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October 28, 2008

Document Control Desk
U.S. Nuclear Regulatory Commission
Washington, DC 20555-0001

Subject: Duke Energy Carolinas, LLC
William States Lee III Nuclear Station - Docket Nos. 52-018 and 52-019
AP1000 Combined License Application for the
William States Lee III Nuclear Station Units 1 and 2
Response to Request for Additional Information
Ltr# WLG2008.10-13

Reference: Letter from J.M. Muir (NRC) to B.J. Dolan (Duke Energy), *Request for Additional Information Regarding the Environmental Review of the Combined License Application for William States Lee III Nuclear Station Units 1 and 2*, dated August 21, 2008

This letter provides the Duke Energy response to the Nuclear Regulatory Commission's (NRC) requests for the following additional information (RAI) items listed in the reference letter:

RAI 9, Hydrology
RAI 10, Hydrology
RAI 21, Hydrology
RAI 30, Socioeconomics
RAI 34, Socioeconomics
RAI 42, Socioeconomics
RAI 44, Cultural Resources
RAI 45, Cultural Resources
RAI 47, Cultural Resources
RAI 57, Cultural Resources
RAI 63, Aquatic Ecology
RAI 64, Aquatic Ecology
RAI 69, Terrestrial Ecology
RAI 71, Terrestrial Ecology

A response to each NRC request is addressed in an enclosure which also identifies any associated changes that will be made in a future revision of the William States Lee III Nuclear Station application.

D093
NRO

If you have any questions or need any additional information, please contact Peter Hastings at 980-373-7820.

Bryan J. Dolan
Vice President
Nuclear Plant Development

Enclosures:

1. Response to RAI 9, Hydrology
2. Response to RAI 10, Hydrology
3. Response to RAI 21, Hydrology
4. Response to RAIs 30 and 34, Socioeconomics
5. Response to RAI 42, Cultural Resources
6. Response to RAI 44, Cultural Resources
7. Response to RAI 45, Cultural Resources
8. Response to RAI 47, Cultural Resources
9. Response to RAIs 57 (Aquatic Ecology) and 69 (Terrestrial Ecology)
10. Response to RAI 63, Aquatic Ecology
11. Response to RAI 64, Aquatic Ecology
12. Response to RAI 71, Terrestrial Ecology

AFFIDAVIT OF BRYAN J. DOLAN

Bryan J. Dolan, being duly sworn, states that he is Vice President, Nuclear Plant Development, Duke Energy Carolinas, LLC, that he is authorized on the part of said Company to sign and file with the U. S. Nuclear Regulatory Commission this supplement to the combined license application for the William States Lee III Nuclear Station and that all the matter and facts set forth herein are true and correct to the best of his knowledge.

Bryan J. Dolan
Bryan J. Dolan

Subscribed and sworn to me on October 28, 2008

Elaine Falcone
Notary Public

My commission expires: Feb. 27, 2021

SEAL

xc (wo/enclosures):

Michael Johnson, Director, Office of New Reactors
Gary Holahan, Deputy Director, Office of New Reactors
David Matthews, Director, Division of New Reactor Licensing
Scott Flanders, Director, Division of Site and Environmental Reviews
Glenn Tracy, Director, Division of Construction Inspection and Operational Programs
Luis Reyes, Regional Administrator, Region II
Loren Plisco, Deputy Regional Administrator, Region II
Thomas Bergman, Deputy Division Director, DNRL
Stephanie Coffin, Branch Chief, DNRL

xc (w/enclosures):

Linda Tello, Project Manager, DSER
Brian Hughes, Senior Project Manager, DNRL

Lee Nuclear Station Response to Request for Additional Information (RAI)

RAI Letter Dated: August 21, 2008

Reference NRC RAI Number: ER RAI-9

NRC RAI

Submit monthly precipitation amounts for the period October 2005 through April 2007 which predates and corresponds with the water table data in Figure 2.3-15. Submit an explanation for the relationship between precipitation received during this period, groundwater levels, and normal monthly amounts of precipitation.

Duke Energy Response:

The Lee Nuclear Site meteorological data (average monthly precipitation amounts) were available for the months of December 2005 through November 2006. These site-specific data were compared with National Oceanic and Atmospheric Administration (NOAA) data collected at the Greenville-Spartanburg (GSP) Airport (approximately 45 miles west of the Lee Nuclear Site) for the period October 2005 through April 2007. The correlation between precipitation data obtained from GSP and the Lee Nuclear Site was relatively good, as shown on the attached figure (Attachment 9-1).

Additionally, using the GSP precipitation data from 1950 to 2008, average monthly values were calculated (Attachment 9-1, Page 1) to determine "normal" monthly precipitation to evaluate whether the observed average monthly precipitation at the Lee Nuclear Site was relatively wet or dry during the investigation; "normal" in the remainder of this response refers to those average monthly values. The graph presented on Attachment 9-1, Page 3, shows the monthly precipitation data observed at the Lee Nuclear Site and GSP. It also shows the normal average monthly data described above. From October 2005 to January 2006, above normal precipitation occurred at the Lee Nuclear Site. From January 2006 to around October 2006, Lee Nuclear Site conditions were typically drier than normal. November 2006 was wetter than normal. From December 2006 through April 2007, the Lee Nuclear Site had around normal to below normal precipitation amounts.

A comparison was made between the observed monthly precipitation for the period October 2005 through April 2007 at the Lee Nuclear Site and GSP versus the groundwater levels observed in monitoring wells. The comparison is presented on the attached figure (Attachment 9-2). Monthly precipitation amounts correlate poorly with observed groundwater levels. Water levels appear to rise in winter, reaching peaks around April – May, then decline through summer and fall, reaching their lowest levels in October – November. These water level fluctuations are consistent with water levels observed in the Piedmont province, with declining water levels due to evapotranspiration through late spring and summer and rising water levels during cooler periods with less evaporation and plant use in late fall and winter.

Associated Revisions to the Lee Nuclear Station Combined License Application:

1. Revise COLA Part 3, ER Chapter 2, Subsection 2.3.1.5.7, Paragraph 7, as follows:

   Following well development, water levels were measured monthly from April 2006 to April 2007 (Table 2.3-5) to characterize seasonal trends in groundwater levels and to identify preferential flow pathways surrounding the Lee Nuclear Site. The hydrograph for this groundwater data is presented in Figure 2.3-14. Surface waters at four locations were also gauged as part of the monitoring program. These locations included the Make-Up Pond B, a water retention impoundment below the Make-Up Pond B, the Make-Up Pond A, and the Hold-Up Pond A. Based on data collected during this year of study, groundwater levels fluctuate an average of 4.4 ft., ~~with highest rising groundwater elevations observed between December~~ with rising groundwater elevations observed between December 2006 and April 2007 and declining groundwater elevations observed between May and November 2006. ~~This trend appears to correlate with both the river flow and rainfall patterns indicating that both groundwater levels and river flow are governed by local precipitation volume. This trend suggests a significant influence by evapotranspiration on groundwater levels.~~ The groundwater levels in the Piedmont typically decline during the late spring and summer due to evapotranspiration and rise in the late fall and winter when the evaporation potential is reduced (Reference 32).

2. Revise COLA Part 3, ER Chapter 2, Subsection 2.3.4, References, as follows:

   32. LeGrand, Harry E. Sr., *A Master Conceptual Model for Hydrogeological Site Characterization in the Piedmont and Mountain Region of North Carolina*, North Carolina Department of Environment and Natural Resources, Division of Water Quality, Groundwater Section, 2004.

Associated Attachments:

Attachment 9-1 Historical Precipitation National Oceanic and Atmospheric Administration (NOAA) and Lee Nuclear Site Data.

Attachment 9-2 Lee Nuclear Site Precipitation and Water Table Graphs

Attachment 9-3 LeGrand, Harry E. Sr., *A Master Conceptual Model for Hydrogeological Site Characterization in the Piedmont and Mountain Region of North Carolina*, North Carolina Department of Environment and Natural Resources, Division of Water Quality, Groundwater Section, 2004.

Lee Nuclear Station Response to Request for Additional Information (RAI)

Attachment 9-1 to RAI 9

Historical Precipitation National Oceanic and Atmospheric Administration (NOAA) and Lee Nuclear Site Data

Monthly Precipitation
Greenville-Spartanburg Area
From: NOAA Website, www.erh.noaa.gov/gsp/climate/gsppcp.htm
Last Accessed 8/15/2008

YEAR	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC	ANNUAL
1950	3.09	1.49	3.89	1.02	4.44	3.11	9.02	1.74	3.67	4.47	0.70	4.50	41.14
1951	1.59	2.32	5.25	3.70	0.52	4.61	4.86	7.02	8.85	1.10	2.23	7.71	49.76
1952	3.68	4.71	11.99	3.13	1.90	2.18	3.60	7.27	1.28	1.34	1.35	4.66	47.09
1953	5.16	7.29	4.47	3.09	2.57	1.78	4.27	5.66	6.94	0.49	1.10	6.74	49.56
1954	7.35	2.14	7.08	1.19	2.90	2.02	2.89	1.49	0.52	0.77	3.08	3.62	35.05
1955	2.74	4.01	3.15	6.03	4.46	3.27	7.00	1.01	2.42	3.72	2.73	1.05	41.59
1956	1.58	9.74	4.84	6.57	3.88	2.44	8.14	1.94	8.14	1.97	2.62	2.72	54.58
1957	5.15	4.20	3.62	4.82	2.66	3.61	0.58	3.94	7.09	2.65	7.59	3.56	49.47
1958	4.54	3.66	5.37	8.50	2.60	1.77	6.60	2.72	1.37	1.52	1.60	3.54	43.79
1959	2.74	3.08	5.53	5.88	5.63	1.41	7.04	3.55	8.20	7.32	1.64	3.28	55.30
1960	5.60	5.65	5.65	1.91	2.16	4.38	4.33	5.48	4.76	4.74	0.54	3.26	48.46
1961	2.39	8.34	4.54	4.84	2.60	4.24	5.03	8.46	1.49	0.90	2.94	10.10	55.87
1962	4.65	4.71	8.92	5.37	1.48	7.03	3.57	3.88	2.28	3.24	4.47	3.38	52.98
1963	3.93	3.25	9.66	5.95	3.06	4.73	2.46	1.16	4.68	0.24	4.19	3.78	47.09
1964	5.44	4.67	7.11	11.30	1.59	8.07	7.44	6.64	0.93	10.24	3.36	3.62	70.41
1965	2.39	5.22	7.60	4.93	1.09	8.62	3.13	3.57	2.32	3.60	2.82	0.37	45.66
1966	4.64	6.78	3.26	2.53	3.06	3.84	2.98	5.01	7.98	3.78	1.93	3.15	48.94
1967	3.97	3.32	1.98	2.36	4.97	4.87	3.86	7.51	2.05	2.35	3.50	7.40	48.14
1968	4.12	1.00	3.68	2.40	3.93	5.71	6.92	1.31	3.04	2.82	5.07	3.18	43.18
1969	3.94	5.24	4.56	7.18	1.93	9.59	3.17	6.53	3.68	2.38	2.24	4.60	55.04
1970	1.74	3.74	3.45	2.94	3.13	3.60	2.31	3.59	1.34	7.02	1.77	2.88	37.51
1971	3.33	7.43	5.52	3.09	5.72	2.19	5.64	2.44	3.28	9.51	4.22	3.79	56.16
1972	6.14	3.04	4.59	2.28	8.89	8.16	4.18	3.21	2.20	3.44	5.31	6.68	58.12
1973	4.33	4.88	8.73	4.04	5.59	3.87	3.70	2.03	7.56	0.98	1.34	7.55	54.60
1974	4.24	4.90	3.26	4.06	5.45	3.78	3.23	4.03	3.76	0.24	4.81	2.50	44.26
1975	5.42	5.78	8.64	1.14	7.81	5.39	4.79	3.21	11.65	7.45	3.98	3.07	68.33
1976	4.49	2.15	7.30	0.69	8.10	2.81	5.75	2.09	8.28	8.49	2.75	6.21	59.11
1977	3.53	2.00	8.47	3.23	2.71	2.88	0.80	4.99	9.44	6.39	4.43	3.55	52.42
1978	6.93	0.53	6.09	2.97	4.84	3.51	6.77	2.98	0.27	0.81	1.93	3.39	41.02
1979	7.19	6.11	4.19	10.15	5.69	3.74	8.66	4.34	7.50	3.33	3.91	1.25	66.06
1980	4.28	1.19	11.37	3.47	5.92	6.72	1.05	3.33	5.82	2.83	4.11	0.64	50.73
1981	0.29	3.86	3.22	0.88	4.15	1.29	5.30	1.17	2.08	4.40	1.66	7.19	35.49
1982	6.27	5.21	2.77	4.57	6.18	3.32	12.52	1.66	1.44	3.07	4.17	5.02	56.20
1983	2.70	5.26	6.26	4.66	5.80	4.67	1.13	3.27	3.59	3.05	5.29	8.45	54.13
1984	3.04	7.04	5.67	4.76	8.30	3.07	13.57	4.00	1.34	2.28	2.60	2.22	**57.89**
1985	4.94	4.29	1.13	1.31	2.42	2.85	6.96	5.93	1.62	4.55	7.52	1.44	**44.96**
1986	1.10	1.46	2.64	1.10	6.34	0.93	1.63	5.93	2.56	6.11	5.37	4.17	39.34
1987	4.65	7.33	5.01	2.30	1.31	6.68	3.58	2.79	3.33	0.37	2.81	4.62	44.78
1988	3.91	1.79	3.67	3.41	1.96	3.25	2.18	3.93	4.57	3.38	4.26	1.90	38.21
1989	1.51	4.93	4.48	3.15	3.64	6.00	5.11	4.71	5.42	3.10	3.74	4.76	50.55
1990	4.37	5.97	6.67	2.22	2.70	0.90	3.61	6.21	2.12	9.45	1.93	3.26	49.41
1991	4.72	2.24	5.82	5.65	6.37	1.72	5.74	9.02	1.44	0.24	1.39	2.90	47.25
1992	2.50	6.12	5.45	4.81	5.03	4.97	2.66	5.54	4.30	6.27	7.85	5.08	60.58
1993	7.19	3.56	10.27	2.91	3.08	0.17	0.75	0.87	1.71	2.07	3.73	2.94	**39.25**
1994	4.24	3.47	4.46	2.61	1.44	10.12	6.56	5.76	2.06	4.28	2.43	3.96	**51.39**
1995	6.42	5.08	2.30	1.58	4.53	4.84	2.69	17.37	2.13	5.96	5.13	2.05	60.08
1996	5.54	3.75	7.64	3.09	5.00	4.03	4.43	6.27	4.62	0.82	4.34	4.17	53.70
1997	4.82	6.07	2.67	4.11	3.37	6.02	6.02	0.92	3.26	4.85	3.70	4.25	50.06
1998	6.76	6.94	4.31	9.15	1.77	3.80	3.27	2.27	4.31	2.77	2.39	4.24	51.98
1999	3.84	2.84	2.33	3.95	1.37	4.67	1.95	0.79	3.04	5.86	2.67	2.62	35.93
2000	3.72	1.87	4.35	4.70	2.19	1.31	5.23	1.42	4.24	0.00	4.06	1.95	35.04
2001	3.01	2.31	6.69	1.10	2.14	3.77	6.01	1.01	6.74	3.39	1.98	2.23	40.38
2002	4.86	1.39	5.11	0.74	3.84	0.52	4.41	4.23	7.20	4.66	4.42	6.47	47.85
2003	1.91	4.02	6.71	7.13	7.64	6.24	8.03	11.34	1.72	2.07	3.64	2.66	63.11
2004	1.36	4.52	1.26	1.84	3.33	5.32	4.74	3.19	11.12	0.89	3.65	6.48	**47.70**
2005	1.47	3.16	5.79	3.41	3.92	9.99	8.85	3.66	0.16	4.12	3.79	4.82	**53.14**
2006	3.81	1.19	1.34	3.60	1.22	5.18	2.52	6.48	3.96	4.58	3.58	4.34	41.80
2007	4.67	2.42	3.70	1.82	1.56	3.21	2.99	1.78	1.31	1.58	0.89	5.15	31.08
2008	2.28	3.83	4.34	4.11	1.88								
Avg Since 1950	4.00	4.14	5.25	3.82	3.79	4.19	4.76	4.20	4.04	3.52	3.33	4.05	49.18

Precipitation measured in inches.

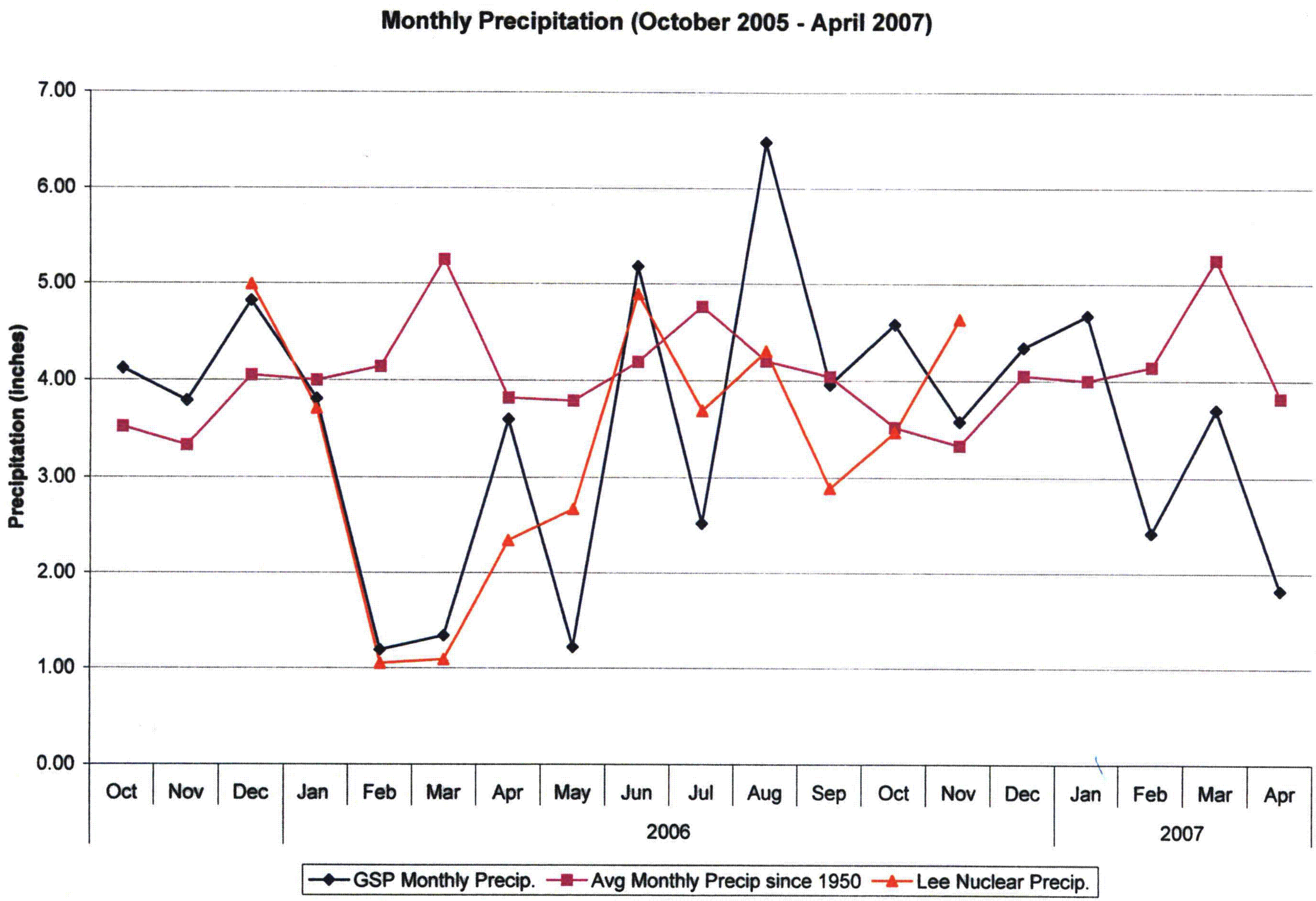
p.173 mm

Monthly Precipitation
Greenville-Spartanburg Area

From: NOAA Website, www.erh.noaa.gov/gsp/climate/gsppcp.htm
Last Accessed 8/15/2008

		Monthly Precipitation (in.) from Greenville-Spartanburg Area (GSP)	Average Monthly Precipitation (in.) Based on GSP data collected since 1950 (see page 1)	Lee Nuclear Precipitation (in.)
2005	Jan	1.47		
	Feb	3.16	4.14	
	Mar	5.79	5.25	
	Apr	3.41	3.82	
	May	3.92	3.79	
	Jun	9.99	4.19	
	Jul	8.85	4.76	
	Aug	3.66	4.20	
	Sep	0.16	4.04	
	Oct	4.12	3.52	
	Nov	3.79	3.33	
	Dec	4.82	4.05	4.99
2006	Jan	3.81	4.00	3.71
	Feb	1.19	4.14	1.05
	Mar	1.34	5.25	1.09
	Apr	3.60	3.82	2.34
	May	1.22	3.79	2.67
	Jun	5.18	4.19	4.89
	Jul	2.52	4.76	3.69
	Aug	6.48	4.20	4.30
	Sep	3.96	4.04	2.89
	Oct	4.58	3.52	3.47
	Nov	3.58	3.33	4.63
	Dec	4.34	4.05	
2007	Jan	4.67	4.00	
	Feb	2.42	4.14	
	Mar	3.70	5.25	
	Apr	1.82	3.82	
	May	1.56	3.79	
	Jun	3.21	4.19	
	Jul	2.99	4.76	
	Aug	1.78	4.20	
	Sep	1.31	4.04	
	Oct	1.58	3.52	
	Nov	0.89	3.33	
	Dec	5.15	4.05	
2008	Jan	2.28	4.00	
	Feb	3.83	4.14	
	Mar	4.34	5.25	
	Apr	4.11	3.82	
	May	1.88	3.79	
	Average	**3.53**	**4.09**	**3.31**

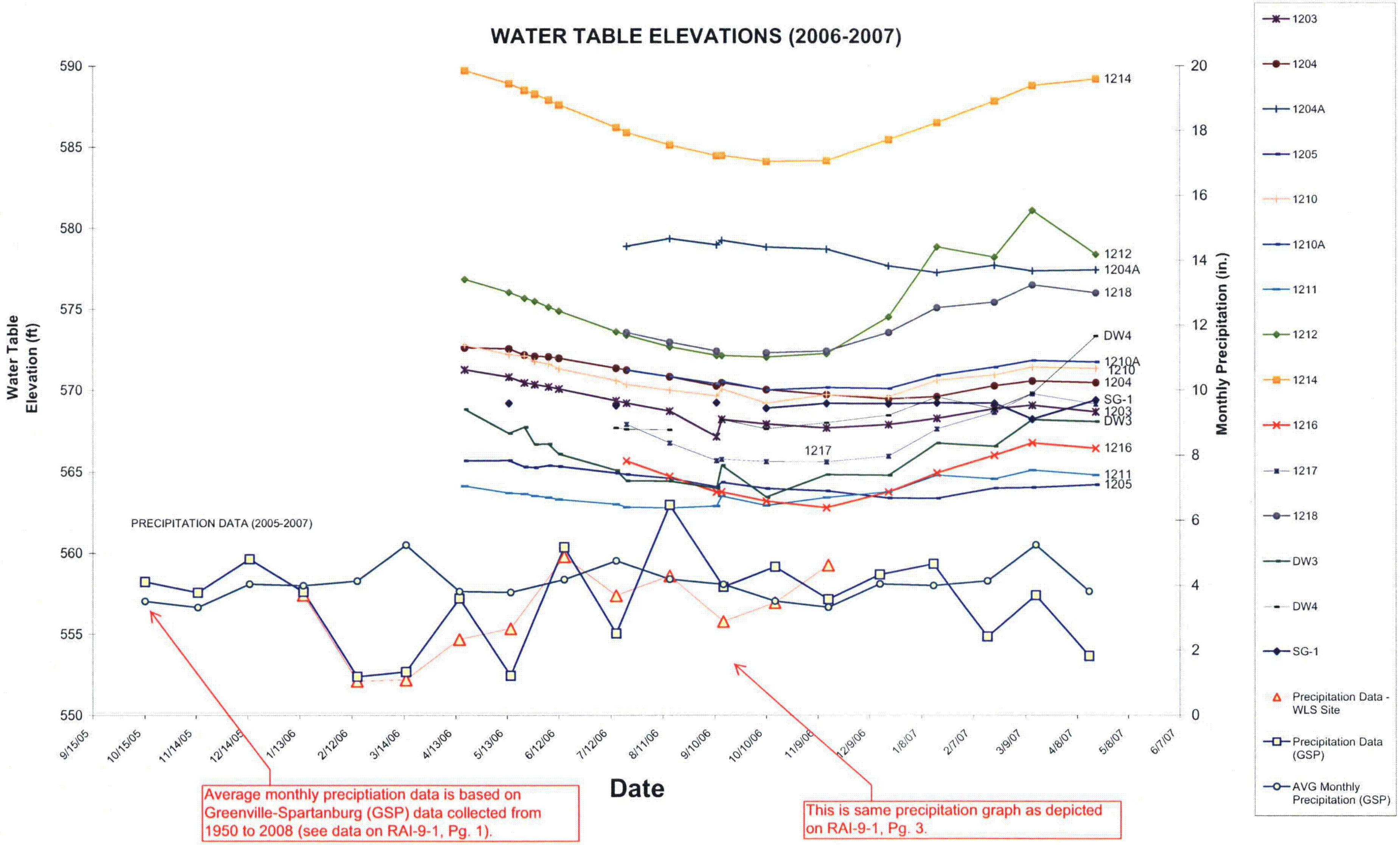
p.213 MM


Monthly Precipitation (October 2005 - April 2007)
7.00
6.00
5.00
4.00
3.00
2.00
1.00
0.00
Precipitation (inches)
Oct
Nov
Dec
Jan
Feb
Mar
Apr
May
Jun
Jul
Aug
Sep
Oct
Nov
Dec
Jan
Feb
Mar
Apr
2006
2007
GSP Monthly Precip.
Avg Monthly Precip since 1950
Lee Nuclear Precip.

Lee Nuclear Station Response to Request for Additional Information (RAI)

Attachment 9-2 to RAI 9

Lee Nuclear Site Precipitation and Water Table Graphs


WATER TABLE ELEVATIONS (2006-2007)
Water Table Elevation (ft)
Monthly Precipitation (in.)
Date
PRECIPITATION DATA (2005-2007)
1214
1212
1204A
1218
DW4
1210A
1210
1204
SG-1
1203
DW3
1217
1216
1211
1205
1205
Precipitation Data - WLS Site
Precipitation Data (GSP)
AVG Monthly Precipitation (GSP)
9/15/05
10/15/05
11/14/05
12/14/05
1/13/06
2/12/06
3/14/06
4/13/06
5/13/06
6/12/06
7/12/06
8/11/06
9/10/06
10/10/06
11/9/06
12/9/06
1/8/07
2/7/07
3/9/07
4/8/07
5/8/07
6/7/07
Average monthly preciptiation data is based on Greenville-Spartanburg (GSP) data collected from 1950 to 2008 (see data on RAI-9-1, Pg. 1).
This is same precipitation graph as depicted on RAI-9-1, Pg. 3.

Lee Nuclear Station Response to Request for Additional Information (RAI)

Attachment 9-3 to RAI 9

LeGrand, Harry E. Sr., *A Master Conceptual Model for Hydrogeological Site Characterization in the Piedmont and Mountain Region of North Carolina*, North Carolina Department of Environment and Natural Resources, Division of Water Quality, Groundwater Section, 2004

A Master Conceptual Model for Hydrogeological Site Characterization in the Piedmont and Mountain Region of North Carolina

A Guidance Manual

North Carolina Department of Environment and Natural Resources
Division of Water Quality
Groundwater Section

Prepared for the Groundwater Section

by

Harry E. LeGrand, Sr.
Independent Hydrogeologist

2004

Preface

Contrary to prevailing thoughts and practices, much knowledge about groundwater conditions at almost any site in the Piedmont and Mountain Region of North Carolina can be developed for practical use before new data are collected. Bringing into focus some useful knowledge gained and recast from past studies can offer optimal value in virtually seeing much of what is under ground at any place. This manual attempts to demonstrate that interested persons can gain knowledge quickly at an early stage of investigation.

Groundwater in the Piedmont and Mountain Region of North Carolina occurs in a complex underground environment that is difficult to understand and explain. Adding to the complexities is a variety of reactions that occur as water is withdrawn from wells or as man modifies the natural settings. It is not surprising that in many cases some problems and serious consequences of human actions occur before useful knowledge can be applied.

Groundwater occurs almost everywhere throughout the Region, not in a single, widespread aquifer, but in thousands of local aquifer systems and compartments that have similar characteristics and are hydraulically connected. Interspersed among water-supply wells are at least an equal number of waste sites or contaminated zones beneath land surface. Some environmental problems are known to exist. Others are unrecognized and may reach serious proportions. Wherever activities involving groundwater exist, there are likely degrees of concern about problems that could occur. Unanswered questions prevail.

Trying to sort out favorable and unfavorable actions related to groundwater is essential, but elements of contrariness are commonly involved in considering actions and reactions. For example, relatively low-yield wells on nearly flat, populated uplands in the Piedmont tend to compete for space under ground with nearby waste sites and contamination zones. High-yielding wells are more likely in adjacent, low topographic positions, but are likely to be inconvenient for human use and may be in the path of contaminated groundwater from upland areas. The opposite conditions occur in the Mountains, where the population and groundwater activity are chiefly in the valleys. Striving for favorable conditions in the environmental mix with unfavorable conditions places constraints and limitations on proper human actions and decisions. Some types of constraints and serious undesirable consequences have not been fully studied. Ideal regulatory measures are difficult to achieve.

Rather than trying to focus on solving specific problems, this manual puts forward some key generalizations, or scientific rules of thumb that should help interested persons gain a basic understanding of some groundwater features common to the Region. In doing so, the report brings into play many useful, imprecise statements that are difficult to express with precision-oriented approaches. The proposed methodology should enable an investigator to forge ahead at the earliest opportunity with the best information available.

Many useful studies of the Region have been made, but they have not completely jelled in a form for widespread use. In spite of misgivings and shortcomings, we attempt to improve overall knowledge of many groundwater activities and problems in the Region.

The manual is written in common narrative language without quantitative values and equation-based expressions. Although planned chiefly for groundwater specialists, much information should be understandable and useful to others. The manual contains concise, synthesized scientific information that can be expanded by logical reasoning. The typical local system can serve as a generic, or master, conceptual model for all other local systems without the need to collect new data at each locality during the early stages of study. Good reasoning and expressions in narrative language are stressed.

How are benefits derived from use of this manual? Study of the manual and reasoning from the generalizations should offer some useful information. By using the methodology a trained groundwater specialist can prepare a reliable early-stage report of conditions for a setting in a brief period of time, at little or moderate cost, without relying on specific data. This needed approach has been lacking. In spite of an assertion here that more good information can be readily disclosed, modesty is almost everywhere needed because knowledge about the groundwater system must be expressed in imprecise and qualified terms. Inherent vagueness and uncertainty can be reduced readily but rarely eliminated.

Harry E. LeGrand, Sr.
February 2004

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Figures

Tables

Appendix

A Master Conceptual Model for Hydrogeological Site Characterization In the Piedmont and Mountain Region of North Carolina

A Guidance Manual

Introduction

Public and private interests have directed much effort, often at great cost, toward the study and application of remedies to existing and potential groundwater related problems in the Piedmont and Mountain Region of North Carolina. Yet, these efforts represent only a small fraction of the problems, potential problems, and concerns that prevail. A better distribution of work and funding is critically needed, and a greater understanding of groundwater conditions in the region is required for proper management of groundwater related issues. A method of developing an early-stage conceptual model of key groundwater conditions is needed.

The purpose of this manual is to present a new method to help interested persons understand groundwater conditions in the Region. A challenge to any method is the fact that the geologic settings in the Region are very complex. The proposed method relies on extensive use of conventional language and reasoning to develop an understanding of site groundwater conditions without the collection of new data. The manual is planned chiefly for use by groundwater specialists but should benefit interested non-professionals as well.

It may seem strange that the method is designed for both specialists in groundwater and others having limited knowledge of the science. The narrative language and reasoning allows the interested individual to assemble bits of information, sort, and integrate them to develop a reasonable picture of various groundwater conditions. For example, using the conceptual model, one may observe a nearly flat wetland and reason that the water table is near land surface, and that the wetland is underlain by relatively impermeable material, such as clay or poorly fractured rock.

By using this manual groundwater specialists can broaden their reasoning power to see how many factors interplay to form a reasonable, preliminary conceptual model. The specialists should be able to express the results of their reasoning in narrative language, which can be more understandable than mathematical and technical language. The specialists should be able to prepare a two- to five-page informal report of conditions at a site that approximates the state-of-the-art understanding. LeGrand and Rosen (2000) refer to this type of report as a Prior Conceptual Model Explanation (PCME).

At the core of the method are 25 key statements, or generalizations, that encapsulate much needed knowledge and from which many useful inferences may be generated. The generalizations are somewhat similar to laws of other sciences, such as physics and chemistry, although, by correctness and necessity, they are not universal in application but are expressed in imprecise and qualified terms. Their value lies in their interrelationship and associated inferences, which often results in the creation of more knowledge. The key generalizations and inferences derived from them constitute the master conceptual model.

Although many excellent studies of groundwater in the Region have been conducted, they typically provide specific data and expansive information about local sites and areas. Though helpful, they may not be adequate for public needs. The prevailing effort and mindset has been to put early emphasis on the collection of new data for processing by precision-oriented mathematical methods and routine interpretations. The process is commonly directed from an arena of rigid regulatory procedures. Being time consuming and costly to varying degrees, studies and investigations relying on this process can only cope with a small fraction of the problems and questions needing attention.

To some extent, the mathematical approach is based on the assumption that the computational results of data from the Piedmont and Mountain groundwater system are equivalent to the results derived from data from porous, granular aquifer material, such as is typical of the Coastal Plain. This precision-oriented approach can be pretentious or misleading when applied to the complex geology of the Region. Moreover, this approach is difficult to understand for those not trained in hydrogeology. Thus, the distribution of useful information to the public has been limited. In this manual, the main effort is directed toward making optimal use of imprecise information.

Missing from the work being done is a knowledge base that can be widely applied. The method proposed here derives optimal value from past experience and knowledge for application at an early stage in the evaluation of a site.

Acknowledgements
The author wishes to thank the many members of the North Carolina Department of Environment and Natural Resources, the Raleigh District Office of the U.S. Geological Survey, and Ralph Heath, consulting hydrogeologist, for their assistance in the critical review of this manual. Special thanks are extended to Perry Nelson, who assisted the author throughout the preparation of the manuscript, particularly in confirming the validity of the generalizations and their application. The author also wishes to thank Walter Haven, of the Groundwater Section, for his assistance in the preparation of the manual, and Carl Bailey, Assistant Chief of the Groundwater Section, for his sponsorship and continuing support of the project.

Use of Generalizations and Connecting Inferences

Twenty-five generalizations represent the core of the method by which a broad understanding of the groundwater conditions can be generated. They have been reproduced, with modifications, from a paper (LeGrand, 1992) included in a symposium volume published by Clemson University (Daniel and others, editors, 1992). The generalizations have been developed from many years of study by experienced groundwater specialists and are drawn chiefly from various reports included in the references listed at the end of this document. The generalized statements were developed by a combination of statistical studies, observations, and logical deductive reasoning. The skillful and intensive studies by Charles C. Daniel, III, of the U.S. Geological Survey, in the past two decades have verified almost all of the general statements, as indicated in his referenced published reports. The studies conducted by Ralph Heath have also contributed greatly to the development of the generalizations.

Most of the generalizations are expressed in the form of tendencies because precise information at a particular place is not likely to be known. The generalizations provide a reservoir of background information from which inferences can be exploited for optimal value.

Values of various parameters and factors are needed in the evaluation of a site. Although specific values from measured data have appeal and are needed in quantitative studies, they may not fit in this practical, early-stage method. Rather, the values selected are imprecise estimates from a range of conditions. If the approximate value of one factor is not easily known, connective inferences of the other factors can help to estimate an acceptable value.

Each generalization need not stand alone for routine interpretation. An inference derived from a generalization can be connected to another inference of the same generalization or another associated generalization. For example, a view of a specific topographic setting likely reveals the (1) direction of groundwater flow, (2) concentration or divergence of flow, (3) approximate hydraulic gradient, (4) area of groundwater discharge, (5) depth to the water table at various positions, and (6) inklings of the relative distribution of permeability.

The interplay of cause and effect relations can be compounded and anchored to many generalizations. The generalizations and various inferences can be linked and connected to reveal a true conceptual model. The linkage is not of a decision tree or single-chain type that can be simply weakened or broken. Rather, the linkage is derived from a matrix of various generalizations and inferences that form a pictorial fabric. If one or more inferences do not fit, the situation is re-examined and flagged as an anomaly or error. There can be almost interlocking proof that a conceptual model constructed in this manner is reliable and fairly expansive in broad interpretations.

Benefits of Conceptual Model Application

The following benefits may be expected from application of the Master Conceptual Model:

- Assisting in early-stage planning of hydrogeological investigations.
- Screening contamination sites for priority ranking.
- Reducing costs of site studies.
- Assisting in wellhead protection studies.
- Providing information in the early stages of environmental audits and brownfield studies.
- Providing early orientation on possible remedial action.
- Providing a basis for early-stage risk assessments.

- Estimating potential for natural attenuation at groundwater contamination sites.
- Providing insight to prevent purely mechanical interpolation and extrapolation of hydrogeologic information.

Description of the Region

As shown in Figure 1, North Carolina includes parts of three physiographic provinces: the Atlantic Coastal Plain, Piedmont, and Blue Ridge (Fenneman, 1938). All of North Carolina, west of the Coastal Plain, lies in the Piedmont and Blue Ridge Provinces. They include all or part of 65 of the state's 100 counties and a population of over six million, of which approximately 47 percent rely on groundwater as a source of water supply. The authors have taken the liberty of referring to the two provinces as "the "Region," and to the Blue Ridge Province as the "Mountains."

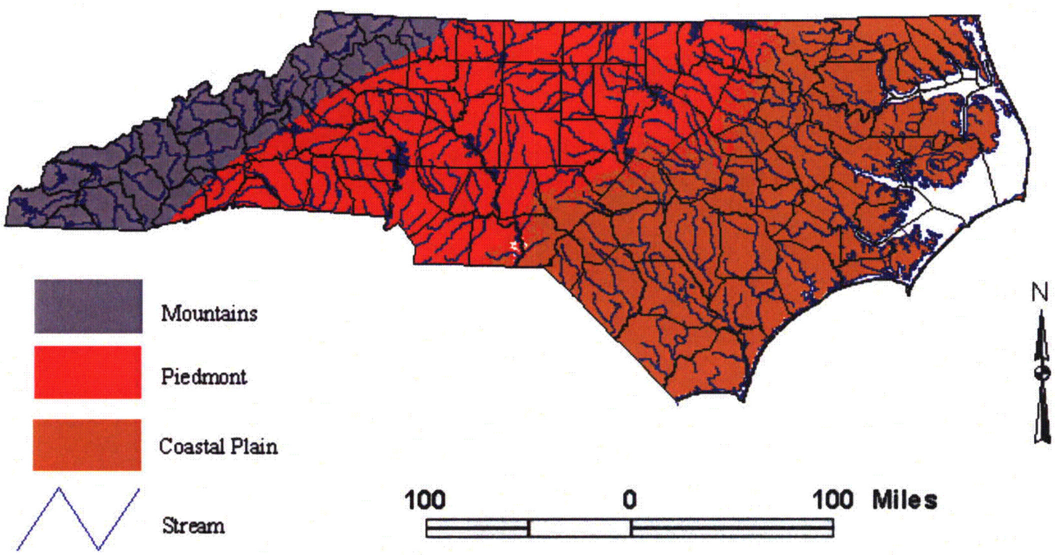

Figure 1. Physiographic provinces in North Carolina.

Physiography

In North Carolina the Piedmont extends from its boundary with the Coastal Plain westward to the escarpment of the Blue Ridge Mountains, a distance of 150 to 225 miles. It is characterized by gently rolling hills rising from a base altitude of about 300 feet above mean sea level at its eastern boundary, to about 1500 feet at the foot of the Blue Ridge escarpment. Topographic relief, from stream valley to ridge top, ranges from 75 to 200 feet. Scattered across the province are remnants of ancient mountains that have resisted erosion and now stand from 500 to 1,500 feet above the surrounding terrain.

The Mountains extend from the base of the Blue Ridge escarpment, west into Tennessee, a distance of from 30 to 120 miles, where they border the Valley and Ridge Province. They comprise an area of rugged, forested slopes rising from an altitude of about 1,500 feet at the base of the escarpment, to over 6,000 feet among the highest mountain peaks. Of the many rivers that drain the mountains, all but three, the Broad, Catawba, and the Yadkin-Peedee, rise on the western side of the eastern continental divide and flow generally northwest towards the Tennessee River. It is interesting to note that the rural population in the Mountains tends to congregate in the valleys, while in the Piedmont, communities are generally found along the ridgelines. From the standpoint of hydrogeology such positioning of rural homes and communities could have important implications.

Geology

The geology of the Region is complex and includes representatives of all of the three main classes of rocks; igneous, metamorphic, and sedimentary. Of these, metamorphic rocks predominate. Among the metamorphic rocks, gneiss, schist and metamorphosed granitic rocks are the most prevalent. Quartzite, slate, phyllite, argillite, and marble are less widely distributed. Intrusive igneous rocks, such as granite, diorite, and gabbro are significant, but account for only about 6 percent of the area (Daniel and Dahlen, 2002). Over geologic time all or part of the region has experienced uplift, folding and faulting, alteration, and erosion.

The major rock units occur as northeast trending belts, corresponding to the trend of the regional geologic structure. Four sedimentary basins, formed during the Triassic and Jurassic Periods, occur in a southwest-northeast trending belt across the Piedmont. As this report pertains primarily to areas underlain by igneous and metamorphic rocks, a discussion of the Triassic sediments is excluded.

Throughout the Region, bedrock is overlain by a mantle of unconsolidated material known as regolith. The regolith includes, where present, the soil zone, a zone of weathered, decomposed bedrock known as saprolite, and alluvium. Saprolite, the product of chemical and mechanical weathering of the underlying bedrock, is typically composed of clay and coarser granular material up to boulder size, and may reflect the texture of the rock from which it was formed. Thus, the weathering product of granitic rocks may be quartz-rich and sandy-textured, whereas rocks poor in quartz and rich in feldspar and other soluble minerals form a more clayey saprolite. Alluvial and terrace deposits are generally restricted in area and thickness and represent a very small fraction of the geology of the region.

Hydrogeology

The main characteristics of the hydrogeology of the Region are highlighted in the lists of generalizations found on later pages.

The groundwater system in the region is essentially a two-part system (Figure 2) comprised of the regolith and the underlying bedrock.

The regolith, which may have a porosity ranging from 35 to 55 percent (Heath, 1980), serves as the principal storage reservoir for the underlying bedrock. Precipitation infiltrates the regolith until it reaches the saturated zone, typically in saprolite, where it is stored as groundwater in inter-granular pore spaces. Where saprolite is very thin, the saturated zone may be entirely contained in fractured bedrock.

In many locations, the regolith includes a transition zone between saprolite and fractured bedrock. The transition zone consists of coarse fragments of partially weathered bedrock and lesser amounts of saprolite (Daniel and Dahlen, 2002).

Some groundwater moves through the regolith and into interconnected fractures in the underlying bedrock while another component flows through the regolith parallel to the bedrock surface (Figure 3). The destination of both components is an area where groundwater discharges as seepage into streams, lakes, or other surface water bodies, and also as evapotranspiration in lowland areas.

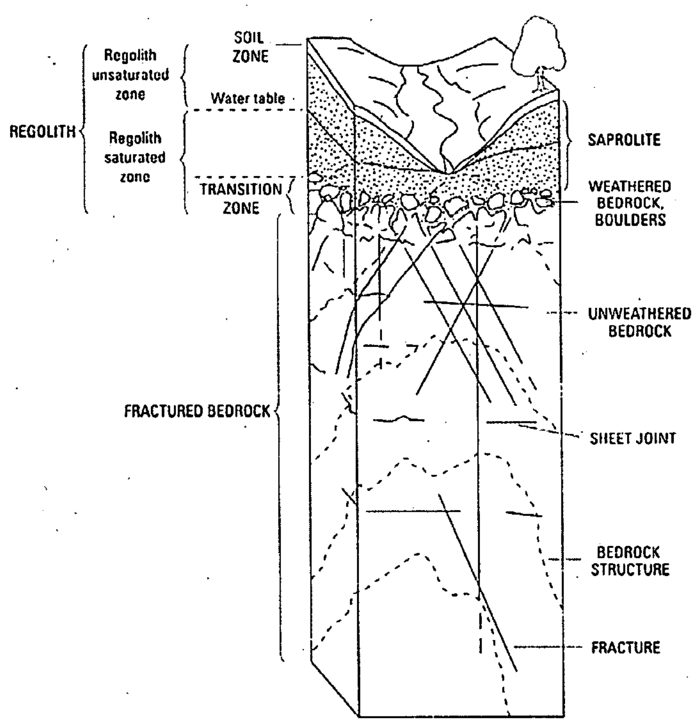

Figure 2. Diagram showing the principal components of the groundwater system in the Piedmont and Mountain Region of North Carolina. (from Harned and Daniel, 1992)

The Master Conceptual Model

In the event of groundwater contamination, or threat of contamination, it is imperative to assess rapidly the effect on groundwater users and inform them of the nature and severity of the incident. In the likely event that multiple incidents compete for attention, priority must be determined swiftly in order to minimize the threat to human health and the environment.

The Master Conceptual Model is designed to create a plateau of knowledge of the hydrogeology of the Region in the early stage of site characterization, not dependent upon acquisition of new data. The model thus developed establishes a sound foundation for more detailed studies and provides an early indication of site vulnerability and sensitivity.

Fortunately, significant knowledge exists concerning the occurrence and movement of groundwater in the Piedmont and Mountain Region. From this body of knowledge, certain conclusions have been reached regarding the groundwater system. Where individual sites have geologic and terrain characteristics in common, conclusions concerning groundwater conditions may be drawn that are applicable to most sites sharing those features. These common characteristics are referred to as "generalizations."

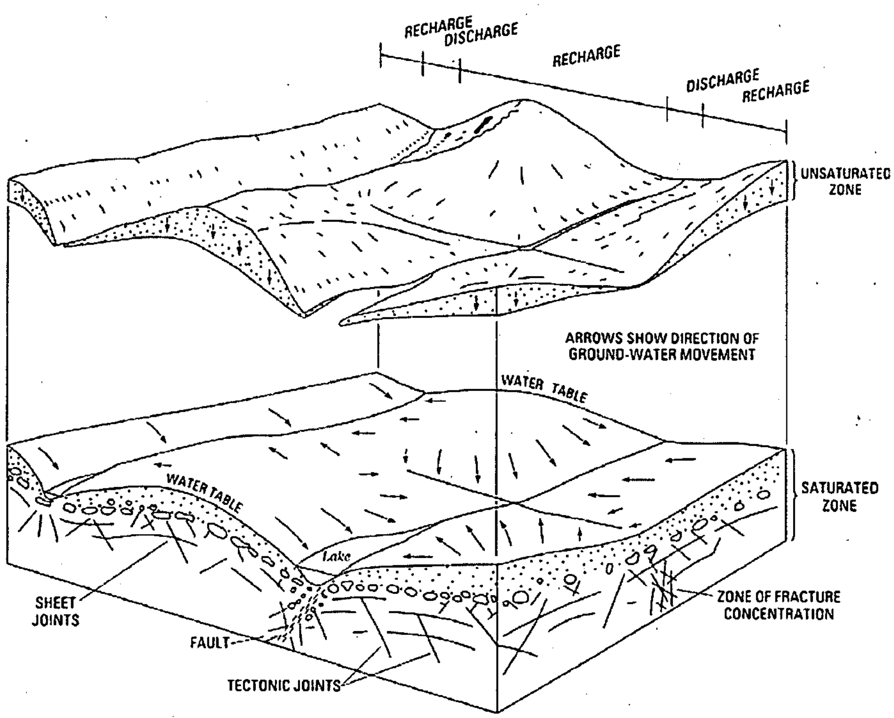

Figure 3. Diagram showing a conceptual view of the groundwater flow system in the Piedmont and Mountain Region of North Carolina. (from Daniel, 1990)

Armed with a foreknowledge of conditions affecting a site, it is possible to develop a rational estimate of site conditions before the first test boring is advanced, allowing specific additional data needs to be defined more accurately and acquired at the least cost and in the most timely manner.

Key Generalizations

A generalization may be defined as an inductive conclusion stating that something is true about all or some members of a class. Some generalizations, such as in Darcy's law, are considered universal, and are applicable in almost all situations. Many universal generalizations are derived directly from physics and chemistry and can be translated into mathematical form for application. Non-universal generalizations, such as those offered herein, have their basis in empirical knowledge derived from decades of field observations by trained investigators. They may be applicable in every conceivable geologic setting and are necessary for proper interpretation and expression.

Generalizations may be used in the absence of typical site-specific data such as soil borings, test wells, cores, and geophysical surveys, to establish a reasonable level of knowledge about a site. On the strength of that knowledge, decisions may be reached regarding such factors as water-table depth, direction of groundwater flow, hydraulic gradient, recharge potential, and groundwater vulnerability. The generalizations may form the foundation for locating and designing monitoring wells, as well as production or recovery wells, and may indicate the need for the provision of alternative water supplies to local users.

It is important to understand that the generalizations presented in this report have limitations in their application and, in many circumstances, must be augmented with traditional investigative methods, such as drilling or geophysical technology. -

The following generalizations, grouped into those associated with natural conditions and those resulting from man's activities, are directly applicable to the Piedmont and Mountain Region. Most of the generalizations associated with natural conditions are products of geologic processes and are interrelated in varying degrees (Figure 4).

Generalizations Associated with Natural Conditions

The following generalizations are associated with natural conditions. Additional commentary follows the generalizations where appropriate.

N-1. ROCK TYPES

> *Igneous and metamorphic rocks are closely interspersed throughout most of the Region. Geologic maps at various scales show the distribution of rock types, which tend to have locally erratic outcrop and subsurface distribution patterns, but regionally trend generally northeast-southwest. Although the igneous rocks are predominantly granite, subordinate amounts of diorite and gabbro are widespread. Metamorphic rocks, chiefly gneiss and schist, are common and tend to be folded and faulted extensively. Argillites occur extensively in the southeastern Piedmont.*
>
> *As the bedrock is characterized by fracture-type permeability,*

some general knowledge of the fracture characteristics of the predominant rock type in a specific area or site is desirable. Fortunately, indirect evidence of the degree of fracturing of a particular rock may be derived from terrain analysis, chiefly soil thickness and topographic expression. In most places, massive granite and gabbro have thin soils and are poorly fractured, whereas gneiss and schist have thicker soils and moderate to relatively high fracture densities.

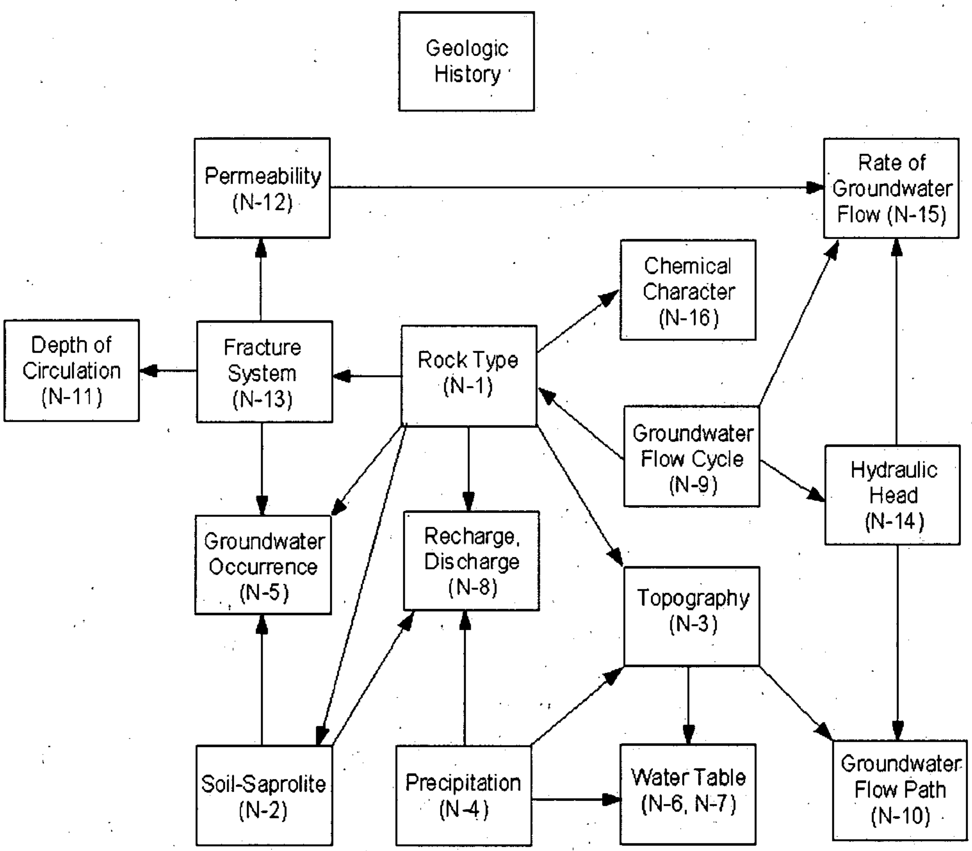

Figure 4. Diagram showing some interrelationships of key generalizations. Arrows indicate significant influence of one characteristic (generalization) on others. Numbers in parenthesis correspond to numbered generalizations in text.

As igneous and metamorphic rocks have little or no primary porosity, their importance as sources of groundwater is dependent upon the extent to which they have developed, or have the potential to develop, secondary porosity in the form of fractures and solution openings. Daniel (1989) developed a hydrogeologic classification based on the origin, composition and texture of rocks and their water-bearing potential. His statistical analysis of 4,815 wells (excluding those in the Triassic basins) indicated that the highest average yields occurred in wells constructed in schist, phyllite, and undifferentiated metavolcanics. Lowest average yields occurred in argillite and metavolcanic tuffs.

N-2. SOIL–SAPROLITE

Soil and soft, highly weathered rock, known as saprolite, overlie bedrock in most places. The soil-saprolite and the underlying fractured bedrock represent a composite water-table aquifer system. There are no underlying aquifers. The thickness of the soil-saprolite zone varies according to the type of parent rock, topography, and geologic history. Saprolite thickness ranges from zero to as much as 100 feet in some places. In the Piedmont, the zone is usually thicker beneath broad upland areas than in valleys. In the Mountains, ridge tops and upper slopes generally have thin soil-saprolite zones due to the resistant nature of the underlying, ridge-forming bedrock. A soil-saprolite zone only a few feet thick may suggest poorly fractured rocks below, especially in the Piedmont.

A transition zone of partially weathered rock may occur at the base of the regolith between the soil-saprolite and unweathered bedrock (Stewart and others, 1964; Nutter and Otten, 1969; Harned and Daniel, 1992). A transition zone is a zone of relatively high permeability resulting from incomplete mechanical and chemical alteration of the bedrock. It may be composed of rock fragments of varying size, depending upon the composition of the parent rock, and generally contains less clay than the overlying saprolite. The transition zone may serve as a zone of rapid flow within the fractured rock system and may also be a conduit for the transmission of contaminated groundwater to a well or other point or area of discharge. The concept of the transition zone is useful in distinguishing between distinctive soil-saprolite and unweathered bedrock. The zone may thicken and thin within short distances, and upper and lower boundaries may be difficult to identify. Thus, establishing a reasonable thickness or the degree of permeability within an area of a few acres is arbitrary. Figure 2 illustrates the relationship between the transition zone, soil-saprolite, and bedrock.

N-3 TOPOGRAPHY

The topography of the Piedmont is characterized by hills and valleys; the hills commonly having gentle, rounded slopes. A close network of perennial streams prevails, and in most inter-stream areas a perennial stream is within 3,000 feet. The topography of the Mountains is more rugged, and typified by steep, forested slopes.

Subtleties or extremes of terrain and vegetation may limit visual analysis of site physiography. A topographic map reveals in detail the arrangement of landscape features such as surface water bodies, hills, ridges and valleys, slope steepness, population centers, and isolated structures. It also may provide evidence of land-use practices and geological features such as rock type and bedrock fractures. A topographic map of a scale of 1:24,000, or larger, is essential to a preliminary site evaluation using the conceptual model. The evaluation of some sites may be improved by enlarging a

1:24,000 map to 1:6,000 scale. The maps may also be used to determine the direction of groundwater movement and provide estimates of water table depth and velocity of groundwater movement.

N-4 PRECIPITATION

Precipitation, the source of groundwater recharge, averages 3.0 to 3.5 inches per month in the Piedmont and 4.0 to 4.5 inches per month in the Mountains. Extreme variations in precipitation occur locally, especially in the southwestern Mountains where more than 80 inches per year has been recorded.

As shown in Figure 5, annual precipitation ranges from less than 40 inches per year in the central Piedmont to more than 80 inches per year in the southwestern mountains (Daniel and Dahlen, 2002).

In much of the Region the annual distribution of precipitation is fairly even throughout the year; yet, the three- or four-inch average monthly precipitation can be misleading. Droughts and floods are common. Droughts tend to reduce greatly groundwater storage in the soil-saprolite zone to the extent that many wells may produce less water or fail completely. Also, a decline in groundwater discharge to streams and lakes during droughts severely affects surface-water supplies. During periods of excessive precipitation, the high stage of the water table can flood some buildings and adversely affect certain human activities.

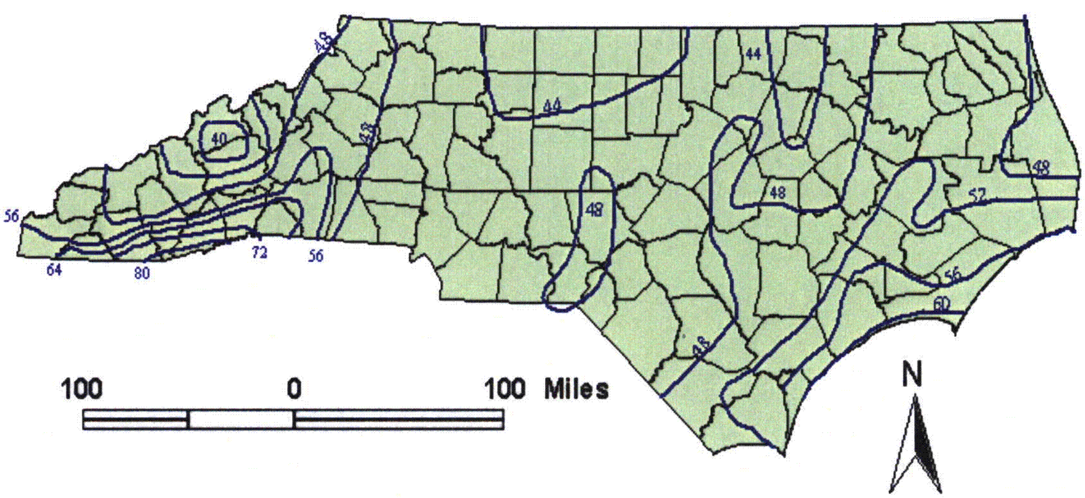

Figure 5. Distribution of mean annual precipitation in North Carolina. (isohyetal lines in inches)

N-5 GROUNDWATER OCCURRENCE

Groundwater occurs in two contrasting media: (a) clayey, granular soil-saprolite that typically becomes less clayey with depth and (b) underlying *fractures and other planar openings in bedrock (Figure 2). The soil-saprolite zone is capable of storing water readily, but transmits it slowly. In contrast, the bedrock fracture system has a relatively low storage capacity but is capable of transmitting water readily where interconnecting fractures occur (Figure 6).*

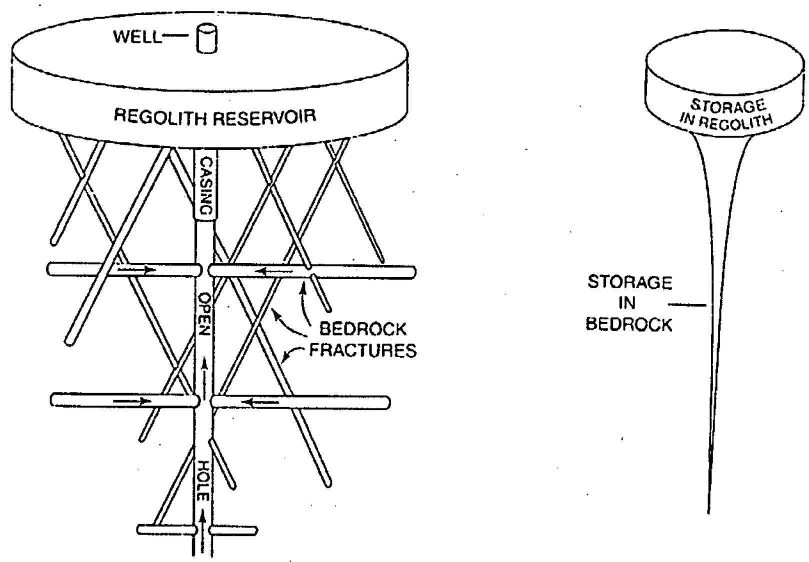

Figure 6. Diagram showing the relative storage and transmission capabilities of the Piedmont and Mountain groundwater system. (modified from Heath, 1984)

The extent to which bedrock functions as a source of water supply to wells depends upon precipitation, the permeability and saturated thickness of the overlying regolith, and the density and interconnection of bedrock fractures. Because igneous and metamorphic rocks consist of interlocking crystals, primary porosity is very low, generally less than three percent. Secondary porosity of crystalline bedrock results from weathering and fracturing and generally ranges from one to ten percent (Freeze and Cherry, 1979) but according to Daniel and Sharpless (1983), porosity values of from one to three percent are more typical. Daniel (1990) reported that the porosity of the regolith ranges from 35 to 55 percent near land surface but decreases with depth as the degree of weathering decreases.

