.E.
Professor of Civil Engineering
The University of Tennessee

cc: Mr. William E. Manrod

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