N-6 DEPTH OF WATER TABLE

The water table is near land surface in valleys and as much as 30 to 50 feet below land surface beneath hills. The range of seasonal fluctuation of the water table is as little as two feet in valleys, but may exceed ten feet beneath hills.

Although precipitation is relatively evenly distributed throughout the year, the water table fluctuates noticeably, rising during the winter to an annual high in April or May, and declining steadily during the summer and fall as a result of evapotranspiration (Figure 7).

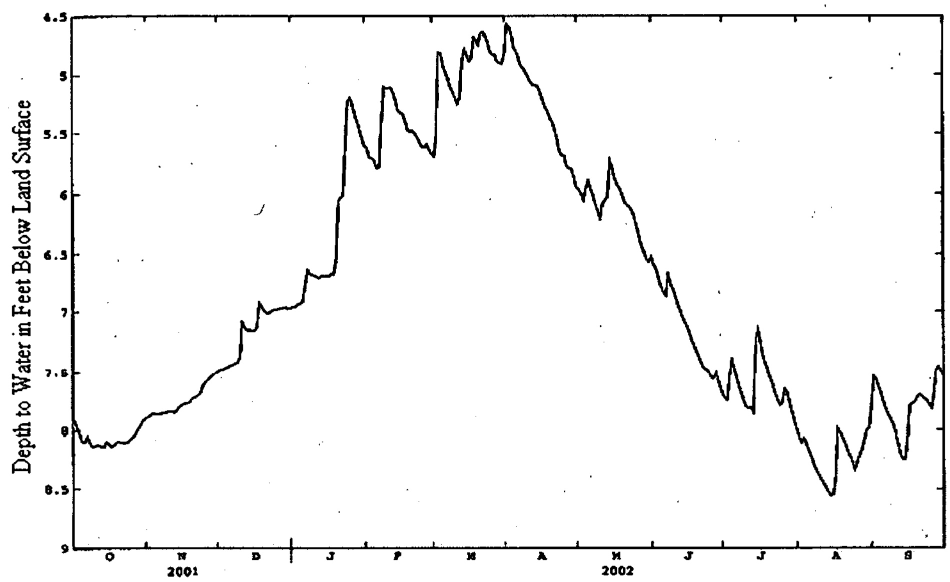

Figure 7. Hydrograph of USGS observation well NC 146, Mecklenburg Co., NC, for the 2002 water year. (USGS, 2003)

During the coldest months of the winter and early spring, a lack of evaporation and plant use allows water levels to recover.

N-7 *WATER TABLE CONFIGURATION*

Streams are linear "lows" in the water table, representing the intersection of the water table and the land surface. Under natural conditions the topography of the water table is crudely similar to that of the land surface, but has less relief (Figure 3).

One may construct synthetic water-table maps without water-table measurements from wells by using USGS 7.5 minute topographic maps scaled at 1:24,000. If possible, the map scale should be increased to 1:12,000 or greater. The maps may be constructed by extrapolating upward from the known elevations along the course of a perennial stream (the points at which topographic contours cross streams) to the hilltop, where the water table is likely to range from 30 to 50 feet below land surface. Water-table contours connecting points along stream courses should be drawn roughly parallel to the topographic contours, but with less intricate curvature. As groundwater moves in the direction of decreasing head, and at right angles to the water-table contour lines, one can approximate the general direction of groundwater flow from the surface topography.

N-8 RECHARGE AND DISCHARGE

Most recharge and discharge is through porous granular material (clayey soil-saprolite or floodplain deposits), but much of the intermediate flow between recharge and discharge areas is through bedrock openings. Recharge occurs chiefly on upland areas and slopes, while discharge is concentrated in lowland areas bordering surface water bodies, marshes, and floodplains. Natural discharge from fractures into a surface body of water is common. Evapotranspiration is a significant part of the natural discharge. Although not easily quantifiable, evapotranspiration is *especially high in lower parts of draws and from flood plains, especially at high stages of the water table.*

On reaching the water table, groundwater flow paths vary greatly in length, depth, and travel time to areas of discharge, depending upon local hydrogeologic conditions. Some moves laterally in the soil-saprolite zone and may remain there until reaching a discharge area. Other paths may be deeper and longer and require groundwater to move erratically through the fractured bedrock and pass again through the soil or alluvium before discharging into a surface stream.

N-9 GROUNDWATER FLOW CYCLE

Groundwater moves continuously toward streams. In transit to an area of discharge, some groundwater is lost to evapotranspiration, especially in valleys; the remainder discharges as small springs and as bank channel seepage into streams. Small springs and seeps are common in draws and other topographic depressions, especially near the base of valleys. Springs and seeps at higher elevations are commonly of the wet-weather type and may suggest poorly fractured rocks below.

N-10 GROUNDWATER FLOW PATH

The path of natural groundwater movement is relatively short. It is almost invariably restricted to the zone underlying the topographic slope extending from a topographic divide to an adjacent stream. Groundwater rarely passes beneath a perennial stream to another, more distant, stream. Thus the concept of a local slope-aquifer system applies. On the opposite sides of an inter-stream topographic divide are two similar slope-aquifer systems, as shown by (A) and (B) in Figure 8. Two similar slope-aquifer systems occur on the opposite sides of a drainage basin (B) and (C).

As described, the region is a network of slope-aquifer systems, the boundaries of which may be arbitrary or indistinct. A double slope-aquifer system can be considered in the vicinity of the groundwater divide at the ridgetop (Figures 8 and 9).

A slope-aquifer system is a unit of the groundwater flow regime that is seemingly separated and free of impact from adjacent, similar units. Commonly, the slope-aquifer system includes smaller hill-and-dale configurations that are observed as topographic "spurs" (ridges branching from a main ridge or mountain crest). Similar undulations, although of lesser amplitude, may also occur in the underlying water table and form important natural groundwater flow-control features. The crests of the water table undulations represent natural groundwater divides within a slope-aquifer system and may limit the area of influence of wells or contaminant plumes located within their boundaries. The concave topographic areas between the topographic divides may be considered as flow compartments that are open-ended down slope.

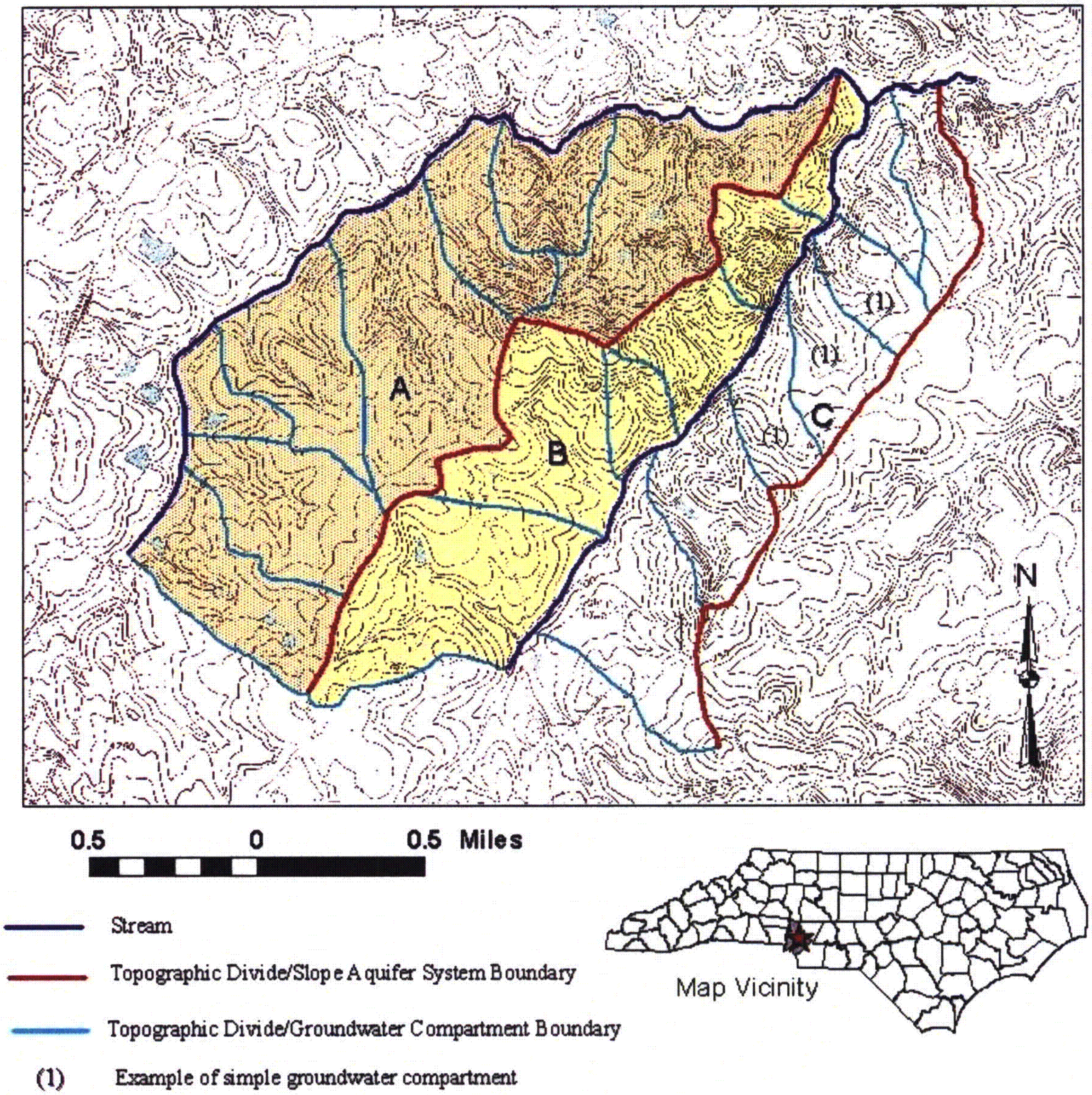

Figure 8. Slope-aquifer systems (A, B, and C) delineated on the USGS (1987) 7.5 minute Harrisburg Quadrangle topographic map.

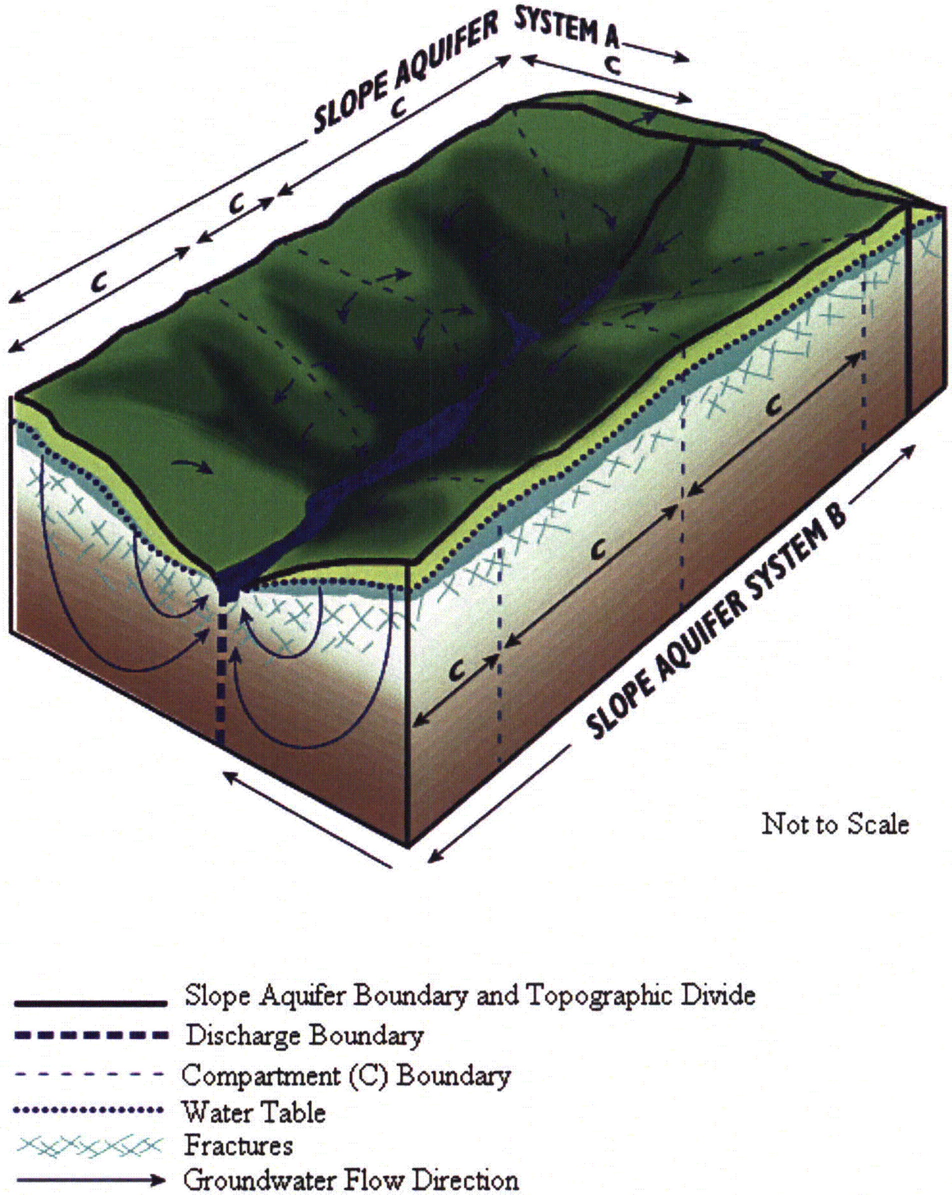

Figure 9. Conceptual view of double slope-aquifer system and included compartments.

Each compartment is hydraulically connected to adjacent compartments but has distinct hydrologic characteristics such as flow direction and gradient. Although each compartment is connected hydraulically to adjacent compartments, the water-table divide restricts natural groundwater flow between them. The relation to adjacent compartments is such that if contamination occurs in one, it would not naturally move laterally to an adjacent compartment. Several compartments are approximated in Figure 8. It is important to note that, because of their small size, not all topographic undulations necessarily describe underlying groundwater compartments. Some groundwater divides defining very small compartments may disappear during periods of water table decline.

Within a slope-aquifer system the behavior of contaminated water from a waste site or spill can be reasonably approximated where natural conditions exist. Where the natural flow of contaminated water reaches a cone of depression surrounding a pumping well, it may be expected to move toward the point of groundwater withdrawal. Even after pumping has ceased for months or years, some contaminated water may likely be trapped in fractures where natural groundwater circulation is restricted.

It is possible, although unusual, that an isolated fracture receiving recharge from one slope-aquifer system could extend beneath a boundary stream and intercept, or fall within, the area of pumping influence of a well in the neighboring slope-aquifer. In that case, the pumping well could have a hydraulic affect on the slope aquifer from which the fracture receives recharge, inducing flow toward the pumped well.

By identifying the slope-aquifer systems and their included compartments, and applying the generalizations, many useful deductions may be made regarding groundwater and the affect of human actions on it. As stated in the generalization, the stream, river, or lake serving as the lower hydraulic boundary is distinctive and the upper boundary is normally the topographic divide at the ridge top. The boundary defining the lateral extent of the system may be indistinct and somewhat arbitrary.

N-11 DEPTH OF CIRCULATION

The upper boundary of the zone of groundwater circulation, the water table, typically lies in the clayey soil-saprolite zone, except in upland areas of the Mountains where it may be in bedrock. The depth of circulation is difficult to define as it is determined by the presence of interconnected bedrock fractures. Although productive fractures have been penetrated at depths exceeding 700 feet, notably in the mountains, they are more likely to occur above a depth of 300-350 feet below bedrock surface.

N-12 PERMEABILITY

The permeability of an aquifer is a measure of its capacity to transmit fluid through its interconnected pore spaces or fractures. Complex geologic features in the Region result in variations in permeability. Three categories of permeability may be considered. The soil-saprolite zone has many features of the low permeability of clays. Where present, the underlying transition zone of prominent, interconnecting fractures has a moderately high permeability. The bedrock, in which fractures typically decrease in number with increasing depth, can be considered also as a zone of low permeability. The aggregate permeability may not be meaningful in many cases, but it affects groundwater movement when wells are pumped. The resulting composite permeability is reflected in the yields of wells and the extension of the cone of depression.

The term "hydraulic conductivity," normally applied in quantitative studies, is not substituted for permeability in the conceptual model because of its implied mathematical precision.

N-13 FRACTURE SYSTEM

Fracture systems occur in bedrock almost everywhere in the region. Fractures typically occur in sets, which are often composed of two sets of vertical fractures at approximately right angles to each other, and a third, nearly horizontal, set. In gneiss and schist, the orientation of some joints and fractures tends to parallel the foliation and compositional layering, which are rarely horizontal. In massive rocks, particularly granite, nearly horizontal tension joints often occur in the upper one hundred feet of bedrock.

Many non-horizontal fracture patterns can be traced by observing their topographic expression on the ground or on topographic maps scaled at 1:24,000 (USGS 7.5-min sheets).

Almost invariably, fractures that are not horizontal are represented by depressions in the topography or by an alignment of topographic features such as stream segments. In pursuing the simple fracture technique developed by Mundorff (1948), LeGrand (1952) demonstrated that many fractures are enlarged by dissolution, especially in gneiss and schist containing silicates of calcium. Many of these enlarged fractures underlie draws or linear depressions in surface topography. Draws, representing zones of relatively high permeability in the bedrock, are now considered by most groundwater specialists as favorable indicators of high well yields.

Although high-yielding wells are more common in topographic lows than in uplands, exceptions to this tendency can be attributed to geological history. The erosion of land surface and deepening of valleys over geologic time may have removed pre-existing fractures, leaving few or none below the relict depression (LeGrand, 1979). This condition is especially true in some valley bottoms where rocks are exposed. On the upland areas, under certain conditions, small tension fractures may develop and become sufficiently enlarged by circulating groundwater to provide substantial yields to wells. Where the upland joints extend laterally to a valley, or the confluence of two valleys, high well yields may be developed.

Fractures are the principal sources of permeability in many bedrock aquifers. They may be observed directly in exposed bedrock but, because of the scarcity of outcrops, are frequently easier to identify by examination of topographic maps. Straight stream segments or draws and tributaries arranged in a more or less parallel pattern and aligned across a main stream at angles of 90 degrees or less are indicators of drainage controlled by vertical or high-angle fractures (Figure 10).

Faults are fractures along which movement has taken place. They are widely distributed throughout the region, and may serve as conduits for groundwater movement, or as impediments, depending upon the extent to which the permeability of the fault zone has been affected by the mechanics of rock movement or mineralization, or both. Examples of major faults are those forming the boundaries of the Triassic basins, and the Brevard fault, which forms much of the boundary between the Piedmont and Mountain Region.

In the early geologic stage of topographic development, many faults have influenced topographic expression, especially stream settings. Most of them may be considered as fractures of moderate significance.

The local unevenness in the size, character and distribution of fractures, and in soil-saprolite characteristics, result in difficulties in extrapolation of hydrogeologic conditions. For example, of three wells in a row, spaced fairly close together, the respective yields may be 40, 6, and 20 gallons per minute, depending primarily on the number, interconnectivity, and character of the fractures they intercept.

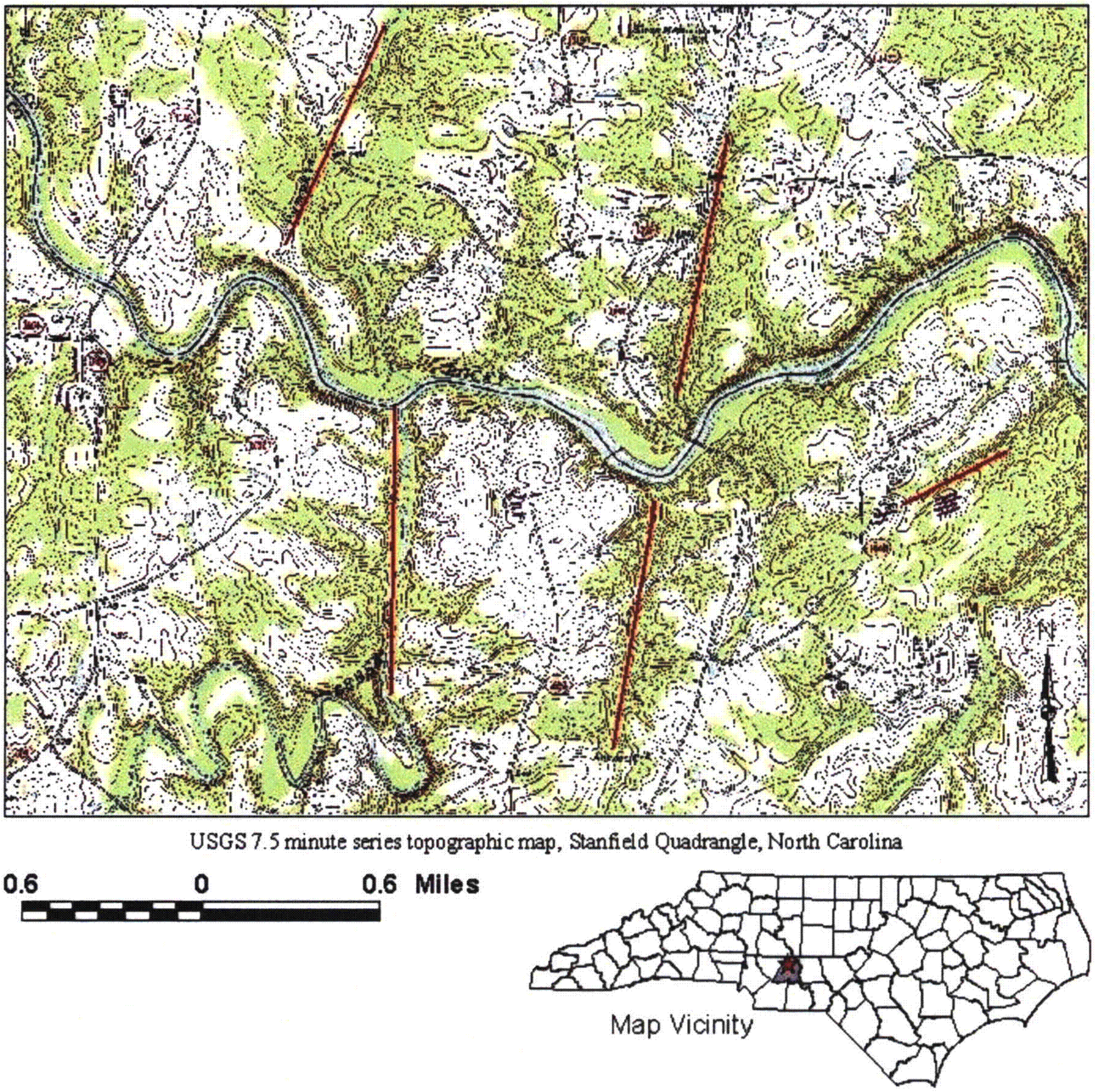

Figure 10. Topographic map showing fracture controlled tributaries of Rock River, Stanly and Cabarrus Counties, N.C.

N-14 HYDRAULIC HEAD

> *Hydraulic head beneath upland areas decreases with depth, resulting in the overall downward movement of groundwater and providing the mechanism for recharge to the aquifer. For example, a well 75 feet deep is likely to have a higher water level than a well 300 feet deep at the same site.*
>
> *Hydraulic head beneath lowland areas increases with depth, indicating upward movement of groundwater. For example, a well 300 feet deep is likely to have a higher water level than a well 75 feet deep at the same site.*

Hydraulic head provides the impetus for groundwater movement. Groundwater flows from areas of high head to areas of low head. The total hydraulic head, in feet or meters of water, in a non-flowing well is determined by subtracting the depth to water in the well from the elevation of the measuring point. The elevation is typically referenced to a common datum, usually mean sea level.

Figure 11 illustrates head differences in recharge and discharge areas in an unconfined aquifer. The solid lines are equipotential lines, representing the elevation of points of equal hydraulic head. The dashed lines are idealized groundwater flow lines illustrating the path of groundwater movement. The water level in the wells in the recharge area rises to the elevation represented by the equipotential line at which the well is open. The deeper the well, the less head is encountered. As depicted in Figure 11, the water level in well A, cased to a depth of 1 meter is higher than that in well B, cased to a depth of 4 meters. On the other hand, open-end wells in the discharge area encounter higher potential at increasing depth and consequently display higher water levels. In Figure 11, the water level in well D, cased to a depth of 7 meters is higher than that in well C, cased to a depth of 4.5 meters.

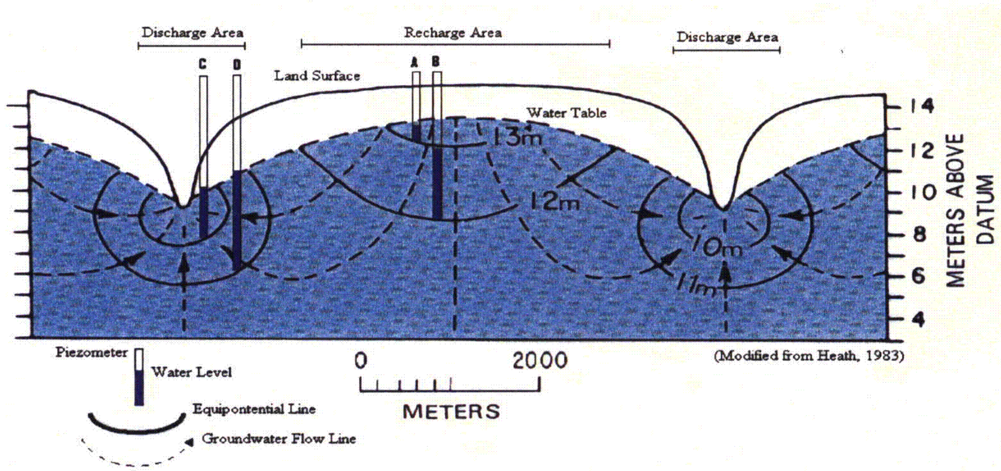

Figure 11. Idealized cross-section showing hydraulic head relationships in recharge and discharge areas. (Modified from Heath, 1983)

N-15 RATE OF GROUNDWATER FLOW

The rate of flow (velocity) of groundwater depends on the permeability and porosity of the medium through which it is moving, and on the hydraulic gradient, a slope defined by the difference in total head between two points of measurement over a unit distance. The greater the permeability and the hydraulic gradient, the higher the velocity. The overall rate of flow is fairly slow because the soil-saprolite zone has low permeability, and the fractures in the bedrock become sparse and poorly connected at increasing depths. Where it consistently occurs, the transition zone, including the uppermost part of bedrock, has the highest permeability and higher rate of flow than other parts of the system. The complex local geologic conditions cause wide differences in rates of flow, ranging from greater than one foot per day to less than one foot per century. Much of the flow is at the rate slightly greater than 10 feet per year.

The residence time for water to stay in the system also ranges greatly, and much of the water stays in the ground for many years. It must be emphasized that water collected at a well or that discharges naturally is a mix of water from both short and long flow paths. Thus, the average rate of travel of contaminated ground water to a well or natural outlet may be much slower than that of the first arrival of the water.

N-16. CHEMICAL CHARACTER

The chemical character of ground water in the Region can be classified as either acidic or basic. Acidic groundwater is typically found in light-colored rocks such as granite, granite gneiss, mica schist, slate, and rhyolite flows and tuffs, and is soft, and low in dissolved solids. Basic groundwater is typically found in dark rocks, such as diorite, gabbro, hornblende gneiss, and andesite flows and tuffs, and is typically hard, slightly alkaline, and relatively high in dissolved solids. Table 1 depicts the chemical characteristics of water from the two predominant rock types.

Constituent[1]	Acidic (granite)[2]	Basic (diorite and gabbro)[3]
Silica (SiO2)	30.0	32.0
Iron (Fe)	0.2	0.2
Calcium (Ca)	5.0	38.0
Magnesium (Mg)	2.0	12.0
Sodium and potassium (Na+K)	7.0	11.0
Bicarbonate (HCO_3)	34.0	127.0
Sulfate (SO_4)	2.0	17.0
Chloride (Cl)	2.0	14.0
Fluoride (F)	0.1	0.1
Nitrate (NO_3)	0.9	1.3
Dissolved solids	71.0	233.0
Hardness as $CaCO_3$	23.0	145.0
pH	6.5	7.1

[1]Chemical constituents in parts per million (ppm) except pH.
[2]Median value of 29 analyses from wells in the granite group.
[3]Median value of 23 analyses from wells in the diorite group.

Table 1. Comparison of natural chemical constituents of groundwater from acidic (granite) and basic or intermediate rocks (diorite) in the Piedmont and Mountain Region, North Carolina (after LeGrand, 1958).

Generalizations Associated with Conditions Imposed by Humans

Generalizations listed here relate to conditions imposed by humans that are generally in the form of diversion or withdrawal of water. They are designated H-1 through H-9, and include the following:

H-1 DIVERSION OF RUNOFF

Rolling topography and poorly permeable subsoil allow humans to divert water readily from the land surface toward nearby streams by way of paved surfaces and other drainage structures. Diversion of runoff may result in a slightly lower than normal water table beneath the upland areas and a reduction in the flow of groundwater to streams.

H-2 TURBULENT FLOW

Much of the flow in fractures is turbulent near pumping wells because of the velocity and erratic direction of movement of groundwater toward the well bore. The erratic movement of water in fractures is related to (a) the cross-linking of fractures, (b) the differing physical characteristics of the soil-saprolite zone and the bedrock, and (c) the conventional sporadic pumping and resting of wells. The mixing and churning of water, trapped air and, in some cases, contaminants in the cone of depression during alternate periods of pumping and non-pumping, result in complex conditions that may affect groundwater quality or well efficiency, or both.

H-3 CONE OF DEPRESSION

When a well is pumped, the decline of the water level in the well creates a hydraulic gradient toward the well in the area from which the groundwater is derived. The gradient steepens as the well is approached because the water converges from all directions and moves through a continually decreasing area until it enters the well bore. The area in which water level decline occurs takes the general shape of an inverted cone.

A crude estimate of the configuration of the cone of depression surrounding a pumped well can be constructed before pumping is begun. In fractured-rock aquifer systems, the cone of depression may not be a smooth circular area as viewed from above, as is common in regional aquifers consisting of porous, granular material. Because of the pronounced slope of the natural water table, the cone of depression tends to extend farther down-gradient from the well than it does up-gradient. Moreover, the cone tends to be elongated parallel to the trend of the greater fractures, generally along the foliation or trend of the rocks. The irregular distribution of fractures results in an irregular shape and extent of the cone of depression. These irregularities are almost never mappable in the absence of numerous monitoring wells. However for the purpose of wellhead protection of a public water supply well, a rough estimate of the size and configuration of the area can be estimated. The area contributing groundwater to a well includes not only the area within the cone of depression, but also the area up-gradient of the well as far as the water-table divide, in which the natural flow of groundwater is down-gradient into the cone of depression. Methods for delineating areas contributing groundwater to wells have been described by Heath (1991).

H-4 AREAL EFFECT OF PUMPING

The hydraulic effect of pumping a domestic well does not generally interfere with another domestic well located more than a few hundred yards away. Closer spacing of wells may result in increased drawdown and a reduction in well efficiency.

The drawdown resulting from pumping a high yield, municipal or industrial well may be areally extensive and may breach the natural barriers imposed by the groundwater divides defining slope-aquifer systems or compartments.

H-5 EFFECT OF DEPTH ON WELL YIELD

The tendency for fractures to decrease in size and number with increasing depth results in the tendency for yields per foot of well depth to decrease with increasing depth, especially below a depth of about 350 feet.

The yield per foot of drawdown generally decreases with increasing drawdown. Therefore, increasing the well depth to provide for a deep pump setting, or deep drawdown, may not be practicable.

H-6 PREDICTABILITY OF WELL YIELD

The yield of individual wells varies greatly and cannot be predicted within a narrow range of certainty. However, the yield of most wells ranges from less than one gallon per minute to as much as 60 gallons per minute. Wells located in draws where the soil-saprolite zone is thick are likely to have high yields; conversely, wells located on ridges underlain by a very thin soil-saprolite zone are likely to have low yields. Other types of topographic locations and places of intermediate soil-saprolite thickness are likely to have moderate yields. By using the slope-aquifer concept in relation to other generalizations, useful approximations of yield can be made. Hydrogeologic evidence notwithstanding, however, the ultimate selection of a well site may be determined by state and local health regulations.

LeGrand (1967) developed a rating system for estimating potential well yields by comparing topographic and soil conditions at a site. The system is based on the premise that high-yielding wells are common where thick residual soils and relatively low topographic areas are combined, and low-yielding wells are common where thin soils and hilltops are combined. Topographic settings and soil-saprolite thickness are assigned point values as shown in Tables 2 and 3.

The sum of the values determined for topographic setting and estimated soil-saprolite thickness may be used to determine the estimated average yield of a well and the chance, in percent, of obtaining higher yield. In the example shown in Figure 12, a site having a total value of 16 points has a 30 percent chance of yielding 30 gallons per minute and a 60 percent chance of yielding 10 gallons per minute.

Points	Topography
0	Steep ridge top
2	Upland steep slope
4	Pronounced rounded upland
5	Midpoint ridge slope
7	Gentle upland slope
8	Broad flat upland
9	Lower part of upland slope
12	Valley bottom or flood plain
15	Draw in narrow catchment area
18	Draw in large catchment area

Table 2. Site topographic ratings.

Points	Character of soil and rock
0-2	Bare Rock; almost no soil
2-6	Very thin soil; some rock outcrops
6-9	Soil thin; a few rock outcrops
9-12	Moderately thick soil; no fresh outcrops
12-15	Thick soil; no rock outcrops

Table 3. Soil-thickness rating table.

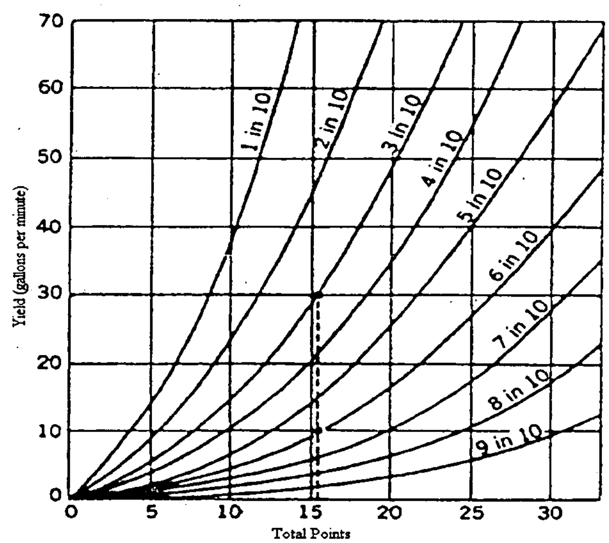

Figure 12. Well-yield probability graph.

H-7 CONTAMINANT MIGRATION AND NATURAL ATTENUATION

Although a thorough discussion of factors affecting contaminant transport is beyond the scope of this report, some general parameters are applicable in the Region.

> *Of principal importance is the chemical nature of the contaminants and the media through which they move. As the groundwater in the Region includes both porous media (regolith) and fractured bedrock, the nature of the contaminant plume migration may be very complex. Yet, it is fortunate that by using the slope-aquifer concept, the behavior of contaminated water from a waste site or spill may be reasonably approximated where natural conditions prevail (Figure 13). However, where the natural flow of contaminated water is diverted by a cone of pumping depression, the future behavior of persistent contaminants cannot be predicted with a high degree of certainty.*

The tendency for contaminants to weaken in strength as they move in groundwater flow from a contaminated source is not easily determined at a site during early stages of an investigation. In simple terms, a measure of natural attenuation can be regarded as a combination of (1) dispersion and dilution, (2) a die-away or transformation of contaminants, (3) sorption on earth materials, and (4) distance to a critical spot, as the contaminated water moves in a buffer zone before reaching a water-supply well or spring. As natural attenuation may be expected to be more effective in soil-saprolite than in fractured bedrock, a thick saprolite zone may be considered favorable. In addition to the type of contaminants, other factors to be considered are the volume and total concentration of the contaminant and the distinction between a one-time spill or leak and the long-term persistence of contaminant movement from the source _

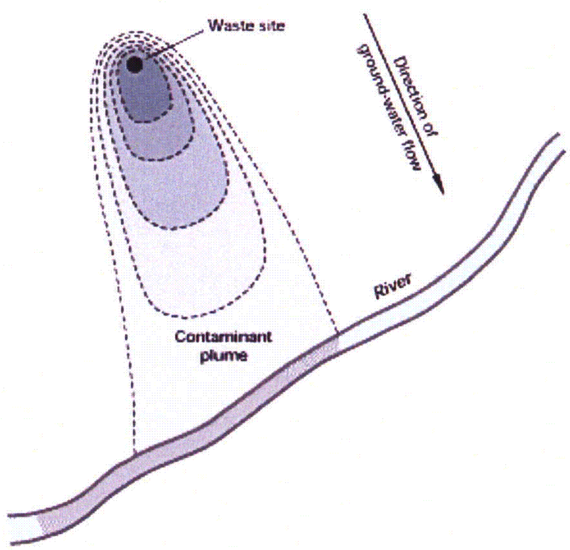

Figure 13. Schematic diagram showing the areal extent and direction of movement of a hypothetical contaminant plume (LeGrand, 1965). Shading indicates relative degrees of contaminant concentration.

The merits of pumping contaminated water from wells for remedial purposes must be determined on a case-by-case basis. Most remedial wells reduce the concentration of contaminants with increased pumping. However, if the goal is complete removal of all contamination, success is rare. Although pumping may have ceased for months or years, some contaminated water is likely trapped for years in fractures where natural groundwater circulation is retarded.

H-8 INFLUENCE OF TOPOGRAPHIC LOCATION ON PUMPING OR CONTAMINANT MIGRATION

Environmental concerns regarding water supply or waste disposal are commonly related to only one slope-aquifer system. However, if a pumping well or contamination zone is situated near a hilltop, both adjoining slope-aquifer systems are likely to be involved. Thus, a double slope-aquifer system, or compartment, applies, and the area of concern may extend to the perennial streams on both sides of a ridge, as shown by A and B in Figure 8. Wells near hilltops can draw water from both compartments, and contaminated groundwater near hilltops may spread divergently according to the varying water-table gradients.

H-9 CHANGE IN GROUNDWATER CHEMISTRY

The chemical character of water may change following the original pumping of a well. For example, in the cone of depression, radon may be trapped and may accumulate in air-filled fractures (LeGrand, 1987). Also, oxidation of pyrite and arsenic-bearing sulfide minerals such as arsenopyrite, in the air-filled part of the cone of depression, may result in increased iron and arsenic, as well as a decrease in pH (LeGrand, 1958).

Model Procedures and Application

No intrusive mechanical or geophysical equipment is required to apply the conceptual model to a site. Prior to a field investigation of a site, the evaluator should determine whether hydrogeologic information pertinent to the site is available in publications or open-file reports of state and federal agencies. Such reports typically contain data on wells, well yield, and groundwater levels, as well as brief geological descriptions and groundwater quality information.

At the site, the evaluator should have in hand the part of a topographic map that includes the particular slope-aquifer system and compartments that display the area of concern. The map should be of a scale of 1:24,000 or larger (a 1:6,000 scale may be ideal for most sites). Sites of interest, such as a well or waste site, should be located. A duplicate topographic map may be helpful for marking various features not included on the original map. In addition to the topographic map, the evaluator should have a geologic map of the area, a copy of the Site Evaluation Matrix (Appendix A-1), the Site Evaluation Worksheet (Appendix A-2), and the Site Evaluation Inventory (Appendix A-3).

Using the Site Evaluation Matrix as a guide, the evaluator should complete the Site Evaluation Worksheet. In the absence of site-specific, subsurface information, it may seem difficult and awkward to complete all factors included in the Worksheet. If the estimated value entered for each factor is not considered to be sufficiently true or representative, the evaluator should make an effort to explain, in each "comment" space, the best estimate of conditions. This explanation may be derived from a study of the generalizations and their interrelations, and from the Site Evaluation Matrix. The interrelations help provide an understanding of the site characteristics and guide the development of an early-stage conceptual model. Each estimated value or expression should be checked for compatibility with values of other factors. For example, a relatively deep water table may not fit with a setting having minimal rock fractures or nearly flat topographic setting.

After completing the Worksheet, the evaluator should follow the instructions and answer the applicable questions contained in the Site Evaluation Inventory.

After considering the various values in their integrated form, and expanding the comments and explanations, the overall conceptual model begins to unfold. No precision or pinpoint accuracy is claimed, but much useful information about the setting is now at one's fingertips. Some evaluated settings may reveal better information than others, but the quality of the results of the model application should exceed that of any other method or procedure at an early stage.

Evaluators not trained in hydrogeology should be able to derive useful information from this process without pursuing the study to the report phase. Those who wish to prepare a report of their findings may wish to use the format of the Prior Conceptual Model Explanation (PCME) described by LeGrand and Rosen (2000). The report may be prepared in narrative form and may be based largely on approximations and best estimates.

At a minimum, the report should describe:

- the location of the site,
- the purpose of the evaluation (e.g. vulnerability to contamination from a known or anticipated source, groundwater development potential, etc.),
- geologic and topographic characteristics,
- direction of groundwater movement and gradient,
- location and extent of recharge-discharge areas,
- natural groundwater quality, and
- approximations of the potential for groundwater contamination or water-supply development at critical places.

The following are abbreviated examples of the use of the generalizations.

Case 1

The setting consists of a waste disposal site on a topographic slope, halfway between a ridge top and a small creek. It is a common granite gneiss setting, having no rock outcrops and presumably a thick soil-saprolite zone underlying the slope and the adjacent slope across the creek. Mr. Smith, the owner of the facing property across the creek, plans to drill a well, which would be about 1,000 feet horizontally from the waste disposal site. The waste site is about 30 feet higher in elevation than the creek, and the elevation of Mr. Smith's well on the opposite slope is also about 30 feet above the creek. Mr. Smith is concerned about the possibility of his well water being contaminated by leakage from the waste site.

Generalizations N-9 and N-7 form the basis for the development of a preliminary water-table map. They indicate that groundwater naturally flows toward the creek from opposite directions, thereby eliminating a continuous gradient from the lagoon to the well. Each is in a different slope-aquifer system from the other (N-10). There is no deep aquifer system to connect the systems as fractures decrease in size and number with increasing depth (N-12). The creek is a hydraulic boundary for natural flow, and it is extremely unlikely that the water table during pumping of Mr. Smith's well would be depressed to the level of the creek. Even if that were possible, his well should theoretically dry the creek before a true hydraulic gradient from the waste site to the well would be possible (H-7). The contaminated plume from the waste site may reach the creek, where the discharging contaminated groundwater would mix with downstream creek flow, as shown in Figure 12. By reasoning, it seems unlikely that Mr. Smith's well water would be contaminated by the waste disposal site.

Case 2

The setting is a relatively flat area underlain by gabbro, such as that northeast of Harrisburg, in Cabarrus County. Several houses are planned along a rural road, and questions have been posed about a well and septic tank system for each house. Dark brown, sticky clays and a few gabbro boulders are observed on the surface. A thin soil-saprolite zone tends to characterize flat-lying gabbro settings (N-1), and the nearly flat topography indicates a shallow water table and a gentle water-table gradient (N-15). The shallow gradient suggests that there is lack of significant circulation of water deeper than about 100 feet. There are suggestions that fractures do not extend to great depth (N-12). The topography is largely due to dissolution of the rock as water moves along the top of the soluble bedrock. These conditions suggest a very thin soil-saprolite zone and a thin transition zone. The thinness of the soil-saprolite zone results in a thin groundwater reservoir in dry weather and the possibility of noticeably reduced well yields during droughts. Some septic tank systems may not be suitable because of the combination of clay soils and shallow water table. Plumes of contaminated groundwater may rise to the land surface in spots after heavy precipitation. Local areas of soggy ground during wet weather and a rise of the water table to land surface at its high stage may lead to environmental problems such as land drainage. The natural flow of groundwater is slow (N-6). With the prevailing conditions in mind, a rather sparse spacing of wells and septic tank systems in this setting is suggested. Although in some cases some exploration wells and testing may be necessary, the logically deduced information can limit the amount of money spent on projects in this setting.

Conclusions

The generalizations inherently indicate conditions that are normally true. When the generalizations and logical inferences are interrelated and matched, the result is a conceptual model that is presumed to be realistic though imprecise. Extreme or unusual conditions do occur and may be expressed as anomalies. Where an unusual value of a factor appears, further study should be made to determine if the condition is an error in evaluation or an anomaly. Types of anomalies include extremely high well yields and higher than normal concentrations of a chemical constituent in the water.

In summary, the following conclusions support the application of the generalizations to typical hydrogeologic concerns in the Piedmont and Mountain Region.

- Using the generalizations, a higher plateau of knowledge can be developed for an unstudied setting than would otherwise be possible at an early stage of an investigation.

- The generalizations are not mere isolated conclusions, but represent hydrogeologic associations of certain tendencies, which may lead to useful inferences. For example, (1) divergent hydraulic gradients on opposite sides of hills, in combination with (2) a tendency for permeability to decrease with increasing depth beneath all slopes suggest that (3) pumping wells on opposite hill slopes are not likely to have appreciable mutual interference.

- Topography is a major factor in the development of knowledge of groundwater conditions in the Region. As many topographic settings are masked or unclear because of vegetation and buildings, topographic maps of the scale of 1:24,000 are indispensable tools for site evaluations.

- Knowledge that the water table is a subdued replica of land surface topography offers insight to several important aspects of groundwater flow. Thus, by mimicking the land surface contours in a modified way, a local synthetic water table map can be readily developed.

- Fracture traces are almost invariably related to observable topographic expressions.

- The region contains numerous small slope-aquifer systems, each being bounded by a perennial stream and an upland groundwater divide. Within most slope-aquifer systems are smaller, concave topographic configurations representing topographic draws and groundwater compartments that are open-ended toward the perennial streams. Evaluation problems of water supply and waste management can be facilitated by a focus on the hydrogeologic characteristics of the pertinent slope-aquifer system and the compartment.

- The ability to obtain specific information through the use of inferences from the generalizations must be weighed against the objectives of obtaining precise information from drilling and other subsurface techniques. Data collection and costs can be reduced by maximum use of the type of integrated framework derived from the generalizations.

- The proposed method of investigation can lead to a qualitative predictive model expressing likely or common conditions that exist or may occur in the future. Individual deductions may be cross-checked with others derived from the generalizations to confirm the validity of the model. The evaluation process should identify unusual features and anomalous conditions.

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Glossary

Alluvium – Sediment, including clay, silt, sand, and gravel deposited by rivers and streams. The term generally refers to deposits of recent geologic time.

Aquifer – A body of rock, consolidated or unconsolidated, that is sufficiently permeable to conduct groundwater and to yield significant quantities of water to wells and springs.

Attenuation – A reduction in concentration of contaminants in the subsurface.

Bedrock – A general term for the rock that underlies soil or other unconsolidated superficial material. In the Piedmont and Blue Ridge provinces bedrock typically consists of granite, gneiss and schist.

Brownfield – An abandoned, idled, or underused property at which expansion or redevelopment is hindered by actual environmental contamination or the possibility of contamination and that may be subject to remediation.

Buffer Zone – An area between a contaminant plume and a down-gradient receptor, such as a water-supply well or a stream, within which natural attenuation may occur. By special designation, it may be defined in terms of the distance to a position of tolerated acceptance, a position where contamination is completely reduced, a property line, or a surface body of water.

Compartment – In a slope-aquifer system, an area formed by an undulation of the water table generally conforming to an undulation in the overlying topography. The crests of the water-table undulations represent natural groundwater divides that, under natural conditions, restrict the movement of groundwater to the boundaries of the compartment.

Cone of Depression – A depression in the potentiometric surface of a body of groundwater that has the shape of an inverted cone and develops around a well from which water is being withdrawn.

Crystalline Rock – An inexact but convenient term designating an igneous or metamorphic rock characterized by interlocking mineral grains.

Diorite – A group of plutonic rocks intermediate between acidic and basic, characteristically composed of hornblende, oligoclase or andesine, pyroxene and sometimes a small amount of quartz.

Discharge Area – An area in which there is an upward component of hydraulic head in an aquifer. Groundwater flows toward land surface in a discharge area and escapes as a spring, seep, baseflow to streams, or by evaporation and transpiration.

Drainage Basin – A region or area that contributes water to a specific stream, lake, reservoir, or other body of water. Drainage basins are bounded peripherally by a drainage divide. Synonymous with watershed.

Drainage Divide – The boundary between adjacent drainage basins.

Draw – A natural depression or swale; a shallow to moderately steep drainage way. A natural watercourse, usually dry except during and immediately following heavy rains. A shallow drainage way.

Drawdown – The decline of the water table or potentiometric surface as a result of withdrawals from wells or excavations.

Equipotential line – A line in a two-dimensional groundwater flow field on which the total hydraulic head is the same at all points.

Evapotranspiration – That portion of precipitation returned to the atmosphere through evaporation and transpiration.

Fault – A fracture or fracture zone along which there has been displacement of the sides relative to one another parallel to the fracture.

Feldspar – A group of rock-forming aluminosilicate minerals. Feldspars are the most widespread mineral group and constitute 60 percent of the earth's crust.

Felsic – An adjective applied to rocks containing an abundance of light-colored minerals. The chief felsic minerals are quartz, feldspars, feldspathoids, and muscovite. Examples of felsic rocks are granite and syenite. Contrasted with mafic.

Fracture – A crack, joint, fault or other break in rocks caused by mechanical failure.

Gabbro – A group of dark-colored, basic intrusive igneous rocks composed principally of pyroxene and plagioclase feldspar.

Gneiss – A foliated, metamorphic rock in which light colored bands of granular minerals alternate with darker bands of flaky minerals.

Granite – A plutonic rock consisting chiefly of quartz and feldspar. Mica and hornblende may be included.

Hydraulic Conductivity – A coefficient of proportionality describing the rate at which a specific fluid can move through a permeable medium.

Hydraulic Head – Generally, the altitude of the free surface of a body of water above a given datum.

Igneous Rock – A rock that solidified from molten or partially molten material. Examples are solidified lava and plutonic rocks.

Interflow – The lateral movement of water in the unsaturated zone during and immediately after precipitation. Interflow occurs when the zone above a low permeability horizon becomes saturated and lateral flow is initiated parallel to the barrier.

Intermittent Stream – A stream that flows only at certain times of the year, as when it receives water from springs or a surface source. Also known as ephemeral or wet-weather streams.

Isohyetal Line – A line on a map connecting points receiving the same amounts of precipitation.

Joint – A fracture in rock along which there has been no visible movement.

Mafic – An adjective describing igneous rock composed chiefly of dark, ferromagnesian minerals. The complement of felsic.

Metamorphic Rock – A rock formed at depth in the earth's crust from preexisting rocks by mineralogical, chemical and structural changes caused by high temperature, pressure and other factors. Examples include slate, schist and gneiss.

Natural Attenuation – The natural processes contributing to the degradation and dissipation of contaminates. Some of the processes contributing to natural attenuation include dilution, sorption, filtration, oxidation, volatilization, and microbial degradation.

Perched Water Table – The upper surface of a body of unconfined groundwater separated from the main body of groundwater by unsaturated material.

Perennial Stream – A stream that flows continuously throughout the year and whose upper surface generally stands lower than the water table in the region adjoining the stream.

Permeability – The capacity of rock or unconsolidated material to transmit a fluid.

Plume – A body of contaminated groundwater originating from a specific source or sources and influenced by such factors as the local groundwater flow pattern, density of contaminants, and the physical characteristics of the aquifer.

Plutonic – Pertaining to igneous rocks formed at great depth.

Porosity – The ratio of the aggregate volume of interstices in a rock or soil to its total volume. It is usually stated as a percentage.

Potentiometric Surface – An imaginary surface representing the total head of groundwater and defined by the level to which water rises in tightly cased wells. The water table is a particular potentiometric surface.

Regolith – The unconsolidated material lying above bedrock, whether residual or transported, consisting of saprolite, alluvium and soil. The regolith may include a transition zone grading from unaltered bedrock into true saprolite.

Saprolite – A soft, earthy, clay-rich thoroughly decomposed rock formed in place by chemical weathering of igneous or metamorphic rocks. Saprolite is characterized by preservation of structures that were present in the unweathered rock.

Schist – A foliated, crystalline, metamorphic rock of intermediate grain size. Individual folia are relatively thin. Parallel, platy minerals commonly make up one-half of the rock.

Sedimentary Rock – A layered rock resulting from the consolidation of sediment deposited by some geologic agent such as water, wind, or ice. Typical sedimentary rocks include sandstone, limestone and shale.

Slate – A compact, fine-grained metamorphic rock that possesses slaty cleavage. It is generally formed by the metamorphism of shale.

Slope-Aquifer System – In the Piedmont and Mountain Region, a part of the region-wide regolith-bedrock aquifer system in which groundwater recharge, transient flow, and discharge are confined, under natural conditions, to an area bounded up-gradient by a topographic divide, and down-gradient by a perennial stream. Laterally, the system is bounded on one side by an extension of the centerline of the draw containing the headwaters of the perennial stream, up-gradient to the ridge crest, and on the other side, by the terminus of the gross topographic ridge.

Soil – The relatively fine-grained, surficial material formed as the result of weathering of rock, or unconsolidated sediment. Soil may be found in layered horizons varying in organic and mineral content. It is generally capable of supporting vegetation.

Spur – A hill or ridge extending from the crest or side of a more prominent ridge or mountain.

Tension fracture – A fracture caused by stress that tends to pull a body apart.

Water table – The surface of a body of unconfined groundwater at which the pore pressure is atmospheric.

Wellhead Protection Area. – An area designated under the authority of the 1986 Amendments to the Safe Drinking Water Act within which measures to protect groundwater quality may be taken by operators of public water systems. A wellhead protection area is the surface and subsurface area surrounding a well or wellfield supplying a public water system through which contaminants are reasonably likely to move toward and reach the well or well field.

Well Yield – An inexact term referring to the volume of fluid removed from a well per unit period of time, typically measured in gallons per minute.

Appendix

A-1 Site Evaluation Matrix

A-2 Site Evaluation Inventory

A-3 Worksheet for the Evaluation of Factors Influencing the Occurrence and Availability of Groundwater

Appendix A-1
Site Evaluation Matrix
(modified from LeGrand, 1983)

Hydrogeologic Factors	Advantageous Aspects	Disadvantageous Aspects	Remarks	Interrelation of Factors
Permeability	1. High surface permeability allows infiltration of contaminated water, preventing or reducing surface contamination and runoff problems. *2. High permeability may result in a deep water table leading to better opportunities for contaminants to attenuate in the unsaturated zone.* 3. Low permeability retards movement, resulting in additional time for attenuation. Low permeability in porous materials may be related to good sorption.	*1. Low surface permeability causes rejection of contaminated water and helps create problems of contaminants on the ground surface and in streams.* *2. High permeability may lead to faster groundwater movement and less opportunity for decay with time.* *3. Low permeability may result in a shallow water table and less opportunity for attenuation in the unsaturated zone.*	Gravel and clean, coarse sand in floodplain deposits are very permeable. Sandy soil on granite and granite gneiss also tends to be fairly permeable. Residual clays on gabbro and diorite tend to have low permeability. Rock permeability ranges according to type of rock and fracture density, but is typically greater at shallow depths.	The higher the permeability the lower the potential for natural attenuation, and, conversely, the lower the permeability the greater the potential for attenuation. The water table tends to be shallow in poorly permeable materials in low topographic sites in humid regions. Conversely, the water table tends to be deep in permeable materials beneath high topographic sites. Other factors not considered, high permeability might lead to a low water-table gradient. High permeability may lead to a low water table and low stream density, and perhaps also to a great distance from a contamination site to a stream.
Depth of Water Table	1. A deep water table generally allows infiltration of contaminants, preventing overland flow or emergence at the land surface. 2. A deep water table allows increased attenuation of contaminants in the unsaturated zone, relative to a shallow water table. *3. Some contaminants may never reach a deep water table. They appear to remain in the unsaturated zone, where their potential for harm may be less than in the saturated zone.* 4. A shallow water table may allow easy and cheap methods of monitoring and controlling contaminated zones.	1. A shallow water table may cause contaminants to emerge at land surface. 2. A shallow water table reduces attenuation in the unsaturated zone and enables contaminants to enter the saturated zone where lateral dispersion occurs. 3. A deep water table makes monitoring and control of contaminated zones difficult.	For this discussion, a shallow water table is less than 15 feet below land surface, and a deep water table is more than 50 feet below land surface. Shallow water tables are common in humid regions. A moderately deep water table is desirable. A water table that rises during its high stage to the main body of wastes or near land surface is not desirable.	High water table may be associated with material having a high capacity for natural attenuation and low permeability. High water table may be associated with steep gradient of the water table.

Site Evaluation Matrix (continued)

Hydrogeologic Factors	Advantageous Aspects	Disadvantageous Aspects	Remarks	Interrelation of Factors
Water-Table Gradient	1. It is desirable for a point of water use (e.g., a well) to be up-gradient from a contaminant source so that contaminants will not migrate toward the point of use under natural head conditions. 2. A gentle gradient is more acceptable than a steep gradient where direction is toward a point of water use because of slower water movement and greater time for contaminant decay unless the gentle gradient is due to high transmissivity	1. A steep gradient from a contaminant source toward a point of water use is undesirable. 2. Any gradient, either natural or caused by pumping of wells, from a contaminant source toward a nearby point of water use is not desirable.	Gradients are easy to determine where water-table maps are available. However, correct inferences lead to fair approximations of water-table gradients. Steep land surfaces, in combination with low permeability and humid climates, tend to yield steep water-table gradients.	Steep gradient may be associated with low permeability and presence of material having a high capacity for natural attenuation or high stream density. A low water table may be associated with a low water-table gradient and a short distance from a contamination site to a stream.
Stream Density	1. Closely spaced streams limit the areal extent of contaminated zones in the ground and may prevent spread of contamination across streams. 2. Widely spaced streams may allow for attenuation in the ground and thus avoid stream contamination.	*1. Where streams are closely spaced, contaminants may have a short underground course before dispersing into a stream, where they may be objectionable.* 2. Widely spaced streams may result in large contaminated zones in the ground that may be more nearly permanent than where streams are closely spaced.	For this discussion, a network of closely spaced streams has a perennial stream within a mile of all inter-stream points. A stream is a surface outlet for groundwater, and if the groundwater is contaminated the stream generally represents a boundary beyond which the contamination may not extend.	A close network of streams may be related to low permeability; conversely, widely spaced streams may be related to high permeability.
Topography **(1) low relief** **(2) high relief**	1. Low relief is commonly associated with a low water-table gradient and, if permeability is low, with slow movement of ground water. 2. High relief is commonly associated with a deep water table (where permeability is moderate to good).	1. Low relief is commonly associated with a shallow water table, with a minimum of attenuation in the unsaturated zone. 2. High relief is commonly associated with rapidly moving groundwater, which may limit the time for attenuation of contaminants.	For this discussion, topography of low relief does not have high hills or deep valleys. Topography is an important factor, but its value is more tangibly considered within the interrelations of the factors of permeability, depth to the water table, and gradient of the water table.	High topographic relief with high permeability leads to a deep water table and low water-table gradient; high topographic relief with low permeability leads to a shallow water table and steep water-table gradient.
Distance (between source of contamination and well or stream)	1. Great distance is a desirable factor, a factor easy to evaluate.	1. Short distance may be undesirable.	For this discussion, a short distance is less than 100 feet and a great distance is more than 1,000 feet. Distance is the most distinct factor and, by far, the most often used.	Great distance is a favorable factor because favorable aspects of other factors may be included in "great distance."

Appendix A-2

Site Evaluation Worksheet

Type of Rock	Granite	Granite Gneiss	Schist	Quartzite	Gabbro or Diorite	Mafic Gneiss
Comments and Explanation						
Topography **(locate site on 1:24000 scale topographic map)**	Upland Flat	Top of Hill	Upland Slope	Steep Slope	Shallow Slope	Valley
Comments and Explanation						
Distance to Nearest Stream or Point of Concern	Less than 100 ft.	100-300 ft.	300-600 ft.	600-1,000 ft	Greater than 1,000 ft.	
Comments and Explanation						
Thickness, Soil-Saprolite Zone	0-5 ft.	5-10 ft.	10-20 ft.	20-40 ft	40+ ft	
Comments and Explanation						

Worksheet (continued)

Depth to Water Table	0-5 ft.	5-10 ft.	10-20 ft	20-40 ft	40+ft	
Comments and Explanation						
Water-table Gradient	Nearly Flat	Gentle Gradient	Moderately Steep	Steep		
Comments and Explanation						
Water-table Fluctuation	Less than 2 ft.	2- 4 ft	Greater than 4 ft.			
Comments and Explanation						
Base of Aquifer	Less than 100 ft.	100-250 ft.	250-300 ft.	300-500 ft.	Greater than 500 ft	
Comments and Explanation						

Worksheet (continued)

Evapo-transpiration	High	Moderate	Low			
Comments and Explanation						
Overall Permeability	Relatively High	Relatively Moderate	Below Average	Poor		
Comments and Explanation						
Type of Contaminant	Chemical Leaks or Spills	Human or Animal Waste	Landfill Leachate	Agricultural Applications	Other (naturally occurring constituents or physical characteristics)	
Comments and Explanation	gasoline diesel chlorinated hydrocarbons other	septic tank mun. or commercial system animal waste lagoons other	sanitary landfill open dump other	fertilizer pesticides herbicides other		
Natural Attenuation Potential	High	Moderate	Low			
Comments and Explanation						

Appendix A-3

Site Evaluation Inventory

The following questions and instructions are offered as guidance in evaluating the site. Answers should be expressed in approximate or qualified terms, using ranges of conditions and probabilities as necessary. Degrees of probability may be expressed by use of terms such as "likely," "probably," "unlikely," and "slightly." Avoid precision-oriented terms and express modestly the judgements and inferences.

The comments and answers to the following questions include a selection of topics that make up the Prior Conceptual Model Explanation. The preparation of a separate PCME report is desirable but may be optional in some cases.

1. On a topographic map, plot the site of main interest, which may be a well or contamination setting. Plot other features as needed.

2. Is bedrock or saprolite exposed anywhere in the vicinity of the site? If so, describe.

3. Does the type of soil suggest the type of underlying bedrock? If so, describe.

4. Based on physical evidence or generalizations, estimate the approximate thickness of the soil-saprolite zone at key points.

5. Are there surface indications of the trends of geologic structure, such as lineations or fracture trends? If so, describe.

6. Is there evidence that a transition zone exists? If so, is there any evidence suggestive of its consistency and physical character?

7. What is the approximate depth to the water table at key points? If well data is not available, estimate from generalizations.

8. On the premise that the water table is a subdued replica of the land surface with less topographic relief, draw a synthetic water-table map, or indicate by arrows the probable direction of groundwater flow. Can you define the area at the hilltop where the direction of flow is questionable? It would be helpful to circumscribe that area on the map

9. Is the water table in soil-saprolite in both wet and dry seasons at the key points?

10. Is the water table in bedrock in both wet and dry seasons at the key points? Lacking well measurements and geologic knowledge, refer to generalizations.

11. What appears to be the consequences of the difference between high and low stages of the water table?

12. Is there any significance to a particular topographic spur, or ridge, and a broad, concave sag in the topography?

13. What particular inferences can be made from the positions of draws and the upland divide?

14. Is there a spring in the compartment?

15. Does the spring seep from the soil-saprolite zone or does it discharge directly from rock?

16. Is there a significant wet-weather zone in the draw?

17. Is there seepage into a floodplain or from soil-saprolite into the stream?

18. Is there bank seepage from exposed rock?

19. Is bare rock or saprolite exposed in the perennial stream?

20. What is the approximate potential yield of a well at the ridge top or flat upland?

21. What is the approximate yield of a well at two other locations in a compartment?

22. For a well site of interest, express the yield in terms of percent chance of success for yields of 3, 10, 20, and 40 gallons per minute.

23. Has the land surface been altered by humans to the extent that it modifies hydrogeological interpretations?

24. Describe or plot the estimated wellhead protection area for a particular site and indicate whether it extends along the upland area and into another compartment.

25. At the well site, express a degree of concern about a contamination site at various distances from the wellhead protection area. Express types of contaminated sites within the area.

26. Comment on the natural quality of groundwater in the area. Consider hardness, total solids, pH, or some other natural constituents.

27. Comment on type of contaminants of concern, such as nitrates, organic chemicals, conventional septic tank effluent, dense non-aqueous phase liquids (DNAPL), etc. Can suggestive comments be made about the possible occurrence of radon, arsenic, and pharmaceuticals?

28. Indicate, by arrows, the likely direction of contaminated groundwater flow.

29. Comment on the need for monitor wells. Why? Where?

30. Check to see if you have drawn all useful conclusions or best approximations from the generalizations and inferences in the system.

32. Comment on the risk or degree of concern associated with the major problem or proposed activity.

33. If more information in the form of new data were suggested, how would the data be used? Would the benefits justify the cost of the additional work?

34. Express in essay or tabular form, useful thoughts or approximations that may involve some of the following subjects:

(a) What are some constraints or limitations, such as a well near a contamination zone?

(b) Describe any favorable or unfavorable situations.

(c) "Brinkmanship" (approaching regulatory limits or safe environmental limits).

(d) Is the subject of incremental permissiveness involved?

(e) *Possible consequences of some action.*

(f) Aspects of attenuation at contamination site

(g) Property boundaries.

(h) Degree of confidence in statements (slight, moderate, considerable).

Lee Nuclear Station Response to Request for Additional Information (RAI)

RAI Letter Dated: August 21, 2008

Reference NRC RAI Number: ER RAI-10

NRC RAI:

Submit a description of how the depth data in Figure 2.3 - 17 have been adjusted or rectified to reflect the correct elevation for the hydraulic conductivity data points. Include an explanation of how the depth differences add "noise" and "bias" to the K versus depth comparison.

Duke Energy Response:

Depth data in Figure 2.3-17 have not been modified to adjust for changes between pre-Cherokee construction era elevations and the current elevations, but it is recognized that the 2006 data and 1970s data do not share a constant datum (i.e., 1970s surface grade elevations do not equal the 2006 surface grade elevations). The 2006 hydraulic conductivity (K) data verify the typical ranges of 1970s K values relative to lithology [e.g., K values determined in 2006 for partially weathered rock (PWR) were generally consistent with PWR K values determined in the 1970s]. While the depths of the samples collected in areas of cut and fill have changed, the soil and rock characteristics have not. Therefore, the depth changes add "noise" to Figure 2.3-17. Attachment10-1 provides graphs to evaluate the 1970s K data and 2006 K data separately. Separating the data sets allowed independent comparisons of K versus depth.

Potential "bias" in the 2006 K data may exist because one goal of the groundwater investigation was to identify preferential flow paths. Using Cherokee investigation data, an attempt was made to explore for areas with relatively higher Ks than those in other areas of the site. This exploration approach would potentially bias the 2006 results to higher K values than the 1970s K values.

Associated Revisions to the Lee Nuclear station Combined License Application:

Revise COLA Part 3, ER Chapter 2, so that the following is the last paragraph in ER Subsection 2.3.1.5.8, immediately following the bulleted text:

A summary of the various test results is presented in Table 2.3-6. Figure 2.3-17 depicts the distribution of hydraulic conductivities with depth. This figure shows the wide variability of hydraulic conductivities observed across the site during both the Cherokee and Lee Nuclear Site investigations. Hydraulic conductivities appear to increase with depth as materials transition from residual soil to saprolite to partially weathered rock that appears to decrease in hydraulic conductivity as it transitions to continuous rock. Figure 2.3-17 includes the data from samples of partially weathered rock that were subsequently removed during excavation for the Cherokee Nuclear Station reactor buildings.

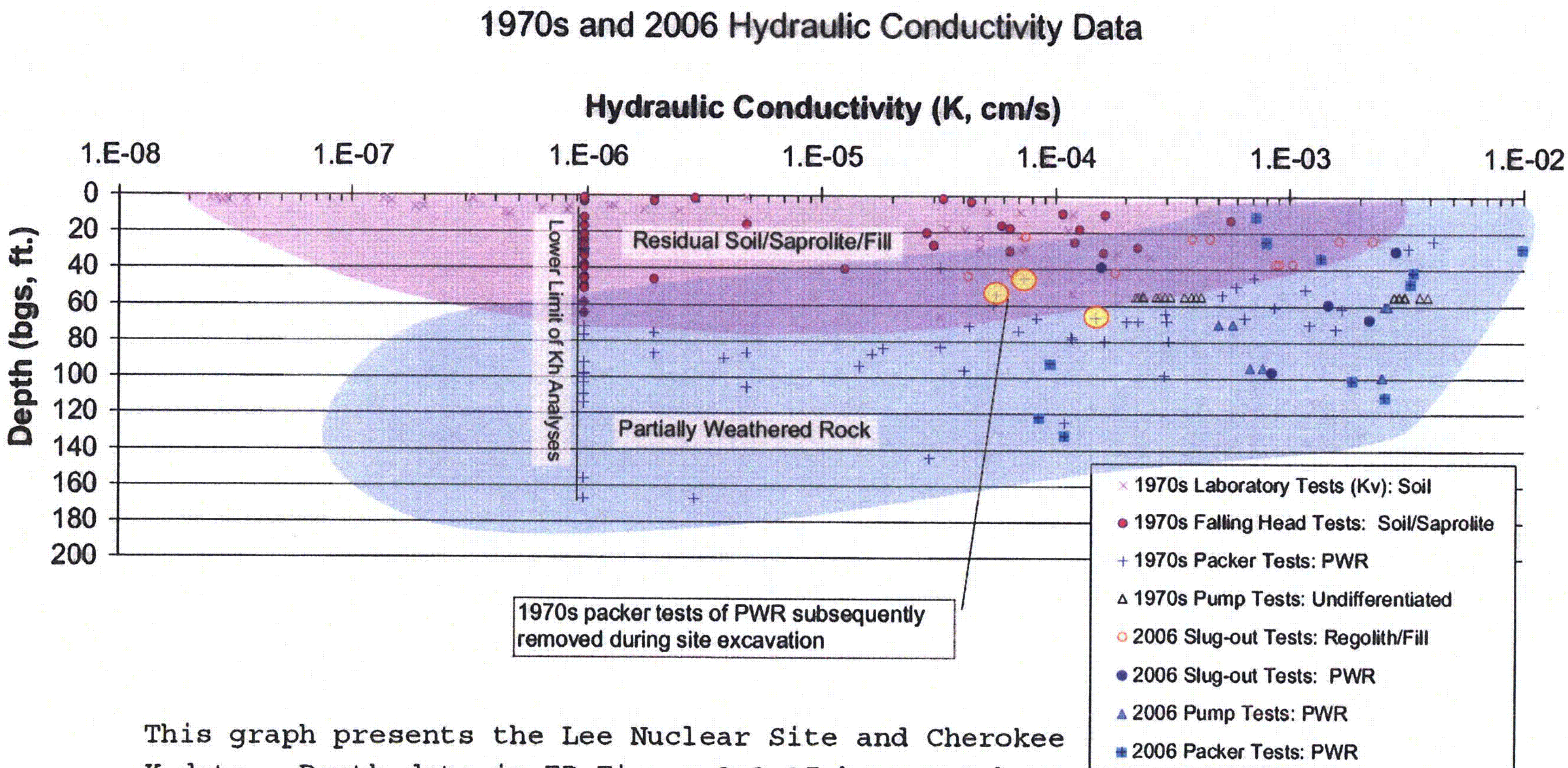
Associated Attachment:

Attachment-10-1 K vs. Depth Analyses for Cherokee and Lee Investigations

Lee Nuclear Station Response to Request for Additional Information (RAI)

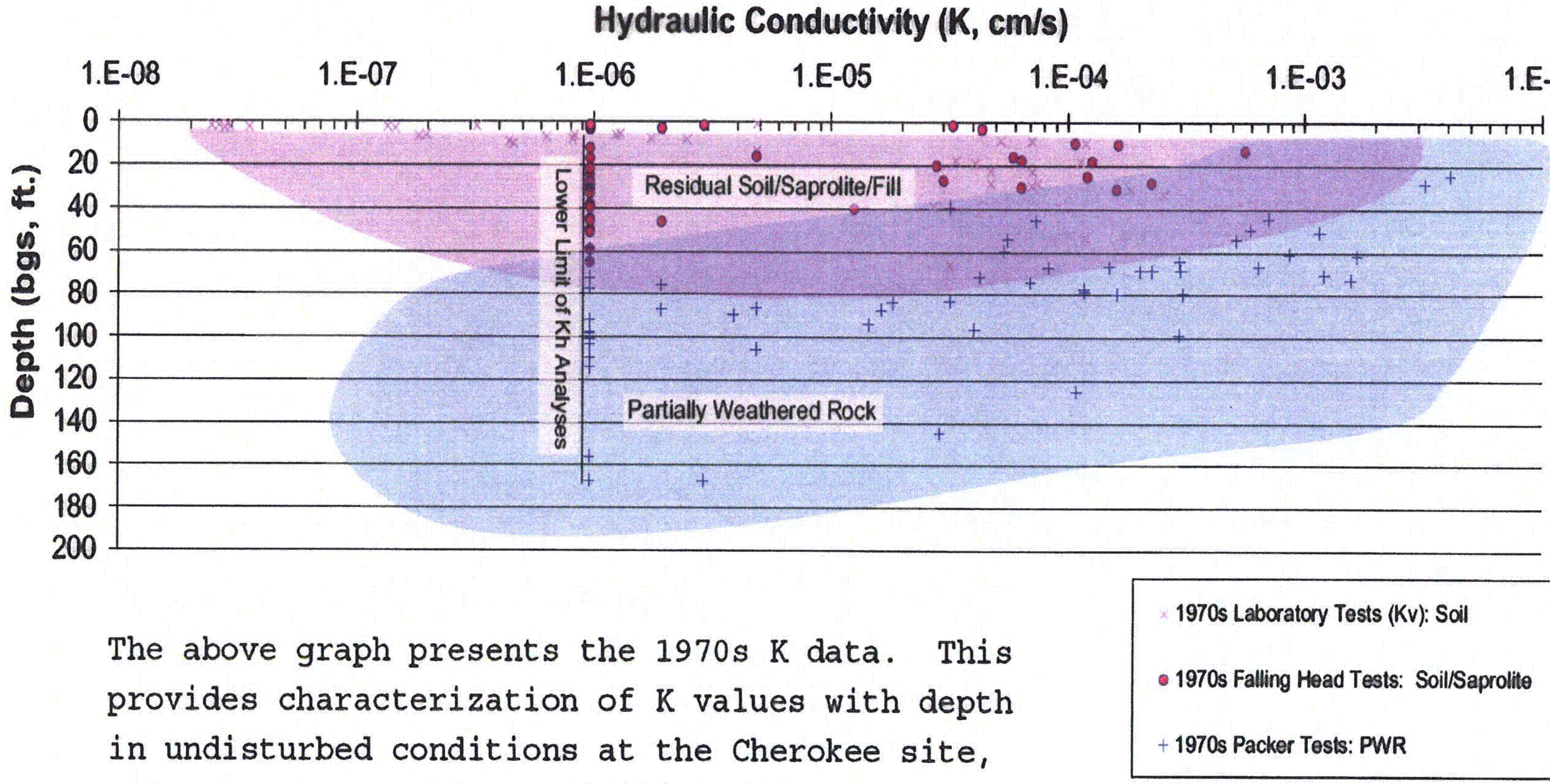
Attachment 10-1 to RAI 10

K vs. Depth Analyses for Cherokee and Lee Investigations

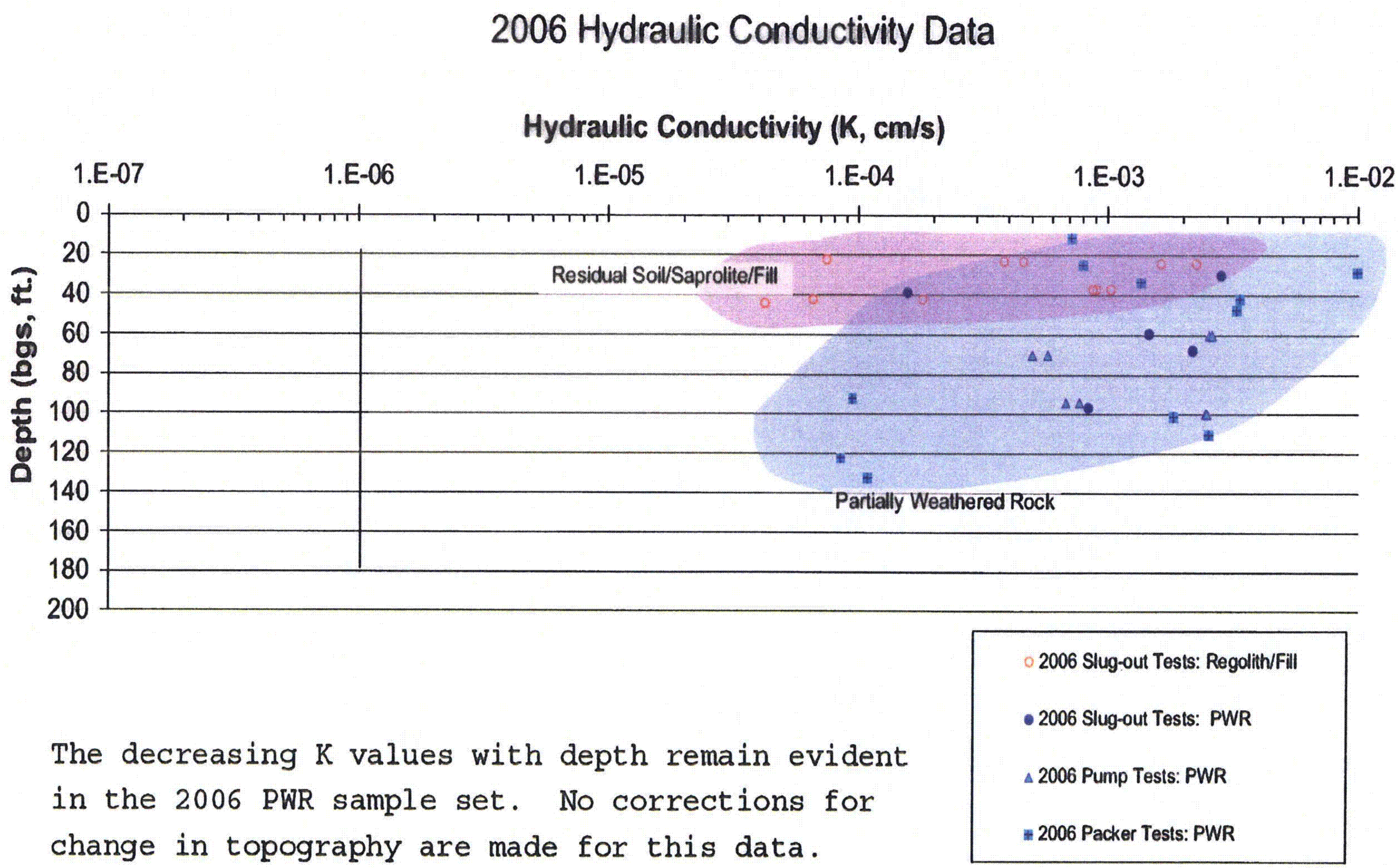


This graph presents the Lee Nuclear Site and Cherokee K data. Depth data in ER Figure 2.3-17 have not been modified to adjust for changes between pre-Cherokee construction era depths and the current depths. Similarly, a 2006 fill area sample would yield an apparently deeper K value than a 1970s sample. The 2006 data were collected to verify the findings of the Cherokee investigation, and both data sets support the apparent decrease in K with increasing depth for partially weathered rock (see Pages 2 and 3 of RAI-10-1). Depth is measured in feet below ground surface (bgs).

1970s Hydraulic Conductivity Data



The above graph presents the 1970s K data. This provides characterization of K values with depth in undisturbed conditions at the Cherokee site, prior to construction activities.



The decreasing K values with depth remain evident in the 2006 PWR sample set. No corrections for change in topography are made for this data.

Lee Nuclear Station Response to Request for Additional Information (RAI)

RAI Letter Dated: August 21, 2008

Reference NRC RAI Number: ER RAI-21

NRC RAI:

Submit a description of any low flow river discharge condition required of plant operation. Include complete documentation of the analysis of the low -flow issue.

Duke Energy Response:

Operation of the Lee Nuclear Station during low-flow conditions is described in ER Section 5.3. A description of the diffuser in relation to the Ninety-Nine Islands Dam and Hydroelectric Station is provided in the response to RAI 56. During low-flow conditions the Ninety-Nine Islands Hydroelectric Station is required by its Federal Energy Regulatory Commission (FERC) license to release 483 cubic feet per second (cfs) or the inflow to the reservoir, which ever is less. As part of the conditions of its license, the Ninety-Nine Islands Dam is required to "*...shut down all units when the pond elevation drops to the seasonal maximum drawdown limit required by Article 401 and shall operate one unit at its minimum hydraulic output for that portion of every hour which is necessary to discharge the approximate accumulated inflow.*" Consequently, some flow through the hydroelectric station is anticipated, including release of the mixed thermal effluent from Lee Nuclear Station, throughout the day, even during severe low-flow conditions. The thermal mass balance estimate discussed in ER Section 5.3.2.1 considers downstream temperature increases during low-flow conditions (< 483 cfs) and estimates a maximum temperature increase below the dam of 1.7°F. The details of the mass balance estimate are provided in Attachment 21-1.

As explained in Attachment 21-1, even during low-flow periods, there is sufficient water released through the hydroelectric station to maintain effective mixing in the forebay of the dam. This is confirmed by field data collected during the 2006 surveys, which indicated that even during the low-flow period, dissolved oxygen in the lower depths of the forebay remained above 88% saturation. Consequently, low dissolved oxygen is not expected to occur in the releases from the Ninety-Nine Islands Hydroelectric Station during low-flow conditions.

Duke Energy does not anticipate any permit limits on Lee Nuclear Station operations resulting from thermal conditions during low-flow periods.

Calculations supporting the conclusions in the ER are available for NRC inspection at the Duke Energy Charlotte office or at the offices of our contractors in Richland, WA and Bethesda, MD.

Duke Energy is conducting additional modeling of the thermal discharge as part of the NPDES permit submittal package being prepared for South Carolina. We anticipate this work to be completed by the first or second quarter of 2009.

Associated Revisions to the Lee Nuclear Station Combined License Application:

None

Associated Attachment:

Attachment 21-1	Strom Thurmond Institute, Final Report, Hydrodynamic Assessment of Discharge from Cooling Tower Blowdown to the Broad River, Lee Nuclear Station, Cherokee County, South Carolina, 2007.

Lee Nuclear Station Response to Request for Additional Information (RAI)

Attachment 21-1 to RAI 21

Strom Thurmond Institute, Final Report, Hydrodynamic Assessment of Discharge from Cooling Tower Blowdown to the Broad River, Lee Nuclear Station, Cherokee County, South Carolina, 2007

THE
STROM THURMOND
INSTITUTE

20 September 2007 ***FINAL REPORT***

Duke Energy *via Hardcopy and Email*
Attn: Ms. Jessica Bednarcik
P.O. Box 1006
Charlotte, NC 28201-1006

Subject: Final Report
Hydrodynamic Assessment of Discharge from Cooling Tower Blowdown to Broad River, Lee Nuclear Station, Cherokee County, South Carolina

Dear Ms Benarcik:

This Final Report responds to Duke Energy's request of the South Carolina Water Resources Center (SCWRC) for a preliminary assessment of the hydrodynamic conditions associated with discharge from the cooling tower blowdown at the proposed Lee Nuclear Station. This report summarizes the work performed by the University's project team, including Dr. Abdul Khan, Principal Engineer responsible for analytical modeling, Dr. Ben Sill, Senior Faculty member responsible for technical project oversight and quality assurance review, and Dr. Dave Hargett, Senior Scholar and project manager. Details of the methodology, output, and results are provided in the accompanying documents. Our analysis is based on review of materials and information provided by Duke Energy, a site visit to the facility and the Ninety-Nine Islands Dam and Hydroelectric Facility on 30 July, and follow-up discussions with Duke Energy staff.

Background: Our understanding, based on information provided by Duke Energy, is that its cooling tower blowdown water is proposed to be discharged from a diffuser of 65-ft length, at approximately 15 cfs and a temperature of 95°F. The diffuser will be located on the upstream shelf of the dam, above and behind the existing dam gates. The nominal low flow of the Broad River will be at or above 483 cfs (the Design Low Flow Condition or DLFC), which is roughly equal to the 7Q10 flow for the river at this location. Under these low flow conditions the discharge through the power units will be released on 30-minute cycles. Regulatory guidance limits the maximum increase in temperature in the mixing zone to 5°F above the ambient condition, which is defined for purposes of this analysis as 81.5°F.

Objectives: We were charged by Duke Energy with examining the extent of the thermal plume build-up in the forebay, upstream of the diffuser. We also examined the effect of releasing the thermal load from the diffuser, through the power units, and to the tailrace downstream.

Technical Approach: Our team employed analytical modeling techniques to assess the fundamental question of whether unacceptable levels of temperature build-up may occur. This approach provides guidance on the nature and extent of any thermal build-up in the upstream forebay. A somewhat simpler dilution calculation technique was used to address the thermal load dispersion downstream, via the power units, and to the tailrace. The analytical model approach applied to the upstream situation does not provide the level of precision that would be rendered by a 3-D hydrodynamic numerical model, but is much more efficient and is appropriate as an initial assessment of thermal effects. This analytical approach is used to evaluate whether there are "fatal flaws" in the diffuser approach, without the effort of constructing a 3-D model. As an initial construct the analytical model provides substantive and valuable insights on whether the plume condition will be unacceptable, marginal, or acceptable, and guidance to what factors may be changed to mitigate heat build-up caused by the discharge configuration.

Analytical Methods: The methods, equations, assumptions, input values, and scenarios tested are described in detail in Dr. Khan's accompanying Final Technical Analysis (Enclosure 1). Five upstream scenarios were evaluated. One downstream scenario was evaluated. Output from the MS-Excel worksheets used in the model is provided in the attached data report (Enclosure 2).

Upstream Scenarios: Five upstream thermal loading scenarios were evaluated using Dr. Khan's analytical model. The physical layout and assumptions with regard to the positioning of the diffuser, the dam, the water column, and other flow barriers were based on input data provided by Duke Energy, and are illustrated in Dr. Khan's accompanying report. These scenarios and the results are summarized in the following Table 1.

Table 1: Thermal Mixing Scenarios and Resulting Temperature Gain in the Forebay

Scenario	Description	Mix Zone Dimensions			Input Flow (cfs)	Resulting Steady State Temperature Gain °F
		Diffuser Length (ft)	Upstream Mix Zone (ft)	Depth (ft)		
S1	Basic Conservative Scenario: Full mixing depth of 12 ft (6 ft above, and 6 ft below diffuser), restricted to mixing in the 65 ft length of the diffuser, and out to 50 ft from the diffuser. *Conservative.*	65	50	12	483	1.2
S2	Flow-Restricted Scenario: Same as S1 but with flow restricted to ½ of DLFC. *Very conservative.*	65	50	12	242	2.2
S3	Mix-Restricted Scenario: Same as S1 but with the mixing zone restricted to the top 6 ft of the water column. *Very conservative.*	65	50	6	483	2.1
S4	Flow- & Mix-Restricted Scenario: Same as S1 but with flow restricted to ½ of DLFC and mixing zone restricted to the top 6 ft of the water column. *Extremely conservative.*	65	50	6	242	3.7
S5*	Shallow Mix-Restricted Scenario: Mixing restricted to the "surface" of the ABCD embayment trapped behind the dam. For comparison only.	65	150+	0.6	1:2 dilution ratio	3.9

* *Scenario S5 was set up to allow diffusion over the entire forebay, defined in the model by Area ABCD, which is approximately 221,000 ft^2. Allowing all of the thermal load to diffuse into this area, and in the near surface, with the defined thermal result, would result in a thermally affected zone of only 0.6 ft thickness.*

Discussion of Upstream Scenarios: All model scenarios were cycled until steady state conditions were reached. Thus, the temperature gain results reported reflect maximum conditions under the defined scenarios. The mixing scenarios summarized in Table 1 are all considered "conservative" to "extremely conservative". The base scenario (S1) represents a reasonable set of input values that reflect a likely and conservative "worst-case" mixing scenario. This scenario produces an increase in temperature in the affected region of only 1.2°F. Scenarios S2-S4 represent adjustments of input values to the analytical model to radically stress the model by reducing the mixing flow by one-half (S2), reducing the mixing depth by one-half (S3), or both simultaneously (S4). Scenario S5 analyzes the extreme conditions in which the thermal load would mix across the entire forebay (Area ABCD), behind the dam, but only in the near surface. None of these extreme scenarios (S2-S5) are considered likely or representative of what would likely occur. Still, using these exceptionally conservative assumptions, the analytical model did not produce thermal gain of more than 3.7°F for any extreme scenario (S2-S4), and 3.9°F for the comparative scenario S5.

Downstream Scenario: The downstream mixing scenario is substantially simpler and was analyzed by a simple dilution calculation. A reasonable and conservative worst-case is defined by a scenario in which all of the thermal load accumulated over a 60-minute period would be discharged through the power units to the downstream tailrace over a 30-minute discharge cycle. Under these assumptions, of the 483 cfs discharged during the 30-minute discharge cycle, 30 cfs at 95°F represents the thermal load from the diffuser to be discharged, and to be mixed in the process of discharge with 453 cfs from the ambient embayment (river) water at 81.5 °F. *(The 30 cfs of 95°F water is comprised of 15 cfs accumulated over 30 minutes during the no discharge half of the cycle, plus 15 cfs that would occur during the 30 minute discharge period).* The result of this extreme worst-case scenario would produce a temperature increase in the tailrace area below the dam of 1.7°F.

Conclusions: The results of analytical modeling of thermal loading of various geometric and flow scenarios in the forebay area upstream of the dam indicate that under reasonable assumptions thermal gain will be no more than about 1.2°F. Additional scenarios were conceived to intentionally stress the model by radically reducing the mixing volume or the mixing depth, or both. Even with these extreme conditions, the model predicted a steady state temperature increase for the basic scenarios (S-1-S4) of no more than 3.7°F. Results of the worst-case downstream mixing scenario showed a maximum temperature gain of 1.7°F. Based on this analysis, under the defined operating conditions and representative low river flows, one can reasonably assume that thermal gain standards will not be violated.

Disclaimer: *The analysis and results provided in this report represent a preliminary assessment of limited scope and are based on information provided by Duke Energy. The authors believe the results of this evaluation are reasonable and accurate and reflect a rational approach to preliminary analysis of the proposed discharge design using generally accepted hydrodynamic principles. However, the reader is cautioned that the methods employed and the input values used in this evaluation represent only those scenarios defined in this report. Extrapolation beyond the scenarios and input assumptions provided in this report should be considered only with appropriate caution.*

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The project team and Clemson University appreciate the opportunity to assist Duke Energy in this important project.

Very truly yours,

South Carolina Water Resources Center

Signed, DLH, 20 Sep 2007

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Enclosures

1) Final Technical Analysis – Dr. Khan, 6 September 2007
2) Analytical Model Worksheets – Dr. Khan, 6 September 2007

cc's w/ Enclosures, via Email: Mr. Theodore Bowling
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1) Final Technical Analysis – Dr. A.A. Khan, 6 September 2007

2) Analytical Model Worksheets – Dr. A.A. Khan, 6 September 2007

FINAL
TECHNICAL
ANALYSIS

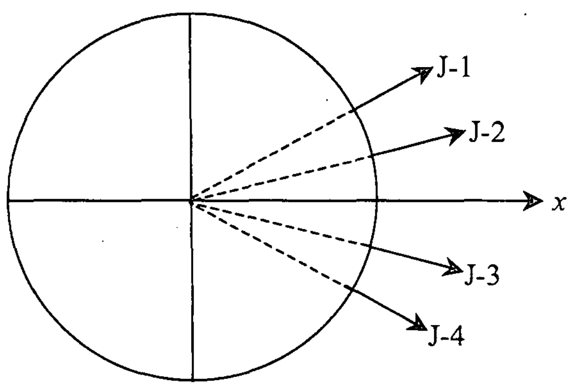
ANALYTICAL MODEL OF HYDRODYNAMIC THERMAL EFFECTS PROPOSED COOLING TOWER BLOWDOWN DISCHARGE LEE NUCLEAR STATION DUKE ENERGY

Analysis by Dr. Abdul A. Khan, Dept. of Civil Engineering, Clemson University
06 September 2007

Quality Assurance Review by Dr. Ben Sill
Dept. of Civil Engineering, Clemson University

Basic Facts:

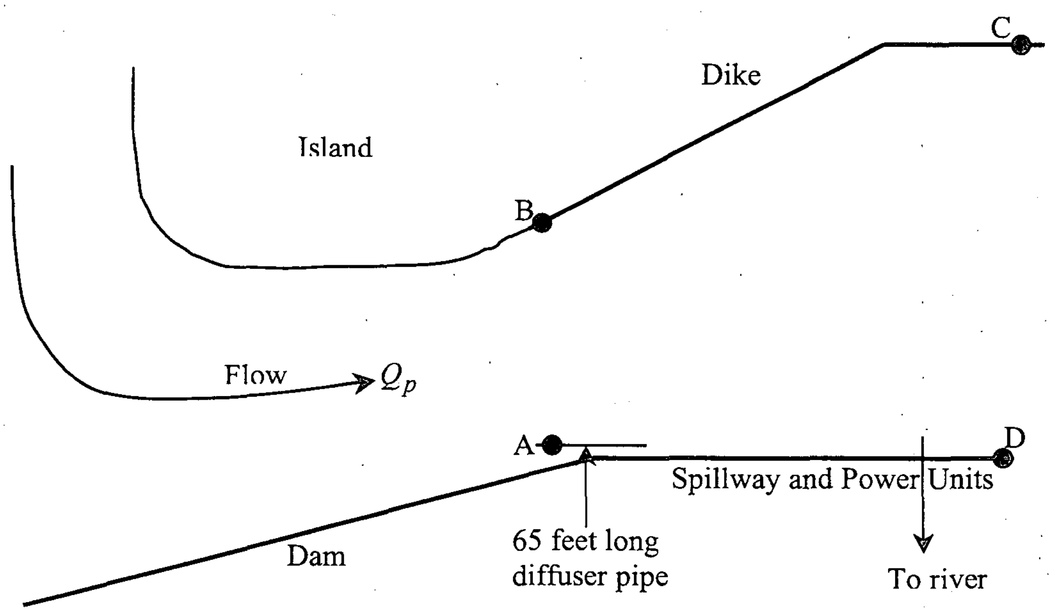
- Diameter of the diffuser pipes 36 inches, and is located approximately at mid-depth of the water column (the center of the diffuser is 6 feet above the bed).
- No of holes in the pipes are 1040 over a length of 65 feet.
- The diameter of orifices in the diffuser pipe is 1 inch with 3-inch spacing along and across the pipe
- Assuming uniform flow from each orifice the initial velocity is 2.64 ft/s.
- Flow through the power unit (units 1 and 4 alternately) is 483 cfs, in a cycle of 30 minutes on and 30 minutes off. *(Note: The operational regime historically used during low flow conditions at the Ninety-Nine Islands Dam is a cycle of 30 min on, and 30 min off, using two alternating power units. This is the only cycling duration/frequency examined in this analytical model).*
- Flow through the diffuser is 15 cfs.
- At any longitudinal section the flow exits of the diffuser are as four circular jets directed upstream into the reservoir. Two jets are directed upward and two jets are directed downward (as shown in the figure below). Jets J-1 and J-4 are at an angle of 14.2 degrees and jets J-2 and J-3 are at an angle of 4.8 degrees from the x-axis.



Section of a diffuser pipe showing four jets

Hydrodynamic Model – Lee Nuclear Station
Dr. Abdul Khan

- Referring to the figure below, the distance AB is 150 feet. The volume of water within the region ABCD is 1,746,300 cubic feet (from bathymetry provided) with a surface area of 220,750 square feet. The distance AB is about 150 feet.
- The volume of water in 30 minutes with 15 cfs discharge at $95^{\circ}F$ is 27,000 cubic feet and the volume of water in 30 minutes with 483 cfs discharge is 864,000 cubic feet.



Layout of the upstream forebay reservoir area

Equations Used:

- Decay of centerline velocity of circular and plane turbulent jets

$$\frac{u_m}{U_o} = \frac{6.3}{x/d} \quad \text{for circular jet}$$

$$\frac{u_m}{U_o} = \frac{3.5}{\sqrt{2x/d}} \quad \text{for plane jet}$$

where u_m is the velocity at the center of the jet at any location x along the jet, U_o is the exit velocity and d is the diameter of the jet. In case of plane turbulent jet, it is assumed that the jets J-1 and J-2 will combine to form a jet that will behave as it is exiting from a slot with that is 65 feet long and has a width of one or two diameters. These equations can be also used to estimate the distance traveled in a given time period.

- The jet dilution, that is increase in discharge as it flows down and entrains the surrounding fluid, is given by

$$\frac{Q}{Q_o} = 0.33x/d \quad \text{for circular jet}$$

$$\frac{Q}{Q_o} = 0.44\sqrt{2x/d} \quad \text{for plane jet}$$

where Q is the volumetric flow rate at any location x along the jet and Q_o is the volumetric flow rate at the exit.

- Due to density difference between the jet and the ambient fluid, the jet will rise to the surface as given by

$$z = \frac{U_{zo}}{U_{xo}}x - \frac{g'}{2U_{xo}^2}x^2$$

where z is the vertical distance and x is the horizontal distance, U_{zo} and U_{xo} are the vertical and horizontal components of the exit velocity, and g' represents the net upward force on the hot water.

- Heat transfer to the air is given by

$$Q_H = KA(T - T_E)$$

where K is the heat exchange coefficient and is equal to 160 $BTU/(ft^2 \cdot day \cdot {}^oF)$ for the month of August in the Greenville-Spartanburg area, A is the surface area, T is the existing temperature, and T_E is the equilibrium and is equal to $81.5°F$ for the month of August in the Greenville-Spartanburg area.

- To calculate the temperature change for the mass of water for a given heat change

$$Q_H = C\rho g\forall(T - T_E)$$

where C is the specific heat and is equal to 1 $BTU/(lb \circ {}^{o}F)$ and $\forall$ is the volume of water. The volume weighted average is used according to the first law of thermodynamics.

Basic Observations:

- The jets J-1 and J-2 will reach the surface at 23.5 feet and 71.83 feet from the diffuser if density difference is ignored. If density difference is included without any dilution, the jets J-1, J-2, J-3, and J-4 will reach the surface at 16.6, 25.4, 39.2, and 56.6 feet from the diffuser. Since dilution will reduce the density difference the jets will reach the surface farther than the above distance. Since the dilution amount is associated with temperature reduction, it is assumed that only 50 feet of length is available for jet mixing. This is a conservative value.
- The jets will travel a distance of 71 feet if it is assumed that the jets will act as individual circular jet (no interaction) and will travel a distance more than 150 feet if upper and lower pairs of jets are considered as plane turbulent jets. These distances are found by integrating the expressions of velocity decay.

Results:

Upstream Assessment: The first set of results is based on the jet mixing across 65-ft width of the diffuser, 12-ft depth, and 50-ft length. Note that the mixing depth assumed here of 50 ft is considered to be reasonable and conservative, given the geometry of the diffuser. The mixing length is based on minimum length required for a jet rising to the surface with density difference. For a 30-minute period, the blowdown discharge mixes with the volume of water which is 65 ft X 12 ft X 50 ft. In the next 30 minutes, the blowdown discharge continues to mix with the above volume and a outflow of 483 cfs takes place from the reservoir through the power unit. The flow has to come around the island to maintain mass balance. A proportionate amount (483 * 50/150 cfs) of ambient fluid at a temperature of $81.5\,^{\circ}F$ will enter the affected volume and the same volume at higher temperature will move towards the power unit. Four different scenarios are considered: (i) the first scenario is as specified above, (ii) in the second scenario only half the discharge,that is 242 cfs, is allowed from the upstream into the affected volume, (iii) in this case the blowdown discharge is allowed to mix only in the upper 6 feet of water with a full 483 cfs from the upstream into the affected area, and (iv) in the last case the blowdown discharge is allowed to mix in the upper 6 feet of the volume and only half the discharge (242 cfs) is allowed from the upstream into the affected volume.

In each case, a steady state temperature in the affected area reached after three cycles. Each cycle consists of 30 minutes off and 30 minutes on period of discharge of 483 cfs through the power unit. The computations are performed in one-minute intervals to accurately compute temperature variation in the affected volume due to blowdown discharge and upstream flow when the power unit is operating. The increase in temperatures in the four cases are $1.2^{\circ}F$, $2.2^{\circ}F$, $2.1^{\circ}F$, and $3.7^{\circ}F$, respectively.

Although the basic mixing configuration with a 50-ft mixing zone is considered reasonable and conservative, to investigate the effect changes in the length of the affected volume on temperature increase, the length was increased to 60 feet, and 75 feet. It was confirmed that increasing the length of the affected volume reduced the temperature increase.

As a last case, the blowdown discharge for a period of 1 hour is allowed to spread over the surface of the reservoir with 1:2 dilution ratio, that is the discharge will increase three times the initial discharge. This level of dilution for plane jet is achieved with 9 feet of travel distance. For circular jet the dilution will be much higher for jet traveling over the same distance. The steady state of temperature is achieved in four cycles with increase in temperature of $3.9^{\circ}F$. It should be recognized that these conditions represent the lowest level of mixing. This last, extremely poor-mixing scenario is unrealistic and was considered only for comparative purposes to examine the sensitivity of the analytical model to mixing parameters.

Downstream Analysis: The worst-case scenario for the flow through the power unit is when 30 cfs is passing through the power unit for a period of 30 minutes. The downstream increase in temperature is $1.7^{\circ}F$.

Conclusions:

1) Four scenarios were evaluated to assess worst-case increases in upstream reservoir forebay temperature, based on the low flows operational regime and diffuser design defined by Duke Energy. Under the basic realistic and conservative scenario, the maximum increase in upstream reservoir forebay temperature is $1.2\ ^{\circ}F$. In the most extreme worst-case scenario the maximum increase in the upstream reservoir forebay temperature is $3.7^{\circ}F$.

2) For the low flows operational regime defined by Duke Energy, the worst-case maximum increase in temperature in the downstream reach of the river is $1.7^{\circ}F$.

Scenario 1

Uo (ft/s) 2.644	Specific heat of water Cp (BTU/lb/F) 1				
		Length Affected (ft) 50	Dt (minutes) 1	Blowdown Volume (ft^3) 900	Volume Affected (ft^3) 39000
Volume of affected zone 12ft X 65ft X 50ft =	39000				
15 cfs for 30 minutes =	27000				
		Depth Affected (ft) 12	Equil. Temperature (F) 81.5	Heat Transfer Coeff BTU/ft^2/day/F 160	Blowdown Temp (F) 95
		Actual Depth (ft) 12	Volume Through Unit (ft^3) 28980	Total Flow Width (ft) 150	Flow area ratio 0.33

Cycle I

Time (Minutes)	New Temp (F)	Heat Transferred BTU	Temp Reduction (F)	Final Temp (F)	Time (Minutes)	New Temp (F)	Heat Transferred BTU	Temp Reduction (F)	Final Temp (F)
0	81.50	0.00	0.00	81.50	30	88.29	0.00	0.00	88.29
1	81.81	112.50	0.00	81.81	31	86.76	1699.23	0.00	86.76
2	82.12	222.39	0.00	82.12	32	85.65	1497.27	0.00	85.65
3	82.41	329.72	0.00	82.41	33	84.83	1204.19	0.00	84.83
4	82.70	434.57	0.00	82.70	34	84.24	990.51	0.00	84.24
5	82.99	536.98	0.00	82.99	35	83.81	834.70	0.00	83.81
6	83.26	637.01	0.00	83.26	36	83.50	721.10	0.00	83.50
7	83.53	734.71	0.00	83.53	37	83.27	638.27	0.00	83.27
8	83.80	830.15	0.00	83.80	38	83.10	577.88	0.00	83.10
9	84.06	923.37	0.00	84.06	39	82.98	533.84	0.00	82.98
10	84.31	1014.43	0.00	84.31	40	82.89	501.74	0.00	82.89
11	84.56	1103.37	0.00	84.56	41	82.82	478.33	0.00	82.82
12	84.80	1190.25	0.00	84.80	42	82.78	461.26	0.00	82.78
13	85.03	1275.11	0.00	85.03	43	82.74	448.81	0.00	82.74
14	85.26	1358.00	0.00	85.26	44	82.72	439.74	0.00	82.72
15	85.48	1438.97	0.00	85.48	45	82.70	433.13	0.00	82.70
16	85.70	1518.05	0.00	85.70	46	82.69	428.30	0.00	82.69
17	85.92	1595.30	0.00	85.92	47	82.68	424.78	0.00	82.68
18	86.13	1670.75	0.00	86.13	48	82.67	422.22	0.00	82.67
19	86.33	1744.45	0.00	86.33	49	82.66	420.35	0.00	82.66
20	86.53	1816.45	0.00	86.53	50	82.66	418.99	0.00	82.66
21	86.72	1886.76	0.00	86.72	51	82.66	417.99	0.00	82.66
22	86.92	1955.45	0.00	86.91	52	82.66	417.27	0.00	82.66
23	87.10	2022.54	0.00	87.10	53	82.65	416.74	0.00	82.65
24	87.28	2088.07	0.00	87.28	54	82.65	416.35	0.00	82.65
25	87.46	2152.08	0.00	87.46	55	82.65	416.07	0.00	82.65
26	87.63	2214.61	0.00	87.63	56	82.65	415.87	0.00	82.65
27	87.80	2275.68	0.00	87.80	57	82.65	415.72	0.00	82.65
28	87.97	2335.34	0.00	87.97	58	82.65	415.61	0.00	82.65
29	88.13	2393.61	0.00	88.13	59	82.65	415.53	0.00	82.65
30	88.29	2450.52	0.00	88.29	60	82.65	415.47	0.00	82.65

Cycle 2

1651860

Time (Minutes)	New Temp (F)	Heat Transferred BTU	Temp Reduction (F)	Final Temp (F)	Time (Minutes)	New Temp (F)	Heat Transferred BTU	Temp Reduction (F)	Final Temp (F)
0	82.65	0.00	0.00	82.65	30	88.85	0.00	0.00	88.85
1	82.94	518.32	0.00	82.94	31	87.17	2048.93	0.00	87.17
2	83.21	618.79	0.00	83.21	32	85.95	1606.42	0.00	85.95
3	83.49	716.92	0.00	83.49	33	85.06	1283.78	0.00	85.05
4	83.75	812.77	0.00	83.75	34	84.40	1048.53	0.00	84.40
5	84.01	906.40	0.00	84.01	35	83.93	877.01	0.00	83.93
6	84.26	997.85	0.00	84.26	36	83.58	751.95	0.00	83.58
7	84.51	1087.18	0.00	84.51	37	83.33	660.76	0.00	83.33
8	84.75	1174.43	0.00	84.75	38	83.15	594.28	0.00	83.15
9	84.99	1259.66	0.00	84.99	39	83.01	545.80	0.00	83.01
10	85.22	1342.91	0.00	85.22	40	82.91	510.45	0.00	82.91
11	85.44	1424.22	0.00	85.44	41	82.84	484.68	0.00	82.84
12	85.66	1503.65	0.00	85.66	42	82.79	465.89	0.00	82.79
13	85.88	1581.23	0.00	85.88	43	82.75	452.19	0.00	82.75
14	86.09	1657.01	0.00	86.09	44	82.72	442.20	0.00	82.72
15	86.29	1731.03	0.00	86.29	45	82.70	434.92	0.00	82.70
16	86.49	1803.33	0.00	86.49	46	82.69	429.61	0.00	82.69
17	86.69	1873.96	0.00	86.69	47	82.68	425.74	0.00	82.68
18	86.88	1942.94	0.00	86.88	48	82.67	422.92	0.00	82.67
19	87.07	2010.32	0.00	87.07	49	82.67	420.86	0.00	82.67
20	87.25	2076.14	0.00	87.25	50	82.66	419.36	0.00	82.66
21	87.43	2140.43	0.00	87.43	51	82.66	418.26	0.00	82.66
22	87.60	2203.22	0.00	87.60	52	82.66	417.46	0.00	82.66
23	87.77	2264.56	0.00	87.77	53	82.65	416.88	0.00	82.65
24	87.94	2324.47	0.00	87.94	54	82.65	416.46	0.00	82.65
25	88.10	2382.99	0.00	88.10	55	82.65	416.15	0.00	82.65
26	88.26	2440.16	0.00	88.26	56	82.65	415.92	0.00	82.65
27	88.41	2495.99	0.00	88.41	57	82.65	415.76	0.00	82.65
28	88.56	2550.53	0.00	88.56	58	82.65	415.64	0.00	82.65
29	88.71	2603.80	0.00	88.71	59	82.65	415.55	0.00	82.65
30	88.85	2655.84	0.00	88.85	60	82.65	415.49	0.00	82.65

Cycle 3

1651860

Time (Minutes)	New Temp (F)	Heat Transferred BTU	Temp Reduction (F)	Final Temp (F)	Time (Minutes)	New Temp (F)	Heat Transferred BTU	Temp Reduction (F)	Final Temp (F)
0	82.65	0.00	0.00	82.65	30	88.85	0.00	0.00	88.85
1	82.94	518.34	0.00	82.94	31	87.17	2048.94	0.00	87.17
2	83.21	618.80	0.00	83.21	32	85.95	1606.43	0.00	85.95
3	83.49	716.93	0.00	83.49	33	85.06	1283.78	0.00	85.05
4	83.75	812.78	0.00	83.75	34	84.40	1048.53	0.00	84.40
5	84.01	906.41	0.00	84.01	35	83.93	877.01	0.00	83.93
6	84.26	997.86	0.00	84.26	36	83.58	751.95	0.00	83.58
7	84.51	1087.19	0.00	84.51	37	83.33	660.76	0.00	83.33
8	84.75	1174.44	0.00	84.75	38	83.15	594.28	0.00	83.15
9	84.99	1259.67	0.00	84.99	39	83.01	545.80	0.00	83.01
10	85.22	1342.92	0.00	85.22	40	82.91	510.46	0.00	82.91
11	85.44	1424.23	0.00	85.44	41	82.84	484.68	0.00	82.84
12	85.66	1503.66	0.00	85.66	42	82.79	465.89	0.00	82.79
13	85.88	1581.24	0.00	85.88	43	82.75	452.19	0.00	82.75
14	86.09	1657.02	0.00	86.09	44	82.72	442.20	0.00	82.72
15	86.29	1731.04	0.00	86.29	45	82.70	434.92	0.00	82.70
16	86.49	1803.35	0.00	86.49	46	82.69	429.61	0.00	82.69
17	86.69	1873.97	0.00	86.69	47	82.68	425.74	0.00	82.68
18	86.88	1942.95	0.00	86.88	48	82.67	422.92	0.00	82.67
19	87.07	2010.33	0.00	87.07	49	82.67	420.86	0.00	82.67
20	87.25	2076.15	0.00	87.25	50	82.66	419.36	0.00	82.66
21	87.43	2140.44	0.00	87.43	51	82.66	418.26	0.00	82.66
22	87.60	2203.23	0.00	87.60	52	82.66	417.46	0.00	82.66
23	87.77	2264.57	0.00	87.77	53	82.65	416.88	0.00	82.65
24	87.94	2324.48	0.00	87.94	54	82.65	416.46	0.00	82.65
25	88.10	2383.00	0.00	88.10	55	82.65	416.15	0.00	82.65
26	88.26	2440.16	0.00	88.26	56	82.65	415.92	0.00	82.65
27	88.41	2496.00	0.00	88.41	57	82.65	415.76	0.00	82.65
28	88.56	2550.54	0.00	88.56	58	82.65	415.64	0.00	82.65
29	88.71	2603.81	0.00	88.71	59	82.65	415.55	0.00	82.65
30	88.85	2655.84	0.00	88.85	60	82.65	415.49	0.00	82.65

Scenario 2

Specific heat of water Cp (BTU/lb/F): 1

Uo (ft/s): 2.644

Volume of affected zone 12ft X 65ft X 50ft =	39000	Length Affected (ft) 50	Dt (minutes) 1	Blowdown Volume (ft^3) 900	Volume Affected (ft^3) 39000
15 cfs for 30 minutes =	27000	Depth Affected (ft) 12	Equil. Temperature (F) 81.5	Heat Transfer Coeff BTU/ft^2/day/F 160	Blowdown Temp (F) 95
		Actual Depth (ft) 12	Volume Through Unit (ft^3) 28980	Total Flow Width (ft) 150	Flow area ratio 0.33

Cycle I

Time (Minutes)	New Temp (F)	Heat Transferred BTU	Temp Reduction (F)	Final Temp (F)	Time (Minutes)	New Temp (F)	Heat Transferred BTU	Temp Reduction (F)	Final Temp (F)
0	81.50	0.00	0.00	81.50	30	88.29	0.00	0.00	88.29
1	81.81	112.50	0.00	81.81	31	87.60	2202.67	0.00	87.60
2	82.12	222.39	0.00	82.12	32	87.01	1991.27	0.00	87.01
3	82.41	329.72	0.00	82.41	33	86.51	1810.95	0.00	86.51
4	82.70	434.57	0.00	82.70	34	86.09	1657.15	0.00	86.09
5	82.99	536.98	0.00	82.99	35	85.73	1525.97	0.00	85.73
6	83.26	637.01	0.00	83.26	36	85.42	1414.08	0.00	85.42
7	83.53	734.71	0.00	83.53	37	85.15	1318.64	0.00	85.15
8	83.80	830.15	0.00	83.80	38	84.93	1237.23	0.00	84.93
9	84.06	923.37	0.00	84.06	39	84.73	1167.80	0.00	84.73
10	84.31	1014.43	0.00	84.31	40	84.57	1108.57	0.00	84.57
11	84.56	1103.37	0.00	84.56	41	84.43	1058.06	0.00	84.43
12	84.80	1190.25	0.00	84.80	42	84.31	1014.97	0.00	84.31
13	85.03	1275.11	0.00	85.03	43	84.21	978.22	0.00	84.21
14	85.26	1358.00	0.00	85.26	44	84.12	946.87	0.00	84.12
15	85.48	1438.97	0.00	85.48	45	84.05	920.14	0.00	84.05
16	85.70	1518.05	0.00	85.70	46	83.98	897.33	0.00	83.98
17	85.92	1595.30	0.00	85.92	47	83.93	877.88	0.00	83.93
18	86.13	1670.75	0.00	86.13	48	83.89	861.29	0.00	83.88
19	86.33	1744.45	0.00	86.33	49	83.85	847.13	0.00	83.85
20	86.53	1816.45	0.00	86.53	50	83.81	835.06	0.00	83.81
21	86.72	1886.76	0.00	86.72	51	83.78	824.77	0.00	83.78
22	86.92	1955.45	0.00	86.91	52	83.76	815.99	0.00	83.76
23	87.10	2022.54	0.00	87.10	53	83.74	808.50	0.00	83.74
24	87.28	2088.07	0.00	87.28	54	83.72	802.11	0.00	83.72
25	87.46	2152.08	0.00	87.46	55	83.71	796.66	0.00	83.71
26	87.63	2214.61	0.00	87.63	56	83.69	792.01	0.00	83.69
27	87.80	2275.68	0.00	87.80	57	83.68	788.04	0.00	83.68
28	87.97	2335.34	0.00	87.97	58	83.67	784.66	0.00	83.67
29	88.13	2393.61	0.00	88.13	59	83.66	781.78	0.00	83.66
30	88.29	2450.52	0.00	88.29	60	83.66	779.32	0.00	83.66

Cycle 2

1651860

Time (Minutes)	New Temp (F)	Heat Transferred BTU	Temp Reduction (F)	Final Temp (F)	Time (Minutes)	New Temp (F)	Heat Transferred BTU	Temp Reduction (F)	Final Temp (F)
0	83.66	0.00	0.00	83.66	30	89.35	0.00	0.00	89.35
1	83.92	873.72	0.00	83.92	31	88.51	2531.16	0.00	88.51
2	84.17	965.93	0.00	84.17	32	87.79	2271.45	0.00	87.79
3	84.42	1056.00	0.00	84.42	33	87.18	2049.94	0.00	87.18
4	84.67	1143.98	0.00	84.67	34	86.65	1860.99	0.00	86.65
5	84.91	1229.91	0.00	84.91	35	86.21	1699.84	0.00	86.21
6	85.14	1313.85	0.00	85.14	36	85.83	1562.37	0.00	85.83
7	85.37	1395.84	0.00	85.36	37	85.50	1445.13	0.00	85.50
8	85.59	1475.93	0.00	85.59	38	85.22	1345.12	0.00	85.22
9	85.80	1554.15	0.00	85.80	39	84.99	1259.82	0.00	84.99
10	86.02	1630.56	0.00	86.01	40	84.79	1187.07	0.00	84.79
11	86.22	1705.20	0.00	86.22	41	84.62	1125.01	0.00	84.61
12	86.42	1778.10	0.00	86.42	42	84.47	1072.08	0.00	84.47
13	86.62	1849.31	0.00	86.62	43	84.34	1026.93	0.00	84.34
14	86.81	1918.87	0.00	86.81	44	84.24	988.42	0.00	84.24
15	87.00	1986.81	0.00	87.00	45	84.15	955.57	0.00	84.15
16	87.19	2053.17	0.00	87.18	46	84.07	927.56	0.00	84.07
17	87.37	2117.99	0.00	87.36	47	84.00	903.66	0.00	84.00
18	87.54	2181.31	0.00	87.54	48	83.95	883.28	0.00	83.95
19	87.71	2243.15	0.00	87.71	49	83.90	865.89	0.00	83.90
20	87.88	2303.56	0.00	87.88	50	83.86	851.06	0.00	83.86
21	88.04	2362.57	0.00	88.04	51	83.82	838.41	0.00	83.82
22	88.20	2420.21	0.00	88.20	52	83.79	827.62	0.00	83.79
23	88.36	2476.50	0.00	88.36	53	83.77	818.42	0.00	83.77
24	88.51	2531.49	0.00	88.51	54	83.74	810.57	0.00	83.74
25	88.66	2585.21	0.00	88.66	55	83.73	803.88	0.00	83.73
26	88.80	2637.68	0.00	88.80	56	83.71	798.17	0.00	83.71
27	88.95	2688.92	0.00	88.95	57	83.70	793.30	0.00	83.70
28	89.08	2738.98	0.00	89.08	58	83.69	789.14	0.00	83.68
29	89.22	2787.88	0.00	89.22	59	83.68	785.60	0.00	83.68
30	89.35	2835.64	0.00	89.35	60	83.67	782.58	0.00	83.67

Cycle 3

1651860

Time (Minutes)	New Temp (F)	Heat Transferred BTU	Temp Reduction (F)	Final Temp (F)	Time (Minutes)	New Temp (F)	Heat Transferred BTU	Temp Reduction (F)	Final Temp (F)
0	83.67	0.00	0.00	83.67	30	89.36	0.00	0.00	89.36
1	83.93	876.91	0.00	83.93	31	88.51	2532.53	0.00	88.51
2	84.18	969.04	0.00	84.18	32	87.79	2272.62	0.00	87.79
3	84.43	1059.04	0.00	84.43	33	87.18	2050.94	0.00	87.18
4	84.68	1146.95	0.00	84.68	34	86.66	1861.85	0.00	86.66
5	84.91	1232.81	0.00	84.91	35	86.21	1700.56	0.00	86.21
6	85.15	1316.68	0.00	85.15	36	85.83	1563.00	0.00	85.83
7	85.37	1398.61	0.00	85.37	37	85.50	1445.66	0.00	85.50
8	85.59	1478.63	0.00	85.59	38	85.23	1345.57	0.00	85.23
9	85.81	1556.79	0.00	85.81	39	84.99	1260.21	0.00	84.99
10	86.02	1633.14	0.00	86.02	40	84.79	1187.39	0.00	84.79
11	86.23	1707.72	0.00	86.23	41	84.62	1125.29	0.00	84.62
12	86.43	1780.56	0.00	86.43	42	84.47	1072.32	0.00	84.47
13	86.63	1851.71	0.00	86.63	43	84.34	1027.13	0.00	84.34
14	86.82	1921.21	0.00	86.82	44	84.24	988.59	0.00	84.24
15	87.01	1989.10	0.00	87.01	45	84.15	955.72	0.00	84.15
16	87.19	2055.41	0.00	87.19	46	84.07	927.68	0.00	84.07
17	87.37	2120.18	0.00	87.37	47	84.00	903.77	0.00	84.00
18	87.55	2183.44	0.00	87.55	48	83.95	883.37	0.00	83.95
19	87.72	2245.24	0.00	87.72	49	83.90	865.97	0.00	83.90
20	87.88	2305.60	0.00	87.88	50	83.86	851.13	0.00	83.86
21	88.05	2364.56	0.00	88.05	51	83.82	838.47	0.00	83.82
22	88.21	2422.15	0.00	88.21	52	83.79	827.67	0.00	83.79
23	88.36	2478.40	0.00	88.36	53	83.77	818.46	0.00	83.77
24	88.52	2533.35	0.00	88.51	54	83.74	810.61	0.00	83.74
25	88.66	2587.02	0.00	88.66	55	83.73	803.91	0.00	83.73
26	88.81	2639.45	0.00	88.81	56	83.71	798.20	0.00	83.71
27	88.95	2690.65	0.00	88.95	57	83.70	793.32	0.00	83.70
28	89.09	2740.67	0.00	89.09	58	83.69	789.16	0.00	83.69
29	89.22	2789.53	0.00	89.22	59	83.68	785.62	0.00	83.68
30	89.36	2837.25	0.00	89.36	60	83.67	782.59	0.00	83.67

Scenario 3

Specific heat of water Cp (BTU/lb/F)
1

Uo (ft/s)
2.644

Volume of affected zone 12ft X 65ft X 50ft =	39000	Length Affected (ft) 50	Dt (minutes) 1	Blowdown Volume (ft^3) 900	Volume Affected (ft^3) 19500
15 cfs for 30 minutes =	27000	Depth Affected (ft) 6	Equil. Temperature (F) 81.5	Heat Transfer Coeff BTU/ft^2/day/F 160	Blowdown Temp (F) 95
		Actual Depth (ft) 12	Volume Through Unit (ft^3) 28980	Total Flow Width (ft) 150	Flow area ratio 0.17

Cycle I

Time (Minutes)	New Temp (F)	Heat Transferred BTU	Temp Reduction (F)	Final Temp (F)	Time (Minutes)	New Temp (F)	Heat Transferred BTU	Temp Reduction (F)	Final Temp (F)
0	81.50	0.00	0.00	81.50	30	91.69	0.00	0.00	91.69
1	82.12	225.00	0.00	82.12	31	89.32	2824.07	0.00	89.32
2	82.72	439.55	0.00	82.72	32	87.64	2218.63	0.00	87.64
3	83.28	644.14	0.00	83.28	33	86.46	1791.23	0.00	86.46
4	83.82	839.23	0.00	83.82	34	85.62	1489.51	0.00	85.62
5	84.34	1025.26	0.00	84.34	35	85.03	1276.51	0.00	85.03
6	84.83	1202.65	0.00	84.83	36	84.62	1126.15	0.00	84.62
7	85.30	1371.80	0.00	85.30	37	84.32	1020.00	0.00	84.32
8	85.75	1533.10	0.00	85.74	38	84.12	945.06	0.00	84.12
9	86.17	1686.91	0.00	86.17	39	83.97	892.16	0.00	83.97
10	86.58	1833.57	0.00	86.58	40	83.87	854.82	0.00	83.87
11	86.96	1973.43	0.00	86.96	41	83.79	828.45	0.00	83.79
12	87.33	2106.79	0.00	87.33	42	83.74	809.84	0.00	83.74
13	87.69	2233.95	0.00	87.68	43	83.71	796.70	0.00	83.71
14	88.02	2355.22	0.00	88.02	44	83.68	787.43	0.00	83.68
15	88.34	2470.85	0.00	88.34	45	83.66	780.88	0.00	83.66
16	88.65	2581.11	0.00	88.65	46	83.65	776.26	0.00	83.65
17	88.94	2686.25	0.00	88.94	47	83.64	772.99	0.00	83.64
18	89.22	2786.51	0.00	89.21	48	83.63	770.69	0.00	83.63
19	89.48	2882.11	0.00	89.48	49	83.63	769.07	0.00	83.63
20	89.73	2973.27	0.00	89.73	50	83.63	767.92	0.00	83.63
21	89.97	3060.21	0.00	89.97	51	83.62	767.11	0.00	83.62
22	90.20	3143.10	0.00	90.20	52	83.62	766.53	0.00	83.62
23	90.42	3222.14	0.00	90.42	53	83.62	766.13	0.00	83.62
24	90.63	3297.52	0.00	90.63	54	83.62	765.85	0.00	83.62
25	90.83	3369.39	0.00	90.83	55	83.62	765.64	0.00	83.62
26	91.02	3437.93	0.00	91.02	56	83.62	765.50	0.00	83.62
27	91.20	3503.28	0.00	91.20	57	83.62	765.40	0.00	83.62
28	91.37	3565.60	0.00	91.37	58	83.62	765.33	0.00	83.62
29	91.54	3625.02	0.00	91.54	59	83.62	765.28	0.00	83.62
30	91.70	3681.69	0.00	91.69	60	83.62	765.25	0.00	83.62

Cycle 2 1651860

Time (Minutes)	New Temp (F)	Heat Transferred BTU	Temp Reduction (F)	Final Temp (F)	Time (Minutes)	New Temp (F)	Heat Transferred BTU	Temp Reduction (F)	Final Temp (F)
0	83.62	0.00	0.00	83.62	30	92.20	0.00	0.00	92.20
1	84.14	954.71	0.00	84.14	31	89.68	2953.80	0.00	89.68
2	84.64	1135.38	0.00	84.64	32	87.90	2310.22	0.00	87.90
3	85.12	1307.65	0.00	85.12	33	86.64	1855.89	0.00	86.64
4	85.58	1471.93	0.00	85.57	34	85.75	1535.15	0.00	85.75
5	86.01	1628.58	0.00	86.01	35	85.12	1308.73	0.00	85.12
6	86.42	1777.95	0.00	86.42	36	84.68	1148.89	0.00	84.68
7	86.82	1920.39	0.00	86.82	37	84.37	1036.05	0.00	84.37
8	87.19	2056.21	0.00	87.19	38	84.15	956.40	0.00	84.15
9	87.55	2185.73	0.00	87.55	39	83.99	900.16	0.00	83.99
10	87.89	2309.23	0.00	87.89	40	83.88	860.46	0.00	83.88
11	88.22	2427.00	0.00	88.22	41	83.81	832.44	0.00	83.80
12	88.53	2539.29	0.00	88.53	42	83.75	812.66	0.00	83.75
13	88.83	2646.38	0.00	88.83	43	83.71	798.69	0.00	83.71
14	89.11	2748.49	0.00	89.11	44	83.68	788.83	0.00	83.68
15	89.38	2845.86	0.00	89.38	45	83.67	781.87	0.00	83.66
16	89.64	2938.70	0.00	89.64	46	83.65	776.96	0.00	83.65
17	89.88	3027.24	0.00	89.88	47	83.64	773.49	0.00	83.64
18	90.12	3111.66	0.00	90.11	48	83.64	771.04	0.00	83.63
19	90.34	3192.17	0.00	90.34	49	83.63	769.31	0.00	83.63
20	90.55	3268.93	0.00	90.55	50	83.63	768.09	0.00	83.63
21	90.76	3342.13	0.00	90.75	51	83.62	767.23	0.00	83.62
22	90.95	3411.94	0.00	90.95	52	83.62	766.62	0.00	83.62
23	91.13	3478.50	0.00	91.13	53	83.62	766.19	0.00	83.62
24	91.31	3541.96	0.00	91.31	54	83.62	765.89	0.00	83.62
25	91.48	3602.49	0.00	91.47	55	83.62	765.67	0.00	83.62
26	91.64	3660.20	0.00	91.63	56	83.62	765.52	0.00	83.62
27	91.79	3715.23	0.00	91.79	57	83.62	765.42	0.00	83.62
28	91.93	3767.71	0.00	91.93	58	83.62	765.34	0.00	83.62
29	92.07	3817.75	0.00	92.07	59	83.62	765.29	0.00	83.62
30	92.20	3865.46	0.00	92.20	60	83.62	765.25	0.00	83.62

Cycle 3 1651860

Time (Minutes)	New Temp (F)	Heat Transferred BTU	Temp Reduction (F)	Final Temp (F)	Time (Minutes)	New Temp (F)	Heat Transferred BTU	Temp Reduction (F)	Final Temp (F)
0	83.62	0.00	0.00	83.62	30	92.20	0.00	0.00	92.20
1	84.14	954.72	0.00	84.14	31	89.68	2953.80	0.00	89.68
2	84.64	1135.38	0.00	84.64	32	87.90	2310.22	0.00	87.90
3	85.12	1307.66	0.00	85.12	33	86.64	1855.89	0.00	86.64
4	85.58	1471.93	0.00	85.57	34	85.75	1535.15	0.00	85.75
5	86.01	1628.58	0.00	86.01	35	85.12	1308.73	0.00	85.12
6	86.42	1777.96	0.00	86.42	36	84.68	1148.89	0.00	84.68
7	86.82	1920.39	0.00	86.82	37	84.37	1036.05	0.00	84.37
8	87.19	2056.22	0.00	87.19	38	84.15	956.40	0.00	84.15
9	87.55	2185.73	0.00	87.55	39	83.99	900.16	0.00	83.99
10	87.89	2309.23	0.00	87.89	40	83.88	860.46	0.00	83.88
11	88.22	2427.00	0.00	88.22	41	83.81	832.44	0.00	83.80
12	88.53	2539.30	0.00	88.53	42	83.75	812.66	0.00	83.75
13	88.83	2646.38	0.00	88.83	43	83.71	798.69	0.00	83.71
14	89.11	2748.49	0.00	89.11	44	83.68	788.83	0.00	83.68
15	89.38	2845.86	0.00	89.38	45	83.67	781.87	0.00	83.66
16	89.64	2938.71	0.00	89.64	46	83.65	776.96	0.00	83.65
17	89.88	3027.24	0.00	89.88	47	83.64	773.49	0.00	83.64
18	90.12	3111.67	0.00	90.11	48	83.64	771.04	0.00	83.63
19	90.34	3192.17	0.00	90.34	49	83.63	769.31	0.00	83.63
20	90.55	3268.93	0.00	90.55	50	83.63	768.09	0.00	83.63
21	90.76	3342.14	0.00	90.75	51	83.62	767.23	0.00	83.62
22	90.95	3411.94	0.00	90.95	52	83.62	766.62	0.00	83.62
23	91.13	3478.50	0.00	91.13	53	83.62	766.19	0.00	83.62
24	91.31	3541.97	0.00	91.31	54	83.62	765.89	0.00	83.62
25	91.48	3602.49	0.00	91.47	55	83.62	765.67	0.00	83.62
26	91.64	3660.20	0.00	91.63	56	83.62	765.52	0.00	83.62
27	91.79	3715.23	0.00	91.79	57	83.62	765.42	0.00	83.62
28	91.93	3767.71	0.00	91.93	58	83.62	765.34	0.00	83.62
29	92.07	3817.75	0.00	92.07	59	83.62	765.29	0.00	83.62
30	92.20	3865.46	0.00	92.20	60	83.62	765.25	0.00	83.62

Scenario 4

Uo (ft/s)	2.644
Specific heat of water Cp (BTU/lb/F)	1
Volume of affected zone 12ft X 65ft X 50ft =	39000
15 cfs for 30 minutes =	27000
Length Affected (ft)	50
Dt (minutes)	1
Blowdown Volume (ft^3)	900
Volume Affected (ft^3)	19500
Depth Affected (ft)	6
Equil. Temperature (F)	81.5
Heat Transfer Coeff BTU/ft^2/day/F	160
Blowdown Temp (F)	95
Actual Depth (ft)	12
Volume Through Unit (ft^3)	28980
Total Flow Width (ft)	150
Flow area ratio	0.17

Cycle I

Time (Minutes)	New Temp (F)	Heat Transferred BTU	Temp Reduction (F)	Final Temp (F)
0	81.50	0.00	0.00	81.50
1	82.12	225.00	0.00	82.12
2	82.72	439.55	0.00	82.72
3	83.28	644.14	0.00	83.28
4	83.82	839.23	0.00	83.82
5	84.34	1025.26	0.00	84.34
6	84.83	1202.65	0.00	84.83
7	85.30	1371.80	0.00	85.30
8	85.75	1533.10	0.00	85.74
9	86.17	1686.91	0.00	86.17
10	86.58	1833.57	0.00	86.58
11	86.96	1973.43	0.00	86.96
12	87.33	2106.79	0.00	87.33
13	87.69	2233.95	0.00	87.68
14	88.02	2355.22	0.00	88.02
15	88.34	2470.85	0.00	88.34
16	88.65	2581.11	0.00	88.65
17	88.94	2686.25	0.00	88.94
18	89.22	2786.51	0.00	89.21
19	89.48	2882.11	0.00	89.48
20	89.73	2973.27	0.00	89.73
21	89.97	3060.21	0.00	89.97
22	90.20	3143.10	0.00	90.20
23	90.42	3222.14	0.00	90.42
24	90.63	3297.52	0.00	90.63
25	90.83	3369.39	0.00	90.83
26	91.02	3437.93	0.00	91.02
27	91.20	3503.28	0.00	91.20
28	91.37	3565.60	0.00	91.37
29	91.54	3625.02	0.00	91.54
30	91.70	3681.69	0.00	91.69

Time (Minutes)	New Temp (F)	Heat Transferred BTU	Temp Reduction (F)	Final Temp (F)
30	91.69	0.00	0.00	91.69
31	90.58	3279.89	0.00	90.58
32	89.66	2946.50	0.00	89.66
33	88.89	2669.87	0.00	88.89
34	88.26	2440.34	0.00	88.26
35	87.73	2249.88	0.00	87.73
36	87.29	2091.84	0.00	87.29
37	86.93	1960.72	0.00	86.93
38	86.63	1851.91	0.00	86.63
39	86.38	1761.63	0.00	86.38
40	86.17	1686.72	0.00	86.17
41	86.00	1624.56	0.00	86.00
42	85.86	1572.99	0.00	85.85
43	85.74	1530.19	0.00	85.74
44	85.64	1494.68	0.00	85.64
45	85.56	1465.22	0.00	85.56
46	85.49	1440.77	0.00	85.49
47	85.43	1420.48	0.00	85.43
48	85.39	1403.65	0.00	85.39
49	85.35	1389.69	0.00	85.35
50	85.32	1378.10	0.00	85.32
51	85.29	1368.48	0.00	85.29
52	85.27	1360.50	0.00	85.27
53	85.25	1353.88	0.00	85.25
54	85.23	1348.39	0.00	85.23
55	85.22	1343.83	0.00	85.22
56	85.21	1340.05	0.00	85.21
57	85.20	1336.91	0.00	85.20
58	85.20	1334.31	0.00	85.19
59	85.19	1332.15	0.00	85.19
60	85.18	1330.35	0.00	85.18

Cycle 2

Time (Minutes)	New Temp (F)	Heat Transferred BTU	Temp Reduction (F)	Final Temp (F)
0	85.18	0.00	0.00	85.18
1	85.64	1493.57	0.00	85.63
2	86.07	1649.22	0.00	86.07
3	86.48	1797.63	0.00	86.48
4	86.87	1939.16	0.00	86.87
5	87.24	2074.11	0.00	87.24
6	87.60	2202.79	0.00	87.60
7	87.94	2325.50	0.00	87.94
8	88.26	2442.51	0.00	88.26
9	88.57	2554.09	0.00	88.57
10	88.87	2660.49	0.00	88.87
11	89.15	2761.94	0.00	89.15
12	89.42	2858.69	0.00	89.41
13	89.67	2950.94	0.00	89.67
14	89.92	3038.90	0.00	89.91
15	90.15	3122.79	0.00	90.15
16	90.37	3202.77	0.00	90.37
17	90.58	3279.05	0.00	90.58
18	90.78	3351.78	0.00	90.78
19	90.97	3421.13	0.00	90.97
20	91.16	3487.27	0.00	91.15
21	91.33	3550.33	0.00	91.33
22	91.50	3610.46	0.00	91.50
23	91.66	3667.80	0.00	91.65
24	91.81	3722.48	0.00	91.81
25	91.95	3774.62	0.00	91.95
26	92.09	3824.34	0.00	92.09
27	92.22	3871.75	0.00	92.22
28	92.35	3916.96	0.00	92.34
29	92.47	3960.06	0.00	92.46
30	92.58	4001.17	0.00	92.58

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Time (Minutes)	New Temp (F)	Heat Transferred BTU	Temp Reduction (F)	Final Temp (F)
30	92.58	0.00	0.00	92.58
31	91.32	3544.99	0.00	91.31
32	90.27	3166.47	0.00	90.27
33	89.40	2852.39	0.00	89.40
34	88.68	2591.78	0.00	88.68
35	88.08	2375.54	0.00	88.08
36	87.58	2196.11	0.00	87.58
37	87.17	2047.23	0.00	87.17
38	86.83	1923.70	0.00	86.83
39	86.54	1821.20	0.00	86.54
40	86.31	1736.14	0.00	86.31
41	86.11	1665.57	0.00	86.11
42	85.95	1607.01	0.00	85.95
43	85.82	1558.43	0.00	85.81
44	85.70	1518.11	0.00	85.70
45	85.61	1484.66	0.00	85.61
46	85.53	1456.90	0.00	85.53
47	85.47	1433.87	0.00	85.47
48	85.42	1414.76	0.00	85.42
49	85.37	1398.90	0.00	85.37
50	85.34	1385.74	0.00	85.34
51	85.31	1374.82	0.00	85.31
52	85.28	1365.77	0.00	85.28
53	85.26	1358.25	0.00	85.26
54	85.24	1352.01	0.00	85.24
55	85.23	1346.84	0.00	85.23
56	85.22	1342.54	0.00	85.22
57	85.21	1338.98	0.00	85.21
58	85.20	1336.02	0.00	85.20
59	85.19	1333.57	0.00	85.19
60	85.19	1331.54	0.00	85.19

Cycle 3

Time (Minutes)	New Temp (F)	Heat Transferred BTU	Temp Reduction (F)	Final Temp (F)
0	85.19	0 00	0.00	85.19
1	85.64	1494.70	0.00	85.64
2	86.07	1650.29	0.00	86.07
3	86.48	1798.66	0.00	86.48
4	86.87	1940.13	0.00	86.87
5	87.25	2075.04	0.00	87.24
6	87.60	2203.68	0.00	87.60
7	87.94	2326.35	0.00	87.94
8	88.27	2443.32	0.00	88.26
9	88.58	2554.86	0.00	88.57
10	88.87	2661.22	0.00	88.87
11	89.15	2762.64	0.00	89.15
12	89.42	2859.35	0.00	89.42
13	89.67	2951.57	0.00	89.67
14	89.92	3039.51	0.00	89.91
15	90.15	3123.37	0.00	90.15
16	90.37	3203.33	0.00	90.37
17	90.58	3279.57	0.00	90.58
18	90.78	3352.28	0.00	90.78
19	90.98	3421.61	0.00	90.97
20	91.16	3487.72	0.00	91.16
21	91.33	3550.76	0.00	91.33
22	91.50	3610.88	0.00	91.50
23	91.66	3668.20	0.00	91.66
24	91.81	3722.86	0.00	91.81
25	91.95	3774.98	0.00	91.95
26	92.09	3824.68	0.00	92.09
27	92.22	3872.08	0.00	92.22
28	92.35	3917.27	0.00	92.34
29	92.47	3960.36	0.00	92.46
30	92.58	4001.46	0.00	92.58

1651860

Time (Minutes)	New Temp (F)	Heat Transferred BTU	Temp Reduction (F)	Final Temp (F)
30	92.58	0.00	0.00	92.58
31	91.32	3545.22	0.00	91.31
32	90.27	3166.66	0.00	90.27
33	89.40	2852.55	0.00	89.40
34	88.68	2591.91	0.00	88.68
35	88.08	2375.65	0.00	88.08
36	87.58	2196.20	0.00	87.58
37	87.17	2047.31	0.00	87.17
38	86.83	1923.76	0.00	86.83
39	86.54	1821.25	0.00	86.54
40	86.31	1736.19	0.00	86.31
41	86.11	1665.61	0.00	86.11
42	85.95	1607.04	0.00	85.95
43	85.82	1558.45	0.00	85.81
44	85.70	1518.13	0.00	85.70
45	85.61	1484.67	0.00	85.61
46	85.53	1456.91	0.00	85.53
47	85.47	1433.88	0.00	85.47
48	85.42	1414.77	0.00	85.42
49	85.37	1398.91	0.00	85.37
50	85.34	1385.75	0.00	85.34
51	85.31	1374.83	0.00	85.31
52	85.28	1365.77	0.00	85.28
53	85.26	1358.25	0.00	85.26
54	85.24	1352.02	0.00	85.24
55	85.23	1346.84	0.00	85.23
56	85.22	1342.55	0.00	85.22
57	85.21	1338.98	0.00	85.21
58	85.20	1336.03	0.00	85.20
59	85.19	1333.57	0.00	85.19
60	85.19	1331.54	0.00	85.19

Surface Spreading

Uo (ft/s)		Specific heat of water Cp (BTU/lb/F)			Heat Transfer Coeff BTU/ft^2/day/F
2.644		1			160

		Length Affected (ft)	Blowout Temp (F)	Equil Temp (F)
Volume of affected zone 12ft X 65ft X 50ft =	39000	50	95	81.5
15 cfs for 30 minutes =	27000			

Spread Area (ft^2)	Blow out Volume in 60 Minutes (ft^3)	Depth of Spread (ft)	Percentage Removed
220764	54000	0.24	0.1

	Extra Mixing Depth (ft)	DT (Min)
Downstream Conditions	0.37	1

Assuming 30 cfs at 95 F is discharged as outflow

Cycle 1

Discharge Temp (F)	Assuming Depth (ft)	Spread Area (ft^2)	Heat Removed (BTU)	Temp Reduction (F)	Final Temp (F)
83.18	3	289800	1620000	0.03	83.15

Cycle I

Volume discharged from unit in 30 Minutes (ft^3)
869400

Time (Minutes)	Initial Temp (F)	Heat Removed (BTE)	Temp Reduction (F)	New Temp (F)	Outflow Voluem (ft^3)	Final Temp (F)
0	86.90	0.00	0.00	86.90	0.00	86.90
1	86.90	132458.40	0.02	86.88	28980.00	86.88
2	86.88	132072.70	0.02	86.87	28980.00	86.87
3	86.87	131688.13	0.02	86.85	28980.00	86.85
4	86.85	131304.67	0.02	86.84	28980.00	86.84
5	86.84	130922.34	0.02	86.82	28980.00	86.82
6	86.82	130541.11	0.02	86.81	28980.00	86.81
7	86.81	130161.00	0.02	86.79	28980.00	86.79
8	86.79	129781.99	0.02	86.78	28980.00	86.78
9	86.78	129404.08	0.02	86.76	28980.00	86.76
10	86.76	129027.28	0.02	86.74	28980.00	86.74
11	86.74	128651.57	0.02	86.73	28980.00	86.73
12	86.73	128276.96	0.02	86.71	28980.00	86.71
13	86.71	127903.44	0.02	86.70	28980.00	86.70
14	86.70	127531.00	0.02	86.68	28980.00	86.68
15	86.68	127159.65	0.02	86.67	28980.00	86.67
16	86.67	126789.39	0.02	86.65	28980.00	86.65
17	86.65	126420.20	0.02	86.64	28980.00	86.64
18	86.64	126052.08	0.01	86.62	28980.00	86.62
19	86.62	125685.04	0.01	86.61	28980.00	86.61
20	86.61	125319.06	0.01	86.59	28980.00	86.59
21	86.59	124954.15	0.01	86.58	28980.00	86.58
22	86.58	124590.31	0.01	86.56	28980.00	86.56
23	86.56	124227.52	0.01	86.55	28980.00	86.55
24	86.55	123865.79	0.01	86.53	28980.00	86.53
25	86.53	123505.11	0.01	86.52	28980.00	86.52
26	86.52	123145.49	0.01	86.51	28980.00	86.51
27	86.51	122786.91	0.01	86.49	28980.00	86.49
28	86.49	122429.37	0.01	86.48	28980.00	86.48
29	86.48	122072.87	0.01	86.46	28980.00	86.46
30	86.46	121717.42	0.01	86.45	28980.00	86.45
31	86.45	121363.00	0.01	86.43	28980.00	86.33
32	86.43	121009.61	0.01	86.42	28980.00	86.31
33	86.42	120657.25	0.01	86.40	28980.00	86.30
34	86.40	120305.91	0.01	86.39	28980.00	86.29
35	86.39	119955.60	0.01	86.38	28980.00	86.27
36	86.38	119606.31	0.01	86.36	28980.00	86.26
37	86.36	119258.04	0.01	86.35	28980.00	86.24
38	86.35	118910.77	0.01	86.33	28980.00	86.23
39	86.33	118564.53	0.01	86.32	28980.00	86.22
40	86.32	118219.28	0.01	86.31	28980.00	86.20
41	86.31	117875.05	0.01	86.29	28980.00	86.19
42	86.29	117531.82	0.01	86.28	28980.00	86.17
43	86.28	117189.58	0.01	86.26	28980.00	86.16
44	86.26	116848.35	0.01	86.25	28980.00	86.15
45	86.25	116508.10	0.01	86.24	28980.00	86.13
46	86.24	116168.85	0.01	86.22	28980.00	86.12
47	86.22	115830.58	0.01	86.21	28980.00	86.11
48	86.21	115493.30	0.01	86.19	28980.00	86.09
49	86.19	115157.01	0.01	86.18	28980.00	86.08
50	86.18	114821.69	0.01	86.17	28980.00	86.07
51	86.17	114487.34	0.01	86.15	28980.00	86.05
52	86.15	114153.98	0.01	86.14	28980.00	86.04
53	86.14	113821.58	0.01	86.13	28980.00	86.03
54	86.13	113490.15	0.01	86.11	28980.00	86.01
55	86.11	113159.68	0.01	86.10	28980.00	86.00
56	86.10	112830.18	0.01	86.09	28980.00	85.99
57	86.09	112501.64	0.01	86.07	28980.00	85.97
58	86.07	112174.05	0.01	86.06	28980.00	85.96
59	86.06	111847.42	0.01	86.05	28980.00	85.95
60	86.05	111521.74	0.01	86.03	28980.00	85.94

Cycle 2

Depth Factor
2

Time (Minutes)	Initial Temp (F)	Heat Removed (BTE)	Temp Reduction (F)	New Temp (F)	Volume Outflow (ft^3)	Final Temp (F)
0	86.42	0.00	0.00	86.42	0.00	86.42
1	86.42	120634.19	0.01	86.41	28980.00	86.41
2	86.41	120458.55	0.01	86.40	28980.00	86.40
3	86.40	120283.17	0.01	86.40	28980.00	86.40
4	86.40	120108.05	0.01	86.39	28980.00	86.39
5	86.39	119933.18	0.01	86.38	28980.00	86.38
6	86.38	119758.57	0.01	86.38	28980.00	86.38
7	86.38	119584.21	0.01	86.37	28980.00	86.37
8	86.37	119410.11	0.01	86.36	28980.00	86.36
9	86.36	119236.26	0.01	86.35	28980.00	86.35
10	86.35	119062.66	0.01	86.35	28980.00	86.35
11	86.35	118889.31	0.01	86.34	28980.00	86.34
12	86.34	118716.22	0.01	86.33	28980.00	86.33
13	86.33	118543.38	0.01	86.33	28980.00	86.33
14	86.33	118370.79	0.01	86.32	28980.00	86.32
15	86.32	118198.45	0.01	86.31	28980.00	86.31
16	86.31	118026.36	0.01	86.30	28980.00	86.30
17	86.30	117854.53	0.01	86.30	28980.00	86.30
18	86.30	117682.94	0.01	86.29	28980.00	86.29
19	86.29	117511.60	0.01	86.28	28980.00	86.28
20	86.28	117340.51	0.01	86.28	28980.00	86.28
21	86.28	117169.68	0.01	86.27	28980.00	86.27
22	86.27	116999.09	0.01	86.26	28980.00	86.26
23	86.26	116828.75	0.01	86.26	28980.00	86.26
24	86.26	116658.65	0.01	86.25	28980.00	86.25
25	86.25	116488.81	0.01	86.24	28980.00	86.24
26	86.24	116319.21	0.01	86.24	28980.00	86.24
27	86.24	116149.86	0.01	86.23	28980.00	86.23
28	86.23	115980.75	0.01	86.22	28980.00	86.22
29	86.22	115811.89	0.01	86.21	28980.00	86.21
30	86.21	115643.28	0.01	86.21	28980.00	86.21
31	86.21	115474.91	0.01	86.20	28980.00	86.15
32	86.20	115306.79	0.01	86.19	28980.00	86.14
33	86.19	115138.91	0.01	86.19	28980.00	86.14
34	86.19	114971.28	0.01	86.18	28980.00	86.13
35	86.18	114803.89	0.01	86.17	28980.00	86.12
36	86.17	114636.75	0.01	86.17	28980.00	86.12
37	86.17	114469.84	0.01	86.16	28980.00	86.11
38	86.16	114303.19	0.01	86.15	28980.00	86.10
39	86.15	114136.77	0.01	86.15	28980.00	86.10
40	86.15	113970.60	0.01	86.14	28980.00	86.09
41	86.14	113804.66	0.01	86.13	28980.00	86.08
42	86.13	113638.97	0.01	86.13	28980.00	86.08
43	86.13	113473.52	0.01	86.12	28980.00	86.07
44	86.12	113308.32	0.01	86.11	28980.00	86.06
45	86.11	113143.35	0.01	86.11	28980.00	86.06
46	86.11	112978.62	0.01	86.10	28980.00	86.05
47	86.10	112814.13	0.01	86.09	28980.00	86.04
48	86.09	112649.88	0.01	86.09	28980.00	86.04
49	86.09	112485.87	0.01	86.08	28980.00	86.03
50	86.08	112322.10	0.01	86.07	28980.00	86.02
51	86.07	112158.57	0.01	86.07	28980.00	86.02
52	86.07	111995.28	0.01	86.06	28980.00	86.01
53	86.06	111832.22	0.01	86.05	28980.00	86.00
54	86.05	111669.40	0.01	86.05	28980.00	86.00
55	86.05	111506.82	0.01	86.04	28980.00	85.99
56	86.04	111344.48	0.01	86.03	28980.00	85.98
57	86.03	111182.37	0.01	86.03	28980.00	85.98
58	86.03	111020.50	0.01	86.02	28980.00	85.97
59	86.02	110858.86	0.01	86.01	28980.00	85.96
60	86.01	110697.46	0.01	86.01	28980.00	85.96

Cycle 2

Depth Factor
2

Time (Minutes)	Initial Temp (F)	Heat Removed (BTE)	Temp Reduction (F)	New Temp (F)	Volume Outflow (ft^3)	Final Temp (F)
0	86.27	0.00	0.00	86.27	0.00	86.27
1	86.27	117052.71	0.00	86.27	28980.00	86.27
2	86.27	116939.10	0.00	86.26	28980.00	86.26
3	86.26	116825.60	0.00	86.26	28980.00	86.26
4	86.26	116712.20	0.00	86.25	28980.00	86.25
5	86.25	116598.92	0.00	86.25	28980.00	86.25
6	86.25	116485.75	0.00	86.24	28980.00	86.24
7	86.24	116372.69	0.00	86.24	28980.00	86.24
8	86.24	116259.73	0.00	86.24	28980.00	86.24
9	86.24	116146.89	0.00	86.23	28980.00	86.23
10	86.23	116034.16	0.00	86.23	28980.00	86.23
11	86.23	115921.53	0.00	86.22	28980.00	86.22
12	86.22	115809.02	0.00	86.22	28980.00	86.22
13	86.22	115696.61	0.00	86.21	28980.00	86.21
14	86.21	115584.31	0.00	86.21	28980.00	86.21
15	86.21	115472.13	0.00	86.20	28980.00	86.20
16	86.20	115360.05	0.00	86.20	28980.00	86.20
17	86.20	115248.08	0.00	86.19	28980.00	86.19
18	86.19	115136.22	0.00	86.19	28980.00	86.19
19	86.19	115024.46	0.00	86.18	28980.00	86.18
20	86.18	114912.82	0.00	86.18	28980.00	86.18
21	86.18	114801.28	0.00	86.18	28980.00	86.18
22	86.18	114689.86	0.00	86.17	28980.00	86.17
23	86.17	114578.54	0.00	86.17	28980.00	86.17
24	86.17	114467.33	0.00	86.16	28980.00	86.16
25	86.16	114356.22	0.00	86.16	28980.00	86.16
26	86.16	114245.23	0.00	86.15	28980.00	86.15
27	86.15	114134.34	0.00	86.15	28980.00	86.15
28	86.15	114023.56	0.00	86.14	28980.00	86.14
29	86.14	113912.89	0.00	86.14	28980.00	86.14
30	86.14	113802.32	0.00	86.13	28980.00	86.13
31	86.13	113691.86	0.00	86.13	28980.00	86.10
32	86.13	113581.51	0.00	86.13	28980.00	86.09
33	86.13	113471.27	0.00	86.12	28980.00	86.09
34	86.12	113361.13	0.00	86.12	28980.00	86.08
35	86.12	113251.10	0.00	86.11	28980.00	86.08
36	86.11	113141.18	0.00	86.11	28980.00	86.08
37	86.11	113031.36	0.00	86.10	28980.00	86.07
38	86.10	112921.65	0.00	86.10	28980.00	86.07
39	86.10	112812.05	0.00	86.09	28980.00	86.06
40	86.09	112702.55	0.00	86.09	28980.00	86.06
41	86.09	112593.16	0.00	86.09	28980.00	86.05
42	86.09	112483.88	0.00	86.08	28980.00	86.05
43	86.08	112374.70	0.00	86.08	28980.00	86.04
44	86.08	112265.63	0.00	86.07	28980.00	86.04
45	86.07	112156.66	0.00	86.07	28980.00	86.04
46	86.07	112047.80	0.00	86.06	28980.00	86.03
47	86.06	111939.04	0.00	86.06	28980.00	86.03
48	86.06	111830.40	0.00	86.05	28980.00	86.02
49	86.05	111721.85	0.00	86.05	28980.00	86.02
50	86.05	111613.41	0.00	86.05	28980.00	86.01
51	86.05	111505.08	0.00	86.04	28980.00	86.01
52	86.04	111396.85	0.00	86.04	28980.00	86.00
53	86.04	111288.73	0.00	86.03	28980.00	86.00
54	86.03	111180.71	0.00	86.03	28980.00	86.00
55	86.03	111072.80	0.00	86.02	28980.00	85.99
56	86.02	110964.99	0.00	86.02	28980.00	85.99
57	86.02	110857.28	0.00	86.01	28980.00	85.98
58	86.01	110749.68	0.00	86.01	28980.00	85.98
59	86.01	110642.19	0.00	86.01	28980.00	85.97
60	86.01	110534.80	0.00	86.00	28980.00	85.97

Lee Nuclear Station Response to Request for Additional information (RAI)

RAI Letter Dated: August 21, 2008

Reference NRC RAI Numbers: ER RAIs-30 and 34

NRC RAIs:

ER RAI-30: Provide a consistent explanation of taxes.

ER RAI-34: Provide a discussion of Duke's tax/fee in lieu payments to the county.

Duke Energy Response:

The amount of 2007 property taxes paid by Duke Energy to Cherokee County, South Carolina, because of the Lee Nuclear Station, formerly known as the Cherokee Nuclear Station, is $69,486.47 (see Attachment RAI-30/34-1). According to South Carolina state statutes, property tax would not be paid while construction is in progress. Upon completion of the construction phase at the Lee Nuclear Station and with the first South Carolina post-construction tax assessment, a "Fee in-Lieu" and an "Infrastructure Tax Credit Agreement" payment structure will be adopted with Cherokee County. In South Carolina, the in-lieu agreement is based upon a standard 10.5 percent assessment rate that decreases in increments as the monetary investment in a construction project increases. Should the valuation of a project investment reach $2 billion, the Fee in-Lieu assessment and Infrastructure Tax Credit drops the assessment rate to 2 percent. It is anticipated that the valuation of Duke Energy's investment in construction of the Lee Nuclear Station will reach approximately $8 – 8.9 billion, and thus the assessment rate will fall within this 2 percent criterion. The length of the "Infrastructure Tax Credit Agreement" between Duke Energy and Cherokee County is 30 years. The anticipated in-lieu payment to Cherokee County is expected to range from $8,500,000 to $9,461,000 annually (see Attachment RAI-30/34-3). The anticipated percentage of additional taxes contributed to Cherokee County because of the Lee Nuclear Station ranges from 16.40 percent to 17.92 percent (see Attachment RAI-30/34-2 and Attachment RAI-30/34-3).

Associated Revisions to the Lee Nuclear Station Combined License Application:

1. Revise COLA Part 3, ER Chapter 2, Subsection 2.5.2.3, Paragraph 2, as follows:

   Several tax revenue categories are affected by the construction and operation of new nuclear units. These include (1) income taxes on wages, salaries, and corporate profits; (2) sales and use taxes on construction- and operations-related purchases and on the purchases made by project-related workers; (3) property taxes related to the construction and operation of new nuclear ~~newnuclear~~ units; and (4) property taxes on owned real property. Table 2.5-14 shows Cherokee County, South Carolina, tax collections by category.

2. Revise COLA Part 3, ER Chapter 2, Subsection 2.5.2.3, Paragraph 8, as follows:

   Table 2.5-15 shows property tax categories as used in Cherokee County, South Carolina, and South Carolina as a whole (Reference 106). Based on ordinance 2005-20, passed by County Council of Cherokee County, South Carolina, Duke Energy is entitled to make payments in-lieu of taxes provided that the overall investment in the project is at least $2.5 billion (Reference 61). The amount of 2007 property taxes paid by Duke Energy to Cherokee County, South Carolina, because of the Lee Nuclear Station, formerly known as the Cherokee Nuclear Station, is $69,486.47. The overall Cherokee County, South Carolina, property tax revenue for 2007 is $43,346,496.42. Duke Energy's percentage of property tax revenue paid to Cherokee County because of the Lee Nuclear Station is 0.16 percent.

3. Revise COLA Part 3, ER Chapter 4, Subsection 4.4.2.2.1, Paragraph 1, as follows:

   Regional taxes and the political structure within the Lee Nuclear Site region are discussed in Subsection 2.5.2.3. Several types of taxes are generated by construction activities and purchases, and by site workforce expenditures. These would include income taxes on corporate profits, wages, and salaries; sales and use taxes on corporate and employee purchases; ~~and real property taxes related to Lee Nuclear Site,~~ and personal property taxes associated with employees. No property taxes related to the Lee Nuclear Station are expected to be collected during construction. Duke Energy and Cherokee County have an agreement for payments made in-lieu of taxes; however, those payments start at the beginning of operation and are discussed in Subsection 5.8.2.2.1.

4. Revise COLA Part 3, ER Chapter 5, Subsection 5.8.2.2.1, Paragraph 1, as follows:

   Regional taxes and the political structure within the Lee Nuclear Site region are discussed in Subsection 2.5.2. Cherokee County is the tax district that is expected to be most directly affected by the operation of Lee Nuclear Station. ~~During the initial 30 years of operation of the plant, Duke Energy is expected to make fee payments in lieu of taxes at a rate of 4 percent of the taxable property value in Cherokee County, South Carolina~~. Should the valuation of a project investment reach $2 billion, the in-lieu assessment drops to 2 percent. It is anticipated that the valuation of Duke Energy's investment in construction of the Lee Nuclear Station reaches approximately $8 – 8.9 billion, and their assessment falls within the 2 percent criterion. The expected Infrastructure Tax Credit Agreement between Duke Energy and Cherokee County is a 30-year agreement. The anticipated in-lieu payment to Cherokee County is expected to range from $8,500,000 to $9,461,000. The anticipated percentage of additional taxes contributed to Cherokee County because of the Lee Nuclear Station ranges from 16.4 percent to 17.92 percent.

5. Revise COLA Part 3, ER Chapter 10, Subsection 10.1.1, Paragraph 3, as follows:

   Nearly all of these impacts, other than socioeconomic, from construction of the station, railroad, and associated transmission lines are SMALL. The moderate or large socioeconomic impacts are reduced through mitigation. The influx of construction workers has the potential to lead to a short-term housing shortage and short-term capacity concerns in local schools. The impact of a short-term housing shortage due to the influx of workers would likely generate additional temporary rentals and trailer parks, thus mitigating this short-term impact. Also, increased construction traffic has the potential to affect existing traffic patterns and levels of service in the vicinity of the ~~Lee Nuclear Site~~ Lee Nuclear Station. However, increased income ~~property~~ tax revenues from the influx of construction workers during new unit construction funds additional teachers and needed school resources. Duke Energy intends to implement traffic mitigation programs such as carpooling or staggered shifts, signage, and turn lanes to alleviate traffic concerns.

6. Revise COLA Part 3, ER Chapter 10, Subsection 10.4.1.1.1, Paragraph 2, as follows:

   South Carolina has license taxes on utilities and electric cooperatives. In South Carolina, the in-lieu agreement is based upon a standard 10.5 percent assessment that decreases in increments as the monetary investment in a construction project increases. It is anticipated that the valuation of Duke Energy's investment in construction of the Lee Nuclear Station reaches approximately $8 – 8.9 billion, and their assessment falls within the 2 percent criterion. The anticipated in-lieu payment to Cherokee County is expected to range from $8,500,000 to $9,461,000 annually. ~~Corporations are charged $1 for every $1000 of assessed fair market value of property as determined for property tax purposes the preceding taxable year.~~ They are also charged $3 per $1000 of gross receipts derived from services rendered during the preceding taxable year (Section 2.5). Customer cost for electricity in South Carolina in 2007, based on all sectors, is reported to be $0.0695 per kilowatt hour (kWh)

(Reference 12). At approximately 18,200,000 ~~17,600,000~~ megawatt hours (MWh) of electricity generated annually, the Lee Nuclear Station should contribute over $3.5 million to the annual South Carolina state tax base over the operational life of the station.

Associated Attachments:

Attachment 30/34-1	2007 Total Duke Carolinas Property Tax Payments for Cherokee County, SC, as provided by Duke Energy.
Attachment 30/34-2	2007 Cherokee County Property Tax, as provided by Duke Energy.
Attachment 30/34-3	Tax Percentage Calculation, as provided by Duke Energy.

Lee Nuclear Station Response to Request for Additional Information (RAI)

Attachment 30/34-1 to RAI 30/34

2007 Total Duke Carolinas Property Tax Payments for Cherokee County, SC, as provided by Duke Energy

Duke Carolinas
2007 pay 2008 Property Tax Payments
Cherokee County, SC

FD & Towns	Tax District	Map #	Appraisal Value	Ratio	2007 Total Assessed Valuation	Tax Rate	Exemption/ Abatement	Total Paid
Cherokee	000							
Gaffney (District 10)	501	Personal Property	1,323,429	10.50%	138,960	27.1262%		$37,694.57
District 27	002/009/011/012	Personal Property	1,259,333	10.50%	132,230	27.1262%		$35,868.97
District 04	010	Personal Property	1,438,857	10.50%	151,080	27.1262%		$40,982.26
District 20	007	Personal Property	1,454,762	10.50%	152,750	27.1262%		$41,435.27
District 17	002/009/011/012	Personal Property	502,857	10.50%	52,800	27.1262%		$14,322.63
District 15 (Chesnee)	016	Personal Property	29,429	10.50%	3,090	45.8190%		$1,415.81
District 18	010	Personal Property	5,364,381	10.50%	563,260	27.9262%		$157,297.11
District 12	007	Personal Property	3,674,857	10.50%	385,860	28.2062%		$108,836.44
District 13	008	Personal Property	3,793,524	10.50%	398,320	32.6190%		$129,928.00
District 09 (Blacksburg)	502	Personal Property	1,399,619	10.50%	146,960	27.1262%		$39,864.66
District 11	006	Personal Property	5,369,714	10.50%	563,820	28.3262%		$159,708.78
District 23	015	Personal Property	1,679,714	10.50%	176,370	27.9262%		$49,253.44
District 29	013	Personal Property	789,333	10.50%	82,880	28.6262%		$23,725.39
District 05	003	Personal Property	1,668,952	10.50%	175,240	28.3262%		$49,638.83
District 06	004	Personal Property	1,331,143	10.50%	139,770	28.4262%		$39,731.30
District 08	005	Personal Property	1,828,857	10.50%	192,030	27.9262%		$53,626.68
District 92	014	Personal Property	412,381	10.50%	43,300	32.3390%		$14,002.79
District 08- 92 Fisher 28 x52	005	211-00-00-028.005	79,500	6.00%	4,770	27.9262%		$1,332.08
District 18- River Access only	010	112-00-00-080.000	3,000	6.00%	180	27.9262%		$50.27
District 06 215.76 acre Dravo R	004	114-00-00-008.001	223,600	6.00%	13,420	28.4262%		$3,814.80
99 Dam Island Rd	003	179-00-00-001.004	183,200	6.00%	10,990	28.3262%		$3,113.05
14.10 Non Operating Unit	018	113-00-00-099.000	14,200	6.00%	850	27.9262%		$237.37
Corporate Drive Deed 22/56	011	063-00-00-001.010	116,000	6.00%	6,960	28.3262%		$1,971.50
Lovers Lane	004	185-00-00-001.001	2,200	6.00%	130	27.1262%		$35.26
Mill Creek Rd 13J 418	008	211-00-00-028.000	71,600	6.00%	4,300	27.9262%		$1,200.83
Lot 2 13S 454 S 32	008	211-00-00-028.006	34,600	6.00%	2,080	27.9262%		$580.86
Lot 3 13T 492	008	211-00-00-028.007	7,300	6.00%	440	27.9262%		$122.88
330 Elm Rd/RI	008	220-00-00-004.000	29,400	6.00%	1,760	27.9262%		$491.50
Elm Rd 130 772 782	008	211-00-00-023.000	225,000	6.00%	13,500	27.9262%		$3,770.04
154 Mill Creek Village	008	211-00-00-028.002	7,900	6.00%	470	27.9262%		$131.25
92 Fleetwood 14x66	008	211-00-00-028.003	7,900	6.00%	470	27.9262%		$131.25
School District 1 Subject to Exemptio	001	Personal Property	10,121,910	10.50%	1,062,800	27.1262%	$59,752.96	$228,544.29
Cherokee Falls Nuclear Site	001	179-00-00-001. 000	4,269,360	6.00%	256,160	27.1262%		$69,486.47
285 Elm Road 11H	008	220-00-00-004.001						$191.14
District 09 (Blacksburg)	009	Personal Property	1,399,619	10.50%	146,960	15.9250%		$23,403.38
Fee in Lieu (Total Cherokee County)								$800,490.00
								$2,136,431.15
						Total Cherokee Taxed		$43,346,496
						Duke Percentage		4.929%

Lee Nuclear Station Response to Request for Additional Information (RAI)

Attachment 30/34-2 to RAI 30/34

2007 Cherokee County Property Tax, as provided by Duke Energy

2007 CHEROKEE COUNTY PROPERTY TAX

	ASSESSMENTS	DOLLARS
ORIGINALS	128,228,450	35,820,136.70
SUPPLEMENTALS	39,611,918	10,836,585.61
ERRORS	(11,991,856)	(3,310,225.89)
TOTAL NOTICES	155,848,512	43,346,496.42
TOTAL COLLECTED	148,674,312	41,347,284.05
UNPAID TO DELINQUENT	7,174,200	1,999,212.37

TOTAL NOTICES BREAKDOWN

REAL PROPERTY	86,652,070
BOATS & MOTORS	440,610
AIRPLANES	13,900
BUSINESS PERSONAL 311	780,680
BUSINESS PERSONAL 511	15,502,500
PERSONAL MANUFACTURING	9,776,500
REAL MANUFACTURING	4,376,410
UTILITIES & RAILROAD	15,520,350
FEE IN LIEUS	22,785,492
	155,848,512

Lee Nuclear Station Response to Request for Additional Information (RAI)

Attachment 30/34-3 to RAI 30/34

Tax Percentage Calculation, as provided by Duke Energy

		Upon Completetion Calculation	
Cherokee County Overall Property Tax Revenue for 2007	$43,346,496	$52,807,973	Upper limit Co. Est. Revenues
Duke Energy Property Tax Payments for 2007 Due to the Cherokee Falls Nuclear Site	$69,486	$51,851,194	Lower limit Co. Est. Revenues
Duke Energy Percentage of Revenue	0.16%		
Cherokee County Millage Rate		24.0300%	(agreement with the county sets the milage rate at 24.02)
Duke Energy Expected Value Upper Limit		1,968,680,000	
Duke Energy Expected Value Lower Limit		1,769,600,000	
In Lieu of Tax Rate		2%	
Duke Energy Expected Property Tax Upper Limit		$9,461,476	
Duke Energy Expected Property Tax Lower Limit		$8,504,698	
Duke Energy Percentage of Revenue Upper Limit		0.179167569	
Duke Energy Percentage of Revenue Lower Limit		0.164021249	

Lee Nuclear Station Response to Request for Additional Information (RAI)

RAI Letter Dated: August 21, 2008

Reference NRC RAI Number: ER RAI-42

NRC RAI:

What consultation process will be used to contact interested parties? Will interested parties be formally consulted with for all APEs? (including on - site, off - site, above - ground, and transmission lines)?

Duke Energy Response:

As required in NUREG-1555 ("...consultation with Federal, State, regional, local, and affected Native American tribal agencies..."), Duke Energy consulted with the South Carolina State Historic Preservation Office (SHPO) and the appropriate Native American tribes. In 2006 the formal consultation process was initiated by sending letters to the SHPO and tribes. These letters briefly described the proposed Lee Nuclear Station project, stated the known cultural resources environment on the site, and requested agency advisement of any other nearby historic sites, archaeological sites, traditional cultural properties, or other cultural resources under their jurisdiction that should be analyzed in the Environmental Report. Only the SHPO and Eastern Band of Cherokee Indians (EBCI) indicated a desire to engage with Duke Energy concerning the cultural resources assessment. Since that time, the consultation process has continued through meetings with the SHPO and submittal of scopes of work for review and approval by the SHPO and EBCI. The Phase I intensive survey reports were submitted to the SHPO and EBCI for review and approval. In 2008 Duke Energy became aware that the Seminole Tribe of Florida (STF) has an interest in South Carolina projects and initiated consultations with this tribe. These agency consultations are expected to continue until all areas of potential effect (APE) have been surveyed and cleared for construction by the SHPO.

With regard to interested parties, on March 17, 2007, Duke Energy sent letters to all 4,306 individuals who own land within the defined transmission line study area (approximately 400 square miles) for the Lee Nuclear Station. This letter and its enclosures contained key information on the transmission line study area (including a map of this area), announced two planned community workshops on the siting of the transmission lines, and included a survey form to inventory property-owner concerns about the potential impacts of transmission line construction and operations on cultural resources and other aspects of the environment. The completed survey form could be mailed back to Duke Energy or be submitted at one of the workshops. These workshops were held on April 3, 2007, at Bethlehem United Methodist Church in Union, South Carolina, and on April 5, 2007, at Hillcrest Baptist Church in York, South Carolina. Each workshop was scheduled for a 4-hour period (4:00 p.m. to 8:00 p.m.). At these workshops, general plans for the transmission lines were presented, and all interested parties in attendance were afforded an opportunity to ask questions and voice concerns. No alternate transmission line corridors had been identified at the time of these workshops. One hundred and sixteen individuals attended the first workshop and 348 survey forms were returned. The results of the survey are presented in Appendix C of *Siting and Environmental Report for the William States Lee III Nuclear Station 230 kV and 525 kV Fold-In Lines, Cherokee and Union Counties, SC*, submitted to the NRC on January 28, 2008.

When alternate corridors for the transmission lines were later determined, Duke Energy implemented a similar process for a follow-up workshop with landowner interested parties. Workshops were held on June 18, 2007, at Rehoboth Baptist Church and at Hillcrest Baptist Church on June 19, 2007. The 21 alternate corridors were identified, and individuals were provided an opportunity to comment on the corridors.

Using the field data collected during identification of the 21 alternate corridors, survey results, and qualitative information obtained from property owners at the June 2007 workshops, the 21 alternative corridors were compared and two final corridors were selected. A letter illustrating the selected routes was sent to all landowners.

With regard to the other on-site and off-site historic properties APEs for the Lee Nuclear Station, no additional consultations with interested parties other than the SHPO, EBCI, and STF are planned.

Associated Revisions to the Lee Nuclear Station Combined License Application:

None

Associated Attachments:

None

Lee Nuclear Station Response to Request for Additional Information (RAI)

RAI Letter Dated: August 21, 2008

Reference NRC RAI Number: ER RAI-44

NRC RAI:

Describe how it was concluded that cultural resources monitoring will not be conducted.

Duke Energy Response:

In 2006 Duke Energy initiated the Section 106 compliance process for construction and operation of the Lee Nuclear Station by sending consultation letters to the South Carolina State Historic Preservation Office (SHPO) and the Native American tribes with a traditional interest in the Lee Nuclear Site and the surrounding lands in Cherokee and York counties. The SHPO responded by recommending a Phase I intensive survey of the areas of potential effect (APE) for the Lee Nuclear Station project, and the Eastern Band of Cherokee Indians (EBCI) requested a Phase I survey of the same areas. In 2008 Duke Energy became aware that the Seminole Tribe of Florida (STF) has an interest in South Carolina projects and initiated consultations with this tribe. Because the Lee Nuclear Site is within an area of historic and archaeological interest to the STF, the tribe requested copies of the archaeological survey reports for the Lee Nuclear Station before making any further comments on the project. Duke Energy has provided the requested reports and the letters from the SHPO approving these reports.

Based on an initial consultation meeting with the SHPO, Brockington and Associates, Inc., Duke Energy's cultural resources survey subcontractor, developed a scope of work for the initial Phase I intensive surveys. The survey plan was reviewed and approved by the SHPO. Completed in January 2007, this scope of work included the definition of several on-site APEs for construction and operation of the Lee Nuclear Station and detailed plans for surveying them. The identified on-site archaeological APEs were the main plant site (including all access improvements, parking, and laydown areas), a proposed road right-of-way to the top of McKowns Mountain, the cooling water intake structure area, and MET Tower 3. One identified off-site APE was the area within 1 mile of the cooling tower pads and MET Tower 3, used for assessment of impacts on the local aesthetic environment and aboveground historic properties outside of the Lee Nuclear Site. In August 2007, Brockington and Associates completed a similar scope of work for another off-site area. This scope of work defined the APE for the realignment and reconstruction of the Lee Nuclear Station railroad spur from East Gaffney to the Lee Nuclear Site and set forth detailed work plans for a Phase I intensive survey of this APE. All of these 2007 scopes of work were submitted to the SHPO and EBCI for approval. The SHPO approved all survey plans in 2007, and the EBCI did not provide any comments on the survey plans.

Phase I intensive surveys of the foregoing APEs were performed in accordance with the approved work plans in 2007. These surveys included appropriate shovel testing and pedestrian transect survey along with architectural inventories within the off-site APE for the railroad spur and an architectural/aboveground property inventory of the 1-mile visual/aesthetic APE. The purposes of the Phase I intensive surveys were to thoroughly evaluate each APE for the presence or absence of properties greater than 50 years old, gather information sufficient to determine whether such properties are eligible for or listed on the National Register of Historic Places (NRHP), and determine if any such properties would be impacted by construction and operation of the Lee Nuclear Station. No such properties were identified within the on-site APEs or within the APE for the Lee Nuclear Station railroad spur. Two NRHP-eligible aboveground historic properties were identified within 1 mile of the cooling towers and MET Tower 3. These were the Ninety-Nine Islands Dam and the adjacent Ninety-Nine Islands Hydroelectric Plant. The Environmental Report (ER) for the Lee Nuclear Station determined that these two properties would receive SMALL aesthetic impacts from construction and operation of the Lee Nuclear Station because both are active industrial facilities used for the generation of electricity. The SHPO concurred with the conclusions of this report.

In addition to the APEs mentioned above, two APEs still need to be defined and subjected to a Phase I intensive survey. These are the APEs for the on-site cooling water discharge structure and the off-site transmission line routes. As was the case for the other APEs, these two APEs and the detailed survey plans for them are expected to be submitted to the SHPO and EBCI, as well as the STF, for review and approval before implementation of the surveys. In the future, if Duke Energy identifies additional APEs that are not recognizable at this time, it is anticipated that this process would continue until all of these APEs have been thoroughly defined and subjected to a Phase I intensive survey.

Because of the foregoing process for identifying planned construction areas on-site and off-site, careful definition of the APEs, thorough scoping of all Phase I intensive surveys, and SHPO review and approval of the APEs and Phase I intensive survey scopes, it is unlikely that any historic properties will elude identification, evaluation, and proper management under the Section 106 process for the Lee Nuclear Station. Therefore, it is concluded that formal monitoring for cultural resources is not necessary and would not be conducted during construction of the Lee Nuclear Station. However, if artifacts, features, or human remains are encountered inadvertently during construction, an event considered unlikely, Duke Energy plans to stop work immediately in the area of the discovery and contact the SHPO.

Associated Revisions to the Lee Nuclear Station Combined License Application:

Revise COLA Part 3, ER Chapter 4, Subsection 4.1.3.3, Paragraphs 1 and 2, as follows:

4.1.3.3 ~~Archaeological Monitoring~~ Inadvertent Discoveries during Construction

If artifacts, features, or human remains are encountered inadvertently during construction of the Lee Nuclear Station, an event considered unlikely, Duke Energy plans to stop work immediately in the area of the discovery and contact the SHPO. ~~Duke Energy plans to monitor vegetation clearing, excavation, grading, and other soil intrusive activities during construction of the Lee Nuclear Station, its railroad, and the transmission lines. This monitoring is focused on the identification of prehistoric artifacts, Historic Period artifacts, man-made subsurface features, human burials, and other indicators of an archaeological site that might have escaped identification during the Section 106 review process. The monitoring is performed by personnel who meet or exceed the Secretary of the Interior's Historic Preservation Professional Qualification Standards and have professional training in prehistoric archaeology, Historic Period archaeology, and human osteology.~~

~~In the unlikely event of such finds, Duke Energy plans to stop work immediately at the location of the find and in the surrounding area. If Historic Period artifacts or anthropic features are discovered, appropriate notification is sent to the Deputy State Archaeologist. If Native American artifacts, human remains, or Native American mortuary artifacts associated with human remains are found, notification is sent to the Deputy State Archaeologist, Cherokee County Coroner (human remains only), and Tribal Historic Preservation Offices (THPOs) for the Eastern Band of Cherokee Indians, Catawba Indian Tribe, and Eastern Shawnee Tribe of Oklahoma.~~ Human remains and artifacts subject to the Native American Graves Protection and Repatriation Act are managed in compliance with its provisions and the regulations in 43 CFR 10 (Reference 7).

Associated Attachments:

None

Lee Nuclear Station Response to Request for Additional Information (RAI)

RAI Letter Dated: August 21, 2008

Reference NRC RAI Number: ER RAI-45

NRC RAI:

Is there a written procedure that outlines how Duke will formalize a process (such as stop work orders, consultation with SHPO, tribes and avoidance/mitigation measures) for dealing with inadvertent and unanticipated discoveries?

Duke Energy Response:

Duke Energy does not have a written corporate procedure that documents a formal internal process for dealing with inadvertent and unanticipated discoveries of artifacts, features, or human remains during construction and operation of the Lee Nuclear Station. In the past, on other Duke Energy projects, the detailed provisions for dealing with such discoveries have been included in agreements between the State Historic Preservation Office (SHPO) and the federal agency with license jurisdiction (NRC for Lee Nuclear Station). It is anticipated that such provisions would be included in a similar agreement between the SHPO and NRC to cover Lee Nuclear Station construction and operations. If artifacts, features, or human remains are encountered inadvertently during construction or operations, an event considered unlikely, Duke Energy plans to stop work immediately in the area of the discovery and contact the SHPO.

Associated Revisions to the Lee Nuclear Station Combined License Application:

No COLA revisions have been identified with this response.

Associated Attachments:

None

Lee Nuclear Station Response to Request for Additional information (RAI)

RAI Letter Dated: August 21, 2008

Reference NRC RAI Number: ER RAI-47

NRC RAI:

Describe process for weighting cultural resources in the alternative site analysis. Provide references consulted for this analysis.

Duke Energy Response:

The discussion of cultural resources in Section 9.3 of the Environmental Report (ER) is based on information utilized for the site selection process described in ER 9.3. The evaluation of sites relative to the land-use criterion was based on the compatibility of a new nuclear station with existing land uses; this involved many factors, including current land uses (e.g., residential, agricultural), current zoning, planned developments, and cultural resources (specifically, proximity to any significant historic properties). Specifically, historic properties were defined as those properties currently listed on, or identified as eligible for listing on, the National Register of Historic Places (NRHP). Historic properties can include any significant prehistoric archaeological sites, Historic Period archaeological sites, aboveground historic sites, or traditional cultural properties located on or in close enough proximity to the proposed or alternative sites to be potentially impacted by the Lee project. The process for identification of historic properties included examination of the following publicly available data sources and the ERs previously prepared by Duke Energy for the Cherokee (now the proposed Lee Nuclear Site) and Perkins sites:

- National Register of Historic Places (NRHP) website at www.nationalregisterofhistoricplaces.com. Duke Energy conducted a records search on the National Park Service's National Register of Historic Places database for the host counties of the proposed and alternative sites: Cherokee County (Lee Nuclear Site), Anderson County (Middleton Shoals Site), Oconee County (Keowee Site); and Davie County (Perkins Site). The NRHP website was searched on August 24, 2005, in support of the site selection process. Site listings were reviewed to identify historic properties located on or nearest to the proposed and alternative sites. The listings included street addresses and towns for most properties, or at least the closest town for those with a restricted address. The results of the NRHP records search were as follows:

    - Keowee Site – 19 sites in Oconee County, with locations in nearby Newry (6 miles), and Seneca (7 miles), with the closest location being the Old Pickens Presbyterian Church, which is located near the Oconee-Pickens County Line within the boundaries of the Oconee Nuclear Station, approximately 1 mile from the site. The NRHP website indicated that the Old Pickens Presbyterian Church is listed on the NRHP.
    - Lee Nuclear Site – 26 sites in Cherokee County, with the closest locations in Kings Creek (4.5 miles from the site) and in Gaffney (approximately 10 miles from the site and containing the majority of sites).
    - Middleton Shoals Site – 19 sites in Anderson County, with the majority located in Anderson (approximately 15 miles from the site).

  - Perkins Site – 16 sites in Davie County, with the closest locations in Cooleemee (5 miles from the site), Mocksville (7 miles from the site, and containing the majority of sites), and Advance (8 miles from the site).

- USGS 1:100,000 scale topographic maps for Greenville, SC 1991 (Keowee Site); Gastonia, NC and SC 1991 and Spartanburg, SC 1986 (Cherokee Site); Abbeville, SC and GA 1979 (Middleton Shoals Site); and Salisbury, NC 1985 (Perkins Site).
- Duke Power Company Project 81, Cherokee Nuclear Station Environmental Report, Volume I, October 1975 (Section 2.3, Regional, Historic, Scenic, Cultural and Natural Landmarks).
- Duke Power Company Project 81, Perkins Nuclear Station Environmental Report, Volume I, October 1975 (Section 2.3, Regional, Historic, Scenic, Cultural and Natural Landmarks) – identified an "Indian Circle" in site vicinity (distance not specified) as being possibly eligible for the NRHP.
- Nuclear Regulatory Commission, License Renewal Generic Environmental Impact Statement, NUREG-1437, Supplement 2. Oconee Nuclear Station Units 1, 2 and 3. December 1999.This document identified the Old Pickens Presbyterian Church as an NRHP-listed site at Oconee, which is adjacent to the Keowee Site. However, it was not identified as a concern during relicensing. [http://www.nrc.gov/reading-rm/doc-collections/nuregs/staff/sr1437].
- Bailey, R., Jr., A. Agha, and E. Salo, Cultural Resources Survey of the Proposed Lee Nuclear Station, Cherokee County, South Carolina, Brockington and Associates, Inc., Charleston, South Carolina, August 2007. This report identified the Ninety-Nine Islands Dam and Hydroelectric Plant as eligible for listing on the NRHP. These are the eligible sites closest to the Lee Nuclear Site. No eligible archaeological sites were identified on the Lee Nuclear Site or in nearby areas outside of its boundary. With the exception of the dam and hydrolelectric plant, no other aboveground historic properties were identified on the Lee Nuclear Site or within a 1-mile radius of its cooling towers and MET Tower 3.

No other site-specific cultural resource reports were identified for the Middleton Shoals Site; therefore, the evaluation of Middleton Shoals relied only on information included in the NRHP website and was based on the presence or absence of listed NRHP sites that could be affected by the proposed project.

It should also be noted that the above references identified no NRHP site in the immediate vicinity of the three alternative sites. The Old Pickens Presbyterian Church (listed on the NRHP in 1996) is approximately 1 mile from the Keowee Site. This historic site is actually located within the boundaries of the Oconee Nuclear Station, where it is well-protected from existing plant operations. In general, based on a review of the NRHP website, the majority of NRHP sites appeared to be located in nearby towns that were several miles away from the proposed and alternative sites; therefore, they would not be impacted by the proposed development.

As referenced in ER 9.3, one NRHP-eligible or potentially eligible property is the "Indian Circle" located in the vicinity of the Perkins Site. Because of its distance from the Perkins Site, it had been determined previously (in the Perkins ER) that this site would not be impacted by construction or operation of a nuclear station within the site boundary.

Duke Energy has plans to install the cooling water discharge structure for the Lee Nuclear Station at a location immediately above the Ninety-Nine Islands Dam. However, these plans are not fully developed, and the discharge structure location has not been subjected to a Phase I intensive survey for historic properties. Therefore, the potential impacts of construction and operations on this NRHP-eligible historic property cannot be assessed at this time. When plans for the discharge structure are more fully developed, the State Historic Preservation Office (SHPO) will be consulted, a Phase I intensive survey of the Area of Potential Effect (APE) for the cooling water discharge structure will be conducted, and the potential impacts from construction and operations will be assessed.

With regard to the weighting process for the cultural resources evaluation, a weight was assigned to the land-use criterion (which included a consideration of cultural resources) as part of the site-selection process. The screening process, including the assignment of criterion weights, is discussed in ER Section 9.3.1. Also described in ER Section 9.3.1, ratings were assigned to each site based on professional judgment after a careful consideration of land-use-related information pertaining to each site. Because cultural resources were not evaluated as a separate criterion, the evaluation and conclusions relating to cultural resource impacts in the alternative site analysis in the ER were conducted independently.

In conclusion, with regard to the alternative site analysis, potential impacts to properties listed on or eligible for listing on the NRHP served as the basis for the impacts evaluation for cultural resources. No sites listed on or eligible for listing on the NRHP were identified on or in close proximity to the three alternative sites. No historic properties would be affected by the proposed project at these sites. Therefore, impacts on cultural resources at these sites were estimated to be SMALL. The same assessment of a SMALL impact would apply to the Lee Nuclear Site, with one possible exception. The proposed cooling water discharge structure for the Lee Nuclear Station is planned for a location adjacent to the upstream side of the Ninety-Nine Islands Dam, which is eligible for listing on the NRHP. At this time, the APE for the discharge pipeline and structure has not been formally defined in consultation with the SHPO; consequently, it has not been subjected to a Phase I intensive survey for historic properties. When plans for the discharge pipeline and structure are more fully developed and the APE has been defined in consultation with the SHPO, a Phase I intensive survey of this APE would be implemented. Based on the results of the survey, and in consultation with the SHPO, the potential impacts of discharge structure construction and operations on the Ninety-Nine Islands Dam would be assessed. Impacts on any other historic properties that might be identified within this APE would also be assessed at that time. This finding formed the basis of the evaluation and conclusions relating to cultural resources in ER 9.3.

Associated Revisions to the Lee Nuclear Station Combined License Application:

None

Associated Attachments:

None

Lee Nuclear Station Response to Request for Additional information (RAI)

RAI Letter Dated: August 21, 2008

Reference NRC RAI Number: ER RAIs-57 and 69

NRC RAI:

ER RAI 57: Provide an assessment of the potential impacts from construction of the intake structure and intake pipeline on the alluvial wetland located upstream from the proposed intake location.

ER RAI 69: Please provide a summary of Duke Energy's expected work windows for construction of the intake and discharge structures. These should be linked to the USACE and SCDNR permit requirements for working in waterways.

Duke Energy Response:

No adverse impacts are expected to occur to the small alluvial wetland located to the southwest of the intake. Environmental Report (ER) Figures 4.1-1 and 4.3-3 show the construction outline of the plant site, including the intake structure and the clear separation between the wetland and the intake. Subsection 4.2.2 states that no construction will occur within wetlands, and Subsection 4.3.1.1.2 specifically states that the alluvial wetland in question is outside of the construction footprint. The delineation reports provided by Duke Energy surveyors and aerial photographs of the proposed construction area indicate no wetlands within the area being disturbed by intake construction. It is anticipated that the intake pipeline and access road will pass by the wetland in question with no impact. All intake construction will be behind the cofferdam, thus preventing the liberation of sediment during construction. There are no anticipated impediments to flow except for areas behind the cofferdam.

Work on the intake structure is anticipated to last approximately 16 months. Approximately 4 months will be dedicated to installing the cofferdam assembly, and it should take another 2 months to remove it at the completion of construction. Actual construction is expected to be completed within 7 – 10 months in order to limit construction-related occupation of the riparian area and river bottom (Subsection 4.3.2.1). Both construction and removal of the cofferdam will be scheduled to avoid spawning runs to the extent practical (Subsection 4.3.2.1.1) and minimize the extent and magnitude of impacts to aquatic habitats. The cofferdam is expected to be removed prior to high flows in the spring (Subsection 4.3.2.1). No commercial fishing exists in this area, and recreational fishing is not expected to be curtailed (Subsection 4.3.2.1.4).

The diffuser pipe will be constructed using divers and a barge. This portion of the project is expected to last 3 months and is scheduled for the late summer to fall time frame. Construction of a cofferdam will not be necessary. Almost no substrate disturbance is anticipated because actual construction in the river will be minimal.

Work will be compliant with the conditions of applicable permits (Subsection 4.3.2.1.2). The United States Army Corps of Engineers (USACE) (§404 wetlands and §10 navigable waters programs), Cherokee County flood plain administration, and South Carolina Department of health and Environmental Control (SCDHEC) (§401 certification and National Pollutant Discharge Elimination System (NPDES) program) will each have independently enforceable permit authority over activities undertaken in the river.

Associated Revisions to the Lee Nuclear Station Combined License Application:

1. Revise COLA Part 3, ER Chapter 4, Subsection 4.3.2.1.1, beginning with current Paragraph 5 and adding a new Paragraph 6, as follows:

   Construction in the river will be scheduled to minimize the extent of aquatic habitat impacted during construction. Some siltation and increased turbidity may be generated by installing sheet pile and the other structures used to isolate construction activities from the aquatic environment. This siltation is expected to be limited in magnitude and duration and is not expected to appreciably increase the Broad River's overall sediment bed load nor result in a significant loss of benthic macroinvertebrates because steep banks and mud/silt substrates in the reservoir limit macroinvertebrate density. Work on the intake structure is anticipated to last approximately 16 months. Approximately 4 months are expected to be dedicated to installing the cofferdam assembly, and it should take another 2 months to remove it. Actual construction is expected to be completed within 7 – 10 months in order to limit construction-related occupation of the riparian area and river bottom (Subsection 4.3.2.1). Both construction and removal of the cofferdam are expected to be scheduled to avoid spawning runs to the extent practical, and minimize the extent and magnitude of the impact to aquatic habitats. The cofferdam is expected to be removed prior to high flows in the spring (Subsection 4.3.2.1). No commercial fishing exists in this area, and recreational fishing is not expected to be curtailed (Subsection 4.3.2.1.4).

   The diffuser pipe is expected to be constructed using divers and a barge. This portion of the project is planned to last 3 months and is scheduled for the late summer to fall time frame. Construction of a cofferdam is not expected to be necessary. No diversion of the river flow is anticipated nor is any disturbance of river substrate expected. Actual construction occupation of the river is expected to be minimal. The pipe sections would be assembled onshore, positioned using the barge, and attached to the Ninety-Nine Islands Dam using divers. The use of divers and very short construction time is expected to minimize stress to the aquatic community. The timing of this part of the construction should avoid any disruption in the spawning runs or seasonal migration.

2. Revise COLA Part 3, ER Chapter 4, subsection 4.3.2.1.1, by adding new Paragraph 11 as follows:

   Leaks and spills would also be minimized through scheduled equipment maintenance performed in the maintenance yard located away from the river. The spill prevention plan for this project (see Subsection 4.3.1.1.3), which is specific to the construction period, would also provide a procedure for immediate response and cleaning of accidental spills so their potential effects would be mitigated. Personnel using fuel or lubricants in the field are trained to respond to, clean, and report spills. Additionally, adequate spill response materials are always available in every transport vehicle used regularly on the project site. Contaminated materials are managed and disposed in accordance with federal and state laws and regulations, and the spill prevention plan prevents any adverse effects of these materials on the environment. Therefore, the potential effects to the Broad River of construction of the Lee Nuclear Station are SMALL and do not warrant any additional mitigation.

Work will be compliant with the conditions of applicable permits (Subsection 4.3.2.1.2). The USACE (§404 wetlands and §10 navigable waters programs), the Cherokee County floodplain administration, and SCDHEC (§401 certification and NPDES program) are expected to each have independently enforceable permit authority over activities undertaken in the river.

Associated Attachments:

None

Lee Nuclear Station Response to Request for Additional Information (RAI)

RAI Letter Dated: August 21, 2008

Reference NRC RAI Number: ER RAI-63

NRC RAI:

Duke is requested to conduct further modeling of low flow events focusing on temperature increases during low flow periods and the predicted durations of these elevated temperature events to help ecologists determine the level of impacts to the small mouth bass population below the Ninety - Nine Islands dam. Modeling should include a re - evaluation of the CORMIX modeling results downstream of the dam, considering smallmouth bass thermal tolerances as an input.

Duke Energy Response:

Table 5.2-1 of the Environmental Report (ER) summarizes the CORMIX outputs from the analysis of the thermal plume predicted to be released from the Lee Nuclear Station into the Broad River. Although CORMIX is not designed to model the specific conditions (a discharge to penstocks and mixing through the hydroelectric dam) being implemented at this site. Its use allowed for a first pass evaluation of thermal mixing. Actual thermal impacts on the receiving water were projected using a mass balance equation. Calculations were performed using the 7Q10 flow of 479 cfs and the normal flow of 2537 cfs. Maximum and minimum temperatures for the river used in the calculation were 85.3° F and 40.8°F, respectively. These values are derived from USGS gauge data (02153551 Broad River below Cherokee Falls) shown on ER Table 2.3-3. All calculations used 95°F for the maximum plant effluent temperature even though normal discharge temperatures will be below that. Separate calculations were performed using 2 and 4 cycles of concentration (COC) (64 and 18.3 cfs respectively). Normal operation will use 4 COC as specified in ER Subsection 5.2.3.1. Projections based upon conditions expected to be found in the river indicate the maximum influence of the thermal effluent will occur at normal river flow, minimum temperature, and two cycles of concentration. Mass balance equations assume complete mixing of the waters, which is expected when releasing and homogenizing water through the penstocks. The implementation of cooling towers and discharge diffusers reduces thermal impacts of the Lee Nuclear Station effluent to less than 1.4°F above ambient water temperature in the forebay of the hydroelectric station.

Independent modeling was performed by engineers associated with the Strom Thurmond Institute of Clemson University to confirm results attained using the mass balance equation (Attachment 63-1). The mixing zone was defined as 6 feet above and below the diffuser, the length of the diffuser, and 50 feet downstream. Diffuser design and location, effluent temperature and velocity, regulatory temperature limit, and ambient water temperatures modeled remained identical to previous CORMIX and Duke Energy mass balance calculations at the Lee Nuclear Station. Engineers at the Strom Thurmond Institute arrived at a ΔT in the forebay area upstream of the dam of 1.2°F, similar to temperature differences calculated previously.

The NRC referred to a temperature of 79°F in the "Supporting Information" for the RAI, presumably for the protection of smallmouth bass specified in the RAI. Water temperature measurements from the United States Geological Survey (USGS) gauges (02153551) on the Broad River below Cherokee Falls and (02156500) on the Broad River near Carlisle, South Carolina, reveal that daily mean water temperatures over the 10-year period 1997-2007 routinely exceeded 79°F for approximately 10-12 weeks from mid-June to mid-September. Daily mean temperatures were recorded as high as 84°F. Multiple sources indicate that this is well within the tolerance range for the smallmouth bass (Attachments 63-2 and 63-3).

In the literature, thermal ranges for smallmouth bass are similar but not identical (Attachments 63-2 and 63-3). Data in the Oroville (California) Federal Energy Regulatory Commission (FERC) relicensing documents (2003) indicate optimum water temperatures for adult growth range from 77°F to 80.6°F; however, rapid growth is observed in water temperatures as high as 84.2°F. Armour (1993) reported temperature responses for smallmouth bass as published by various authors. Preferred temperatures were reported between 86.5°F and 87.8°F and various maximums for juveniles and adults ranged from 89.6°F to 95°F.

Using the mass balance results and daily median data from the USGS Carlisle gauge, the only time that the Lee Nuclear Station effluent would contribute to a river temperature exceeding 79°F would be approximately one week in June (as water temperatures rise at the beginning of summer) and again in September (as water temperatures fall at the end of summer) when river temperatures are within 1.4°F of 79°F. During the entire interim period, ambient river water temperatures will typically exceed 79°F. However, the warmer the river, the less influence the thermal effluent will have because the temperature differential between the two is decreased. Because effluent flows are not expected to exceed 5 percent of river flow, there is no mechanism whereby the thermal effluent could contribute to waters becoming warmer than 90°F.

The discussion in ER Subsection 5.3.2.2 indicates that the hydroelectric dam may cease operation periodically, potentially causing a thermal plume behind the dam. It should be noted that FERC has mandated in the hydroelectric operation permit that 483 cfs be allowed to pass through the dam at all flows during July through November (Subsection 5.2.1.2). From January to April, this amount increases to 988 cfs. For May, June, and December, the minimum release through the dam is required to be 725 cfs. However, there are stipulations in the permit for conditions anytime the inflow to the reservoir is less than 483 cfs. The Ninety-Nine Islands Dam is required to "*...shut down all units when the pond elevation drops to the seasonal maximum drawdown limit required by Article 401 and shall operate one unit at its minimum hydraulic output for that portion of every hour which is necessary to discharge the approximate accumulated inflow.*" Accumulation of heated water above the dam is expected to occur only if the upstream flow has dropped below 483 cfs and Lee Nuclear Station is still operating aligned to the ponds. As discussed in the response to RAI 21, even under these conditions, it is not anticipated that heated water will accumulate for more than part of an hour before being released with the next operation of the hydroelectric dam. The Strom Thurmond Institute study estimated that, even under these rare conditions, the temperature increase should not be more than 1.7°F below the dam (Attachment 63-1).

Given these conditions and modeling results, there is no reason to believe that Lee Nuclear Station will produce adverse effects on smallmouth bass.

Duke Energy is conducting additional modeling of the thermal discharge as part of the NPDES permit submittal package. This information will not be available until the first or second quarter of 2009.

Associated Revisions to the Lee Nuclear Station Combined License Application:

1. Revise COLA Part 3, ER Chapter 5, Table 5.2-1, Sheet 2 of 2, as follows:

   SUMMARY OF THERMAL PLUME ANALYSIS (~~CORMIX~~ MASS BALANCE)

2. Revise COLA Part 3, ER Chapter 5, Subsection 5.3.2.1, Paragraph 2, as follows:

   The mathematical modeling tool CORMIX (Reference 17) is a computer code for the analysis, prediction, and design of aqueous toxic or conventional pollutant discharges into diverse water bodies. It is an EPA-recommended analysis tool for the permitting of industrial, municipal, thermal, and other point-source discharges to receiving waters. The CORMIX system~~, which~~ is used for prediction of subsurface multi-port discharges.~~, was used exclusively for this analysis~~.

3. Revise COLA Part 3, ER Chapter 5, Subsection 5.3.2.2, Paragraph 4, as follows:

   ~~Given the location of the proposed blowdown diffuser, a thermal plume may build just upstream along the face of the Ninety Nine Islands Dam during low flow conditions when the Hydroelectric Station ceases operation for short periods of time. When the Hydroelectric Station resumes operation this heated water will be mixed with river water as both pass through the Hydroelectric Station turbines. This combined flow is then discharged through the tailrace of the Hydroelectric Station. Based on previous discussion Duke Energy assumes that the temperature differential of this combined flow will be no more than 1.7°F.~~

   A smallmouth bass (*Micropterus dolomieu*) fishery does exist in the Broad River, but fish populations are not anticipated to be affected by discharges from the plant. Thermal ranges for smallmouth bass in reference documents are similar, although not identical. Data used in the Oroville (California) FERC relicensing documents (Reference 19) indicate optimum water temperatures for adult growth range from 77°F to 80.6°F; however, rapid growth is observed in water temperatures as high as 84.2°F. Reference 20 reports temperature responses for smallmouth bass as published by various authors. Preferred temperatures are reported between 86.5°F and 87.8°F, and various maximums for juveniles and adults range from 89.6°F to 95°F.

4. Revise COLA Part 3, ER Chapter 5, Subsection 5.3.5, References, as follows:

   19. State of California, The Resources Agency, Department of Water Resources, *Matrix of Life History and Habitat Requirements of Feather River Fish Species*, Oroville Facilities Relicensing, FERC Project 2100, SP-F15 TASK 1, SP-F21 TASK 1, SP-F3.2 TASK 2, Appendix A (Smallmouth Bass), 2004.

   20. Armour, C., *Evaluating Temperature Regimes for Protection of Smallmouth Bass*, U.S. Department of the Interior, Fish and Wildlife Service Resource Publication 191, 1993.

Associated Attachments:

Attachment 63-1 Hargett, D., A. Khan, and B. Sill. *Hydrodynamic Assessment of Discharge from Cooling Tower Blowdown to Broad River, Lee Nuclear Station, Cherokee County, South Carolina*, Final Report, The Strom Thurmond Institute, Clemson University, Clemson, S.C., 2007.

Attachment 63-2 State of California, The Resources Agency, Department of Water Resources, *Matrix of Life History and Habitat Requirements of Feather River Fish Species*, Oroville Facilities Relicensing, FERC Project 2100, SP-F15 TASK 1, SP-F21 TASK 1, SP-F3.2 TASK 2, Appendix A (Smallmouth Bass), 2004.

Attachment 63-3 Armour, C., *Evaluating Temperature Regimes for Protection of Smallmouth Bass*, U.S. Department of the Interior, Fish and Wildlife Service Resource Publication 191, 1993.

Lee Nuclear Station Response to Request for Additional Information (RAI)

Attachment 63-1 to RAI 63

Hargett, D., A. Khan, and B. Sill. *Hydrodynamic Assessment of Discharge from Cooling Tower Blowdown to Broad River, Lee Nuclear Station, Cherokee County, South Carolina*, Final Report, The Strom Thurmond Institute, Clemson University, Clemson, S.C., 2007

20 September 2007 ***FINAL REPORT***

Duke Energy *via Hardcopy and Email*
Attn: Ms. Jessica Bednarcik
P.O. Box 1006
Charlotte, NC 28201-1006

Subject: Final Report
Hydrodynamic Assessment of Discharge from Cooling Tower Blowdown to Broad River, Lee Nuclear Station, Cherokee County, South Carolina

Dear Ms Benarcik:

This Final Report responds to Duke Energy's request of the South Carolina Water Resources Center (SCWRC) for a preliminary assessment of the hydrodynamic conditions associated with discharge from the cooling tower blowdown at the proposed Lee Nuclear Station. This report summarizes the work performed by the University's project team, including Dr. Abdul Khan, Principal Engineer responsible for analytical modeling, Dr. Ben Sill, Senior Faculty member responsible for technical project oversight and quality assurance review, and Dr. Dave Hargett, Senior Scholar and project manager. Details of the methodology, output, and results are provided in the accompanying documents. Our analysis is based on review of materials and information provided by Duke Energy, a site visit to the facility and the Ninety-Nine Islands Dam and Hydroelectric Facility on 30 July, and follow-up discussions with Duke Energy staff.

Background: Our understanding, based on information provided by Duke Energy, is that its cooling tower blowdown water is proposed to be discharged from a diffuser of 65-ft length, at approximately 15 cfs and a temperature of 95°F. The diffuser will be located on the upstream shelf of the dam, above and behind the existing dam gates. The nominal low flow of the Broad River will be at or above 483 cfs (the Design Low Flow Condition or DLFC), which is roughly equal to the 7Q10 flow for the river at this location. Under these low flow conditions the discharge through the power units will be released on 30-minute cycles. Regulatory guidance limits the maximum increase in temperature in the mixing zone to 5°F above the ambient condition, which is defined for purposes of this analysis as 81.5°F.

Objectives: We were charged by Duke Energy with examining the extent of the thermal plume build-up in the forebay, upstream of the diffuser. We also examined the effect of releasing the thermal load from the diffuser, through the power units, and to the tailrace downstream.

Technical Approach: Our team employed analytical modeling techniques to assess the fundamental question of whether unacceptable levels of temperature build-up may occur. This approach provides guidance on the nature and extent of any thermal build-up in the upstream forebay. A somewhat simpler dilution calculation technique was used to address the thermal load dispersion downstream, via the power units, and to the tailrace. The analytical model approach applied to the upstream situation does not provide the level of precision that would be rendered by a 3-D hydrodynamic numerical model, but is much more efficient and is appropriate as an initial assessment of thermal effects. This analytical approach is used to evaluate whether there are "fatal flaws" in the diffuser approach, without the effort of constructing a 3-D model. As an initial construct the analytical model provides substantive and valuable insights on whether the plume condition will be unacceptable, marginal, or acceptable, and guidance to what factors may be changed to mitigate heat build-up caused by the discharge configuration.

Analytical Methods: The methods, equations, assumptions, input values, and scenarios tested are described in detail in Dr. Khan's accompanying Final Technical Analysis (Enclosure 1). Five upstream scenarios were evaluated. One downstream scenario was evaluated. Output from the MS-Excel worksheets used in the model is provided in the attached data report (Enclosure 2).

Upstream Scenarios: Five upstream thermal loading scenarios were evaluated using Dr. Khan's analytical model. The physical layout and assumptions with regard to the positioning of the diffuser, the dam, the water column, and other flow barriers were based on input data provided by Duke Energy, and are illustrated in Dr. Khan's accompanying report. These scenarios and the results are summarized in the following Table 1.

Table 1: Thermal Mixing Scenarios and Resulting Temperature Gain in the Forebay

Scenario	Description	Mix Zone Dimensions			Input Flow (cfs)	Resulting Steady State Temperature Gain °F
		Diffuser Length (ft)	Upstream Mix Zone (ft)	Depth (ft)		
S1	Basic Conservative Scenario: Full mixing depth of 12 ft (6 ft above, and 6 ft below diffuser), restricted to mixing in the 65 ft length of the diffuser, and out to 50 ft from the diffuser. *Conservative.*	65	50	12	483	1.2
S2	Flow-Restricted Scenario: Same as S1 but with flow restricted to ½ of DLFC. *Very conservative.*	65	50	12	242	2.2
S3	Mix-Restricted Scenario: Same as S1 but with the mixing zone restricted to the top 6 ft of the water column. *Very conservative.*	65	50	6	483	2.1
S4	Flow- & Mix-Restricted Scenario: Same as S1 but with flow restricted to ½ of DLFC and mixing zone restricted to the top 6 ft of the water column. *Extremely conservative.*	65	50	6	242	3.7
S5*	Shallow Mix-Restricted Scenario: Mixing restricted to the "surface" of the ABCD embayment trapped behind the dam. *For comparison only.*	65	150+	0.6	1:2 dilution ratio	3.9

* *Scenario S5 was set up to allow diffusion over the entire forebay, defined in the model by Area ABCD, which is approximately 221,000 ft². Allowing all of the thermal load to diffuse into this area, and in the near surface, with the defined thermal result, would result in a thermally affected zone of only 0.6 ft thickness.*

Discussion of Upstream Scenarios: All model scenarios were cycled until steady state conditions were reached. Thus, the temperature gain results reported reflect maximum conditions under the defined scenarios. The mixing scenarios summarized in Table 1 are all considered "conservative" to "extremely conservative". The base scenario (S1) represents a reasonable set of input values that reflect a likely and conservative "worst-case" mixing scenario. This scenario produces an increase in temperature in the affected region of only 1.2°F. Scenarios S2-S4 represent adjustments of input values to the analytical model to radically stress the model by reducing the mixing flow by one-half (S2), reducing the mixing depth by one-half (S3), or both simultaneously (S4). Scenario S5 analyzes the extreme conditions in which the thermal load would mix across the entire forebay (Area ABCD), behind the dam, but only in the near surface. None of these extreme scenarios (S2-S5) are considered likely or representative of what would likely occur. Still, using these exceptionally conservative assumptions, the analytical model did not produce thermal gain of more than 3.7°F for any extreme scenario (S2-S4), and 3.9°F for the comparative scenario S5.

Downstream Scenario: The downstream mixing scenario is substantially simpler and was analyzed by a simple dilution calculation. A reasonable and conservative worst-case is defined by a scenario in which all of the thermal load accumulated over a 60-minute period would be discharged through the power units to the downstream tailrace over a 30-minute discharge cycle. Under these assumptions, of the 483 cfs discharged during the 30-minute discharge cycle, 30 cfs at 95°F represents the thermal load from the diffuser to be discharged, and to be mixed in the process of discharge with 453 cfs from the ambient embayment (river) water at 81.5 °F. *(The 30 cfs of 95°F water is comprised of 15 cfs accumulated over 30 minutes during the no discharge half of the cycle, plus 15 cfs that would occur during the 30 minute discharge period).* The result of this extreme worst-case scenario would produce a temperature increase in the tailrace area below the dam of 1.7°F.

Conclusions: The results of analytical modeling of thermal loading of various geometric and flow scenarios in the forebay area upstream of the dam indicate that under reasonable assumptions thermal gain will be no more than about 1.2°F. Additional scenarios were conceived to intentionally stress the model by radically reducing the mixing volume or the mixing depth, or both. Even with these extreme conditions, the model predicted a steady state temperature increase for the basic scenarios (S-1-S4) of no more than 3.7°F. Results of the worst-case downstream mixing scenario showed a maximum temperature gain of 1.7°F. Based on this analysis, under the defined operating conditions and representative low river flows, one can reasonably assume that thermal gain standards will not be violated.

Disclaimer: *The analysis and results provided in this report represent a preliminary assessment of limited scope and are based on information provided by Duke Energy. The authors believe the results of this evaluation are reasonable and accurate and reflect a rational approach to preliminary analysis of the proposed discharge design using generally accepted hydrodynamic principles. However, the reader is cautioned that the methods employed and the input values used in this evaluation represent only those scenarios defined in this report. Extrapolation beyond the scenarios and input assumptions provided in this report should be considered only with appropriate caution.*

The project team and Clemson University appreciate the opportunity to assist Duke Energy in this important project.

Very truly yours,

South Carolina Water Resources Center

Signed, DLH, 20 Sep 2007

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Enclosures

1) Final Technical Analysis – Dr. Khan, 6 September 2007
2) Analytical Model Worksheets – Dr. Khan, 6 September 2007

cc's w/ Enclosures, via Email: Mr. Theodore Bowling
Dr. Abdul Khan
Dr. Ben Sill
Dr. Jeff Allen

Final Report
Hydrodynamic Assessment of Discharge from Cooling Tower Blowdown To Broad River, Lee Nuclear Station, Cherokee County, South Carolina

Enclosures

1) Final Technical Analysis – Dr. A.A. Khan, 6 September 2007

2) Analytical Model Worksheets – Dr. A.A. Khan, 6 September 2007

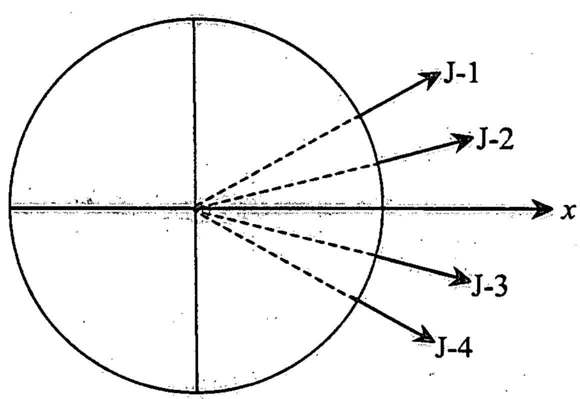
ANALYTICAL MODEL OF HYDRODYNAMIC THERMAL EFFECTS PROPOSED COOLING TOWER BLOWDOWN DISCHARGE LEE NUCLEAR STATION DUKE ENERGY

Analysis by Dr. Abdul A. Khan, Dept. of Civil Engineering, Clemson University
06 September 2007

Quality Assurance Review by Dr. Ben Sill
Dept. of Civil Engineering, Clemson University

Basic Facts:

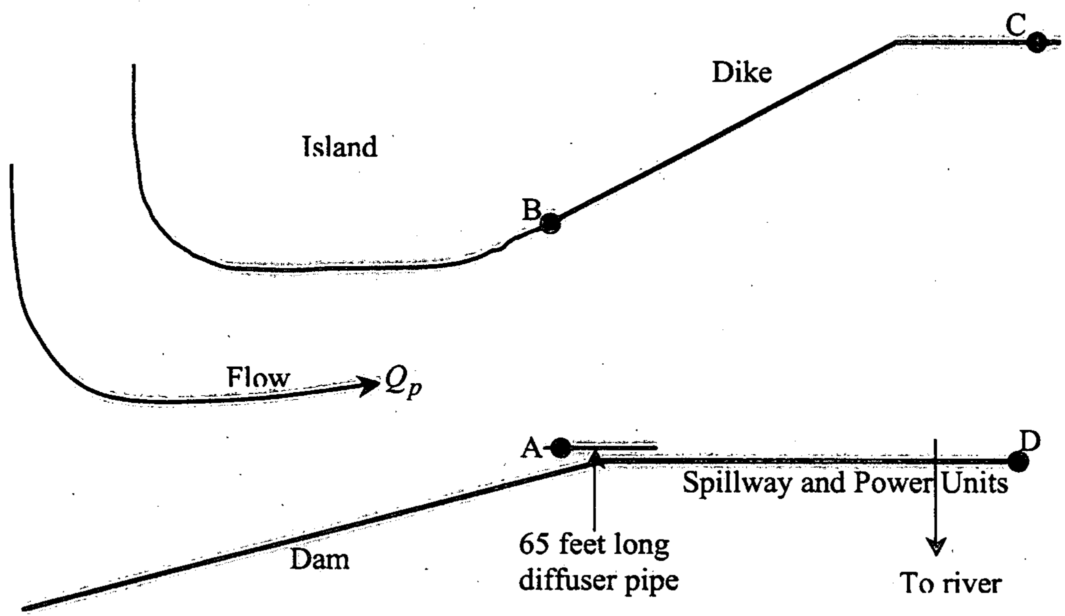
- Diameter of the diffuser pipes 36 inches, and is located approximately at mid-depth of the water column (the center of the diffuser is 6 feet above the bed).
- No of holes in the pipes are 1040 over a length of 65 feet.
- The diameter of orifices in the diffuser pipe is 1 inch with 3-inch spacing along and across the pipe
- Assuming uniform flow from each orifice the initial velocity is 2.64 ft/s.
- Flow through the power unit (units 1 and 4 alternately) is 483 cfs, in a cycle of 30 minutes on and 30 minutes off. *(Note: The operational regime historically used during low flow conditions at the Ninety-Nine Islands Dam is a cycle of 30 min on, and 30 min off, using two alternating power units. This is the only cycling duration/frequency examined in this analytical model).*
- Flow through the diffuser is 15 cfs.
- At any longitudinal section the flow exits of the diffuser are as four circular jets directed upstream into the reservoir. Two jets are directed upward and two jets are directed downward (as shown in the figure below). Jets J-1 and J-4 are at an angle of 14.2 degrees and jets J-2 and J-3 are at an angle of 4.8 degrees from the x-axis.



Section of a diffuser pipe showing four jets

Hydrodynamic Model – Lee Nuclear Station
Dr. Abdul Khan

- Referring to the figure below, the distance AB is 150 feet. The volume of water within the region ABCD is 1,746,300 cubic feet (from bathymetry provided) with a surface area of 220,750 square feet. The distance AB is about 150 feet.
- The volume of water in 30 minutes with 15 cfs discharge at $95^{\circ}F$ is 27,000 cubic feet and the volume of water in 30 minutes with 483 cfs discharge is 864,000 cubic feet.



Layout of the upstream forebay reservoir area

Equations Used:

- Decay of centerline velocity of circular and plane turbulent jets

$$\frac{u_m}{U_o} = \frac{6.3}{x/d} \text{ for circular jet}$$

$$\frac{u_m}{U_o} = \frac{3.5}{\sqrt{2x/d}} \text{ for plane jet}$$

where u_m is the velocity at the center of the jet at any location x along the jet, U_o is the exit velocity and d is the diameter of the jet. In case of plane turbulent jet, it is assumed that the jets J-1 and J-2 will combine to form a jet that will behave as it is exiting from a slot with that is 65 feet long and has a width of one or two diameters. These equations can be also used to estimate the distance traveled in a given time period.

- The jet dilution, that is increase in discharge as it flows down and entrains the surrounding fluid, is given by

$$\frac{Q}{Q_o} = 0.33x/d \quad \text{for circular jet}$$

$$\frac{Q}{Q_o} = 0.44\sqrt{2x/d} \quad \text{for plane jet}$$

where Q is the volumetric flow rate at any location x along the jet and Q_o is the volumetric flow rate at the exit.

- Due to density difference between the jet and the ambient fluid, the jet will rise to the surface as given by

$$z = \frac{U_{zo}}{U_{xo}}x - \frac{g'}{2U_{xo}^2}x^2$$

where z is the vertical distance and x is the horizontal distance, U_{zo} and U_{xo} are the vertical and horizontal components of the exit velocity, and g' represents the net upward force on the hot water.

- Heat transfer to the air is given by

$$Q_H = KA(T - T_E)$$

where K is the heat exchange coefficient and is equal to 160 $BTU/(ft^2 \cdot day \cdot {}^oF)$ for the month of August in the Greenville-Spartanburg area, A is the surface area, T is the existing temperature, and T_E is the equilibrium and is equal to $81.5°F$ for the month of August in the Greenville-Spartanburg area.

- To calculate the temperature change for the mass of water for a given heat change

$$Q_H = C\rho g \forall (T - T_E)$$

where C is the specific heat and is equal to 1 *BTU/(lb•°F)* and $\forall$ is the volume of water. The volume weighted average is used according to the first law of thermodynamics.

Basic Observations:

- The jets J-1 and J-2 will reach the surface at 23.5 feet and 71.83 feet from the diffuser if density difference is ignored. If density difference is included without any dilution, the jets J-1, J-2, J-3, and J-4 will reach the surface at 16.6, 25.4, 39.2, and 56.6 feet from the diffuser. Since dilution will reduce the density difference the jets will reach the surface farther than the above distance. Since the dilution amount is associated with temperature reduction, it is assumed that only 50 feet of length is available for jet mixing. This is a conservative value.
- The jets will travel a distance of 71 feet if it is assumed that the jets will act as individual circular jet (no interaction) and will travel a distance more than 150 feet if upper and lower pairs of jets are considered as plane turbulent jets. These distances are found by integrating the expressions of velocity decay.

Results:

Upstream Assessment: The first set of results is based on the jet mixing across 65-ft width of the diffuser, 12-ft depth, and 50-ft length. Note that the mixing depth assumed here of 50 ft is considered to be reasonable and conservative, given the geometry of the diffuser. The mixing length is based on minimum length required for a jet rising to the surface with density difference. For a 30-minute period, the blowdown discharge mixes with the volume of water which is 65 ft X 12 ft X 50 ft. In the next 30 minutes, the blowdown discharge continues to mix with the above volume and a outflow of 483 cfs takes place from the reservoir through the power unit. The flow has to come around the island to maintain mass balance. A proportionate amount (483 * 50/150 cfs) of ambient fluid at a temperature of $81.5^{\circ}F$ will enter the affected volume and the same volume at higher temperature will move towards the power unit. Four different scenarios are considered: (i) the first scenario is as specified above, (ii) in the second scenario only half the discharge,that is 242 cfs, is allowed from the upstream into the affected volume, (iii) in this case the blowdown discharge is allowed to mix only in the upper 6 feet of water with a full 483 cfs from the upstream into the affected area, and (iv) in the last case the blowdown discharge is allowed to mix in the upper 6 feet of the volume and only half the discharge (242 cfs) is allowed from the upstream into the affected volume.

In each case, a steady state temperature in the affected area reached after three cycles. Each cycle consists of 30 minutes off and 30 minutes on period of discharge of 483 cfs through the power unit. The computations are performed in one-minute intervals to accurately compute temperature variation in the affected volume due to blowdown discharge and upstream flow when the power unit is operating. The increase in temperatures in the four cases are $1.2°F$, $2.2°F$, $2.1°F$, and $3.7°F$, respectively.

Although the basic mixing configuration with a 50-ft mixing zone is considered reasonable and conservative, to investigate the effect changes in the length of the affected volume on temperature increase, the length was increased to 60 feet, and 75 feet. It was confirmed that increasing the length of the affected volume reduced the temperature increase.

As a last case, the blowdown discharge for a period of 1 hour is allowed to spread over the surface of the reservoir with 1:2 dilution ratio, that is the discharge will increase three times the initial discharge. This level of dilution for plane jet is achieved with 9 feet of travel distance. For circular jet the dilution will be much higher for jet traveling over the same distance. The steady state of temperature is achieved in four cycles with increase in temperature of $3.9°F$. It should be recognized that these conditions represent the lowest level of mixing. This last, extremely poor-mixing scenario is unrealistic and was considered only for comparative purposes to examine the sensitivity of the analytical model to mixing parameters.

Downstream Analysis: The worst-case scenario for the flow through the power unit is when 30 cfs is passing through the power unit for a period of 30 minutes. The downstream increase in temperature is $1.7°F$.

Conclusions:

1) Four scenarios were evaluated to assess worst-case increases in upstream reservoir forebay temperature, based on the low flows operational regime and diffuser design defined by Duke Energy. Under the basic realistic and conservative scenario, the maximum increase in upstream reservoir forebay temperature is $1.2\ °F$. In the most extreme worst-case scenario the maximum increase in the upstream reservoir forebay temperature is $3.7°F$.

2) For the low flows operational regime defined by Duke Energy, the worst-case maximum increase in temperature in the downstream reach of the river is $1.7°F$.

Scenario 1

Uo (ft/s)		Specific heat of water Cp (BTU/lb/F)			
2.644		1			
		Length Affected (ft)	Dt (minutes)	Blowdown Volume (ft^3)	Volume Affected (ft^3)
Volume of affected zone 12ft X 65ft X 50ft =	39000	50	1	900	39000
15 cfs for 30 minutes =	27000				
		Depth Affected (ft)	Equil. Temperature (F)	Heat Transfer Coeff BTU/ft^2/day/F	Blowdown Temp (F)
		12	81.5	160	95
		Actual Depth (ft)	Volume Through Unit (ft^3)	Total Flow Width (ft)	Flow area ratio
		12	28980	150	0.33

Cycle I

Time (Minutes)	New Temp (F)	Heat Transferred BTU	Temp Reduction (F)	Final Temp (F)	Time (Minutes)	New Temp (F)	Heat Transferred BTU	Temp Reduction (F)	Final Temp (F)
0	81.50	0.00	0.00	81.50	30	88.29	0.00	0.00	88.29
1	81.81	112.50	0.00	81.81	31	86.76	1899.23	0.00	86.76
2	82.12	222.39	0.00	82.12	32	85.65	1497.27	0.00	85.65
3	82.41	329.72	0.00	82.41	33	84.83	1204.19	0.00	84.83
4	82.70	434.57	0.00	82.70	34	84.24	990.51	0.00	84.24
5	82.99	536.98	0.00	82.99	35	83.81	834.70	0.00	83.81
6	83.26	637.01	0.00	83.26	36	83.50	721.10	0.00	83.50
7	83.53	734.71	0.00	83.53	37	83.27	638.27	0.00	83.27
8	83.80	830.15	0.00	83.80	38	83.10	577.88	0.00	83.10
9	84.06	923.37	0.00	84.06	39	82.98	533.84	0.00	82.98
10	84.31	1014.43	0.00	84.31	40	82.89	501.74	0.00	82.89
11	84.56	1103.37	0.00	84.56	41	82.82	478.33	0.00	82.82
12	84.80	1190.25	0.00	84.80	42	82.78	461.26	0.00	82.78
13	85.03	1275.11	0.00	85.03	43	82.74	448.81	0.00	82.74
14	85.26	1358.00	0.00	85.26	44	82.72	439.74	0.00	82.72
15	85.48	1438.97	0.00	85.48	45	82.70	433.13	0.00	82.70
16	85.70	1518.05	0.00	85.70	46	82.69	428.30	0.00	82.69
17	85.92	1595.30	0.00	85.92	47	82.68	424.78	0.00	82.68
18	86.13	1670.75	0.00	86.13	48	82.67	422.22	0.00	82.67
19	86.33	1744.45	0.00	86.33	49	82.66	420.35	0.00	82.66
20	86.53	1816.45	0.00	86.53	50	82.66	418.99	0.00	82.66
21	86.72	1886.76	0.00	86.72	51	82.66	417.99	0.00	82.66
22	86.92	1955.45	0.00	86.91	52	82.66	417.27	0.00	82.66
23	87.10	2022.54	0.00	87.10	53	82.65	416.74	0.00	82.65
24	87.28	2088.07	0.00	87.28	54	82.65	416.35	0.00	82.65
25	87.46	2152.08	0.00	87.46	55	82.65	416.07	0.00	82.65
26	87.63	2214.61	0.00	87.63	56	82.65	415.87	0.00	82.65
27	87.80	2275.68	0.00	87.80	57	82.65	415.72	0.00	82.65
28	87.97	2335.34	0.00	87.97	58	82.65	415.61	0.00	82.65
29	88.13	2393.61	0.00	88.13	59	82.65	415.53	0.00	82.65
30	88.29	2450.52	0.00	88.29	60	82.65	415.47	0.00	82.65

Cycle 2 1651860

Time (Minutes)	New Temp (F)	Heat Transferred BTU	Temp Reduction (F)	Final Temp (F)	Time (Minutes)	New Temp (F)	Heat Transferred BTU	Temp Reduction (F)	Final Temp (F)
0	82.65	0.00	0.00	82.65	30	88.85	0.00	0.00	88.85
1	82.94	518.32	0.00	82.94	31	87.17	2048.93	0.00	87.17
2	83.21	618.79	0.00	83.21	32	85.95	1606.42	0.00	85.95
3	83.49	716.92	0.00	83.49	33	85.06	1283.78	0.00	85.05
4	83.75	812.77	0.00	83.75	34	84.40	1048.53	0.00	84.40
5	84.01	906.40	0.00	84.01	35	83.93	877.01	0.00	83.93
6	84.26	997.85	0.00	84.26	36	83.58	751.95	0.00	83.58
7	84.51	1087.18	0.00	84.51	37	83.33	660.76	0.00	83.33
8	84.75	1174.43	0.00	84.75	38	83.15	594.28	0.00	83.15
9	84.99	1259.66	0.00	84.99	39	83.01	545.80	0.00	83.01
10	85.22	1342.91	0.00	85.22	40	82.91	510.45	0.00	82.91
11	85.44	1424.22	0.00	85.44	41	82.84	484.68	0.00	82.84
12	85.66	1503.65	0.00	85.66	42	82.79	465.89	0.00	82.79
13	85.88	1581.23	0.00	85.88	43	82.75	452.19	0.00	82.75
14	86.09	1657.01	0.00	86.09	44	82.72	442.20	0.00	82.72
15	86.29	1731.03	0.00	86.29	45	82.70	434.92	0.00	82.70
16	86.49	1803.33	0.00	86.49	46	82.69	429.61	0.00	82.69
17	86.69	1873.96	0.00	86.69	47	82.68	425.74	0.00	82.68
18	86.88	1942.94	0.00	86.88	48	82.67	422.92	0.00	82.67
19	87.07	2010.32	0.00	87.07	49	82.67	420.86	0.00	82.67
20	87.25	2076.14	0.00	87.25	50	82.66	419.36	0.00	82.66
21	87.43	2140.43	0.00	87.43	51	82.66	418.26	0.00	82.66
22	87.60	2203.22	0.00	87.60	52	82.66	417.46	0.00	82.66
23	87.77	2264.56	0.00	87.77	53	82.65	416.88	0.00	82.65
24	87.94	2324.47	0.00	87.94	54	82.65	416.46	0.00	82.65
25	88.10	2382.99	0.00	88.10	55	82.65	416.15	0.00	82.65
26	88.26	2440.16	0.00	88.26	56	82.65	415.92	0.00	82.65
27	88.41	2495.99	0.00	88.41	57	82.65	415.76	0.00	82.65
28	88.56	2550.53	0.00	88.56	58	82.65	415.64	0.00	82.65
29	88.71	2603.80	0.00	88.71	59	82.65	415.55	0.00	82.65
30	88.85	2655.84	0.00	88.85	60	82.65	415.49	0.00	82.65

Cycle 3 1651860

Time (Minutes)	New Temp (F)	Heat Transferred BTU	Temp Reduction (F)	Final Temp (F)	Time (Minutes)	New Temp (F)	Heat Transferred BTU	Temp Reduction (F)	Final Temp (F)
0	82.65	0.00	0.00	82.65	30	88.85	0.00	0.00	88.85
1	82.94	518.34	0.00	82.94	31	87.17	2048.94	0.00	87.17
2	83.21	618.80	0.00	83.21	32	85.95	1606.43	0.00	85.95
3	83.49	716.93	0.00	83.49	33	85.06	1283.78	0.00	85.05
4	83.75	812.78	0.00	83.75	34	84.40	1048.53	0.00	84.40
5	84.01	906.41	0.00	84.01	35	83.93	877.01	0.00	83.93
6	84.26	997.86	0.00	84.26	36	83.58	751.95	0.00	83.58
7	84.51	1087.19	0.00	84.51	37	83.33	660.76	0.00	83.33
8	84.75	1174.44	0.00	84.75	38	83.15	594.28	0.00	83.15
9	84.99	1259.67	0.00	84.99	39	83.01	545.80	0.00	83.01
10	85.22	1342.92	0.00	85.22	40	82.91	510.46	0.00	82.91
11	85.44	1424.23	0.00	85.44	41	82.84	484.68	0.00	82.84
12	85.66	1503.66	0.00	85.66	42	82.79	465.89	0.00	82.79
13	85.88	1581.24	0.00	85.88	43	82.75	452.19	0.00	82.75
14	86.09	1657.02	0.00	86.09	44	82.72	442.20	0.00	82.72
15	86.29	1731.04	0.00	86.29	45	82.70	434.92	0.00	82.70
16	86.49	1803.35	0.00	86.49	46	82.69	429.61	0.00	82.69
17	86.69	1873.97	0.00	86.69	47	82.68	425.74	0.00	82.68
18	86.88	1942.95	0.00	86.88	48	82.67	422.92	0.00	82.67
19	87.07	2010.33	0.00	87.07	49	82.67	420.86	0.00	82.67
20	87.25	2076.15	0.00	87.25	50	82.66	419.36	0.00	82.66
21	87.43	2140.44	0.00	87.43	51	82.66	418.26	0.00	82.66
22	87.60	2203.23	0.00	87.60	52	82.66	417.46	0.00	82.66
23	87.77	2264.57	0.00	87.77	53	82.65	416.88	0.00	82.65
24	87.94	2324.48	0.00	87.94	54	82.65	416.46	0.00	82.65
25	88.10	2383.00	0.00	88.10	55	82.65	416.15	0.00	82.65
26	88.26	2440.16	0.00	88.26	56	82.65	415.92	0.00	82.65
27	88.41	2496.00	0.00	88.41	57	82.65	415.76	0.00	82.65
28	88.56	2550.54	0.00	88.56	58	82.65	415.64	0.00	82.65
29	88.71	2603.81	0.00	88.71	59	82.65	415.55	0.00	82.65
30	88.85	2655.84	0.00	88.85	60	82.65	415.49	0.00	82.65

Scenario 2

Uo (ft/s)		Specific heat of water Cp (BTU/lb/F)			
2.644		1			
		Length Affected (ft)	Dt (minutes)	Blowdown Volume (ft^3)	Volume Affected (ft^3)
Volume of affected zone 12ft X 65ft X 50ft =	39000	50	1	900	39000
15 cfs for 30 minutes =	27000				
		Depth Affected (ft)	Equil. Temperature (F)	Heat Transfer Coeff BTU/ft^2/day/F	Blowdown Temp (F)
		12	81.5	160	95
		Actual Depth (ft)	Volume Through Unit (ft^3)	Total Flow Width (ft)	Flow area ratio
		12	28980	150	0.33

Cycle I

Time (Minutes)	New Temp (F)	Heat Transferred BTU	Temp Reduction (F)	Final Temp (F)	Time (Minutes)	New Temp (F)	Heat Transferred BTU	Temp Reduction (F)	Final Temp (F)
0	81.50	0.00	0.00	81.50	30	88.29	0.00	0.00	88.29
1	81.81	112.50	0.00	81.81	31	87.60	2202.67	0.00	87.60
2	82.12	222.39	0.00	82.12	32	87.01	1991.27	0.00	87.01
3	82.41	329.72	0.00	82.41	33	86.51	1810.95	0.00	86.51
4	82.70	434.57	0.00	82.70	34	86.09	1657.15	0.00	86.09
5	82.99	536.98	0.00	82.99	35	85.73	1525.97	0.00	85.73
6	83.26	637.01	0.00	83.26	36	85.42	1414.08	0.00	85.42
7	83.53	734.71	0.00	83.53	37	85.15	1318.64	0.00	85.15
8	83.80	830.15	0.00	83.80	38	84.93	1237.23	0.00	84.93
9	84.06	923.37	0.00	84.06	39	84.73	1167.80	0.00	84.73
10	84.31	1014.43	0.00	84.31	40	84.57	1108.57	0.00	84.57
11	84.56	1103.37	0.00	84.56	41	84.43	1058.06	0.00	84.43
12	84.80	1190.25	0.00	84.80	42	84.31	1014.97	0.00	84.31
13	85.03	1275.11	0.00	85.03	43	84.21	978.22	0.00	84.21
14	85.26	1358.00	0.00	85.26	44	84.12	946.87	0.00	84.12
15	85.48	1438.97	0.00	85.48	45	84.05	920.14	0.00	84.05
16	85.70	1518.05	0.00	85.70	46	83.98	897.33	0.00	83.98
17	85.92	1595.30	0.00	85.92	47	83.93	877.88	0.00	83.93
18	86.13	1670.75	0.00	86.13	48	83.89	861.29	0.00	83.88
19	86.33	1744.45	0.00	86.33	49	83.85	847.13	0.00	83.85
20	86.53	1816.45	0.00	86.53	50	83.81	835.06	0.00	83.81
21	86.72	1886.76	0.00	86.72	51	83.78	824.77	0.00	83.78
22	86.92	1955.45	0.00	86.91	52	83.76	815.99	0.00	83.76
23	87.10	2022.54	0.00	87.10	53	83.74	808.50	0.00	83.74
24	87.28	2088.07	0.00	87.28	54	83.72	802.11	0.00	83.72
25	87.46	2152.08	0.00	87.46	55	83.71	796.66	0.00	83.71
26	87.63	2214.61	0.00	87.63	56	83.69	792.01	0.00	83.69
27	87.80	2275.68	0.00	87.80	57	83.68	788.04	0.00	83.68
28	87.97	2335.34	0.00	87.97	58	83.67	784.66	0.00	83.67
29	88.13	2393.61	0.00	88.13	59	83.66	781.78	0.00	83.66
30	88.29	2450.52	0.00	88.29	60	83.66	779.32	0.00	83.66

Cycle 2

1651860

Time (Minutes)	New Temp (F)	Heat Transferred BTU	Temp Reduction (F)	Final Temp (F)	Time (Minutes)	New Temp (F)	Heat Transferred BTU	Temp Reduction (F)	Final Temp (F)
0	83.66	0.00	0.00	83.66	30	89.35	0.00	0.00	89.35
1	83.92	873.72	0.00	83.92	31	88.51	2531.16	0.00	88.51
2	84.17	965.93	0.00	84.17	32	87.79	2271.45	0.00	87.79
3	84.42	1056.00	0.00	84.42	33	87.18	2049.94	0.00	87.18
4	84.67	1143.98	0.00	84.67	34	86.65	1860.99	0.00	86.65
5	84.91	1229.91	0.00	84.91	35	86.21	1699.84	0.00	86.21
6	85.14	1313.85	0.00	85.14	36	85.83	1562.37	0.00	85.83
7	85.37	1395.84	0.00	85.36	37	85.50	1445.13	0.00	85.50
8	85.59	1475.93	0.00	85.59	38	85.22	1345.12	0.00	85.22
9	85.80	1554.15	0.00	85.80	39	84.99	1259.82	0.00	84.99
10	86.02	1630.56	0.00	86.01	40	84.79	1187.07	0.00	84.79
11	86.22	1705.20	0.00	86.22	41	84.62	1125.01	0.00	84.61
12	86.42	1778.10	0.00	86.42	42	84.47	1072.08	0.00	84.47
13	86.62	1849.31	0.00	86.62	43	84.34	1026.93	0.00	84.34
14	86.81	1918.87	0.00	86.81	44	84.24	988.42	0.00	84.24
15	87.00	1986.81	0.00	87.00	45	84.15	955.57	0.00	84.15
16	87.19	2053.17	0.00	87.18	46	84.07	927.56	0.00	84.07
17	87.37	2117.99	0.00	87.36	47	84.00	903.66	0.00	84.00
18	87.54	2181.31	0.00	87.54	48	83.95	883.28	0.00	83.95
19	87.71	2243.15	0.00	87.71	49	83.90	865.89	0.00	83.90
20	87.88	2303.56	0.00	87.88	50	83.86	851.06	0.00	83.86
21	88.04	2362.57	0.00	88.04	51	83.82	838.41	0.00	83.82
22	88.20	2420.21	0.00	88.20	52	83.79	827.62	0.00	83.79
23	88.36	2476.50	0.00	88.36	53	83.77	818.42	0.00	83.77
24	88.51	2531.49	0.00	88.51	54	83.74	810.57	0.00	83.74
25	88.66	2585.21	0.00	88.66	55	83.73	803.88	0.00	83.73
26	88.80	2637.68	0.00	88.80	56	83.71	798.17	0.00	83.71
27	88.95	2688.92	0.00	88.95	57	83.70	793.30	0.00	83.70
28	89.08	2738.98	0.00	89.08	58	83.69	789.14	0.00	83.68
29	89.22	2787.88	0.00	89.22	59	83.68	785.60	0.00	83.68
30	89.35	2835.64	0.00	89.35	60	83.67	782.58	0.00	83.67

Cycle 3

1651860

Time (Minutes)	New Temp (F)	Heat Transferred BTU	Temp Reduction (F)	Final Temp (F)	Time (Minutes)	New Temp (F)	Heat Transferred BTU	Temp Reduction (F)	Final Temp (F)
0	83.67	0.00	0.00	83.67	30	89.36	0.00	0.00	89.36
1	83.93	876.91	0.00	83.93	31	88.51	2532.53	0.00	88.51
2	84.18	969.04	0.00	84.18	32	87.79	2272.62	0.00	87.79
3	84.43	1059.04	0.00	84.43	33	87.18	2050.94	0.00	87.18
4	84.68	1146.95	0.00	84.68	34	86.66	1861.85	0.00	86.66
5	84.91	1232.81	0.00	84.91	35	86.21	1700.56	0.00	86.21
6	85.15	1316.68	0.00	85.15	36	85.83	1563.00	0.00	85.83
7	85.37	1398.61	0.00	85.37	37	85.50	1445.66	0.00	85.50
8	85.59	1478.63	0.00	85.59	38	85.23	1345.57	0.00	85.23
9	85.81	1556.79	0.00	85.81	39	84.99	1260.21	0.00	84.99
10	86.02	1633.14	0.00	86.02	40	84.79	1187.39	0.00	84.79
11	86.23	1707.72	0.00	86.23	41	84.62	1125.29	0.00	84.62
12	86.43	1780.56	0.00	86.43	42	84.47	1072.32	0.00	84.47
13	86.63	1851.71	0.00	86.63	43	84.34	1027.13	0.00	84.34
14	86.82	1921.21	0.00	86.82	44	84.24	988.59	0.00	84.24
15	87.01	1989.10	0.00	87.01	45	84.15	955.72	0.00	84.15
16	87.19	2055.41	0.00	87.19	46	84.07	927.68	0.00	84.07
17	87.37	2120.18	0.00	87.37	47	84.00	903.77	0.00	84.00
18	87.55	2183.44	0.00	87.55	48	83.95	883.37	0.00	83.95
19	87.72	2245.24	0.00	87.72	49	83.90	865.97	0.00	83.90
20	87.88	2305.60	0.00	87.88	50	83.86	851.13	0.00	83.86
21	88.05	2364.56	0.00	88.05	51	83.82	838.47	0.00	83.82
22	88.21	2422.15	0.00	88.21	52	83.79	827.67	0.00	83.79
23	88.36	2478.40	0.00	88.36	53	83.77	818.46	0.00	83.77
24	88.52	2533.35	0.00	88.51	54	83.74	810.61	0.00	83.74
25	88.66	2587.02	0.00	88.66	55	83.73	803.91	0.00	83.73
26	88.81	2639.45	0.00	88.81	56	83.71	798.20	0.00	83.71
27	88.95	2690.65	0.00	88.95	57	83.70	793.32	0.00	83.70
28	89.09	2740.67	0.00	89.09	58	83.69	789.16	0.00	83.69
29	89.22	2789.53	0.00	89.22	59	83.68	785.62	0.00	83.68
30	89.36	2837.25	0.00	89.36	60	83.67	782.59	0.00	83.67

Scenario 3

Specific heat of water Cp (BTU/lb/F): 1

Uo (ft/s): 2.644

Volume of affected zone 12ft X 65ft X 50ft = 39000

15 cfs for 30 minutes = 27000

Length Affected (ft)	Dt (minutes)	Blowdown Volume (ft^3)	Volume Affected (ft^3)
50	1	900	19500
Depth Affected (ft)	**Equil. Temperature (F)**	**Heat Transfer Coeff BTU/ft^2/day/F**	**Blowdown Temp (F)**
6	81.5	160	95
Actual Depth (ft)	**Volume Through Unit (ft^3)**	**Total Flow Width (ft)**	**Flow area ratio**
12	28980	150	0.17

Cycle I

Time (Minutes)	New Temp (F)	Heat Transferred BTU	Temp Reduction (F)	Final Temp (F)
0	81.50	0.00	0.00	81.50
1	82.12	225.00	0.00	82.12
2	82.72	439.55	0.00	82.72
3	83.28	644.14	0.00	83.28
4	83.82	839.23	0.00	83.82
5	84.34	1025.26	0.00	84.34
6	84.83	1202.65	0.00	84.83
7	85.30	1371.80	0.00	85.30
8	85.75	1533.10	0.00	85.74
9	86.17	1686.91	0.00	86.17
10	86.58	1833.57	0.00	86.58
11	86.96	1973.43	0.00	86.96
12	87.33	2106.79	0.00	87.33
13	87.69	2233.95	0.00	87.68
14	88.02	2355.22	0.00	88.02
15	88.34	2470.85	0.00	88.34
16	88.65	2581.11	0.00	88.65
17	88.94	2686.25	0.00	88.94
18	89.22	2786.51	0.00	89.21
19	89.48	2882.11	0.00	89.48
20	89.73	2973.27	0.00	89.73
21	89.97	3060.21	0.00	89.97
22	90.20	3143.10	0.00	90.20
23	90.42	3222.14	0.00	90.42
24	90.63	3297.52	0.00	90.63
25	90.83	3369.39	0.00	90.83
26	91.02	3437.93	0.00	91.02
27	91.20	3503.28	0.00	91.20
28	91.37	3565.60	0.00	91.37
29	91.54	3625.02	0.00	91.54
30	91.70	3681.69	0.00	91.69

Time (Minutes)	New Temp (F)	Heat Transferred BTU	Temp Reduction (F)	Final Temp (F)
30	91.69	0.00	0.00	91.69
31	89.32	2824.07	0.00	89.32
32	87.64	2218.63	0.00	87.64
33	86.46	1791.23	0.00	86.46
34	85.62	1489.51	0.00	85.62
35	85.03	1276.51	0.00	85.03
36	84.62	1126.15	0.00	84.62
37	84.32	1020.00	0.00	84.32
38	84.12	945.06	0.00	84.12
39	83.97	892.16	0.00	83.97
40	83.87	854.82	0.00	83.87
41	83.79	828.45	0.00	83.79
42	83.74	809.84	0.00	83.74
43	83.71	796.70	0.00	83.71
44	83.68	787.43	0.00	83.68
45	83.66	780.88	0.00	83.66
46	83.65	776.26	0.00	83.65
47	83.64	772.99	0.00	83.64
48	83.63	770.69	0.00	83.63
49	83.63	769.07	0.00	83.63
50	83.63	767.92	0.00	83.63
51	83.62	767.11	0.00	83.62
52	83.62	766.53	0.00	83.62
53	83.62	766.13	0.00	83.62
54	83.62	765.85	0.00	83.62
55	83.62	765.64	0.00	83.62
56	83.62	765.50	0.00	83.62
57	83.62	765.40	0.00	83.62
58	83.62	765.33	0.00	83.62
59	83.62	765.28	0.00	83.62
60	83.62	765.25	0.00	83.62

Cycle 2

Time (Minutes)	New Temp (F)	Heat Transferred BTU	Temp Reduction (F)	Final Temp (F)
0	83.62	0.00	0.00	83.62
1	84.14	954.71	0.00	84.14
2	84.64	1135.38	0.00	84.64
3	85.12	1307.65	0.00	85.12
4	85.58	1471.93	0.00	85.57
5	86.01	1628.58	0.00	86.01
6	86.42	1777.95	0.00	86.42
7	86.82	1920.39	0.00	86.82
8	87.19	2056.21	0.00	87.19
9	87.55	2185.73	0.00	87.55
10	87.89	2309.23	0.00	87.89
11	88.22	2427.00	0.00	88.22
12	88.53	2539.29	0.00	88.53
13	88.83	2646.38	0.00	88.83
14	89.11	2748.49	0.00	89.11
15	89.38	2845.86	0.00	89.38
16	89.64	2938.70	0.00	89.64
17	89.88	3027.24	0.00	89.88
18	90.12	3111.66	0.00	90.11
19	90.34	3192.17	0.00	90.34
20	90.55	3268.93	0.00	90.55
21	90.76	3342.13	0.00	90.75
22	90.95	3411.94	0.00	90.95
23	91.13	3478.50	0.00	91.13
24	91.31	3541.96	0.00	91.31
25	91.48	3602.49	0.00	91.47
26	91.64	3660.20	0.00	91.63
27	91.79	3715.23	0.00	91.79
28	91.93	3767.71	0.00	91.93
29	92.07	3817.75	0.00	92.07
30	92.20	3865.46	0.00	92.20

1651860

Time (Minutes)	New Temp (F)	Heat Transferred BTU	Temp Reduction (F)	Final Temp (F)
30	92.20	0.00	0.00	92.20
31	89.68	2953.80	0.00	89.68
32	87.90	2310.22	0.00	87.90
33	86.64	1855.89	0.00	86.64
34	85.75	1535.15	0.00	85.75
35	85.12	1308.73	0.00	85.12
36	84.68	1148.89	0.00	84.68
37	84.37	1036.05	0.00	84.37
38	84.15	956.40	0.00	84.15
39	83.99	900.16	0.00	83.99
40	83.88	860.46	0.00	83.88
41	83.81	832.44	0.00	83.80
42	83.75	812.66	0.00	83.75
43	83.71	798.69	0.00	83.71
44	83.68	788.83	0.00	83.68
45	83.67	781.87	0.00	83.66
46	83.65	776.96	0.00	83.65
47	83.64	773.49	0.00	83.64
48	83.64	771.04	0.00	83.63
49	83.63	769.31	0.00	83.63
50	83.63	768.09	0.00	83.63
51	83.62	767.23	0.00	83.62
52	83.62	766.62	0.00	83.62
53	83.62	766.19	0.00	83.62
54	83.62	765.89	0.00	83.62
55	83.62	765.67	0.00	83.62
56	83.62	765.52	0.00	83.62
57	83.62	765.42	0.00	83.62
58	83.62	765.34	0.00	83.62
59	83.62	765.29	0.00	83.62
60	83.62	765.25	0.00	83.62

Cycle 3

Time (Minutes)	New Temp (F)	Heat Transferred BTU	Temp Reduction (F)	Final Temp (F)
0	83.62	0.00	0.00	83.62
1	84.14	954.72	0.00	84.14
2	84.64	1135.38	0.00	84.64
3	85.12	1307.66	0.00	85.12
4	85.58	1471.93	0.00	85.57
5	86.01	1628.58	0.00	86.01
6	86.42	1777.96	0.00	86.42
7	86.82	1920.39	0.00	86.82
8	87.19	2056.22	0.00	87.19
9	87.55	2185.73	0.00	87.55
10	87.89	2309.23	0.00	87.89
11	88.22	2427.00	0.00	88.22
12	88.53	2539.30	0.00	88.53
13	88.83	2646.38	0.00	88.83
14	89.11	2748.49	0.00	89.11
15	89.38	2845.86	0.00	89.38
16	89.64	2938.71	0.00	89.64
17	89.88	3027.24	0.00	89.88
18	90.12	3111.67	0.00	90.11
19	90.34	3192.17	0.00	90.34
20	90.55	3268.93	0.00	90.55
21	90.76	3342.14	0.00	90.75
22	90.95	3411.94	0.00	90.95
23	91.13	3478.50	0.00	91.13
24	91.31	3541.97	0.00	91.31
25	91.48	3602.49	0.00	91.47
26	91.64	3660.20	0.00	91.63
27	91.79	3715.23	0.00	91.79
28	91.93	3767.71	0.00	91.93
29	92.07	3817.75	0.00	92.07
30	92.20	3865.46	0.00	92.20

1651860

Time (Minutes)	New Temp (F)	Heat Transferred BTU	Temp Reduction (F)	Final Temp (F)
30	92.20	0.00	0.00	92.20
31	89.68	2953.80	0.00	89.68
32	87.90	2310.22	0.00	87.90
33	86.64	1855.89	0.00	86.64
34	85.75	1535.15	0.00	85.75
35	85.12	1308.73	0.00	85.12
36	84.68	1148.89	0.00	84.68
37	84.37	1036.05	0.00	84.37
38	84.15	956.40	0.00	84.15
39	83.99	900.16	0.00	83.99
40	83.88	860.46	0.00	83.88
41	83.81	832.44	0.00	83.80
42	83.75	812.66	0.00	83.75
43	83.71	798.69	0.00	83.71
44	83.68	788.83	0.00	83.68
45	83.67	781.87	0.00	83.66
46	83.65	776.96	0.00	83.65
47	83.64	773.49	0.00	83.64
48	83.64	771.04	0.00	83.63
49	83.63	769.31	0.00	83.63
50	83.63	768.09	0.00	83.63
51	83.62	767.23	0.00	83.62
52	83.62	766.62	0.00	83.62
53	83.62	766.19	0.00	83.62
54	83.62	765.89	0.00	83.62
55	83.62	765.67	0.00	83.62
56	83.62	765.52	0.00	83.62
57	83.62	765.42	0.00	83.62
58	83.62	765.34	0.00	83.62
59	83.62	765.29	0.00	83.62
60	83.62	765.25	0.00	83.62

Scenario 4

Uo (ft/s)		Specific heat of water Cp (BTU/lb/F)			
2.644		1			
		Length Affected (ft)	Dt (minutes)	Blowdown Volume (ft^3)	Volume Affected (ft^3)
Volume of affected zone 12ft X 65ft X 50ft =	39000	50	1	900	19500
15 cfs for 30 minutes =	27000				
		Depth Affected (ft)	Equil. Temperature (F)	Heat Transfer Coeff BTU/ft^2/day/F	Blowdown Temp (F)
		6	81.5	160	95
		Actual Depth (ft)	Volume Through Unit (ft^3)	Total Flow Width (ft)	Flow area ratio
		12	28980	150	0.17

Cycle I

Time (Minutes)	New Temp (F)	Heat Transferred BTU	Temp Reduction (F)	Final Temp (F)	Time (Minutes)	New Temp (F)	Heat Transferred BTU	Temp Reduction (F)	Final Temp (F)
0	81.50	0.00	0.00	81.50	30	91.69	0.00	0.00	91.69
1	82.12	225.00	0.00	82.12	31	90.58	3279.89	0.00	90.58
2	82.72	439.55	0.00	82.72	32	89.66	2946.50	0.00	89.66
3	83.28	644.14	0.00	83.28	33	88.89	2669.87	0.00	88.89
4	83.82	839.23	0.00	83.82	34	88.26	2440.34	0.00	88.26
5	84.34	1025.26	0.00	84.34	35	87.73	2249.88	0.00	87.73
6	84.83	1202.65	0.00	84.83	36	87.29	2091.84	0.00	87.29
7	85.30	1371.80	0.00	85.30	37	86.93	1960.72	0.00	86.93
8	85.75	1533.10	0.00	85.74	38	86.63	1851.91	0.00	86.63
9	86.17	1686.91	0.00	86.17	39	86.38	1761.63	0.00	86.38
10	86.58	1833.57	0.00	86.58	40	86.17	1686.72	0.00	86.17
11	86.96	1973.43	0.00	86.96	41	86.00	1624.56	0.00	86.00
12	87.33	2106.79	0.00	87.33	42	85.86	1572.99	0.00	85.85
13	87.69	2233.95	0.00	87.68	43	85.74	1530.19	0.00	85.74
14	88.02	2355.22	0.00	88.02	44	85.64	1494.68	0.00	85.64
15	88.34	2470.85	0.00	88.34	45	85.56	1465.22	0.00	85.56
16	88.65	2581.11	0.00	88.65	46	85.49	1440.77	0.00	85.49
17	88.94	2686.25	0.00	88.94	47	85.43	1420.48	0.00	85.43
18	89.22	2786.51	0.00	89.21	48	85.39	1403.65	0.00	85.39
19	89.48	2882.11	0.00	89.48	49	85.35	1389.69	0.00	85.35
20	89.73	2973.27	0.00	89.73	50	85.32	1378.10	0.00	85.32
21	89.97	3060.21	0.00	89.97	51	85.29	1368.48	0.00	85.29
22	90.20	3143.10	0.00	90.20	52	85.27	1360.50	0.00	85.27
23	90.42	3222.14	0.00	90.42	53	85.25	1353.88	0.00	85.25
24	90.63	3297.52	0.00	90.63	54	85.23	1348.39	0.00	85.23
25	90.83	3369.39	0.00	90.83	55	85.22	1343.83	0.00	85.22
26	91.02	3437.93	0.00	91.02	56	85.21	1340.05	0.00	85.21
27	91.20	3503.28	0.00	91.20	57	85.20	1336.91	0.00	85.20
28	91.37	3565.60	0.00	91.37	58	85.20	1334.31	0.00	85.19
29	91.54	3625.02	0.00	91.54	59	85.19	1332.15	0.00	85.19
30	91.70	3681.69	0.00	91.69	60	85.18	1330.35	0.00	85.18

Cycle 2

1651860

Time (Minutes)	New Temp (F)	Heat Transferred BTU	Temp Reduction (F)	Final Temp (F)	Time (Minutes)	New Temp (F)	Heat Transferred BTU	Temp Reduction (F)	Final Temp (F)
0	85.18	0.00	0.00	85.18	30	92.58	0.00	0.00	92.58
1	85.64	1493.57	0.00	85.63	31	91.32	3544.99	0.00	91.31
2	86.07	1649.22	0.00	86.07	32	90.27	3166.47	0.00	90.27
3	86.48	1797.63	0.00	86.48	33	89.40	2852.39	0.00	89.40
4	86.87	1939.16	0.00	86.87	34	88.68	2591.78	0.00	88.68
5	87.24	2074.11	0.00	87.24	35	88.08	2375.54	0.00	88.08
6	87.60	2202.79	0.00	87.60	36	87.58	2196.11	0.00	87.58
7	87.94	2325.50	0.00	87.94	37	87.17	2047.23	0.00	87.17
8	88.26	2442.51	0.00	88.26	38	86.83	1923.70	0.00	86.83
9	88.57	2554.09	0.00	88.57	39	86.54	1821.20	0.00	86.54
10	88.87	2660.49	0.00	88.87	40	86.31	1736.14	0.00	86.31
11	89.15	2761.94	0.00	89.15	41	86.11	1665.57	0.00	86.11
12	89.42	2858.69	0.00	89.41	42	85.95	1607.01	0.00	85.95
13	89.67	2950.94	0.00	89.67	43	85.82	1558.43	0.00	85.81
14	89.92	3038.90	0.00	89.91	44	85.70	1518.11	0.00	85.70
15	90.15	3122.79	0.00	90.15	45	85.61	1484.66	0.00	85.61
16	90.37	3202.77	0.00	90.37	46	85.53	1456.90	0.00	85.53
17	90.58	3279.05	0.00	90.58	47	85.47	1433.87	0.00	85.47
18	90.78	3351.78	0.00	90.78	48	85.42	1414.76	0.00	85.42
19	90.97	3421.13	0.00	90.97	49	85.37	1398.90	0.00	85.37
20	91.16	3487.27	0.00	91.15	50	85.34	1385.74	0.00	85.34
21	91.33	3550.33	0.00	91.33	51	85.31	1374.82	0.00	85.31
22	91.50	3610.46	0.00	91.50	52	85.28	1365.77	0.00	85.28
23	91.66	3667.80	0.00	91.65	53	85.26	1358.25	0.00	85.26
24	91.81	3722.48	0.00	91.81	54	85.24	1352.01	0.00	85.24
25	91.95	3774.62	0.00	91.95	55	85.23	1346.84	0.00	85.23
26	92.09	3824.34	0.00	92.09	56	85.22	1342.54	0.00	85.22
27	92.22	3871.75	0.00	92.22	57	85.21	1338.98	0.00	85.21
28	92.35	3916.96	0.00	92.34	58	85.20	1336.02	0.00	85.20
29	92.47	3960.06	0.00	92.46	59	85.19	1333.57	0.00	85.19
30	92.58	4001.17	0.00	92.58	60	85.19	1331.54	0.00	85.19

Cycle 3

1651860

Time (Minutes)	New Temp (F)	Heat Transferred BTU	Temp Reduction (F)	Final Temp (F)	Time (Minutes)	New Temp (F)	Heat Transferred BTU	Temp Reduction (F)	Final Temp (F)
0	85.19	0.00	0.00	85.19	30	92.58	0.00	0.00	92.58
1	85.64	1494.70	0.00	85.64	31	91.32	3545.22	0.00	91.31
2	86.07	1650.29	0.00	86.07	32	90.27	3166.66	0.00	90.27
3	86.48	1798.66	0.00	86.48	33	89.40	2852.55	0.00	89.40
4	86.87	1940.13	0.00	86.87	34	88.68	2591.91	0.00	88.68
5	87.25	2075.04	0.00	87.24	35	88.08	2375.65	0.00	88.08
6	87.60	2203.68	0.00	87.60	36	87.58	2196.20	0.00	87.58
7	87.94	2326.35	0.00	87.94	37	87.17	2047.31	0.00	87.17
8	88.27	2443.32	0.00	88.26	38	86.83	1923.76	0.00	86.83
9	88.58	2554.86	0.00	88.57	39	86.54	1821.25	0.00	86.54
10	88.87	2661.22	0.00	88.87	40	86.31	1736.19	0.00	86.31
11	89.15	2762.64	0.00	89.15	41	86.11	1665.61	0.00	86.11
12	89.42	2859.35	0.00	89.42	42	85.95	1607.04	0.00	85.95
13	89.67	2951.57	0.00	89.67	43	85.82	1558.45	0.00	85.81
14	89.92	3039.51	0.00	89.91	44	85.70	1518.13	0.00	85.70
15	90.15	3123.37	0.00	90.15	45	85.61	1484.67	0.00	85.61
16	90.37	3203.33	0.00	90.37	46	85.53	1456.91	0.00	85.53
17	90.58	3279.57	0.00	90.58	47	85.47	1433.88	0.00	85.47
18	90.78	3352.28	0.00	90.78	48	85.42	1414.77	0.00	85.42
19	90.98	3421.61	0.00	90.97	49	85.37	1398.91	0.00	85.37
20	91.16	3487.72	0.00	91.16	50	85.34	1385.75	0.00	85.34
21	91.33	3550.76	0.00	91.33	51	85.31	1374.83	0.00	85.31
22	91.50	3610.88	0.00	91.50	52	85.28	1365.77	0.00	85.28
23	91.66	3668.20	0.00	91.66	53	85.26	1358.25	0.00	85.26
24	91.81	3722.86	0.00	91.81	54	85.24	1352.02	0.00	85.24
25	91.95	3774.98	0.00	91.95	55	85.23	1346.84	0.00	85.23
26	92.09	3824.68	0.00	92.09	56	85.22	1342.55	0.00	85.22
27	92.22	3872.08	0.00	92.22	57	85.21	1338.98	0.00	85.21
28	92.35	3917.27	0.00	92.34	58	85.20	1336.03	0.00	85.20
29	92.47	3960.38	0.00	92.46	59	85.19	1333.57	0.00	85.19
30	92.58	4001.46	0.00	92.58	60	85.19	1331.54	0.00	85.19

Surface Spreading

Uo (ft/s)		Specific heat of water Cp (BTU/lb/F)			Heat Transfer Coeff BTU/ft^2/day/F
2.644		1			160
			Length Affected (ft)	Blowout Temp (F)	Equil Temp (F)
Volume of affected zone 12ft X 65ft X 50ft =		39000	50	95	81.5
15 cfs for 30 minutes =		27000			
Spread Area (ft^2)	Blow out Volume in 60 Minutes (ft^3)		Depth of Spread (ft)		Percentage Removed
220764	54000		0.24		0.1
			Extra Mixing Depth (ft)		DT (Min)
Downstream Conditions			0.37		1

Assuming 30 cfs at 95 F is discharged as outflow

Cycle 1

Discharge Temp (F)	Assuming Depth (ft)	Spread Area (ft^2)	Heat Removed (BTU)	Temp Reduction (F)	Final Temp (F)
83.18	3	289800	1620000	0.03	83.15

Cycle I

Volume discharged from unit in 30 Minutes (ft^3)
869400

Time (Minutes)	Initial Temp (F)	Heat Removed (BTE)	Temp Reduction (F)	New Temp (F)	Outflow Voluem (ft^3)	Final Temp (F)
0	86.90	0.00	0.00	86.90	0.00	86.90
1	86.90	132458.40	0.02	86.88	28980.00	86.88
2	86.88	132072.70	0.02	86.87	28980.00	86.87
3	86.87	131688.13	0.02	86.85	28980.00	86.85
4	86.85	131304.67	0.02	86.84	28980.00	86.84
5	86.84	130922.34	0.02	86.82	28980.00	86.82
6	86.82	130541.11	0.02	86.81	28980.00	86.81
7	86.81	130161.00	0.02	86.79	28980.00	86.79
8	86.79	129781.99	0.02	86.78	28980.00	86.78
9	86.78	129404.08	0.02	86.76	28980.00	86.76
10	86.76	129027.28	0.02	86.74	28980.00	86.74
11	86.74	128651.57	0.02	86.73	28980.00	86.73
12	86.73	128276.96	0.02	86.71	28980.00	86.71
13	86.71	127903.44	0.02	86.70	28980.00	86.70
14	86.70	127531.00	0.02	86.68	28980.00	86.68
15	86.68	127159.65	0.02	86.67	28980.00	86.67
16	86.67	126789.39	0.02	86.65	28980.00	86.65
17	86.65	126420.20	0.02	86.64	28980.00	86.64
18	86.64	126052.08	0.01	86.62	28980.00	86.62
19	86.62	125685.04	0.01	86.61	28980.00	86.61
20	86.61	125319.06	0.01	86.59	28980.00	86.59
21	86.59	124954.15	0.01	86.58	28980.00	86.58
22	86.58	124590.31	0.01	86.56	28980.00	86.56
23	86.56	124227.52	0.01	86.55	28980.00	86.55
24	86.55	123865.79	0.01	86.53	28980.00	86.53
25	86.53	123505.11	0.01	86.52	28980.00	86.52
26	86.52	123145.49	0.01	86.51	28980.00	86.51
27	86.51	122786.91	0.01	86.49	28980.00	86.49
28	86.49	122429.37	0.01	86.48	28980.00	86.48
29	86.48	122072.87	0.01	86.46	28980.00	86.46
30	86.46	121717.42	0.01	86.45	28980.00	86.45
31	86.45	121363.00	0.01	86.43	28980.00	86.33
32	86.43	121009.61	0.01	86.42	28980.00	86.31
33	86.42	120657.25	0.01	86.40	28980.00	86.30
34	86.40	120305.91	0.01	86.39	28980.00	86.29
35	86.39	119955.60	0.01	86.38	28980.00	86.27
36	86.38	119606.31	0.01	86.36	28980.00	86.26
37	86.36	119258.04	0.01	86.35	28980.00	86.24
38	86.35	118910.77	0.01	86.33	28980.00	86.23
39	86.33	118564.53	0.01	86.32	28980.00	86.22
40	86.32	118219.28	0.01	86.31	28980.00	86.20
41	86.31	117875.05	0.01	86.29	28980.00	86.19
42	86.29	117531.82	0.01	86.28	28980.00	86.17
43	86.28	117189.58	0.01	86.26	28980.00	86.16
44	86.26	116848.35	0.01	86.25	28980.00	86.15
45	86.25	116508.10	0.01	86.24	28980.00	86.13
46	86.24	116168.85	0.01	86.22	28980.00	86.12
47	86.22	115830.58	0.01	86.21	28980.00	86.11
48	86.21	115493.30	0.01	86.19	28980.00	86.09
49	86.19	115157.01	0.01	86.18	28980.00	86.08
50	86.18	114821.69	0.01	86.17	28980.00	86.07
51	86.17	114487.34	0.01	86.15	28980.00	86.05
52	86.15	114153.98	0.01	86.14	28980.00	86.04
53	86.14	113821.58	0.01	86.13	28980.00	86.03
54	86.13	113490.15	0.01	86.11	28980.00	86.01
55	86.11	113159.68	0.01	86.10	28980.00	86.00
56	86.10	112830.18	0.01	86.09	28980.00	85.99
57	86.09	112501.64	0.01	86.07	28980.00	85.97
58	86.07	112174.05	0.01	86.06	28980.00	85.96
59	86.06	111847.42	0.01	86.05	28980.00	85.95
60	86.05	111521.74	0.01	86.03	28980.00	85.94

Cycle 2

Depth Factor
2

Time (Minutes)	Initial Temp (F)	Heat Removed (BTE)	Temp Reduction (F)	New Temp (F)	Volume Outflow (ft^3)	Final Temp (F)
0	86.42	0.00	0.00	86.42	0.00	86.42
1	86.42	120634.19	0.01	86.41	28980.00	86.41
2	86.41	120458.55	0.01	86.40	28980.00	86.40
3	86.40	120283.17	0.01	86.40	28980.00	86.40
4	86.40	120108.05	0.01	86.39	28980.00	86.39
5	86.39	119933.18	0.01	86.38	28980.00	86.38
6	86.38	119758.57	0.01	86.38	28980.00	86.38
7	86.38	119584.21	0.01	86.37	28980.00	86.37
8	86.37	119410.11	0.01	86.36	28980.00	86.36
9	86.36	119236.26	0.01	86.35	28980.00	86.35
10	86.35	119062.66	0.01	86.35	28980.00	86.35
11	86.35	118889.31	0.01	86.34	28980.00	86.34
12	86.34	118716.22	0.01	86.33	28980.00	86.33
13	86.33	118543.38	0.01	86.33	28980.00	86.33
14	86.33	118370.79	0.01	86.32	28980.00	86.32
15	86.32	118198.45	0.01	86.31	28980.00	86.31
16	86.31	118026.36	0.01	86.30	28980.00	86.30
17	86.30	117854.53	0.01	86.30	28980.00	86.30
18	86.30	117682.94	0.01	86.29	28980.00	86.29
19	86.29	117511.60	0.01	86.28	28980.00	86.28
20	86.28	117340.51	0.01	86.28	28980.00	86.28
21	86.28	117169.68	0.01	86.27	28980.00	86.27
22	86.27	116999.09	0.01	86.26	28980.00	86.26
23	86.26	116828.75	0.01	86.26	28980.00	86.26
24	86.26	116658.65	0.01	86.25	28980.00	86.25
25	86.25	116488.81	0.01	86.24	28980.00	86.24
26	86.24	116319.21	0.01	86.24	28980.00	86.24
27	86.24	116149.88	0.01	86.23	28980.00	86.23
28	86.23	115980.75	0.01	86.22	28980.00	86.22
29	86.22	115811.89	0.01	86.21	28980.00	86.21
30	86.21	115643.28	0.01	86.21	28980.00	86.21
31	86.21	115474.91	0.01	86.20	28980.00	86.15
32	86.20	115306.79	0.01	86.19	28980.00	86.14
33	86.19	115138.91	0.01	86.19	28980.00	86.14
34	86.19	114971.28	0.01	86.18	28980.00	86.13
35	86.18	114803.89	0.01	86.17	28980.00	86.12
36	86.17	114636.75	0.01	86.17	28980.00	86.12
37	86.17	114469.84	0.01	86.16	28980.00	86.11
38	86.16	114303.19	0.01	86.15	28980.00	86.10
39	86.15	114136.77	0.01	86.15	28980.00	86.10
40	86.15	113970.60	0.01	86.14	28980.00	86.09
41	86.14	113804.66	0.01	86.13	28980.00	86.08
42	86.13	113638.97	0.01	86.13	28980.00	86.08
43	86.13	113473.52	0.01	86.12	28980.00	86.07
44	86.12	113308.32	0.01	86.11	28980.00	86.06
45	86.11	113143.35	0.01	86.11	28980.00	86.06
46	86.11	112978.62	0.01	86.10	28980.00	86.05
47	86.10	112814.13	0.01	86.09	28980.00	86.04
48	86.09	112649.88	0.01	86.09	28980.00	86.04
49	86.09	112485.87	0.01	86.08	28980.00	86.03
50	86.08	112322.10	0.01	86.07	28980.00	86.02
51	86.07	112158.57	0.01	86.07	28980.00	86.02
52	86.07	111995.28	0.01	86.06	28980.00	86.01
53	86.06	111832.22	0.01	86.05	28980.00	86.00
54	86.05	111669.40	0.01	86.05	28980.00	86.00
55	86.05	111506.82	0.01	86.04	28980.00	85.99
56	86.04	111344.48	0.01	86.03	28980.00	85.98
57	86.03	111182.37	0.01	86.03	28980.00	85.98
58	86.03	111020.50	0.01	86.02	28980.00	85.97
59	86.02	110858.86	0.01	86.01	28980.00	85.96
60	86.01	110697.46	0.01	86.01	28980.00	85.96

Cycle 2

Depth Factor
2

Time (Minutes)	Initial Temp (F)	Heat Removed (BTE)	Temp Reduction (F)	New Temp (F)	Volume Outflow (ft^3)	Final Temp (F)
0	86.27	0.00	0.00	86.27	0.00	86.27
1	86.27	117052.71	0.00	86.27	28980.00	86.27
2	86.27	116939.10	0.00	86.26	28980.00	86.26
3	86.26	116825.60	0.00	86.26	28980.00	86.26
4	86.26	116712.20	0.00	86.25	28980.00	86.25
5	86.25	116598.92	0.00	86.25	28980.00	86.25
6	86.25	116485.75	0.00	86.24	28980.00	86.24
7	86.24	116372.69	0.00	86.24	28980.00	86.24
8	86.24	116259.73	0.00	86.24	28980.00	86.24
9	86.24	116146.89	0.00	86.23	28980.00	86.23
10	86.23	116034.16	0.00	86.23	28980.00	86.23
11	86.23	115921.53	0.00	86.22	28980.00	86.22
12	86.22	115809.02	0.00	86.22	28980.00	86.22
13	86.22	115696.61	0.00	86.21	28980.00	86.21
14	86.21	115584.31	0.00	86.21	28980.00	86.21
15	86.21	115472.13	0.00	86.20	28980.00	86.20
16	86.20	115360.05	0.00	86.20	28980.00	86.20
17	86.20	115248.08	0.00	86.19	28980.00	86.19
18	86.19	115136.22	0.00	86.19	28980.00	86.19
19	86.19	115024.46	0.00	86.18	28980.00	86.18
20	86.18	114912.82	0.00	86.18	28980.00	86.18
21	86.18	114801.28	0.00	86.18	28980.00	86.18
22	86.18	114689.86	0.00	86.17	28980.00	86.17
23	86.17	114578.54	0.00	86.17	28980.00	86.17
24	86.17	114467.33	0.00	86.16	28980.00	86.16
25	86.16	114356.22	0.00	86.16	28980.00	86.16
26	86.16	114245.23	0.00	86.15	28980.00	86.15
27	86.15	114134.34	0.00	86.15	28980.00	86.15
28	86.15	114023.56	0.00	86.14	28980.00	86.14
29	86.14	113912.89	0.00	86.14	28980.00	86.14
30	86.14	113802.32	0.00	86.13	28980.00	86.13
31	86.13	113691.86	0.00	86.13	28980.00	86.10
32	86.13	113581.51	0.00	86.13	28980.00	86.09
33	86.13	113471.27	0.00	86.12	28980.00	86.09
34	86.12	113361.13	0.00	86.12	28980.00	86.08
35	86.12	113251.10	0.00	86.11	28980.00	86.08
36	86.11	113141.18	0.00	86.11	28980.00	86.08
37	86.11	113031.36	0.00	86.10	28980.00	86.07
38	86.10	112921.65	0.00	86.10	28980.00	86.07
39	86.10	112812.05	0.00	86.09	28980.00	86.06
40	86.09	112702.55	0.00	86.09	28980.00	86.06
41	86.09	112593.16	0.00	86.09	28980.00	86.05
42	86.09	112483.88	0.00	86.08	28980.00	86.05
43	86.08	112374.70	0.00	86.08	28980.00	86.04
44	86.08	112265.63	0.00	86.07	28980.00	86.04
45	86.07	112156.66	0.00	86.07	28980.00	86.04
46	86.07	112047.80	0.00	86.06	28980.00	86.03
47	86.06	111939.04	0.00	86.06	28980.00	86.03
48	86.06	111830.40	0.00	86.05	28980.00	86.02
49	86.05	111721.85	0.00	86.05	28980.00	86.02
50	86.05	111613.41	0.00	86.05	28980.00	86.01
51	86.05	111505.08	0.00	86.04	28980.00	86.01
52	86.04	111396.85	0.00	86.04	28980.00	86.00
53	86.04	111288.73	0.00	86.03	28980.00	86.00
54	86.03	111180.71	0.00	86.03	28980.00	86.00
55	86.03	111072.80	0.00	86.02	28980.00	85.99
56	86.02	110964.99	0.00	86.02	28980.00	85.99
57	86.02	110857.28	0.00	86.01	28980.00	85.98
58	86.01	110749.68	0.00	86.01	28980.00	85.98
59	86.01	110642.19	0.00	86.01	28980.00	85.97
60	86.01	110534.80	0.00	86.00	28980.00	85.97

Lee Nuclear Station Response to Request for Additional Information (RAI)

Attachment 63-2 to RAI 63

State of California, The Resources Agency, Department of Water Resources, *Matrix of Life History and Habitat Requirements of Feather River Fish Species*, Oroville Facilities Relicensing, FERC Project 2100, SP-F15 TASK 1, SP-F21 TASK 1, SP-F3.2 TASK 2, Appendix A (Smallmouth Bass), 2004

OROVILLE FERC RELICENSING
(PROJECT NO. 2100)

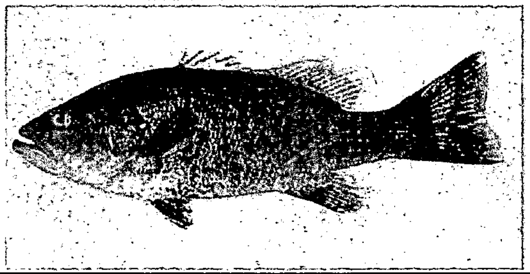
INTERIM REPORT
SP-F3.2 TASK 2
SP-F21 TASK 1

APPENDIX A
MATRIX OF LIFE HISTORY AND HABITAT REQUIREMENTS FOR FEATHER RIVER FISH SPECIES

LITERATURE REVIEW OF LIFE HISTORY AND HABITAT REQUIREMENTS FOR FEATHER RIVER FISH SPECIES

SMALLMOUTH BASS

JANUARY 2003

Element	Element Descriptor	General	Feather River specific
General			
common name (s)	English name (usually used by fishers and laypeople).	Smallmouth bass	
scientific name (s)	Latin name (referenced in scientific publications).	*Micropetus dolomieu*	
taxonomy (family)	Common name of the family to which they belong. Also indicate scientific family name.	Sunfish and bass - *Centrarchidae*	
depiction	Illustration, drawing or photograph.		
range	Broad geographic distribution, specifying California distribution, as available.	Smallmouth bass are native to the Upper Mississippi drainage south through Arkansas, and in the Great Lakes watershed. They were introduced to most of U.S. and worldwide. In California they are present in larger tributaries at elevation of 328-3,280 ft (100-1,000 m) (Moyle 2002).	
native or introduced	If introduced, indicate timing, location, and methods.	Introduced into Central California in 1874 in San Mateo County (Moyle 2002).	

Element	Element Descriptor	General	Feather River specific
ESA listing status	Following the categories according to California Code of Regulations and the Federal Register, indicate whether: SE = State-listed Endangered; ST =State-listed Threatened; FE = Federally listed Endangered; FT = Federally-listed Threatened; SCE = State Candidate (Endangered); SCT = State candidate (Threatened); FPE = Federally proposed (Endangered); FPT = Federally proposed (Threatened); FPD = Federally proposed (Delisting); the date of listing; or N = not listed.	Smallmouth bass are not listed.	
species status	If native, whether: Extinct/extirpated; Threatened or Endangered; Special concern; Watch list; Stable or increasing. If introduced, whether: Extirpated (failed introduction); highly localized; Localized; Widespread and stable; Widespread and expanding.	Smallmouth bass are widespread and stable (Moyle 2002).	
economic or recreational value	Indicate whether target species sought for food or trophy. Whether desirable by recreational fishers, commercial fishers, or both.	Smallmouth bass are a target species for recreational fishers.	
warmwater or coldwater	Warmwater if suitable temperature range is similar to basses; coldwater if suitable temperature range is similar to salmonids.	Warmwater.	
pelagic or littoral	Environment: Pelagic - living far from shore; Littoral - living near the shore.		
bottom or water column distribution	Environment: bottom (benthic) or along water column.	Water column.	
lentic or lotic	Environment: Lentic - pertaining to stagnant water, or lake-like; Lotic - moving water, or river-like.	Lentic.	

Element	Element Descriptor	General	Feather River specific
Adults			
life span	Approximate maximum age obtained.	Although a 15-year old smallmouth bass has been recorded, fish over 7 years of age are uncommon (Edwards et al. 1983).	
adult length	Indicate: Length at which they first reproduce; average length and maximum length the fish can attain.	At the end of the first year, smallmouth bass measure between 2.4-7.1 inches (6-18 cm) TL. By the end of 2nd year, they measure between 5.5-10.6 inches (14-27 cm) TL, while by the end of their 3rd year, smallmouth bass measure between 7.5-10.6 inches (19-27 cm) TL. In their 4th year, smallmouth bass measure between 9.8-16.1 inches (25-41 cm) TL. Growth in Central Valley reservoirs is excellent and so 4-year-old smallmouth bass typically measure 13.8-15.4 inches (35-39 cm) (Moyle 2002). Smallmouth bass range in size from 3.5 inches (90 mm) at age-one to 18 inches (457 mm) at age 15 (Beamesderfer et al. 1995). Age of smallmouth bass at sexual maturity varies throughout its range and is related to latitude and growth rate of local populations. Males and females mature at age-2 in the south and at age-6 in the north. In the central part of their range, males mature at age-3 to age-4, while females mature at age-4 or age-5 (Edwards et al. 1983).	
adult weight	Indicate: Weight at which they first reproduce; average weight and maximum weight the fish can attain.	The largest smallmouth bass caught in California weighed 9 pounds (4.1 kg) (Moyle 2002).	
physical morphology	General shape of the fish: elongated, fusiform, laterally compressed, etc.	Smallmouth bass are fairly streamlined for a bass, but have stocky bodies and mouths that do not reach the hind margin of the eye. Their dorsal fin is spiny and the spiny portion is slightly rounded (Moyle 2002).	
coloration	Indicate color, and color changes, if any, during reproduction phase.	Smallmouth bass are greenish-brown to bronze, with no conspicuous horizontal stripes on the sides, but often faint vertical dark, mottled bars. They have a white belly and three dark bands radiating from reddish eyes. Young-of-year are darker than adults with plain coloration, and a tricolored tail (Moyle 2002).	

Element	Element Descriptor	General	Feather River specific
other physical adult descriptors	Unique physical features for easy identification.	Smallmouth bass are fairly streamlined for bass (Moyle 2002).	
adult food base	Indicate primary diet components.	Smallmouth bass feed mainly on crayfish, but also eat fish, amphibians, and insects (Moyle 2002).	
adult feeding habits	Indicate whether plankton eater, algae eater, bottom feeder, piscivorous, active hunter, ambush predator, filter feeder. Night, day, dusk or dawn feeder.	Smallmouth bass are active hunters (Moyle 2002).	
adult in-ocean residence time	For anadromous species, age when they migrate to the ocean and duration spent in the ocean before returning to freshwater to spawn.	N/A	
adult habitat characteristics in-ocean	For anadromous species, description of the ocean habitat utilized: whether along major current systems, gyres, pelagic (beyond continental shelves) and neritic (above continental shelves) zones, etc.	N/A	
Adult upstream migration (immigration)			
range of adult upstream migration timing	Time of year adults migrate upstream. If applicable, indicate for various runs.	N/A	
peak adult upstream migration timing	Time of year most adults migrate upstream. If applicable, indicate for various runs.	N/A	
adult upstream migration water temperature tolerance	Range of water temperatures allowing survival. Indicate stressful or lethal levels.	N/A	
adult upstream migration water temperature preference	Range of suitable, preferred or reported optimal water temperatures. Indicate whether literature, observational, or experimental.	N/A	

Element	Element Descriptor	General	Feather River specific
Adult holding (freshwater residence)			
water temperature tolerance for holding adults	Range of water temperatures allowing survival. Indicate stressful or lethal levels.	Rapid growth of smallmouth bass occurs at water temperatures as high as 84.2°F (29°C). Water temperatures ranging from 80.6°F-87.8°F (27°C -31°C) are selected under lab conditions. Water temperatures greater than 95°F (35°C) are considered stressful, while water temperatures greater than 100.4°F (38°C) are lethal. Populations rarely establish where water temperatures do not exceed 66.2°F (19°C) in summer for extended periods. In California, smallmouth bass populations typically occur in areas where summer water temperatures are typically 69.8°F-71.6°F (21°C - 22°C) (Moyle 2002).	
water temperature preference for holding adults	Range of suitable, preferred or reported optimal water temperatures. Indicate whether literature, observational, or experimental.	Reported optimum water temperatures for adult growth range from 77°F-80.6°F (25°C -27°C) (Moyle 2002).	
water depth range for holding adults	Reported range of observed (minimum and maximum) water depth utilization.	Smallmouth bass tend to concentrate in areas with water depths of 3.3-32.8 ft (1-10 m) (Moyle 2002). Standing crop of bass is generally largest in pools deeper than 3.9 ft (1.2m). Reported optimum lacustrine habitat is characterized by large, clear lakes and reservoirs with an average water depth of greater than 30 ft (9m) (Edwards et al. 1983).	
water depth preference for holding adults	Reported range of most frequently observed water depth utilization.		
substrate preference for holding adults	If bottom dwellers, indicate substrate: mud, sand, gravel, boulders, aquatic plant beds, etc. If gravel, indicate range or average size of gravel.	Smallmouth bass concentrate in narrow bays or in areas along shore where rocky shelves project under water (Moyle 2002).	
water velocity range for holding adults	Reported range of observed (minimum and maximum) water velocity utilization.	In a Tennessee reservoir, seasonal mean water velocity in bass habitats ranged from 0.36-5.7 ft/sec (10.9-32.0 cm/sec) (Edwards et al. 1983).	
water velocity preference for holding adults	Reported range of most frequently observed water velocity utilization.		

Element	Element Descriptor	General	Feather River specific
other habitat characteristics for holding adults	General description of habitat (e.g. turbid or clear waters, lentic or lotic, presence of aquatic plant beds, debris, cover, etc.).	Smallmouth bass prefer large, clear lakes and clean streams and rivers with abundant cover. Smallmouth bass are most abundant in streams with moderate gradients 0.75 to 4.70 m/km. Smallmouth bass have become established in a number of reservoirs, and they are usually most abundant in the upstream end of the reservoirs (Moyle 2002).	
timing range for adult holding	Time of year (earliest-latest) and duration of stay from upstream migration to spawning.	N/A	
timing peak for adult holding	Time of year when maximum number of adults are present before spawning.	N/A	
Spawning			
fecundity	Average or range in the number of eggs females lay in a spawning season.	Fecundity ranges from 2,000-21,000 eggs/female depending on size (Moyle 2002). Fecundity is approximately 20,825 eggs/female (Wang 1986).	
nest construction	Location and general description of nest -- substrates, aquatic plants, excavations, crevices, habitat types, etc.	Males start fanning out nest depressions 11.8-23.6 inches (30-60 cm) in diameter with their fins when water temperatures reach 55.4°F-60.8°F (13°C -16°C). Nests are built on rubble, gravel, or sand bottoms at depths of about 3.3 ft (1 m) near submerged logs, boulders or other cover. Nests have been recorded on substrates at depths of 1.6-16.4 ft (0.5-5 m) (Moyle 2002).	
nest size	Size and average dimensions of the nest.	Smallmouth bass nests range from 11.8-23.6 inches (30-60 cm) in diameter (Wang 1986).	
spawning process	Indicate whether nest builder, broadcast spawner, or other.	Female releases 10-50 eggs in 4 to 45 second intervals, until all eggs have been released. When spawning is finished, the female leaves the nest or is chased away by male (Moyle 2002).	

Element	Element Descriptor	General	Feather River specific
spawning substrate size/characteristics	Range of substrates used during spawning (e.g. mud, sand, gravel, boulders, beds of aquatic plants). Indicate presence of plant/wood debris, crevices at spawning sites. If gravel, indicate range of average size.	Spawning substrates include gravel, rock, and rubble (Wang 1986).	
preferred spawning substrate	Indicate preferred spawning substrate (e.g. mud, sand, gravel, boulders, plant bed, etc).	Suitable spawning substrate includes rubble, gravel, and sand bottoms approximately 3.3 ft (1 m) in depth, near submerged logs, boulders or other cover (Moyle 2002).	
water temperature tolerance for spawning	Range of water temperatures allowing survival. Indicate stressful or lethal levels.	In Wisconsin, spawning and nest building begin at a water temperature of 59°F (15°C) and continue until water temperatures reach 68°F-71.6°F (20°C-22°C) (Baylis et al. 1993). Water temperatures for spawning range from 54.5°F-74.3°F (12.5°C -23.5°C) (Graham et al. 1986). Males begin fanning out nest depressions with their fins when water temperatures reach 55.4°F-60.8°F (13°C - 16°C).	
water temperature preference for spawning	Range of suitable, preferred or reported optimal water temperatures. Indicate whether literature, observational, or experimental derivation.		
water velocity range for spawning	Minimum and maximum speed of water current the spawning fish can tolerate.	Nesting and reproduction can be disrupted by high flows, either because embryos and fry are washed out of the nests or because lower water temperatures reduce spawning activity (Moyle 2002).	
water velocity preference for spawning	Preferred water current (flow velocity) during spawning.		
water depth range for spawning	Reported range of observed (minimum and maximum) water depth utilization.	Usually smallmouth bass males usually build nests on rubble, gravel, or sand bottoms at depths of approximately 3.3 ft (1m). However, nests have been recorded on varying substrates at depths ranging from 1.6-16.4 ft (0.5-5 m). Spawning occurs in the nest (Moyle 2002).	
water depth preference for spawning	Reported range of most frequently observed water depth utilization.		

Element	Element Descriptor	General	Feather River specific
range for spawning timing	Earliest and latest time of season or year in which spawning occurs.	In Northern California reservoirs, most spawning occurs in May and June, but in streams, spawning may extend into July depending on flow and water temperatures (Moyle 2002). Smallmouth bass spawning occurs from late April through mid-July (Graham et al. 1986). Smallmouth bass spawning occurs from mid April- early June (Lukas et al. 1995).	
peak spawning timing	Time of year most fish start to spawn.	Peak spawning occurs in late spring (Moyle 2002).	
spawning frequency (iteroparous/semelparous)	Semelparous - producing all offspring at one time, such as in most salmon. Usually these fish die after reproduction. Iteroparous - producing offspring in successive, e.g., annual or seasonal batches, as is the case in most fishes.	Smallmouth bass are iteroparous.	
Incubation/early development			
egg characteristics	Shape, size, color, in clusters or individuals, stickiness, and other physical attributes.	Smallmouth bass eggs are demersal and adhesive, spherical, and attach to rocky surfaces in the nest. The yolk is light amber or pale yellow (Wang 1986).	
water temperature tolerance for incubation	Range of water temperatures allowing survival. Indicate stressful or lethal levels.		
water temperature preference for incubation	Range of suitable, preferred or reported optimal water temperatures. Indicate whether literature, observational, or experimental derivation.		
time required for incubation	Time duration from fertilization to hatching. Note: Indicate at which temperature range. Incubation time is temperature-dependent.	Eggs hatch in 10 day at 55°F (12.8°C) and in 2.5 days at 78.1°F (25.6°C) (Wang 1986).	
size of newly hatched larvae	Average size of newly hatched larvae.	Length of larvae at hatching is 0.18 inches (4.6 mm) TL (Wang 1986).	
time newly hatched larvae remain in gravel	Time of year of hatching, and duration between hatching and emergence from gravel.	Newly hatched larvae remain in the nest for several days (Wang 1986).	

Element	Element Descriptor	General	Feather River specific
		Fry remain on the bottom of nest for 3-4 days before they start to become active and rise off the bottom of the nest (Moyle 2002).	
other characteristics of larvae	Alevin -- early life history phase just after hatching (larva) when yolk-sac still present.		
timing range for emergence	Time of year (earliest-latest) hatchlings (larvae and alevins) leave or emerge from the nesting/hatching (gravel) sites.	Once fry become active and rise off the bottom of the nest, the male smallmouth bass of the nesting pair herds them into a shoal, and guards them for 1-4 weeks (Moyle 2002).	
timing peak for emergence	Time of year most hatchlings emerge.		
size at emergence from gravel	Average size of hatchlings at time of emergence.	By the time fry reach 0.8-1.2 inches (2-3 cm) TL they are too difficult for the male of the nesting pair to herd, and they soon disperse into shallow water (Moyle 2002).	
Juvenile rearing			
general rearing habitat and strategies	General description of freshwater environment and rearing behavior.		
water temperature tolerance for juvenile rearing	Range of water temperatures allowing survival. Indicate stressful or lethal levels.	Juvenile smallmouth bass tolerate water temperatures ranging from 77°F-78.8°F (25°C -26°C) (Coutant et al. 1983).	
water temperature preference for juvenile rearing	Range of suitable, preferred, or reported optimal water temperatures. Indicate whether literature, observational, or experimental derivation.		
water velocity ranges for rearing juveniles	Reported range of observed (minimum and maximum) water velocity utilization.	Optimal water velocity for young-of-year bass is 0.26-0.42 ft/sec (80-130 mm/sec) (Moyle 2002).	
water velocities preferred by rearing juveniles	Reported range of most frequently observed water velocity utilization.		
water depth range for juvenile rearing	Reported range of observed (minimum and maximum) water depth utilization.		

Element	Element Descriptor	General	Feather River specific
water depth preference for juvenile rearing	Reported range of most frequently observed water depth utilization.		
cover preferences for rearing juveniles	Type of cover for protection from predators used by rearing juveniles (e.g., crevices, submerged aquatic vegetation, overhanging vegetation, substrate cover, undercover bank, small woody debris, large woody debris).	Juveniles utilize sandy shoals, rocky areas, and shallow stream pools with sand and rocky bottoms, and are continuously guarded by the male parent for 1-3 weeks (Wang 1986). Male guard fry of up to 1 inch (26 mm) for up to 4 weeks (Coutant et al. 1983).	
food base of juveniles	Indicate primary diet components. Also indicate the diet changes, if any, as growth occurs.	Fry feed on crustaceans and aquatic insects until they reach 1.2-2 inches (3-5 cm) TL. At 3.9-5.9 inches (10-15 cm) they feed on larger prey, such as crayfish and fish (Moyle 2002).	
feeding habits of rearing juveniles	Indicate whether plankton eater, algae eater, bottom feeder, piscivorous, active hunter, ambush predator, filter feeder. Night, day, dusk or dawn feeder. Also indicate change of feeding habits growth occurs.	Juvenile smallmouth bass are active hunters (Wang 1986).	
predation of juveniles	Indicate which species prey on juveniles.	Pikeminnow may prey on smallmouth bass fry (Moyle 2002).	
timing range for juvenile rearing	Range of time of year (months) during which rearing occurs.		
timing peak for juvenile rearing	Time of year (months) during which most rearing occurs.		
Juvenile emigration			
time spent in fresh water prior to emigrating	Duration (in years and/or months) from emergence to emigration to the ocean.	N/A	
water temperature tolerances during emigration	Range of water temperatures allowing survival. Indicate stressful or lethal levels.	N/A	

Element	Element Descriptor	General	Feather River specific
water temperature preferences during emigration	Range of suitable, preferred or reported optimal water temperatures. Indicate whether literature, observational, or experimental derivation.	N/A	
emigration timing range	Time of year juveniles commence emigration and duration of emigration.	N/A	
emigration timing peak	Time of year most juveniles are emigrating.	N/A	
size range of juveniles during emigration	Minimum and maximum sizes (inches or mm) of emigrating juveniles. Indicate average size.	N/A	
factors associated with emigration	Pulse flows, water temperature changes, turbidity levels, photoperiod, etc.	N/A	
Other potential factors			
DO	Levels of dissolved oxygen in water expressed in mg/l tolerated by fish.	In excess of 6.0 mg/L dissolved oxygen is needed for growth, and 1-3 mg/L dissolved oxygen is needed for survival (Moyle 2002).	
pH	Alkalinity/acidity of water (expressed in pH) that fish can tolerate.	Smallmouth bass can live at a wide range of pHs, ranging from pH 5.7–9.0 (Moyle 2002).	
turbidity	Indicate turbidity or state of water (e.g., clear water or presence of siltation or organic/inorganic matter in water) that fish can tolerate.		
factors contributing to mortality	e.g., fishing/angling mortality, drastic habitat alterations, unfavorable climatic changes, etc.	Fishing and angling contribute to smallmouth bass mortality (Green 1995).	

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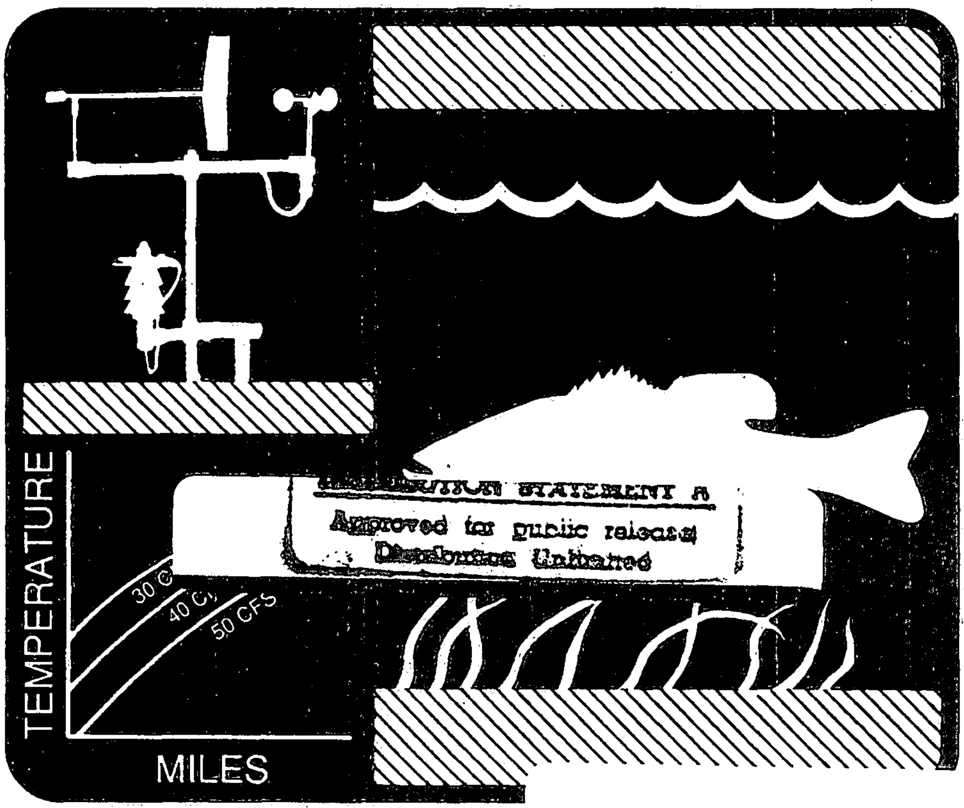
Lee Nuclear Station Response to Request for Additional Information (RAI)

Attachment 63-3 to RAI 63

Armour, C., *Evaluating Temperature Regimes for Protection of Smallmouth Bass*, U.S. Department of the Interior, Fish and Wildlife Service Resource Publication 191, 1993

Evaluating Temperature Regimes for Protection of Smallmouth Bass



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Evaluating Temperature Regimes for Protection of Smallmouth Bass

By Carl L. Armour

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Evaluating Temperature Regimes for Protection of Smallmouth Bass

by

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Abstract. The success of smallmouth bass (*Micropterus dolomieu*) is affected by temperature regimes. Concepts are presented for evaluating the suitability of alternative temperature regimes through experimentally derived data, including ultimate incipient lethal temperatures and maximum weekly average, short-term maximum, and final preferendum temperatures. Also, concepts are described for basing evaluations on temperature tolerances for periods including spawning, egg and larval incubation, growth, and winter survival in the first year of life.

Key words: Alternative temperature regimes, *Micropterus dolomieu*, smallmouth bass, water temperature.

The smallmouth bass (*Micropterus dolomieu*) is an important sport fish species in the United States. Two subspecies are recognized: the northern smallmouth bass (*M. d. dolomieu*), which is native to the Great Lakes and adjacent regions, and the Neosho smallmouth bass (*M. d. velox*), which is native to northwestern Arkansas, northeastern Oklahoma, and southwestern Missouri (Hubbs and Bailey 1940; Ramsey 1975). This report applies mainly to the northern smallmouth bass.

In waters with controlled flows, survival of smallmouth bass is a concern because of potential for temperature changes. Temperature affects all poikilotherms (Fry 1967, 1971; Hutchinson 1976). Responses of fish to temperature changes can be affected by factors including size and sex, life stage, season, day length, water chemistry, disease, and genetic variation (Coutant 1970; Hutchinson 1976).

Smallmouth bass populations are affected by many variables (Fig. 1). Temperature in particular affects smallmouth bass directly by its influence on spawning, egg and larval incubation, and growth. Indirectly, it affects food availability, toxicity of waterborne substances, competition from sympatric species, oxygen saturation capacity of water, and biochemical oxygen demand, among others.

The potential effects of all variables that regulate smallmouth bass populations are incompletely known. However, enough is known about some direct effects of temperature to permit an assessment of probable impacts from alternative temperature regimes.

In writing this document, reliance was on existing literature. This precluded acquisition of new data and the field-testing of procedures for site-specific applications. It is hypothesized that procedures in this guidance are appropriate for evaluating the relative merits (rankings) of temperature

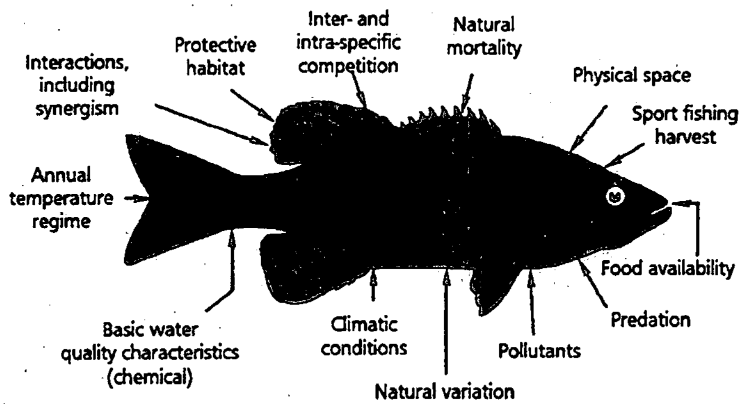

Fig. 1. Variables that affect smallmouth bass (*Micropterus dolomieu*) populations.

regimes for smallmouth bass. Scientists are encouraged to challenge the validity of the assumption and to conduct studies to obtain information to improve the guidance.

Influences of Temperature on Smallmouth Bass

Water temperature is one of the most important environmental variables affecting smallmouth bass. For example, it influences geographic range, migrations to spawning sites, spawning date, nest-guarding by males, success of egg incubation, growth, and responses during the winter period, including feeding curtailment.

Smallmouth bass are sometimes classified as coolwater fish; however, they are tolerant to relatively high temperatures, and for this reason K. E. F. Hokanson (Duluth, Minn., personal communication) categorized them as warmwater fish. For example, in Tennessee, adult bass tagged with transmitters in summer remained in water exceeding 28.0° C, although cooler water existed in the thermally stratified, well-oxygenated reservoir (Bevelhimer and Adams 1991); in tank experiments, 74% of the fish selected a temperature of about 31° C when food was present. In Alabama, temperature experiments were conducted with age 0 fish; mean total length was 111 mm, and mean weight was 14 g. About 45% of the growth occurred at temperatures exceeding 29° C. The four temperature treatments were ambient and 3, 6, and 9° C above ambient. Temperatures ranged from 1 to 30° C for the ambient treatment compared with 10–38° C in the ambient plus 9° C treatment. In the ambient plus 9° C treatment, during the period of the highest temperatures, the fish had access to a refuge zone of 35° C. Growth occurred at temperatures above and below the 25–29° C range reported for optimum growth. Survival for a test period of 322 days was 87% for the ambient and 9° C above ambient treatments. Smallmouth bass in the 9° C above ambient treatment were exposed to temperatures of 35° C for 9 days. After 322 days, the net biomass of fish in the four treatments was not significantly different (Wrenn 1980). Stream conditions tolerated by smallmouth bass in Virginia included ambient temperatures up to 35° C (Stauffer et al. 1976).

In growth experiments in Tennessee with smallmouth bass and largemouth bass (*Micropterus salmoides*) fry, temperatures of 25–27° C promoted the fastest growth rates for both species (Coutant and DeAngelis 1983). The largemouth bass fry were in the 11.9–12.9-mm standard length range at the beginning of the experiments in early May, and the smallmouth bass were in the 10.1–12.5-mm range. The temperature for maximum growth of largemouth bass was about 27° C, compared with 25–26° C for smallmouth bass. Coutant and DeAngelis (1983) thought that growth rates for cool years for both species would probably be comparable.

Streams known for high-quality smallmouth bass populations generally have the following habitat characteristics: cool, nonturbid water, abundant shade and cover, deep pools, and substrates composed of gravel and larger material

(Edwards et al. 1983). Smallmouth bass are commonly successful in eastern mid-order streams that are managed for "put and take" trout fisheries, which usually have these characteristics.

McClendon and Rabeni (1987) evaluated 32 variables thought to influence smallmouth bass populations in a Missouri stream. The highest abundance and biomass correlated with relative amounts of boulders and cobble, availability of undercut banks, and the presence of vegetation. Relative weight (an index of fish condition) correlated positively and best with maximum summer water temperatures (mean = 24° C, range = 14.5–29.7° C) and crayfish abundance (mean = 62,000/ha, range = 21,000–213,989/ha).

Evaluating Regimes with Temperature Tolerance Data

Compiled thermal-table information with regression coefficients (as in Brungs and Jones 1977) is unavailable for smallmouth bass. However, other information from temperature studies (Table 1) can be used in evaluating temperature regimes.

I interpreted from Wrenn (1980) that the upper ultimate incipient lethal temperature (UUILT) for juveniles and adults is 37° C. This is the highest temperature at which tolerance does not increase with increasing acclimation temperatures. The

Table 1. *Temperature response criteria reported for smallmouth bass* (Micropterus dolomieu).

Criterion[a]	Value (° C)	Reference and fish source	Comment
Estimated UUILT for juveniles	37	Wrenn (1980), Carbon Hill National Fish Hatchery, Alabama	Although the author reported 37° C to pertain to the UILT, I interpreted that he meant UUILT
MWAT for adequate juvenile and adult growth	32–33 Alabama	Wrenn (1980), Carbon Hill National Fish Hatchery, 6, and 9° C above ambient	Responses were studied at treatments of ambient and 3,
STM for juveniles and adults for summer growth	35	Wrenn (1980), Carbon Hill National Fish Hatchery, Alabama	Survival in a channel at ambient +9° C was 87%; maximum water temperatures period approximated 35° C for 70 days in the channel and the minimum temperature was 35° C for 9 days; age 0+ fish were held for 322 days in the experiments
STM for embryo development	23	Wrenn (1984), Tennessee River	The value was cited as being conservative; the author believed that a maximum of 26° C is more realistic for spawning and embryo protection
FP	30.3–31.5	Cherry et al. (1977), New River, Virginia area	Seined fish of unreported sizes were used in the experiment; the best statistical fit was for 30.3° C; two values (i.e., 28 and 31° C) of other researchers were reported
FP	30.8	Stauffer et al. (1976), New River, Virginia	Data were from a stream survey; smallmouth bass were sampled at temperatures up to 35° C
FP for adults	27	Hokanson (personal communication); multiple sources	The value was the mean for the range of 20.3–33° C

[a] UUILT = upper ultimate incipient lethal temperature; MWAT = maximum weekly average temperature; STM = short-term maximum; FP = final preferendum.

maximum weekly average temperature (MWAT) reported (Wrenn 1980) for juveniles and adults is 32–33° C. An MWAT value is a temperature between the physiological optimum and the UUILT (Wismer and Christie 1987).

Cherry et al. (1977) reported a range of 30.3–31.5° C for the final preferendum (FP); other authors (Table 1) reported values ranging from 27 to 30.8° C. The FP is the temperature that fish will ultimately select regardless of acclimation temperature (Giattina and Garton 1982). If an FP temperature zone is available, fish should be most abundant there, assuming that adequate food is available and that there are no other habitat problems (e.g., pollution). The physiological significance of an FP temperature is that it potentially corresponds to the temperature at which key physiological, biochemical, and life history activities are optimal (Beitinger and Fitzpatrick 1979).

A short-term maximum (STM) of 35° C for growth was reported for experimental results with Alabama hatchery fish (Table 1; Wrenn 1980). The experiment involved subjecting fish to four temperature treatments of ambient, and ambient plus 3, 6, and 9° C for 322 days in outdoor channels. In the ambient plus 9° C channel, maximum temperatures were near or above 35° C for 70 days, and the minimum temperature was 35° C for 9 days.

Wrenn (1984) studied additional effects of the four temperature regimes described above on the survival of smallmouth bass eggs and larvae. Survival rates from the egg stage to the time fry emerged from the nest approximated 90% for each of the four treatments. Based on results of the study, the recommended limit for spawners and embryo protection was about 26° C.

If temperature information can be simulated for alternative flow regimes, then temperature response information such as that given here can be used to evaluate the relative merits of the thermal regimes for smallmouth bass. For example, the STM for incubating embryos might be the concern (Table 2). Of the three hypothetical temperature regimes, alternative A would be recommended to ensure successful embryo development. The same type of comparisons could be made for UUILT, MWAT, and FP values for appropriate life stages.

Table 2. *Application of the short-term maximum (STM) criterion for incubating smallmouth bass embryos in evaluating alternative temperature regimes.*

	Alternative temperature regime		
	A	B	C
Hypothetical short-term temperature (° C) during the egg incubation period	21.1	25.6	31.1
STM of 23° C exceeded for embryos?	No	Yes	Yes

Evaluations Based on Life Stage and Activity Requirements

When alternative temperature regimes are evaluated, emphasis must be on their capabilities to fulfill requirements for key activities and life stages of smallmouth bass (Table 3). When using Table 3 for a site-specific analysis of the suitability of temperature regimes, professional judgment must be exercised in selecting the most appropriate values for a specific geographic site. Important considerations for year-class success include the suitability of a regime for spawning, embryo development on the nests, and summer growth of fry (Fig. 2). Rates of development are important because they may influence susceptibility of a life stage to mortality from other factors, including predation. For example, within the acceptable range for hatching, there is an inverse relation between temperature and hours until hatching (Fig. 3). Rapid development reduces the time period when nests are susceptible to destruction by predation or weather changes. Information on mortality rates for the first year of life is sparse (Table 4). However, in Missouri creeks there was a 98.5% mortality rate by fall (Pflieger 1966) for young from the first spawning period, compared with an 83% mortality rate from eggs to the fall fingerling stage in a Michigan lake study (Clady 1975). Some critical life stages and the thermal requirements applicable to them are discussed below.

Table 3. *Temperature data for smallmouth bass compiled from the literature.*

Temperature data for activity and life stage	Observation[a]	Reference and fish source	Comments
Spawning migrations			
Adults return to stretches of river abandoned in the fall at 15° C	N	Langhurst and Schoenike (1990), Embarrass River, Wisconsin	The fish overwintered elsewhere and repopulated a 5-km reach of the river vacated in fall
Males migrate to spawning sites when temperatures approximate 15.6° C	N	Coble (1975), source not revealed	Males construct nests and spawning may occur immediately or there may be a week or more of delay, depending on water temperature and availability of ripe females
Initiated when minimum water temperatures exceed 15.6° C	N	Cleary (1956), Iowa streams	A freshet preceded migrations
Spawning occurs			
15–18.3° C range	N	Hubbs and Bailey (1938), assumed to be throughout the smallmouth bass range	Approximately 15° C when temperatures elevate steadily and near 18.3° C if elevations are relatively sudden
12.8–15.6° C	E	Henderson and Foster (1956), Columbia River Slough near Richland, Washington	Temperatures in the main river channel ranged from 7.2 to 10° C; when this water entered the slough and temperatures were reduced to 12.2° C, no bass were observed
19–20° C	E	Wrenn (1980), Carbon Hill National Fish Hatchery, Alabama	Studies were in outdoor channels; spawners were age 1 fish
Initiated at 18.3° C	N	Latta (1963), Waugoshance Point, Lake Michigan	The temperature was expressed as the mean, defined as the average of the daily maximum and minimum temperatures; means were in the 15.6–20.6° C range during all of the spawning season; the 18.3° C value was reported for nesting that is assumed to include spawning
15–21° C	N	Shuter et al. (1980), Baie du Doré and Lake Opeongo, Ontario	Egg-laying suppressed at temperatures <14.2° C and >28° C; fish resume spawning when temperatures reenter 15–27° C range; water temperatures reached and exceeded 15° C before the peak of spawning; mortality of eggs and larvae is 100% if daily mean temperatures drop below 10° C or exceed 30° C; there is no temperature-related mortality in the 15–27° C range; 15° C is the minimum temperature for the complete survival of larvae

Table 3. *Continued.*

Temperature data for activity and life stage	Observation[a]	Reference and fish source	Comments
Spawning occurs (continued)			
Onset observed at 11.6° C	N	Phelan and Philip (1990), St. Lawrence River	At the peak of spawning, the temperature was 15° C; the temperature during the latest date of spawning was 17.6° C
When temperature decreases to 12.8° C, nest preparation and spawning cease, resume at 13.9° C	N	Meehan (1911), unspecified Pennsylvania waters	Eggs were killed when water temperatures dropped to 7.2° C
Spawners occupied water in 20–22° C range	N	Gerber and Haynes (1987), tributaries of Lake Ontario, Canada	Smallmouth bass rarely observed in water exceeding 25° C during the summer; this was assumed to include the post-spawning season
Temperatures much lower than 15.6° C cause a cessation of nest building by males	N	Hubbs and Bailey (1938), assumed to be throughout the range of smallmouth bass	Vacating of a nest by a male usually causes loss of all eggs and fry
Bulk of spawning in 15.6–21.1° C range with peak at 17.8° C	N	Watson (1955), Maine bass in general	Nest-building begins at approximately 12.8° C; at Big Bear Lake it began at 14.4° C
Spawning occurs when temperatures exceed 15.6° C	N	Harlan et al. (1987), Iowa streams	Spawners move up larger streams in early May
Approximate 15–21.1° C range	E	Rawson (1938), Waskesiu Lake, Saskatchewan was location of study but the fish were from the north channel of Lake Huron	Fish were in screened enclosures; temperatures were assumed to be the average of daily maximum and minimum temperatures; spawning was preceded by a temperature rise from 12.8 to 15.6° C
A water temperature rise to approximately 15.6° C precedes spawning	E	Rawson (1945), Prince Albert Park, Saskatchewan	Brood fish were held in rearing enclosures and were observed; in 1936, the range of spawning temperatures was approximately 15–20° C compared with 14.4–18.3° C in 1939, 15–20.6° C in 1941, and 15–18.3° C in 1942; temperatures were assumed to be the average of daily minimum and maximum temperatures
First occurrence of nesting and spawning observed at 18.5° C	N	Winemiller and Taylor (1982), Indian Creek, Ohio	Authors believed that unsuccessful male spawners were relatively small, nondominant fish
Nest construction by males and spawning followed several days during which maximum water temperatures exceeded 15.6° C	N	Pflieger (1966), Little Saline Creek, Missouri	Daily maximum temperatures ranged from 18.9° C early in the season to 26.7° C several days near the end of the season; daily minimum temperatures ranged from 12.2 to 17.8° C; diurnal fluctuations ranged from 3.3 to 7.8° C

Table 3. *Continued*.

Temperature data for activity and life stage	Observation[a]	Reference and fish source	Comments
Spawning occurs (continued)			
Larger males spawned with exposure to fewer degree-days than smaller males	N	Ridgway et al. (1991), Lake Opeongo, Ontario	Degree-days are those with average temperatures higher than 10° C; the same pattern appeared for females; it was hypothesized that large males overwinter with a lower energy deficit and can breed earlier than smaller males, and that large males allocate more energy to reproduction than to growth earlier in the season than small males
Peak egg deposition occurred at 18-22° C, temperatures below 10° C and above 30° C are usually lethal to spawns	E	Wrenn (1984), Tennessee River, Tennessee	Egg incubation success was studied for three temperature regimes (3, 6, and 9° C above ambient); survival from egg to emergent fry approximated 90% for the regimes; Wrenn (1984) concluded that a maximum weekly average temperature of 26° C during the spawning season is suitable for survival of eggs and larvae
Spawning occurred when daily mean temperatures ranged from 12.5 to 23.5° C	N	Graham and Orth (1986), tributaries and main stem of New River in West Virginia and Virginia	Spawning was sharply curtailed when temperatures reached 25° C
Spawning observed at temperatures ranging from 13.3 to 22.5° C	N	Vogele (1981), Bull Shoals Lake, Arkansas	Free-swimming fry were guarded by the male parent for approximately 4 weeks
Usually begins at 12.8° C	N	Newell (1977), New Hampshire	The author reported that spawning is usually completed when the water temperature is 21.1° C
Lower and upper spawning thresholds are 12.3 and 27.2° C	L	Hokanson (personal communication), fish source unspecified	The values are the lower average temperatures for spawning and embryo development
Spawning occurred when daily temperatures ranged from 11.7 to 20° C	N	Brown (1960), Little Miami River, Ohio	Nesting occurred in the daily 9.4-21.1° C range; the author reported that bass in the Toledo Aquarium spawn at an average of 21.1-22.2° C with a range of approximately 20-23.3° C

Table 3. *Continued.*

Temperature data for activity and life stage	Observation[a]	Reference and fish source	Comments
Spawning occurs (continued)			
26° C is the monthly or seasonal maximum limit for spawning and embryo protection	E	Wrenn (1984), Tennessee River, Tennessee	Age 1+ fish were stocked in four temperature regimes—ambient and treatments of 3, 6, and 9° C above ambient; spawning occurred successfully at 22° C; the author stated that a maximum of 17° C for successful spawning and 23° C for embryo survival (Brungs and Jones 1977) is conservative
22.8° C was the water temperature at which eggs were initially observed	N	Smitherman and Ramsey (1972), Mammoth Spring National Fish Hatchery, Arkansas	Fish were stocked in earthen ponds; the effective spawn (resulting in fry production) was at 23.9° C, reported in a table (in the text, 25.6° C was reported); temperatures were taken at water surface
Nest-building and spawning occurred in the 15–18° C range	N	Turner and MacCrimmon (1970), Tadenac Lake, Ontario	Egg incubation lasted 4 days at temperatures of 15.3–18.2° C; temperatures were assumed to be average of daily maximum and minimum recordings
Began by time field work was initiated and daily temperature was in the 17.2–21.1° C range	N	Stone et al. (1954), Millen Bay, Lake Ontario	The observation was on 15 June 1948; the authors concluded that spawning occurred during the first 2 weeks of June; additional nests were found after June 15
12.5–23.5° C	N	Graham and Orth (1986), New River in Virginia and West Virginia	The mean daily water temperature was the most important variable in determining time of spawning
Occurred at a range of 19.4–21.1° C for the first spawning	N	Surber (1939), Cacapon River and South Branch of the Potomac River in West Virginia, and the Shenandoah River in Virginia	The observations were for the first spawning, from 28 April to 2 May; a second spawning occurred at 23.9° C in the Cacapon River and 25° C in the South Branch of the Potomac; the respective dates for the second spawning were 10 June and 14 June
Egg and larvae incubation			
Survival for eggs to the hatch stage is favorable at 15–25° C	E	Kerr (1966), Ontario fish	Research was performed in the laboratory, where hatching success and incubation temperatures were studied; hatching success ranged from 73 to 98%; the peak occurred at 20° C, at which the average percent hatch for two samples was 93.5%

Table 3. *Continued.*

Temperature data for activity and life stage	Observation[a]	Reference and fish source	Comments
Egg and larvae incubation (continued)			
18.3-21.1° C temperatures observed during incubation and hatching phases	N	Rawson (1938), Waskesiu Lake, Saskatchewan was location of study but fish were from the north channel of Lake Huron	Eggs were incubated in June in a cellar at 14.4-15° C and hatched in 4 days; it took 3 weeks to attain a post-hatch development stage that took 2 weeks at normal temperatures
Survival of eggs and fry is 0 if the daily mean temperature drops below 10° C or elevates above 30° C	N, E	Shuter et al. (1980), Lake Opeongo, Ontario	Conclusion based on data from Kerr (1966) and observations of Shuter et al. (1980)
Mortality of embryos occurred when water in the 17.8-20° C range was subjected to a sudden rise to 23.1° C	E	Tester (1930), Lake Nipissing, Ontario	Information is for embryos near hatching stage
Fry hatched from eggs at 15.6-23.9° C in sloughs	N	Henderson and Foster (1956), Columbia River sloughs, near Richland, Washington	Hatching occurred in the sloughs in July or August when temperatures were in the range
Incubation range from 10 to 23.9° C; constant temperature is not lethal and normal temperature alterations within the range are tolerated	E	Webster (1948), Cayuga Lake, New York	Reported that, in a river, temperatures ranged from 10 to 26.7° C during the spawning and nesting season, and the daily mean fluctuation was 5.8 ± 1.9° C; eggs exposed to experimental temperatures had been developing at 18.3° C and the change to different temperatures occurred within a half-hour period
Ranges from 14 to 21° C had no adverse effects on eggs or larvae	N	Neves (1975), South Branch Lake, Maine	The range is for mean daily temperatures, defined as the average of the daily maximum and minimum temperatures
Egg mortality occurred at approximately 14.4° C	E	Rawson (1945), Waskesiu Lake, Saskatchewan	Temperatures declined to approximately 14.4° C in 1939 and the 14.4-16.7° C range in 1942, when mortality was observed; temperatures assumed to be average of daily maximum and minimum temperatures, observations made in spawning beds
For successful egg development, a period of 2-3 weeks is required with temperatures of approximately 18.3° C and higher	E	Rawson (1945), Waskesiu Lake, Saskatchewan	General statement based on observation of nests in enclosures; temperature criterion assumed to be daily mean
Virtually all eggs hatched at a constant temperature of 22° C	E	Peek (1965), Arkansas Game and Fish Commission Hatchery at Centerton	After 24 h from hatching, fry had reached dark-eyed stage

Table 3. *Continued.*

Temperature data for activity and life stage	Observation[a]	Reference and fish source	Comments
Egg and larvae incubation (continued)			
Declining minimum temperatures approximating the 10–12° C range and highs of about 30.6–31.7° C are lethal to embryos and newly hatched fry	N	Brown (1960), Little Miami River, Ohio	When temperatures dropped to the reported range, advanced fry developed in 1 nest out of 71; mortality included influences from indirect effects
Eggs and young-of-year died if temperatures dropped below 14° C during the interval from fertilization and next rise	N	MacLean et al. (1981), Lake Opeongo and Baie du Doré, Ontario	Mortality occurred when a cold front caused cold hypolimnetic water to enter the spawning area
Nest abandonment by males			
Temperature dropped from 16.1 to 12.2° C in sloughs where spawning occurred	N	Henderson and Foster (1956), Columbia River sloughs near Richland, Washington	One week after abandonment, the temperature was 12.2° C and eggs were coated with fungus
Males desert nests when the water temperature drops to 10–15° C and lower	N	Latta (1963), Waugoshance Point, northern Lake Michigan	Eggs were eaten by predators after males left
Temperature falls from 18.3° C to slightly below 10° C	N	Webster (1954), Cayuga Lake, New York	Unguarded nests can produce fry but it is possible that the survival rate is lower than in guarded nests
Nest abandonment occurs if temperatures drop to 15.6° C and lower for a prolonged period	E	Rawson (1945), Waskesiu Lake, Saskatchewan	Temperatures assumed to be average of daily maximum and minimum values; nests were in spawning pens; desertion results in death of eggs and, to a lesser extent, death of unrisen fry
Occurred when temperature drops below 10° C	N	Lyndell (1902), culture ponds in Michigan	Abandonment resulted in the death of eggs and fry; for the production of young-of-year fish, the recommended temperature range is 18.9–23.9° C
Growth			
Optimum temperature for juveniles is 26° C	L	Schlesinger and Regier (1983), general statement	Derived for maximum ration conditions that are probably rare in nature
Maximum growth for juveniles is approximately 26° C, fish held at 35° C had negative growth	E	Horning and Pearson (1973), Osage Catfisheries, Missouri	Results based on constant temperatures with tests on fish weighing 5.1–70.8 g (mean = 29.4 g); tests were for constant temperatures of 16–35° C; food was unlimited

Table 3. *Continued.*

Temperature data for activity and life stage	Observation[a]	Reference and fish source	Comments
Growth (continued)			
A mean weekly average of 32–33° C allows satisfactory growth of juveniles and adults	E	Wrenn (1980), Carbon Hill National Fish Hatchery, Alabama	Fish were 0+ at stocking in experimental channels and averaged 11 cm total length; it was assumed that food was not limited; the experiment was conducted at four temperature treatments (ambient and ambient +3, 6, and 9° C)
Maximal first-month growth of fry occurred at 25–26° C	E	Coutant and DeAngelis (1983), Cohutta National Fish Hatchery, Georgia	Test temperatures (constant) ranged from 15.2 to 27.3° C; food was not limited
Temperature decline from 22.9 to 14.7° C over a 3-day period adversely affected growth of body parts and total length of fry	N	Doan (1939), Lake St. Clair, Ontario	Measurements were in June; temperatures were average of daily maximum and minimum values at nest
Maximum safe temperature limit for growth of fingerlings, juveniles, and adults at 29° C	N, E	Horning and Pearson (1973), Osage Catfisheries, Missouri	Conclusion based on experimental results of authors and their evaluation of information in the literature; food was not limited
An annual thermal sum degree value of less than 1,000 units was attributed to diminished population success	N	Pettit (1976); Clearwater River, Idaho	An annual thermal sum degree value is the sum of mean temperature for days when the 10° C degree-day level is exceeded for a period from July through September; Coble (1967) reported that, predominantly, for average annual length increments of 2.5 cm or more for adult fish, the sum exceeded 1,000 units
Activity in general			
Approximately 10° C is the temperature at which activity diminishes with a lowering trend and resumes with rising temperatures	N	Hubbs and Bailey (1938), assumed to apply throughout the range of the smallmouth bass	Smallmouth bass hibernate in winter when growth stops or activity is greatly reduced
Fish become torpid in the the range of about 4.4–6.1° C	NS	Coble (1975), source not revealed	The fish rarely feed at this temperature range
Fish tend to enter rock substrate and remain when temperatures are <7.8° C	E	Munther (1970), Snake River, Idaho	Fish in tests were young-of-year ranging from 7 to 10 cm total length
Few bass caught until water warms to 10–15.6° C range	N	Watson (1955), lakes in Maine	Water reached the range in late May or early June
Move to wintering habitat at temperatures <15.5° C	N	Munther (1970), Snake River, Idaho	Fish were in still, rocky pools at least 4 m deep when studies occurred in late fall
Migration to winter habitat can initiate at 15.6° C and is pronounced at 10° C and lower	NS	Coble (1975), general statement	Fish move to zones that are dark and devoid of current (e.g., crevices between rocks, holes, caves, hollow logs)

Table 3. *Continued.*

Temperature data for activity and life stage	Observation[a]	Reference and fish source	Comments
Activity in general (continued)			
Fish feed at temperatures exceeding 10° C	E	Munther (1970), Snake River, Idaho	Fish were young-of-year about 7–10 cm total length
At 7.1° C age 0 captive fish consumed virtually no food	E	Oliver (1977), White Lake, Ontario	Tests were in aquaria; the fish were fed trout food
Age 2 and older fish initiated winter migration when temperatures fell below 16° C	N	Langhurst and Schoenike (1990), Embarrass River, Wisconsin	At temperatures below 4.4° C, age 2 and older fish were not in the study area and were assumed to have migrated to overwintering sites; adults (fish >280 mm) migrated sooner than subadults (200–250 mm fish); no evidence was found that smaller fish migrated
At temperatures below 10° C most fish were in a hibernating stage	E	Oliver (1977), citing unpublished data of J. C. MacLeod, Lake Opeongo, Ontario	Oliver (1977) reported that bass in an Ontario study virtually stopped feeding at 7.1° C; the fish were young-of-year from White Lake, Ontario
At temperatures of 6.5–8° C fish had not fed for several weeks	N	Keast (1968), Little Cataraqui Creek, Ontario	Stomachs were shrunken and drawn forward in the body cavity
Other			
Seasonal selection temperatures (° C) were 29–31 for underyearlings (UY) and 30–31 for adults (AD) in summer, 26–30 UY and 21–27 AD in fall, 24–28 UY and 13–26 AD in winter, and 22–28 UY and 18–26 AD in spring	E	Barans and Tubb (1973), western Lake Erie near South Bass Island, Ohio	Acclimation was at ambient lake temperatures at time of seasonal tests
At times, sunning fish selected 26.7° C	N	Munther (1970), Snake River, Idaho	Fish selected shallow backwater areas; sizes of fish unstated
Average summer temperature where fish were observed was 21.4° C	N	Hallam (1959), Ontario streams	Fish sizes not specified; at sampling time, one water temperature was recorded and ranges were not
After spawning and water temperatures dropped from 10 to 15.6° C, eggs became heavily infested with fungus	N	Cleary (1956), Iowa	Air temperatures dropped from 23.9 to 11.1° C in a day and remained low for 10 days
Range of approximately 20.3–21.4° C where fish were observed in mid-summer	L	Ferguson (1958), data for Nebish Lake, Wisconsin and streams in Ontario	Assumed to be preferred temperatures; ages of fish unspecified; final preferendum for laboratory studies was 28° C

Table 3. *Continued.*

Temperature data for activity and life stage	Observation[a]	Reference and fish source	Comments
Other (continued)			
Northern latitudes where smallmouth bass predominate seldom have mid-summer temperatures exceeding 26° C	NS	Coutant and DeAngelis (1983), general statement	Temperature alone may not be the primary factor in determining the relative abundance of smallmouth bass in the presence of largemouth bass
Most adult fish vacated spawning area when temperature approximated 25° C	N	Robbins and MacCrimmon (1977), Pefferlaw River, Ontario	Fish were spent spawners from Simcoe Lake; remaining adults vacated after temperatures elevated to 29° C
Optimum growth of juveniles occurred at approximately 28° C	E	Peek (1965), Arkansas Game and Fish Commission Hatchery at Centerton	The temperature was the average of the preferred temperature for most fish for three test ranges (17-31.4, 20.8-35, and 17.8-38° C); Peek (1965) concluded that bass fingerlings tend to choose the temperature (28-29° C) at which growth is maximum
33-35° C are summer temperatures that fail to form a thermal barrier for migrations	E	Wrenn (1976), Tennessee River, Tennessee	Movements of tagged fish were studied in a thermal plume from a power plant; the author documented preferred temperatures by season
Cold shock mortality occurred when there was a sudden change from 26.7 to 2.2° C	N	Silverman (1971), Susquehanna River, Pennsylvania	The fish were in a thermal discharge that was shut off
During lighted conditions, the highest temperature selected by smallmouth bass was 30.1° C, compared with 28.3° C in darkness	E	Reynolds and Casterlin (1978), source not revealed (assumed to be Pennsylvania stock)	There were alternating periods of 12 h of light and 12 h of darkness; for largemouth bass (*Micropterus salmoides*) the highest selected temperature during light periods was 29.1° C, compared with 29.5° C in darkness; the authors suggested that the behavioral difference relates to niche segregation triggered by circadian rhythms

[a] N = observed under field conditions; E = experimental; L = analysis of literature by cited author; NS = not specified.

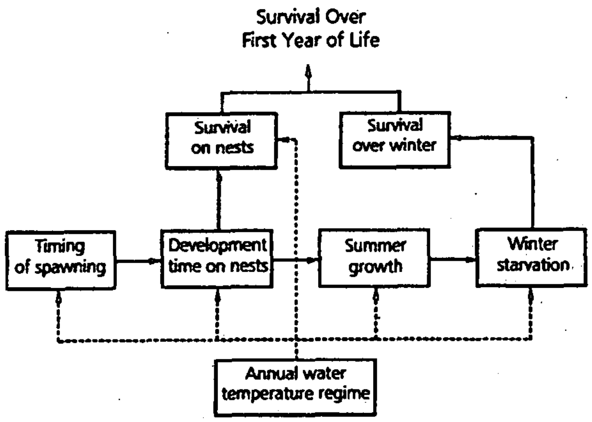

Fig. 2. Conceptual model of the influences of temperature on first year survival of smallmouth bass (Shuter et al. 1980).

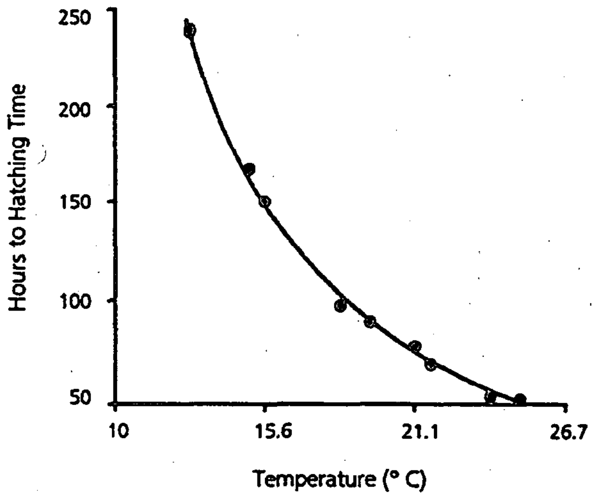

Fig. 3. Temperature versus hatching time for smallmouth bass eggs, assuming at least 50% survival (from Webster 1948).

Table 4. *Mortality (%) data reported for smallmouth bass from the egg stage through the first year of life.*

Egg to hatching	Egg to fry	Egg or fry to fall fingerlings	Fingerling through first year	Reference, fish source	Comment
5.9	6.1	98.5[a]	NR[b]	Pflieger (1966), Little Saline, Bois Brule, and Big Saline creeks, Missouri	The value for eggs is the mean for five nests; the range was 0 to 44.7% with n = 17; an estimated 80,300 fry (two nestings) were produced in 1.6 km of stream; broods of fry were produced in approximately 33 of 41 nests
NR	72.4	NR	NR	Latta (1963), Waugoshance Point, Michigan	The estimate is for values from two nests for which eggs were counted and three for which fry counts were made
37	NR	NR	NR	Vogele (1981), Bull Shoals Lake, Arkansas	The mean number of eggs and larvae for nest was 7,757 and 2,855, respectively
67.5–74.2	NR	83[c]	86	Clady (1975), Katherine Lake, Michigan	Larvae information is for the past larvae stage; annual survival was documented for 3 years from the egg to the fall fingerling stages; the fingerling survival information was based on numbers of fish measured after age 1 for two year classes

[a] Reported as young of the nesting period.
[b] NR = not reported.
[c] From eggs.

Nest Abandonment by Males

An important factor in the production of young-of-year fish is nest and fry-guarding by males after spawning (Surber 1943; Rawson 1945; Latta 1963). If temperatures drop below approximately 14° C, males may abandon nests. Abandonment by the male for any reason can cause young-of-year mortality. For example, sunfish predation on smallmouth bass fry was documented for a Missouri stream (Pflieger 1966) following nest abandonment. One bluegill consumed 39 fry in the absence of the male on the nest, and sunfish were observed attempting to feed on dispersing fry, indicating that fry may be particularly vulnerable to predation when nest abandonment occurs. Neves (1975) observed that three nests without male guards produced about 1,000 fry compared with 3,943 fry per guarded nest. Webster (1954) observed male abandonment in a New York lake when temperatures dropped from 18.3° C to about 10° C; fry were produced in 12 abandoned nests, but Webster thought survival from the egg to the black fry stage would be higher in guarded nests. In a study of Iowa streams (Cleary 1956), fingerlings were produced, but the guarding of newly hatched fry was not observed.

If eggs and fry from the first spawning are destroyed because of low temperatures, respawning and fry production is possible when water temperature increases (Fig. 4; Rawson 1945). A second spawning occurred in two West Virginia streams a month after the first spawning (Surber 1939). The first spawning was unsuccessful because it was followed by a period of cool weather and elevated water levels. Almost all fry from the first spawning were destroyed. The average water temperatures for the first and second spawning were 20 and 24.4° C, respectively. After fry were produced in South Branch Lake in Maine from a first spawning, water temperatures dropped to about 16.1° C, and there was a second spawning when temperatures rose to about 17.8° C (Neves 1975).

Another phenomenon is the inducement of earlier-than-normal spawning in response to higher temperature regimes. In Alabama experiments (Wrenn 1984) with four temperature regimes, the spawning peak (22 March) for the highest temperature regime of ambient plus 9° C was 25 days in advance of the peak (16 April) for the ambient regime. Spawning occurred at 22° C in the ambient plus 9° C treatment, compared with 17.6° C in the ambient treatment.

The period of nest and fry guarding by males varies, but, regardless of the time, if temperature changes cause nest abandonment there can be young-of-year losses. One period of nest and fry-guarding lasted for at least 40 days, including 26 days after fry swarmed above the nest and complete dispersal occurred (Tester 1930). A guarding period in an Ontario lake lasted 19 to 28 days after hatching and dispersal were completed (Turner and MacCrimmon 1970). Guarding continued for 2 to 5 days after fry dispersal in a Missouri stream (Pflieger 1966). Guarding extended to 4 weeks after fry schools were observed in Bull Shoals Lake in Arkansas (Vogele 1981).

Unless site-specific data are available to justify a different conclusion, temperatures resulting in nest abandonment at any time from spawning to the complete dispersal of fry could be considered 100% lethal to offspring.

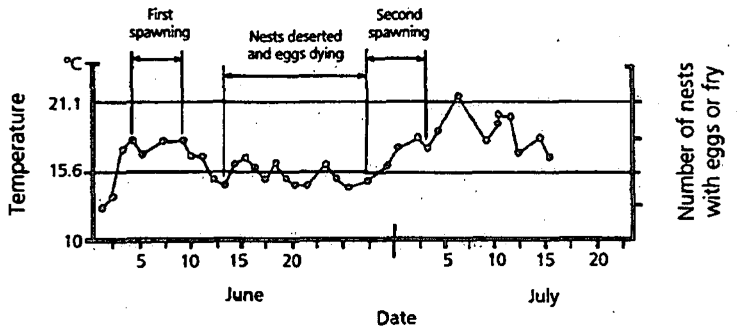

Fig. 4. First spawning, nest desertion by males, and respawning of smallmouth bass in Narrows Bay, Saskatchewan (from Rawson 1945). More nest desertion occurred (for unknown reasons) after the second spawning when the high temperatures approximated 21.8° C, compared with the low of 19.2° C.

Prediction of Spawning, Hatching Time, and Rising from Nests

One challenge in evaluating alterative temperature regimes is the designation of specific periods for important life stages or activities. Periods of special concern are those for spawning, hatching, and rising from the nest. The duration of these periods is temperature dependent, and empirical information pertaining to temperature versus days for hatching through nest abandonment has been documented (Table 5).

Usually, the spawning period for a specific location can be estimated through communications with qualified experts and reference to historical records. However, if the period must be estimated solely from temperature data, one option is to use the degree-day approach (Shuter et al. 1980). This approach requires estimation of the number of degree-days (days with average temperatures exceeding 10° C) to which spawners are exposed after the 15° C level is initially reached in the prespawn period. With this information, the peak time of spawning can be estimated. For example, if 40 degree-days accumulated by 1 May, the date on which the 15° C level initially occurred, the estimated peak of spawning would be about 7 May (Fig. 5).

Alternatively, equations developed by Shuter et al. (1980) can be used to estimate the time for egg laying (D), the time from fertilization to hatching (T_{SH}), and the time from hatching to rising (T_{HR}) of fry from nests. Equation 1 can be used to estimate days (D) until egg laying.

$$D = 8.0 - 0.55d \quad (1)$$

where

d = estimated number of degree-days above 10° C accumulated by the date that average temperatures entered the preferred range of 15-27° C; for example, if the preferred temperature range exists and d = 10 days, then D = 8.0 - 0.55(10) = 2.5 days.

Equation 2 can be used to estimate the time from fertilization to hatching (T_{SH}).

$$T_{SH} = 83.2e^{-0.1606T} \quad (2)$$

where

Table 5. *Temperature versus time reported for smallmouth bass egg hatching through nest desertion by fry.*

Days	Temperature (° C)	Reference
Hatching		
7.0	14.4-15.6	Vogele (1981)
5.0	17.8-18.6	
3.9	Mean = 19, range of daily means = 18.2-20.0 (E)[a]	Neves (1975)
3.5-5.4	15.1-21.1	Rawson (1945)
4.0	15.2-18.2	Turner and MacCrimmon (1970)
6.0	15.6-18.3	Vogele (1981)
6.0	16.7-17.5	
2.2	25.0	Webster (1948)[b]
2.3	23.9	
2.9	21.7	
3.2	21.1	
3.8	19.4	
4.1	18.3	
6.3	15.6	
7.0	15.0	
9.9	12.8	
9.8	12.8	
Hatching to rise		
11.0	20-21.5 (E)	Neves (1975)
8.0-11.0	11.3-18.2 (E)	Turner and MacCrimmon (1970)
3.0-7.0	18.3-23.3	Inslee (1975)
4.1-8.4	17.2-21.1	Rawson (1945)
12.0	12.2-23.1	Tester (1930)
8.0-11.0	17.2-19.5	Turner and MacCrimmon (1970)
Egg deposition to nest desertion by fry		
18.9	15.2-23.8 (E)	Turner and MacCrimmon (1970)
10.3-15.0	17.2-21.1 (E)	Rawson (1938)
8.0	15.3-16.4	Vogele (1981)
6.0	18.3-21.1	
14.0-15.0[c]	15.6-23.9	Pflieger (1966)

[a] E = estimated from the cited data.
[b] Data for time at which 50% of eggs hatched.
[c] Information for first spawning. For the second spawning, fry were dispersed by 10-12 days. Mean temperatures were the average of daily maximum and minimum temperatures.

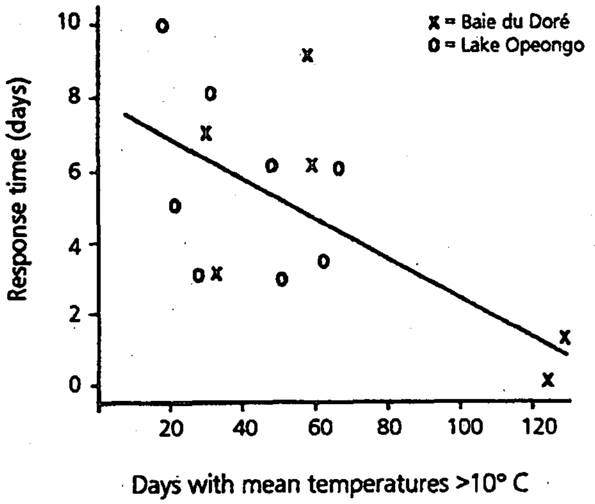

Fig. 5. Relation between degree-day accumulations and days to initiation of spawning. Degree-days are days with average temperatures greater than 10° C following the date on which temperatures initially reach 15° C during the prespawning period (from Shuter et al. 1980).

T = the average postspawning temperature (° C) for the incubation period.

Equation 3 can be used to estimate the period from hatching to rising of fry from the nests.

$$T_{HR} = 134e^{-0.1606T} \quad (3)$$

The equations can be applied to estimate periods for which adverse temperatures could threaten year-class success at a critical early life stage. Suppose, for example, that there is concern that adverse temperatures could induce nest abandonment by males and hence loss of eggs and larvae. Assuming that average temperatures for alternative flow regimes could be estimated and that the maximum and minimum temperatures would be within tolerance limits for satisfactory development, the equations could be used to estimate the period from egg laying to rising of fry from the nests (as in Table 6). Also, the duration of the prewinter growth period (when temperatures exceed 10° C) could be estimated. In the example, it would be about 30 days longer for regime B than for regime A or C.

If temperature-induced mortality of eggs, larvae, and fry is the concern, equations developed by Shuter et al. (1980) can be used for mortality estimates. The equations apply to upper and lower temperature ranges (Fig. 6) for temperature-induced mortality (M) from fertilization to part of the period when fish rise from the nest. Equations 4 and 5 apply to the 10° to 15° C and 27° to 30° C zones. No mortality would be expected for temperatures in the 15–27° C range.

$$M = 3.0 - 0.2\,(T),\ \text{if } 10 \le T \le 15 \quad (4)$$

Table 6. *Estimates of days to hatching, days from hatching to fry rise, and days of postrise growth of young-of-year smallmouth bass at three alternative flow regimes. The average temperatures are hypothetical.*

	Alternative flow regime (cubic feet per second)		
	A 2,500	B 2,000	C 1,950
Temperature (and days to hatching)	15.6° C (6.8)[a]	17.8° C (4.8)	17.5° C (5.0)
Temperature (° C) during (and days in) hatch-rise interval	15.6° C (10.9)[b]	18.8° C (6.5)	18.8° C (6.5)
Total days from spawning to fry rise (and dates)	17.7 (5–23 May)	11.3 (5–16 May)	11.5 (5–17 May)
Days of growth (and mean temperature[c]) between fry rise and winter feeding cessation	138 (16° C)	168 (19° C)	136 (35° C)

[a] Days = $83.2e^{-0.1606T}$ = (83.2) (0.082) = 6.8.
[b] Days = $134e^{-0.1606T}$ = (134) (0.082) = 10.9.
[c] Mean water temperature in winter would approximate 10° C and lower, and growth would not occur.

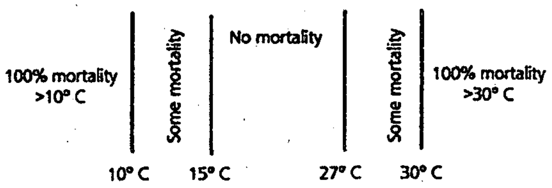

Fig. 6. Thermally induced mortality for smallmouth bass eggs and fry in the temperate zone (from Shuter et al. 1980).

$$M = -9 + 0.33\,(T), \text{ if } 27 \leq T \leq 30 \qquad (5)$$

where

T = the average daily temperature (° C), and

M = level of total mortality for eggs over a period of time including that for fertilization to hatching and part of the hatch-to-rise period.

Equation 5 was used to develop data for a curve from which predicted mortality rates can be read for average daily temperatures in the 27 to 30° C range (Fig. 7). A similar curve could be developed with Equation 4 for the 10 to 15° C range. Based on estimated temperature data for the period that eggs, larvae, and fry would be present, the two equations could be used to estimate total mortality for alternative temperature regimes.

Estimating Prewinter Survival and Growth of Young-of-year Fish

Serns (1982) studied effects of temperature on survival of age 0 smallmouth bass in Wisconsin (Fig. 8). The number of young-of-year fish present in fall was positively correlated with spring and summer water temperatures. Seventy-four percent of the variability was attributed to summer water temperatures. Forbes (1981) also documented a correlation between higher water temperatures during the first growing season and year-class survival. Yields from a Lake Huron fishery correlated with the algebraic sum of monthly deviations of mean air temperatures from July through October of the hatching year (Fry and Watt 1957). In Oneida Lake, in New York, dominant year classes were related to above-normal mean June air temperatures (Forney 1972). There was no correlation between water temperatures and year-class strength at the end of the first summer in Katherine Lake in Michigan, but the opposite was true when postwinter year-class numbers were considered (Clady 1975). Although growth information was not discussed, the implication is that prewinter size attained during the first growing season determines winter survival because improved survival was documented following the June–October periods with the warmest

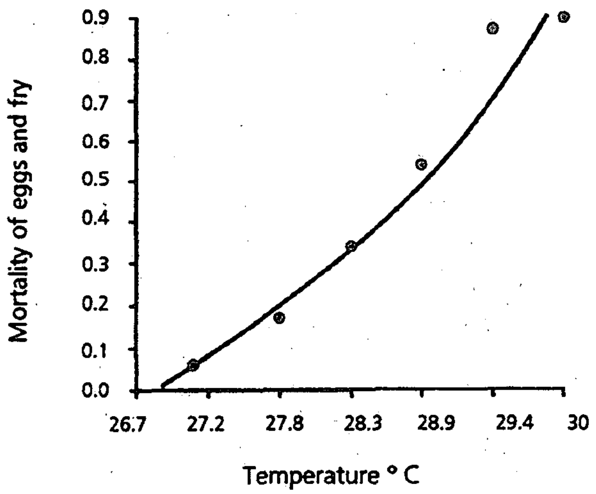

Fig. 7. Temperature versus mortality rate for smallmouth bass eggs, larvae, and fry (developed with equations from Shuter et al. 1980).

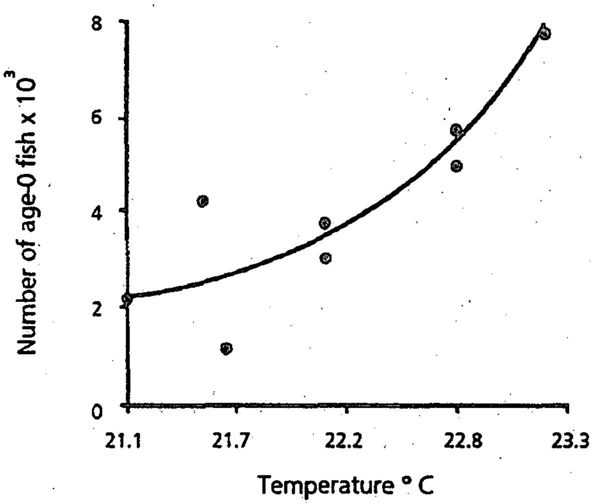

Fig. 8. Mean June through August water temperatures versus number of age 0 smallmouth bass the first fall of life (from Serns 1982).

temperatures. Christie and Regier (1973) hypothesized that the relation between temperature regime and its influences on the size of prewinter fish and their survival applies throughout the geographic range of smallmouth bass.

Shuter et al. (1980) studied effects of temperature on the first-year survival of smallmouth bass in Ontario. The two periods of vulnerability were the times from fertilization to nest abandonment by fry, and in winter, when the young fish were dependent on stored energy to survive. The study populations were north of the 45° N latitude, and I assume that the results would be similar for waters of the United States in which winter water temperatures approximate 7.2° C and lower.

Shuter et al. (1980) found an inverse relation between the time that fry rise from nests and winter survival rates of young-of-year fish, which is indicative of the importance of providing adequate time for growth before winter. There was a positive relation between the total length of young-of-year fish (Fig. 9) at the onset of winter and survival; their explanation was that larger fish store more energy, which is available for metabolism during the winter starvation period. The winter starvation period commences when water temperatures drop into the 7–10° C range (see Table 3). During this period, if fish energy stores are depleted and maintenance requirements are not met, the result is winter mortality. Maintenance requirement energy is required for basic needs for survival including osmoregulation. Shuter et al. (1985) simulated effects of temperature changes in a thermal plume on smallmouth bass (Fig. 10). Mean survival of offspring on nests was related to the spawning date (Fig. 10A), and overwinter survival was dependent on total length by fall (Fig. 10B). MacLean et al. (1981) simulated temperature data for an Ontario lake and described the relation between the date of fry rise from the nests and average survival of young-of-year fish (Fig. 11).

Effects of low winter temperatures on the survival of young-of-year of different sizes was evaluated in aquaria for experimental regimes with endpoint temperatures ranging from 2 to 6° C (Oliver et al. 1979). Final winter temperatures did not affect survival, but there was a positive correlation between fish length and survival rate. There

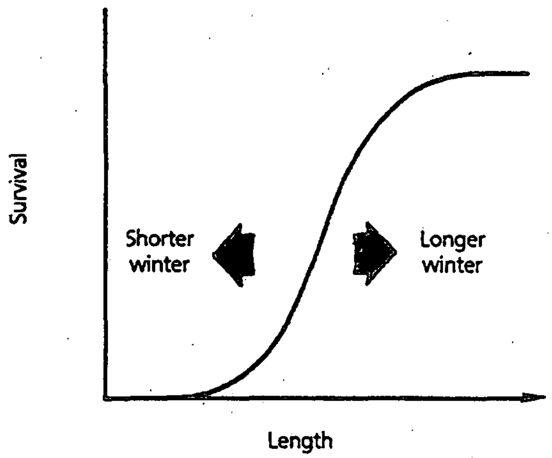

Fig. 9. Conceptual relation between overwinter survival of smallmouth bass and fish length at the end of the first growing season. The position of the curve is affected by the duration of the winter starvation period (from Shuter et al. 1980).

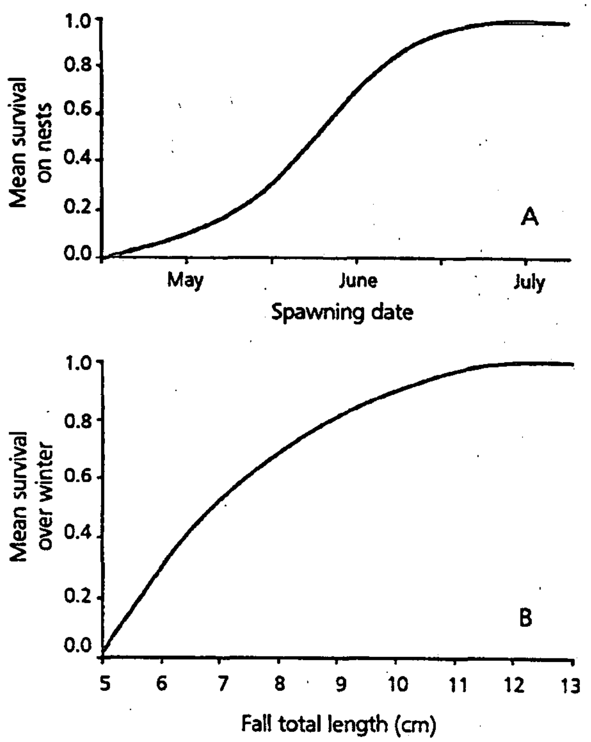

Fig. 10. Empirical relation between the spawning date and survival of young-of-year on nests (A), and fall total length and overwinter survival (B; from Shuter et al. 1985).

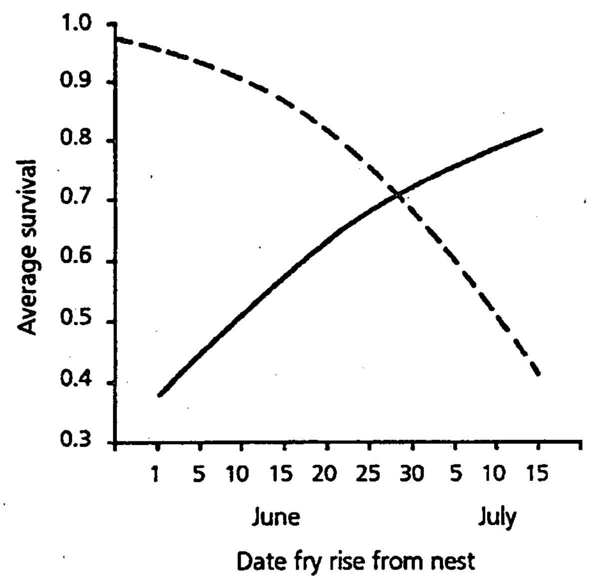

Fig. 11. Relation between the time that fry rise from nests and nest survival, time of rising, and winter survival. The *solid line* represents nest survival, and the *broken line* represents winter survival (from MacLean et al. 1981).

were no temperature-induced mortalities for fish in the 8.0 to 10.9-cm length class. Based on the study, hatchery workers were advised to stock "long" young-of-year fish to minimize first-winter mortalities.

The role of temperature in first-year survival of smallmouth bass was addressed by Shuter and Post (1991). They emphasized size of young-of-year fish at the outset of winter (Fig. 12). There is an inverse relation between fish size and basal mortality rate. When the starvation period is prolonged, stored energy is used sooner in smaller fish, to the extent that available energy is depleted enough to cause mortality. Thus, year-class success can depend on attainment of a minimum young-of-year size before the starvation period. Equations 6–9 (Shuter et al. 1980) can be used to estimate daily growth (G in centimeters per day) for estimating young-of-year prewinter lengths for a specified temperature (T).

$$G = 0.0 \text{ if } 14^\circ\text{ C} > T > 35^\circ\text{ C} \quad (6)$$

$$G = -0.17 + 0.012\,T, \text{ if } 14^\circ\text{ C} \le T < 25.5^\circ\text{ C} \quad (7)$$

$$G = 0.14, \text{ if } 25.5^\circ\text{ C} \le T < 31.5^\circ\text{ C} \quad (8)$$

$$G = 1.4 - 0.04\,T, \text{ if } 31.5^\circ\text{ C} \le T \le 35^\circ\text{ C} \quad (9)$$

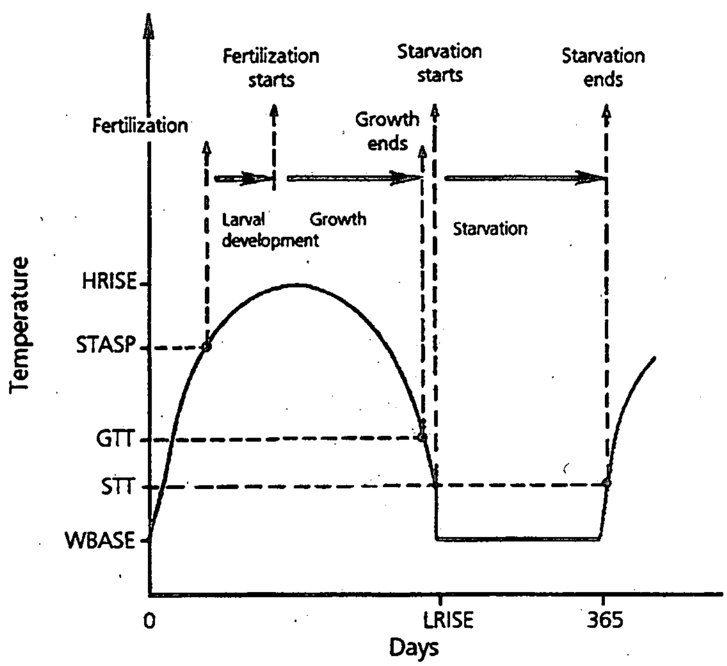

Fig. 12. The annual temperature cycle affecting smallmouth bass larval development, growth, and the winter starvation period. LRISE = days during a year in which the temperature exceeds the winter base temperature (WBASE), HRISE = maximum daily temperature during the year, STASP = temperature at which spawning first occurs during the spring rise, GTT = temperature above which somatic growth can occur, and STT = temperature below which starvation and decline in body weight occur (from Shuter and Post 1991).

where

T = the average temperature (° C) during the course of a growing season when temperatures are greater than 14° C but less than 35° C.

An example of using the equations to evaluate alternative temperature regimes is shown in Table 7. The average temperature for the length of the growing season must be estimated. If size is designated as a limiting factor to overwinter survival for a site, a decision must be made on the minimum prewinter size. For example, if it is agreed that the minimum acceptable size is 6 cm, regime B is recommended (Table 7).

The size that should be attained by the onset of winter depends on the number of days during the starvation period. Lengths required for maximum winter survival can be estimated with Fig. 13: (1) estimate the number of days during the winter starvation period (days when the average temperature is ≤10° C), (2) draw a vertical line that intersects the L_0 and the L_1 lines, and (3) read the lengths on the total length axis corresponding to the points of intersection. For example, for 214 days, when the temperature would be ≤10° C, L_0 = 4.5 compared with 8.5 for L_1. Based on energy stores alone, the L_1 length is minimal for 100% survival.

Horning and Pearson (1973) studied growth rates of juvenile smallmouth bass at constant tem-

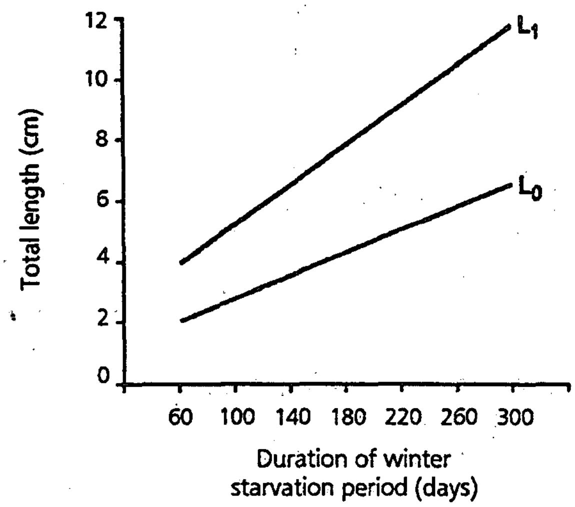

Fig. 13. Relation between duration of the winter starvation period and lengths of young-of-year smallmouth bass for two levels of survival. L_0 = the maximum length for which overwinter survival is 0.0 and L_1 = the minimum length for which survival is 1.0 (from Shuter et al. 1980). See text for an example using the graph.

Table 7. *Estimated lengths attained by young-of-year smallmouth bass before the winter starvation period for three temperature regimes. The mean temperatures pertain to the hypothetical examples in Table 6. It was assumed that the growing season was 60 days and that fry were 1 cm (total length) when they vacated the nest.*

	Alternative temperature regime		
	A	B	C
Mean temperature (° C)	16	19	35
Estimated total length (cm) by winter	3.8[a]	11.1[b]	1.0[c]

[a] Length = 1 cm + (138 days)(0.02 cm/day) = 3.8 cm where 0.02 cm/day = $G = -0.17 + 0.012T$.
[b] Length = 1 cm + (168 days)(0.06 cm/day) = 11.1 cm where 0.06 cm/day = $G = -0.17 + .012T$.
[c] Length = 1 cm + (136 days)(0 cm/day) = 1 cm where 0 cm/day = $G = 1.4 - 0.04T$.

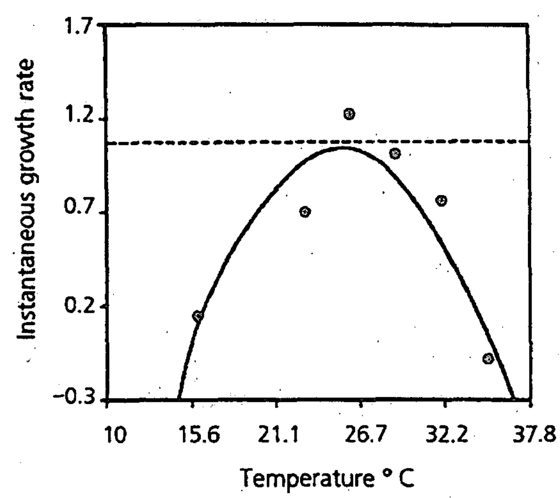

Fig. 14. Relation of temperature and growth rate of juvenile smallmouth bass (from Horning and Pearson 1973).

peratures ranging from 16 to 35° C. The highest instantaneous growth rate was 1.23 at 26° C compared with -0.08 at 35° C (Fig. 14). I assume that the maximum safe temperature of 29° C, which the authors recommended for growth, pertained to fingerling, juvenile, and adult smallmouth bass. The instantaneous growth rate information could be used to compare relative merits of alternative temperature regimes. The approach would be to estimate the average temperature for the growth period for a site and to assume that the regime with the highest growth rate would be preferred, provided that all daily maximum temperatures (not the means) would always be within tolerance limits for growth.

Estimating Effects of Sudden Temperature Drops on Juveniles

If temperature regimes have potential for sudden temperature drops, cold shock and mortality are possible. Equations 10 and 11 (Horning and Pearson 1973) can be used to estimate mortality of juvenile smallmouth bass for sites at which drops occur. The equations only apply to acclimation data within the 15–26° C range. Most mortalities reported for low temperature occurred within 24 h (Horning and Pearson 1973). Although responses to temperature are a function of exposure time, I assume that a short exposure (e.g., ≤1 h) would cause the same results from thermal shock.

$$Y = 0.74X - 9.71 \qquad (10)$$

Equation 10 provides the best fit when estimating the lower exposure temperature (Y) for TL_{50} mortality during a 1–7-day period following a low temperature event; X represents the acclimation temperature (° C).

For example, assume that the average acclimation temperature that preceded a sudden low temperature event is 15° C. Then $Y = 0.74\,(15) - 9.71 = 1.39°$ C.

$$Y = 0.75X - 7.98 \qquad (11)$$

Equation 11 provides the best fit when estimating the exposure temperature (Y) for the predicted 96-h $TL_{0\text{-}10}$ mortality following a low temperature event; X is the acclimation temperature (° C).

In Equation 11 the temperature at which the 96-h $TL_{0\text{-}10}$ mortality would be predicted for an acclimation temperature of 15° C would = 0.75 (15) - 7.98 = 3.27° C.

The time required for acclimation to a given temperature regime is about 7 days (Wismer and Christie 1987). Therefore, when acclimation temperature information is required for Equations 10 and 11, estimation is necessary. One approach would be to assume that the average 7-day temperature that preceded a low temperature event is the acclimation temperature. This value could be specified as the average of the daily maximum and minimum temperatures.

General Considerations

I did not try to address all options for evaluating temperature regimes for protection of smallmouth bass. Instead, several concepts are offered for consideration by field biologists who must decide on approaches for site-specific applications. The following questions should be asked in all applications: Were accurate temperature data (simulated or estimated) used for existing and alternative regimes? Were experts qualified to work on temperature problems involved to attain agreement on appropriate temperature criteria? Was the rationale, including necessary assumptions, clearly documented to disclose the logic for the recommended temperature regime to be implemented? Were the results and recommendations reviewed by qualified experts, and was this step followed by corrective changes that were deemed technically justified?

Other questions to consider when evaluating the quality of simulated temperature regime information should include the following: Is information provided for important life history periods (e.g., spawning)? What is the basis for verifying that simulated temperatures for alternative regimes are accurate? One approach for answering the second question would be to verify that simulation data for previous studies were accurate, based on subsequent monitoring.

The accuracy of worst-case temperatures should receive special emphasis. Knowledge of these temperatures is important; lethal conditions can be a

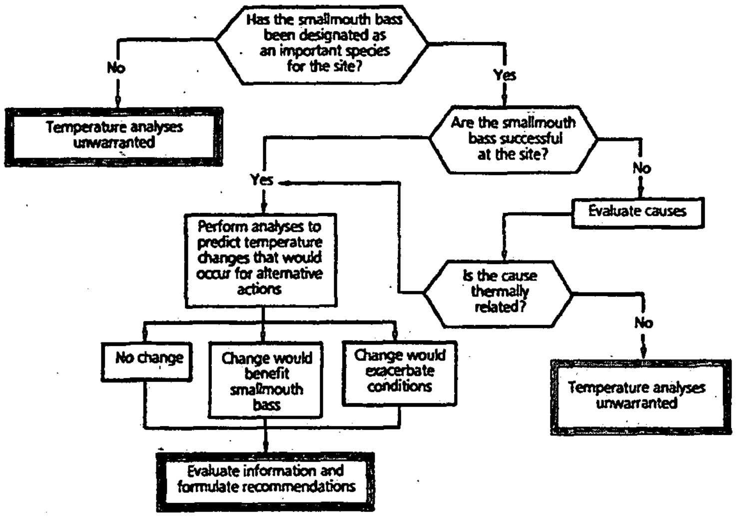

Fig. 15. Flowchart for the temperature analysis process.

one-time event if tolerance levels are exceeded for an important life stage. Accordingly, the temperature range for all critical periods should be simulated for alternative regimes, although emphasis might be on daily mean temperatures for computations. For example, the recommended short-term maximum lethal temperature for incubating eggs is 23° C. Suppose that, for a hypothetical situation, the maximum temperature for 1 day during a hatching period was 25.6° C. Based on temperature-response data, this high temperature for 1 day would be lethal to all eggs. If only the mean temperature (e.g., 17.8° C) for the hatching period were considered, egg mortality would not have been predicted.

Another consideration is the relative growth rates of young-of-year fish. For example, fish require energy in flowing waters to hold position. Accordingly, there might be less energy available for young-of-year growth for a given temperature regime in flowing waters compared with laboratory experiments. Also, in laboratory experiments designed to study growth of young-of-year fish (and other stages), excess rations are usually provided; this condition probably would not exist in nature, which might result in lower growth rates than predicted.

I recommend conducting a preliminary evaluation before deciding that a temperature analysis is warranted (Fig. 15). Basically, three situations exist: smallmouth bass are present and successful, they are absent, or they are present and marginally successful. If smallmouth bass are absent at a site and their establishment is being considered, an attempt should be made to agree on limiting factors, including physical and chemical habitat conditions. Reference information for a preliminary evaluation should include the Fish and Wildlife Service habitat suitability index publication on smallmouth bass (Edwards et al. 1983).

Existing adverse effects of temperature on specific life stages and activities should be documented including an inadequate prewinter growing period for age 0 fish, and intolerable temperature extremes for eggs, fry, or older fish. The purpose of documentation would be to emphasize improvements that might be necessary in a new temperature regime. A proactive approach would be to use the information to propose alternative regimes instead of waiting to respond to those proposed by a developer.

When evaluating alternative temperature regimes, ensure that indirect effects are considered and documented. As an example, suppose that spawning is delayed a month and that, from temperature data alone, it is predicted that young-of-year fish would attain an adequate size for winter survival. This assumption might be invalid because there is no guarantee that a new regime would result in synchronized abundance and size distributions (Adams et al. 1982) of food for young fish.

Acknowledgments

K. Lindgren, the National Ecology Research Center librarian, and her staff provided copies of most of the references in this report. D. Crawford and D. Pondelek drafted the figures. C. Stalnaker recommended useful information sources.

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*U.S. GOVERNMENT PRINTING OFFICE 1993-0-774-275/80001

A list of current *Resource Publications* follows.

174. Obsolete English Names of North American Birds and Their Modern Equivalents, by Richard C. Banks. 1988. 37 pp.
175. Procedures for the Analysis of Band-recovery Data and User Instructions for Program MULT, by Michael J. Conroy, James E. Hines, and Byron K. Williams. 1989. 61 pp.
176. Sago Pondweed (*Potamogeton pectinatus* L.): A Literature Review, by Harold A. Kantrud. 1990. 90 pp.
177. Field Manual for the Investigation of Fish Kills, by Fred P. Meyer and Lee A. Barclay, editors. 1990. 120 pp.
178. Section 404 and Alterations in the Platte River Basin of Colorado, by Douglas N. Gladwin, Mary E. Jennings, James E. Roelle, and Duane A. Asherin. 1992. 19 pp.
179. Hydrology of the Middle Rio Grande From Velarde to Elephant Butte Reservoir, New Mexico, by Thomas F. Bullard and Stephen G. Wells. 1992. 51 pp.
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184. Methods for Detoxifying the Lampricide 3-Trifluoromethyl-4-Nitrophenol in a Stream, by Philip A. Gilderhus, Terry D. Bills, and David A. Johnson. 1992. 5 pp.
185. Group Decision-making Techniques for Natural Resource Management Applications, by Beth A. K. Coughlan and Carl L. Armour. 1992. 55 pp.
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190. Assessment of Habitat of Wildlife Communities on the Snake River, Jackson, Wyoming, by Richard L. Schroeder and Arthur W. Allen. 1992. 21 pp.

TAKE PRIDE

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U.S. DEPARTMENT OF THE INTERIOR
FISH AND WILDLIFE SERVICE

As the Nation's principal conservation agency, the Department of the Interior has responsibility for most of our nationally owned public lands and natural resources. This includes fostering the wisest use of our lands and water resources, protecting our fishes and wildlife, preserving the environmental and cultural values of our national parks and historical places, and providing for the enjoyment of life through outdoor recreation. The Department assesses our energy and mineral resources and attempts to assure that their development is in the best interests of all our people. The Department also has a major responsibility for Native American reservation communities and for people who live in island territories under U.S. administration.

Lee Nuclear Station Response to Request for Additional Information (RAI)

RAI Letter Dated: August 21, 2008

Reference NRC RAI Number: ER RAI-64

NRC RAI:

Explain the rationale behind the coarse screening criteria for the cooling water supply in the Alternative Site Selection report.

Duke Energy Response:

This RAI refers to one of four metrics (lake or river) used in the coarse screen of potential sites with respect to cooling water supply. The four metrics are defined in Table 5-1, Criterion P1, of the Siting Study, and were applied in the coarse screening of potential sites (Appendix C). The following is provided to clarify the metric in question:

- A rating of 4 was assigned to sites that are located directly on a permanent large lake or reservoir system that is part of a major river system (e.g., Oconee Site location on the Keowee Reservoir that is part of the Savannah River watershed/system).
- A rating of 3 was assigned to sites that are located on a smaller reservoir that is part of a run-of-river system.
- A rating of 2 was assigned to sites that are located on a river only (no existing reservoir).

Relative to the coarse screening in Appendix C, note that the Cherokee site, which scored a 4, and the Broad SC 5/Duke 25 site, which scored a 3 for this component of the cooling water supply rating, are both located on smaller reservoirs within the Broad River System, consistent with a rating of 3 as defined above. Because the Cherokee site also possessed an existing off-river reservoir that had been constructed previously as part of the earlier licensing effort, its rating for this particular metric was raised to a 4.

It is important to note that the final ratings assigned to sites during the coarse screen, relative to cooling water supply, were based on a composite (average) of four metrics or subratings: estimated 7Q10 low-flow volumes, 7-day minimum flow volumes, separate Duke Energy assessment of each river system, and the characterization of lake or river (which is the subject of this RAI).

The metric in question does not directly evaluate quantity of water available but considers the location of the site within the water system as a whole. The available water quantity is directly evaluated in the metrics for estimated 7Q10 low-flow volumes, 7-day minimum flow volumes.

The evaluation of potential sites remains unchanged.

Associated Revisions to the Lee Nuclear Station Combined License Application:

None

Associated Attachments:

None

Lee Nuclear Station Response to request for Additional Information (RAI)

RAI Letter Dated: August 21, 2008

Reference NRC RAI Number: ER RAI-71

NRC RAI:

Provide a copy of the ACE 404 permit for Make-Up Ponds A and B.

Duke Energy Response:

A copy of the requested permit is attached to this response.

Associated Revisions to the Lee Nuclear Station Combined License Application:

None

Associated Attachment:

Attachment 71-1 404 permit for Cherokee Nuclear Station

Lee Nuclear Station Response to Request for Additional Information (RAI)

Attachment 71-1 to RAI 71

404 permit for Cherokee Nuclear Station

Lee Nuclear Station Response to Request for Additional Information (RAI)

Attachment 71-1 to RAI 71

404 permit for Cherokee Nuclear Station

DEPARTMENT OF THE ARMY
CHARLESTON DISTRICT, CORPS OF ENGINEERS
P. O. BOX 919
CHARLESTON, S.C. 29402

RECEIVED
JAN 18 1977
DUKE POWER COMPANY
CIVIL/ENV. DIVISION

SACCO-P

12 January 1977

RSB RSC

Duke Power Company
P. O. Box 2178
Charlotte, North Carolina 28242

Gentlemen:

Reference is made to your letter dated 1 April 1976 requesting a Department of the Army permit to deposit dredged and fill material in the waters of Ninety Nine Island Reservoir, which is a tributary of the Broad River, approximately 2000' upstream from Duke's Ninety Nine Island Hydro Station, eight (8) miles southeast of Gaffney and twenty-one (21) miles northeast of Spartanburg in Cherokee County, South Carolina.

There is inclosed Department of the Army Permit #76-4A-115 issued by the District Engineer dated 12 January 1977 authorizing you to perform the work specified therein in accordance with the plans shown on the drawings attached thereto. This permit is issued under the provisions of the Federal laws for the protection and preservation of the navigable waters of the United States.

The inclosed "NOTICE OF AUTHORIZATION" must be conspicuously displayed at the site of work during the entire time of construction.

The copy of "Water Quality Considerations for Construction and Dredging Operations" issued in June 1968 and revised April 1971 by the Water Quality Office of the Environmental Protection Agency is inclosed for your guidance.

Sincerely,

for William C Mattei

HARRY S. WILSON, JR.
Colonel, Corps of Engineers
District Engineer

WILLIAM C. MATTEI
Major, Corps of Engineers
Deputy District Engineer

Incls
as stated

VANGUARD OF FREEDOM BICENTENNIAL 1775-1975 UNITED STATES ARMY

AMERICAN REVOLUTION BICENTENNIAL 1776-1976

DEPARTMENT OF THE ARMY
CORPS OF ENGINEERS

NOTICE OF AUTHORIZATION

12 January 19 77

A PERMIT TO deposit dredged and fill material to construct a nuclear electrical power generating station

AT the waters of Ninety Nine Island Reservoir which is a tributary of the Broad River

HAS BEEN ISSUED TO Duke Power Company ON 12 January 19 77

ADDRESS OF PERMITTEE P.O. Box 2178, Charlotte, NC 28242

PERMIT NUMBER 76-4A-115

William C Mattei, Maj CE
Deputy District Engineer

ENG Form 4336
Jul 70

THIS NOTICE MUST BE CONSPICUOUSLY DISPLAYED AT THE SITE OF WORK.

*GPO 1976 204-377

Application No. 76-4A-115

Name of Applicant Duke Power Company

Effective Date 12 January 1977

Expiration Date (If applicable) 31 December 1982

DEPARTMENT OF THE ARMY
PERMIT

Referring to written request dated 1 April 1976 for a permit to:

( ) Perform work in or affecting navigable waters of the United States, upon the recommendation of the Chief of Engineers, pursuant to Section 10 of the Rivers and Harbors Act of March 3, 1899 (33 U.S.C. 403);

(X) Discharge dredged or fill material into navigable waters upon the issuance of a permit from the Secretary of the Army acting through the Chief of Engineers pursuant to Section 404 of the Federal Water Pollution Control Act (86 Stat. 816, P.L. 92-500);

( ) Transport dredged material for the purpose of dumping it into ocean waters upon the issuance of a permit from the Secretary of the Army acting through the Chief of Engineers pursuant to Section 103 of the Marine Protection, Research and Sanctuaries Act of 1972 (86 Stat. 1052; P.L. 92-532);

Duke Power Company
P. O. Box 2178
Charlotte, North Carolina 28242

◄ (Here insert the full name and address of the permittee)

is hereby authorized by the Secretary of the Army:

to deposit dredged and fill material to construct a nuclear electrical power generating station

◄ (Here describe the proposed structure or activity, and its intended use. In the case of an application for a fill permit, describe the structures, if any, proposed to be erected on the fill. In the case of an application for the discharge of dredged or fill material into navigable waters or the transportation for discharge in ocean waters of dredged material, describe the type and quantity of material to be discharged.)

in the waters of Ninety Nine Island Reservoir, which is a tributary of the Broad River,

◄ (Here to be named the ocean, river, harbor, or waterway concerned.)

at a location approx. 2000' upstream from Duke's Ninety Nine Island Hydro Station, 8 miles southeast of Gaffney & 21 miles northeast of Spartanburg in Cherokee County, South Carolina,

◄ (Here to be named the nearest well-known locality—preferably a town or city—and the distance in miles and tenths from some definite point in the same, stating whether above or below or giving direction by points of compass.)

in accordance with the plans and drawings attached hereto which are incorporated in and made a part of this permit (on drawings: give file number or other definite identification marks);

entitled: Cherokee Nuclear Station, Cherokee County, S. C. Application by: Duke Power Company, dated 5 March 1976,

subject to the following conditions:

I. General Conditions:

a. That all activities identified and authorized herein shall be consistent with the terms and conditions of this permit; and that any activities not specifically identified and authorized herein shall constitute a violation of the terms and conditions of this permit which may result in the modification, suspension or revocation of this permit, in whole or in part, as set forth more specifically in General Conditions j or k hereto, and in the institution of such legal proceedings as the United States Government may consider appropriate, whether or not this permit has been previously modified, suspended or revoked in whole or in part.

b. That all activities authorized herein shall, if they involve a discharge or deposit into navigable waters or ocean waters, be at all times consistent with applicable water quality standards, effluent limitations and standards of performance, prohibitions, and pretreatment standards established pursuant to Sections 301, 302, 306 and 307 of the Federal Water Pollution Control Act of 1972 (P.L. 92-500; 86 Stat. 816), or pursuant to applicable State and local law.

c. That when the activity authorized herein involves a discharge or deposit of dredged or fill material into navigable waters, the authorized activity shall, if applicable water quality standards are revised or modified during the term of this permit, be modified, if necessary, to conform with such revised or modified water quality standards within 6 months of the effective date of any revision or modification of water quality standards, or as directed by an implementation plan contained in such revised or modified standards, or within such longer period of time as the District Engineer, in consultation with the Regional Administrator of the Environmental Protection Agency, may determine to be reasonable under the circumstances.

d. That the permittee agrees to make every reasonable effort to prosecute the work authorized herein in a manner so as to minimize any adverse impact of the work on fish, wildlife and natural environmental values.

e. That the permittee agrees to prosecute the work authorized herein in a manner so as to minimize any degradation of water quality.

f. That the permittee shall permit the District Engineer or his authorized representative(s) or designee(s) to make periodic inspections at any time deemed necessary in order to assure that the activity being performed under authority of this permit is in accordance with the terms and conditions prescribed herein.

g. That the permittee shall maintain the structure or work authorized herein in good condition and in accordance with the plans and drawings attached hereto.

h. That this permit does not convey any property rights, either in real estate or material, or any exclusive privileges; and that it does not authorize any injury to property or invasion of rights or any infringement of Federal, State, or local laws or regulations, nor does it obviate the requirement to obtain State or local assent required by law for the activity authorized herein.

i. That this permit does not authorize the interference with any existing or proposed Federal project and that the permittee shall not be entitled to compensation for damage or injury to the structures or work authorized herein which may be caused by or result from existing or future operations undertaken by the United States in the public interest.

j. That this permit may be summarily suspended, in whole or in part, upon a finding by the District Engineer that immediate suspension of the activity authorized herein would be in the general public interest. Such suspension shall be effective upon receipt by the permittee of a written notice thereof which shall indicate (1) the extent of the suspension, (2) the reasons for this action, and (3) any corrective or preventative measures to be taken by the permittee which are deemed necessary by the District Engineer to abate imminent hazards to the general public interest. The permittee shall take immediate action to comply with the provisions of this notice. Within ten days following receipt of this notice of suspension, the permittee may request a hearing in order to present information relevant to a decision as to whether his permit should be reinstated, modified or revoked. If a hearing is requested, it shall be conducted pursuant to procedures prescribed by the Chief of Engineers. After completion of the hearing, or within a reasonable time after issuance of the suspension notice to the permittee if no hearing is requested, the permit will either be reinstated, modified or revoked.

k. That this permit may be either modified, suspended or revoked in whole or in part if the Secretary of the Army or his authorized representative determines that there has been a violation of any of the terms or conditions of this permit or that such action would otherwise be in the public interest. Any such modification, suspension, or revocation shall become effective 30 days after receipt by the permittee of written notice of such action which shall specify the facts or conduct warranting same unless (1) within the 30-day period the permittee is able to satisfactorily demonstrate that (a) the alleged violation of the terms and the conditions of this permit did not, in fact, occur or (b) the alleged violation was accidental, and the permittee has been operating in compliance with the terms and conditions of the permit and is able to provide satisfactory assurances that future operations shall be in full compliance with the terms and conditions of this permit; or (2) within the aforesaid 30-day period, the permittee requests that a public hearing be held to present oral and written evidence concerning the proposed modification, suspension or revocation. The conduct of this hearing and the procedures for making a final decision either to modify, suspend or revoke this permit in whole or in part shall be pursuant to procedures prescribed by the Chief of Engineers.

l. That in issuing this permit, the Government has relied on the information and data which the permittee has provided in connection with his permit application. If, subsequent to the issuance of this permit, such information and data prove to be false, incomplete or inaccurate, this permit may be modified, suspended or revoked, in whole or in part, and/or the Government may, in addition, institute appropriate legal proceedings.

m. That any modification, suspension, or revocation of this permit shall not be the basis for any claim for damages against the United States.

76-4A-115

n. That the permittee shall notify the District Engineer at what time the activity authorized herein will be commenced, as far in advance of the time of commencement as the District Engineer may specify, and of any suspension of work, if for a period of more than one week, resumption of work and its completion.

o. That if the activity authorized herein is not started on or before 31st day of October, 19 77, (one year from the date of issuance of this permit unless otherwise specified) and is not completed on or before 31st day of December, 19 82 (three years from the date of issuance of this permit unless otherwise specified) this permit, if not previously revoked or specifically extended, shall automatically expire.

p. That no attempt shall be made by the permittee to prevent the full and free use by the public of all navigable waters at or adjacent to the activity authorized by this permit.

q. That if the display of lights and signals on any structure or work authorized herein is not otherwise provided for by law, such lights and signals as may be prescribed by the United States Coast Guard shall be installed and maintained by and at the expense of the permittee.

r. That this permit does not authorize or approve the construction of particular structures, the authorization or approval of which may require authorization by the Congress or other agencies of the Federal Government.

s. That if and when the permittee desires to abandon the activity authorized herein, unless such abandonment is part of a transfer procedure by which the permittee is transferring his interests herein to a third party pursuant to General Condition v hereof, he must restore the area to a condition satisfactory to the District Engineer.

t. That if the recording of this permit is possible under applicable State or local law, the permittee shall take such action as may be necessary to record this permit with the Register of Deeds or other appropriate official charged with the responsibility for maintaining records of title to and interests in real property.

u. That there shall be no unreasonable interference with navigation by the existence or use of the activity authorized herein.

v. That this permit may not be transferred to a third party without prior written notice to the District Engineer, either by the transferee's written agreement to comply with all terms and condition of this permit or by the transferee subscribing to this permit in the space provided below and thereby agreeing to comply with all terms and conditions of this permit. In addition, if the permittee transfers the interests authorized herein by conveyance of realty, the deed shall reference this permit and the terms and conditions specified herein and this permit shall be recorded along with the deed with the Register of Deeds or other appropriate official.

The following Special Conditions will be applicable when appropriate:

STRUCTURES FOR SMALL BOATS: That permittee hereby recognizes the possibility that the structure permitted herein may be subject to damage by wave wash from passing vessels. The issuance of this permit does not relieve the permittee from taking all proper steps to insure the integrity of the structure permitted herein and the safety of boats moored thereto from damage by wave wash and the permittee shall not hold the United States liable for any such damage.

DISCHARGE OF DREDGED MATERIAL INTO OCEAN WATERS: That the permittee shall place a copy of this permit in a conspicuous place in the vessel to be used for the transportation and/or dumping of the dredged material as authorized herein.

ERECTION OF STRUCTURE IN OR OVER NAVIGABLE WATERS: That the permittee, upon receipt of a notice of revocation of this permit or upon its expiration before completion of the authorized structure or work, shall, without expense to the United States and in such time and manner as the Secretary of the Army or his authorized representative may direct, restore the waterway to its former conditions. If the permittee fails to comply with the direction of the Secretary of the Army or his authorized representative, the Secretary or his designee may restore the waterway to its former condition, by contract or otherwise, and recover the cost thereof from the permittee.

76-4A-115

MAINTENANCE DREDGING: (1) That when the work authorized herein includes periodic maintenance dredging, it may be performed under this permit for ______ years from the date of issuance of this permit (ten years unless otherwise indicated); and (2) That the permittee will advise the District Engineer in writing at least two weeks before he intends to undertake any maintenance dredging.

II. **Special Conditions** (Here list conditions relating specifically to the proposed structure or work authorized by this permit):

This permit shall become effective on the date of the District Engineer's signature.

Permittee hereby accepts and agrees to comply with the terms and conditions of this permit.

W H Owen _______________ 12-27-76 _______________

PERMITTEE DATE

Duke Power Company

BY AUTHORITY OF THE SECRETARY OF THE ARMY:

for William C Mattei _______________ 12 JAN 1977 _______________

DATE

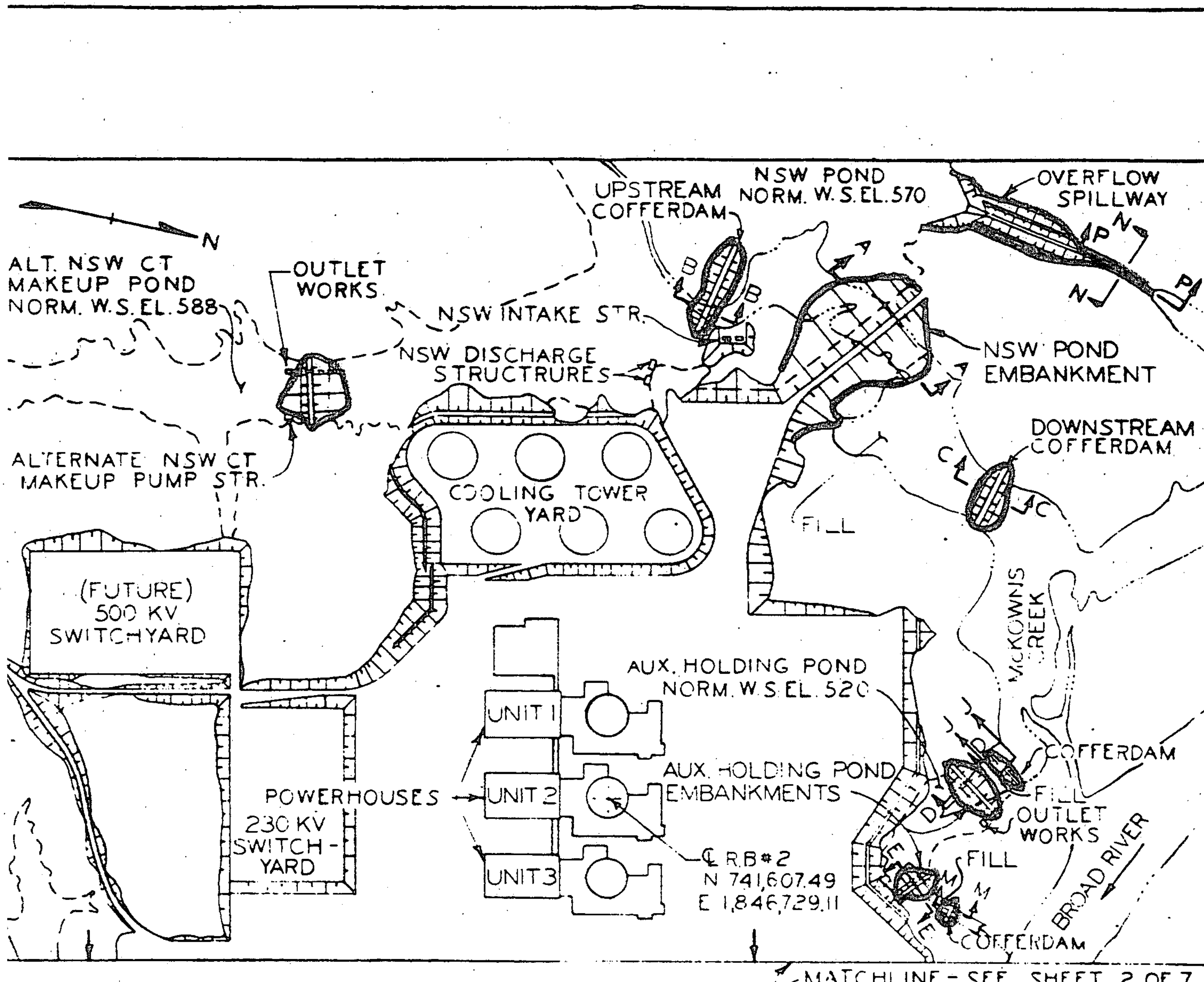
HARRY S. WILSON, JR., Colonel WILLIAM C. MATTEI
DISTRICT ENGINEER,
U.S. ARMY, CORPS OF ENGINEERS
Major, Corps of Engineers
Deputy District Engineer

Transferee hereby agrees to comply with the terms and conditions of this permit.

_______________ _______________

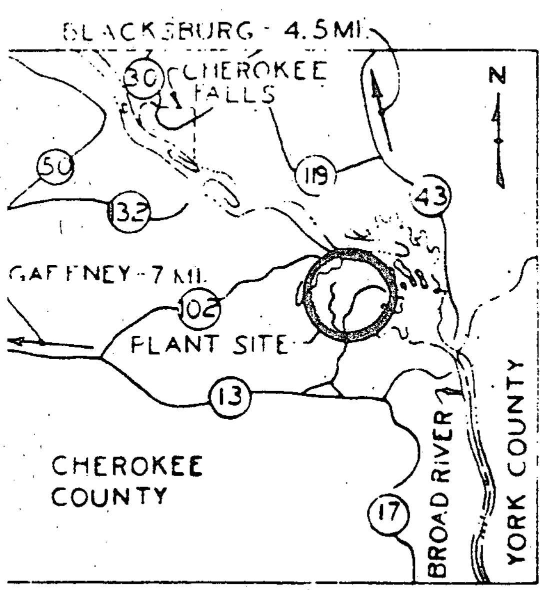
TRANSFEREE DATE

76-4A-115



PLAN

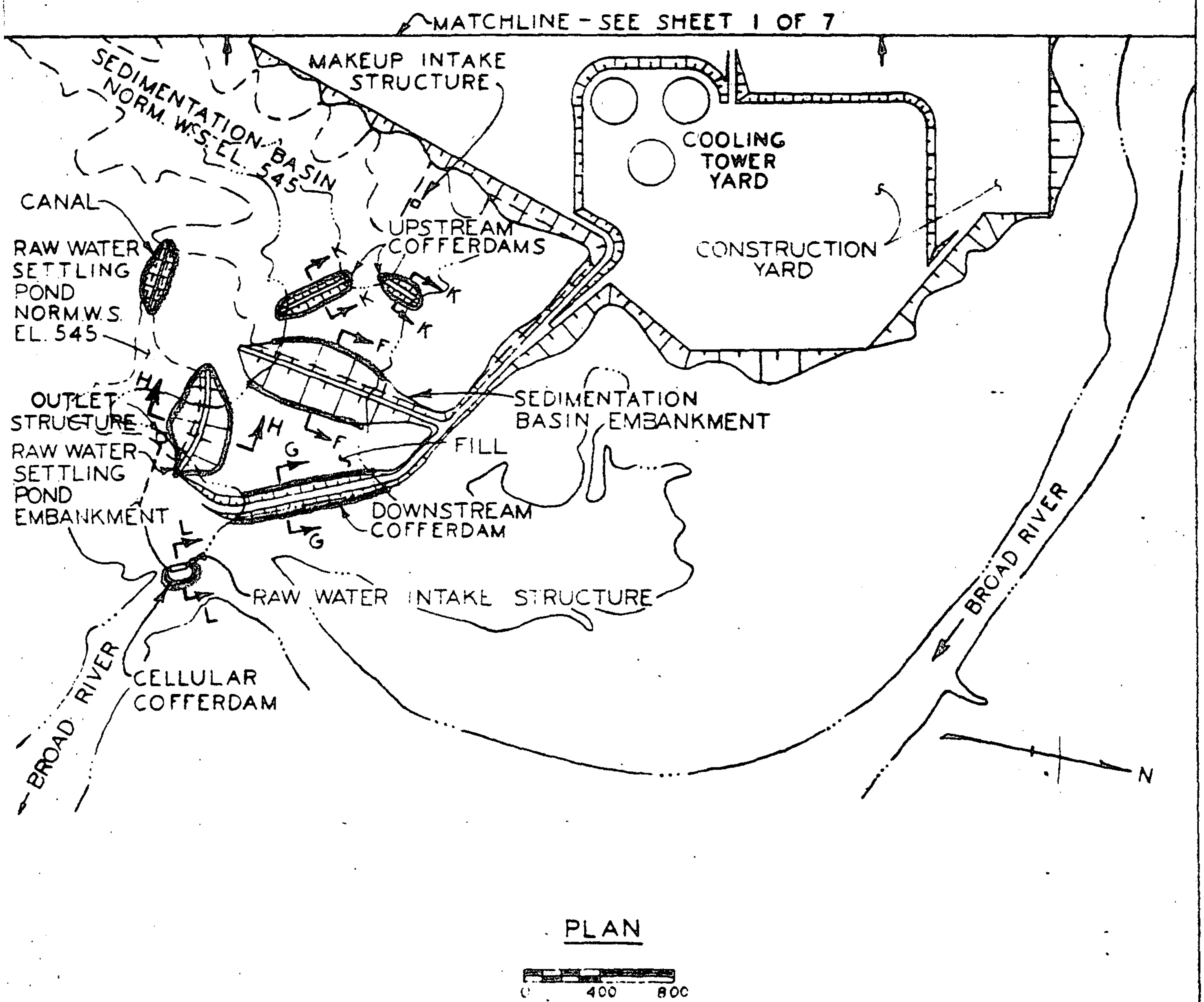
0 400 800



NOTE:
TOTAL FILL = 1,664,200 CU. YD.
TOTAL EXCAVATION = 243,400 CU. YD.

76-4A-115

CHEROKEE NUCLEAR STATION
COUNTY OF CHEROKEE, STATE - SOUTH CAROLINA
APPLICATION BY DUKE POWER COMPANY
SHEET 1 OF 7
MARCH 5, 1976

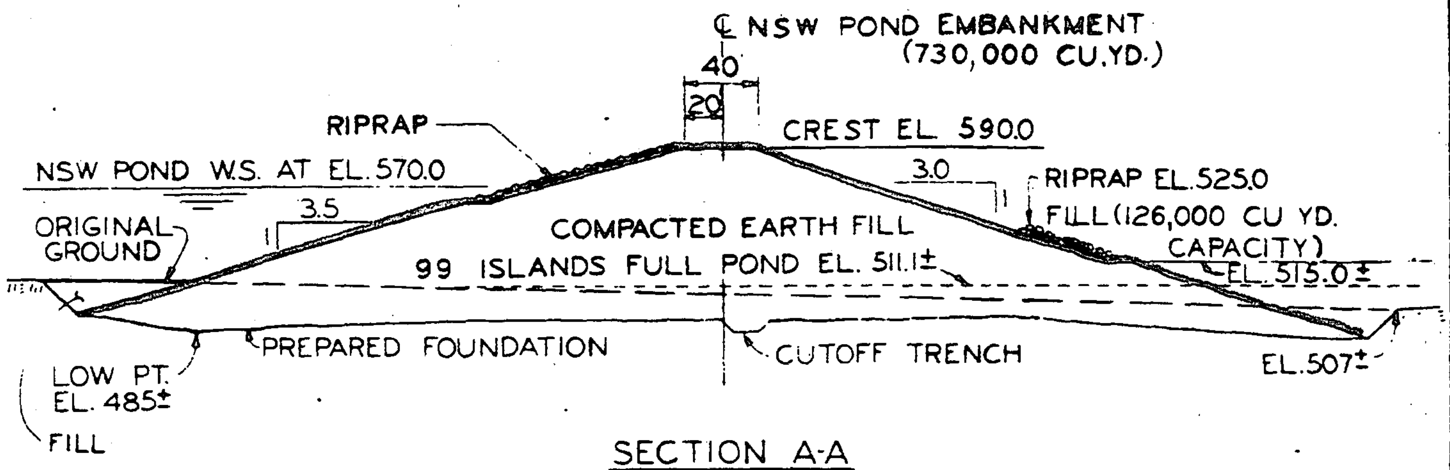


CHEROKEE NUCLEAR STATION

SHEET 2 OF 7

MARCH 5, 1976

76-4A-115



SECTION A-A

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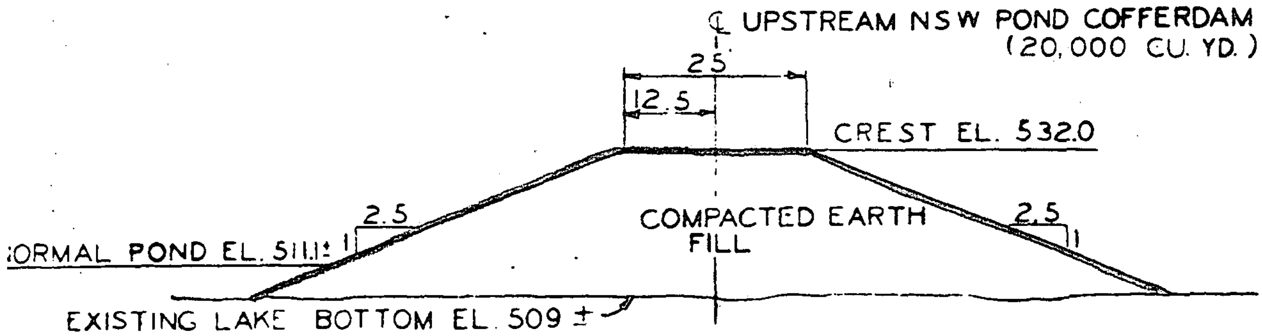

SECTION B-B

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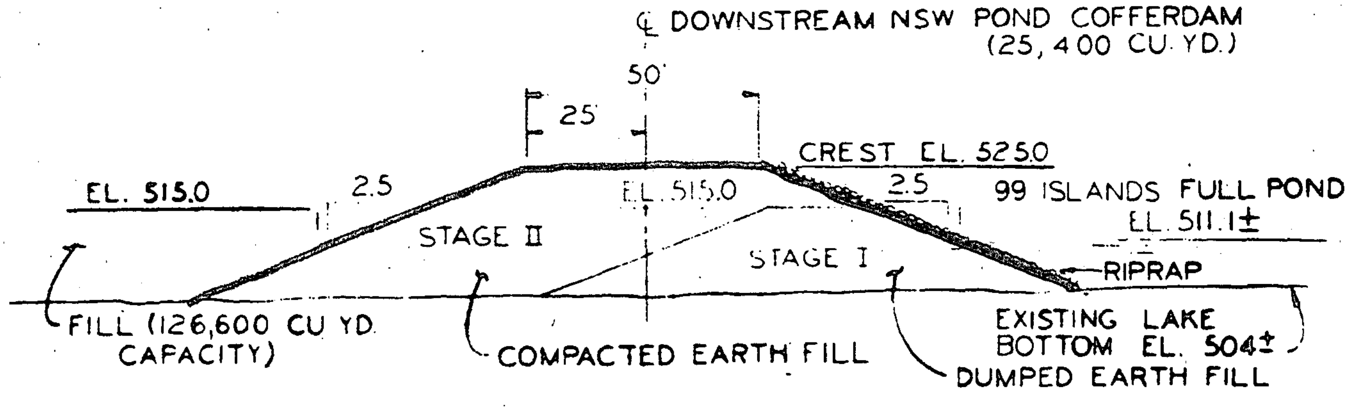

SECTION C-C

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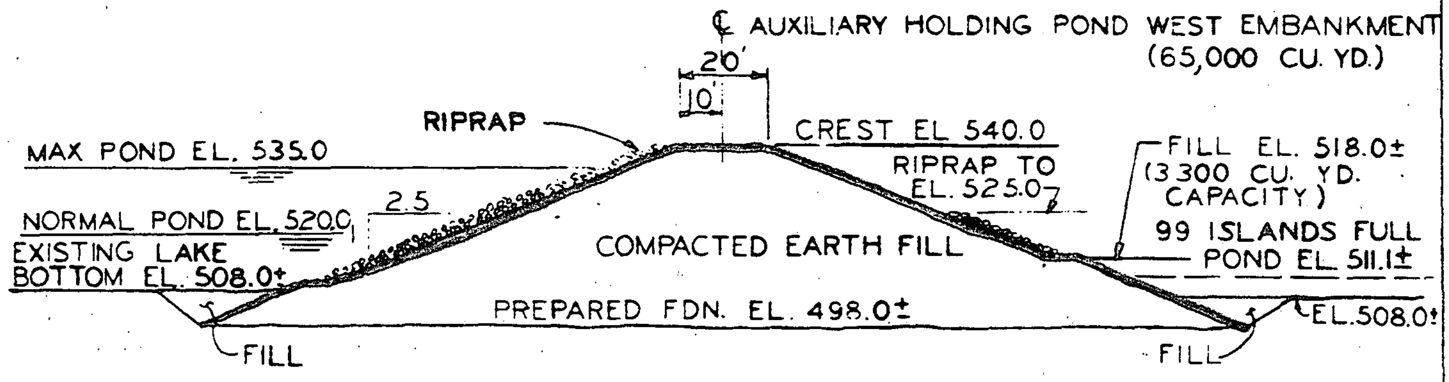
SCALE IN FEET

76-4A-115

CHEROKEE NUCLEAR STA.
SHEET 3 OF 7
MARCH 5, 1976



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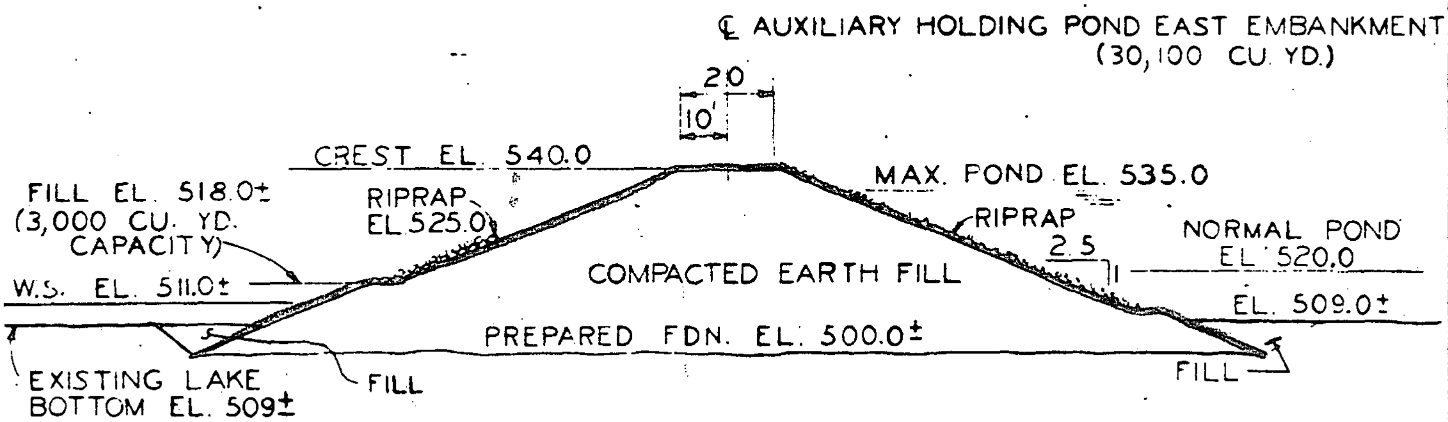

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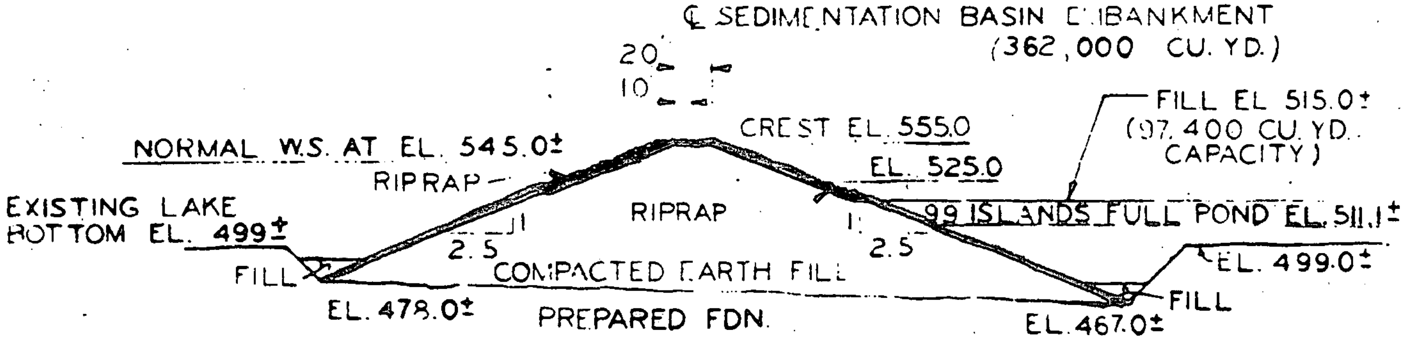

SECTION F-F

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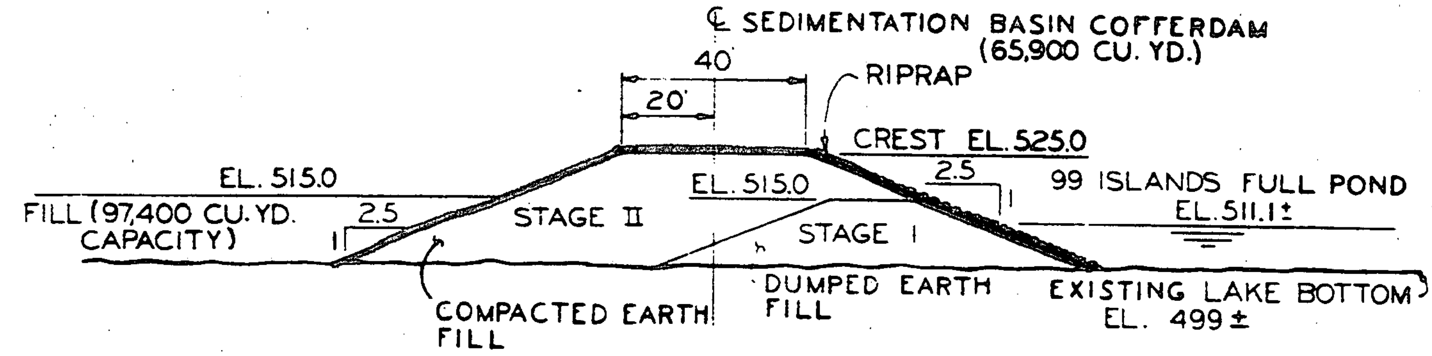
SCALE IN FEET

76-4A-115

CHEROKEE NUCLEAR STA.
SHEET 4 OF 7
MARCH 5, 1976



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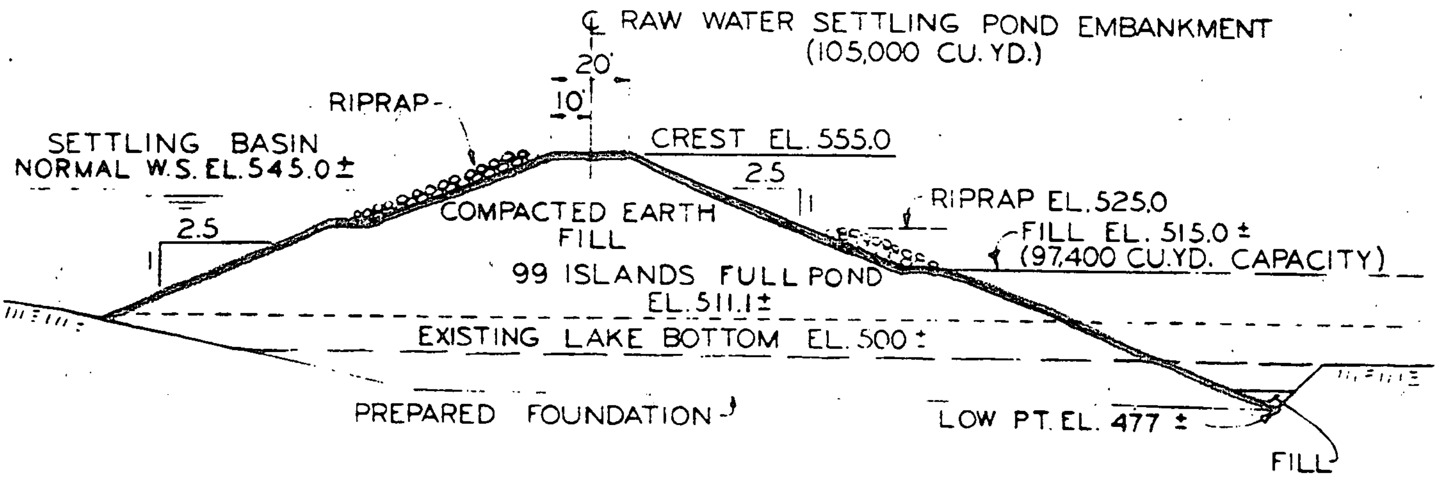

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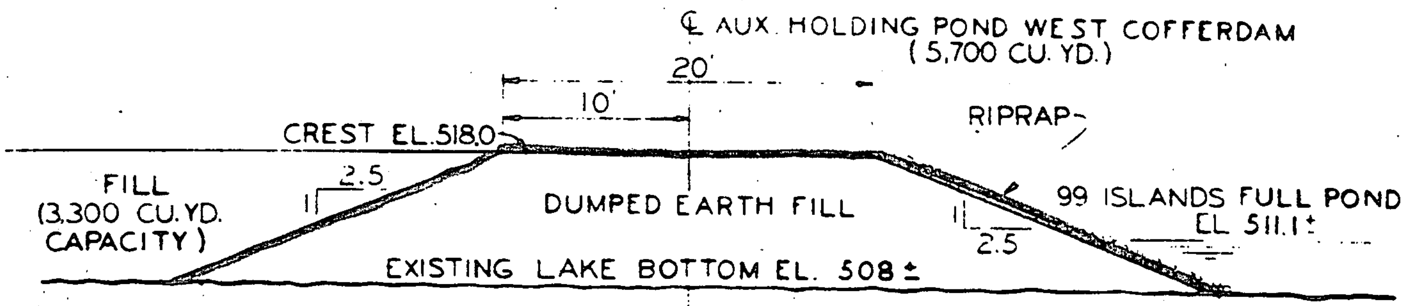

SECTION J-J

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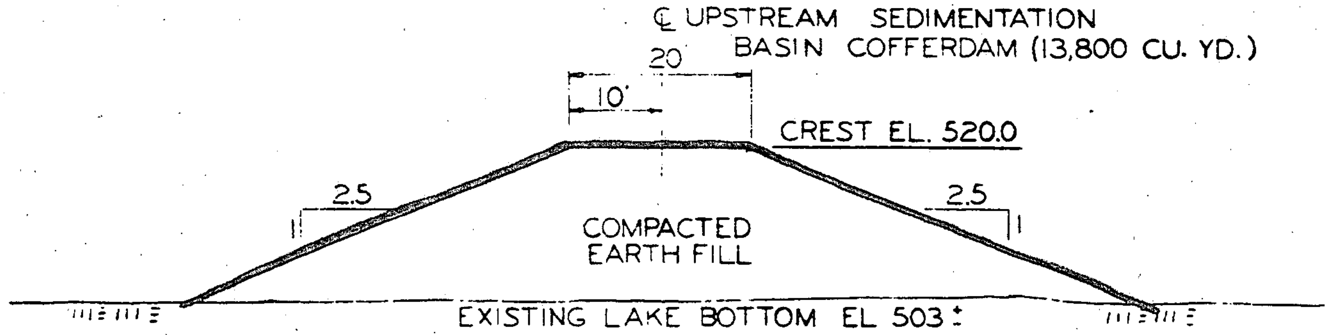
SCALE IN FEET

76--A-115

CHEROKEE NUCLEAR STA.
SHEET 5 OF 7
MARCH 5, 1976



SECTION K·K

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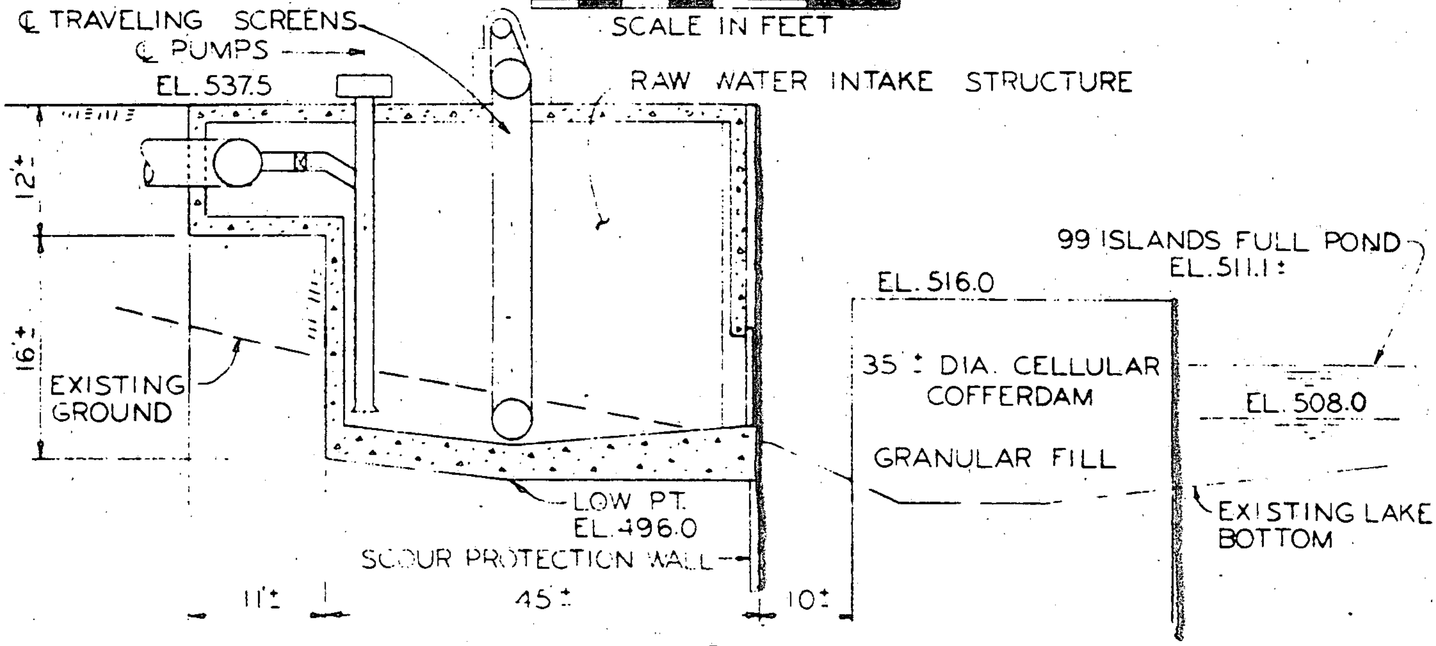

SECTION L-L

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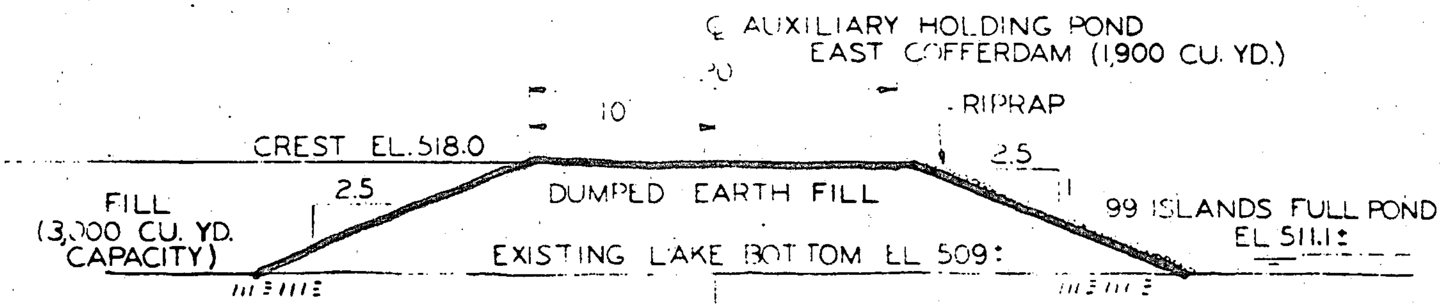

SECTION M·M

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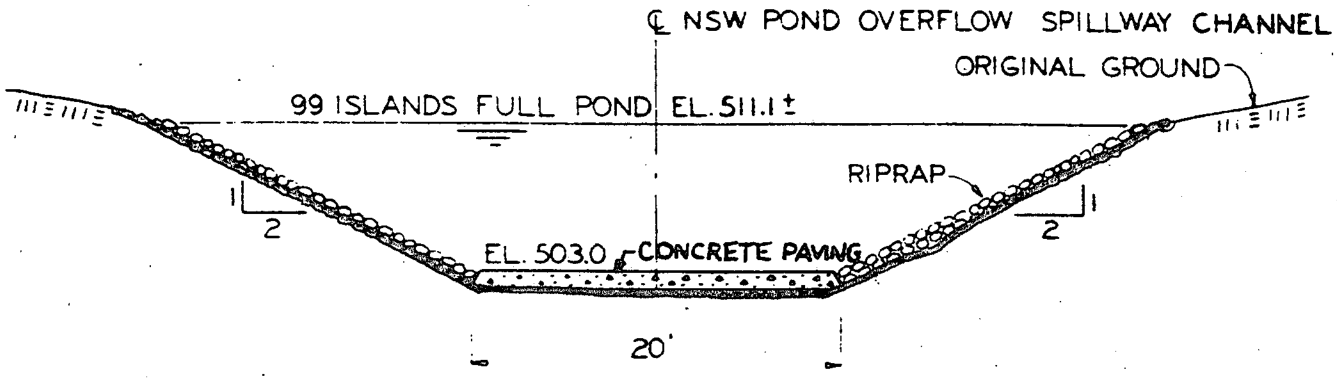
SCALE IN FEET

76-4A-115

CHEROKEE NUCLEAR STA.
SHEET 6 OF 7
MARCH 5, 1976



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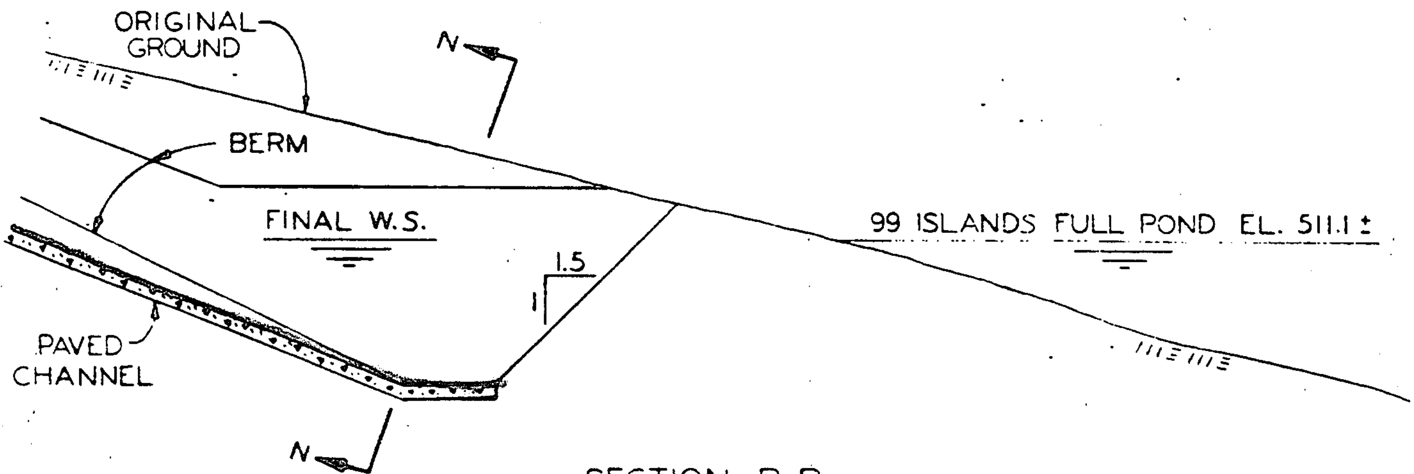

SECTION P-P

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VERT. SCALE IN FEET

76-4A-115

CHEROKEE NUCLEAR STA.
SHEET 7 OF 7
MARCH 5, 1976

ENVIRONMENTAL PROTECTION AGENCY
WATER QUALITY OFFICE
SOUTHEAST REGION
FEDERAL FACILITIES BRANCH

Water Quality Considerations For Construction and Dredging Operations

Revised April 1971

I. General

Construction and dredging operations frequently cause serious water quality problems requiring special considerations. In the planning, design construction, and operation of water oriented projects, fully cooperative actions should be developed with local, State and Federal authorities having responsibilities for public health, conservation and water pollution control. Generally, the criteria for these considerations will be reflected in the State and Federal Water Quality Standards. Section 21(b), Public Law 91-224, "Water Quality Improvement Act of 1970," requires applicants for Federal licenses or permits to conduct any activity which may result in a discharge into navigable waters to provide the licensing or permitting agency certification that there is reasonable assurance that such activity will be conducted in a manner which will not violate applicable water quality standards.

EPA concurrence in the implementation of projects or permits is contingent upon full compliance with existing local, State and Federal laws and regulations. When violations occur in any phase of a program, such concurrence is automatically terminated and responsible corrective action by the sponsor is in order.

II. Waste Disposal

All waste discharges that are generated in connection with the construction and operation of projects shall be provided with adequate treatment in accordance with local, State and Federal laws and regulations. The quality of the effluent from all outfalls constructed or operated by contract or permit shall provide compliance with State and Federal Water Quality Standards.

III. Piers, Docks and Marinas

In the construction of piers, docks and marinas positive steps shall be taken to insure that the proposed project includes adequate safeguards to prevent pollution from marine toilet sources, garbage, bilge, and other discharges. Such safeguards are to include sewage disposal facilities designed in accordance with State and Federal standards to receive and dispose of wastes from boats, docks and private personnel as required to prevent violation of the water quality standards.

Provisions shall be made to require that any petroleum fuel dispensing equipment or material handling equipment on docks be provided with safety features which will prevent the accidental discharge of petroleum products, chemicals, toxicants or other pollutants into the adjacent waters.

Tank farms shall be protected by dikes of sufficient height and freeboard to contain the oil from the tanks in case of leakage. Where drains are provided to drain off water after storms, a "fail safe" system of operation shall be provided.

Trash containers shall be furnished at adequate locations to control solid wastes.

IV. Dredging and Disposal Operations

Dredging and disposal operations shall be carried out in such a manner as to provide compliance with applicable State and Federal Water Quality Standards and minimize damage to aquatic biota and particularly bottom fauna. Attention shall be given to the dredging and disposal of materials containing sanitary and/or industrial sludge or toxic substances. The disturbance of anaerobic and/or toxic deposits often encountered in the vicinity of waste outfalls can seriously affect water quality. Sediments containing pollutants in quantities which will violate the applicable water quality standards shall not be returned to the watercourse and shall not be dredged where such operation will cause a violation of the water quality standards even if the materials are pumped ashore and completely contained.

V. Dredging Techniques

Consideration in the design, maintenance and operation of dredging equipment shall be directed to minimizing pollutional effects.

In order that dredging operations be carried out with the minimum damage to the environment and adjacent water quality values, the EPA recommends the following:

A. The depth of cut in a single swing of the dredge be limited to that depth which precludes the collapse of the facing material.

B. The cutter head speed be controlled to obtain reasonable progress without producing excessive turbidity.

C. Air release devices in the discharge piping be controlled to minimize the spilling of spoil in the waterway.

D. Discharges to settling basins or to watercourses be accomplished with the minimum of turbulence. Discharge pipes to settling basins be located at or near the basin water surface. Discharges from settling basins be controlled so as to prevent erosion in the outlet ditch.

E. Where silting and turbidity must be positively controlled because of the close proximity of the dredging operations to water intakes, resort areas, oyster beds, etc., a diaper or enclosure be provided for the cutter head and/or discharge pipe outlet to control the drift of suspended materials. Lesser control can be obtained by using a submerged outlet.

F. In waters where the dredged materials have a high oxygen reduction potential or in eutrophic waters, consideration be given to scheduling the dredging operations in cold weather.

G. Where possible, dispose of all spoil on land in a site above mean high water line to minimize damage to aquatic biota and water quality.

VI. Land Disposal Sites

Land disposal sites should be selected in areas above mean high water line. The areas selected should be of minimum value to wildlife. The selection of land disposal sites should be closely coordinated with the Bureau of Sports Fisheries and Wildlife, USDI, and the State Fish and Game Commission.

VII. Spoil Area Retention Basins and Settling Ponds

Dredged materials are usually retained and settled in one of the following:

A. A pond formed by a natural depression.

B. An area completely enclosed with perimeter dikes or retention mounds thus forming a retention basin.

C. A pond formed by bulkheads made of sheet piling.

D. A pond formed by a combination of a natural depression and retention mounds or various combinations of retention mounds, bulkheads and/or natural depressions.

E. A hopper dredge.

Retention basins shall be designed to contain safely both the liquid and solids load predicted. The disposal structure shall be considered as a settling pond and designed accordingly. The pond shall have sufficient surface area and depth to adequately settle the type of material being dredged. The expansion of the solids upon removal from the originally deposited location shall be considered in determining pool volume. Sufficient freeboard shall be allowed above the maximum predicted flow line to prevent overtopping. A freeboard of two (2) feet above the maximum predicted pool surface is recommended.

The pool depth should be a minimum of from two (2) to three (3) feet but shall be designed with sufficient surface area and depth to provide a settling time which will produce an effluent with a turbidity meeting water quality standards.

Where not specified in the water quality standards, turbidity in the receiving water due to a discharge should not exceed 50 JTU in warm water streams or estuarine ares or 10 JTU in cold water streams. There should be no discharge to warm water lakes which will cause turbidities exceeding 25 Jackson Units. The turbidity of cold water or oligotrophic lakes should not exceed 10 Jackson Units.

Spoil material containing colloidal or other finely divided particles which are difficult to settle may necessitate the use of two or more ponds in series or coagulant aids such as alum, ferrous salts, or polyelectrolyles. Soil tests to determine soil types and settling characteristics of spoil materials will be required in questionable cases. (See appendix for a typical layout of a settling pond.)

VIII. Retention Mounds

Where used to form a retention basin, by themselves, retention mounds shall be continuous and shall be constructed to completely contain the proposed dredged materials. The design shall provide for structural stability, erosion control and adequate pond capacity to contain the maximum predicted solids plus liquid load without danger of overtopping or structural failure.

Retention mounds shall be constructed of sound fill material which will resist erosion and can be maintained on a relatively steep angle of repose. In general, the retention mounds shall have a minimum crown width of from six (6) to eight (8) feet and side slopes not steeper than two horizontal to one vertical (2 to 1) but shall depend on soil stability and the hydraulic pressure anticipated. It is generally advisable to use a flatter slope on the side of the dike subjected to hydraulic pressure. (Pond side) See appendix for typical cross section.

Retention mounds shall be formed by the use of a dragline or bulldozer wherever practicable; the use of an hydraulic pipeline shall be avoided. Where it is impossible to construct the retention mound in this manner because of terrain or soil conditions, an hydraulic pipeline may be used on submerged land (where approved) to the high water line and completed to design grade by use of a dragline or bulldozer.

Sheet piling may be used in place of a retention mound where it is needed to face off a fill area which would otherwise be subject to erosion. However, if the settled fill is to be placed even with the top of the sheet piling, it may have to be left in an elevated position to allow pool capacity for final settling of fill material or, if driven to final elevation at the beginning of the operation, it will have to be supplemented with a retention mound and overflow weir at the end of the dredging operation.

IX. Inlet Structures

The inlet to the retention basin shall be designed to prevent erosion of the pond bottom and to dispurse flows. A perforated inlet pipe or a solid pipe with a concrete splash block or a stone rubble splash pad may be used effectively. An adjustable inlet pipe which can be adjusted in elevation to enter at or near the water surface will help prevent erosion of the pond bottom.

X. Outlet Structures and Return Water Ditches

Settled water shall be conveyed from the spoil retention--settling basin through outlet structures constructed with plank or other structural material or culvert pipes. Outlet structures shall consist of weirs, drop inlet culverts or rectangular outlet structures, and shall be located so as to minimize flow velocity within the diked spoil area and to assure the maximum settlement of solids. Sheet piling may be used as an outlet structure or weir provided it is left in an elevated position until all fill is in place to allow for proper settling of solids or a supplementary weir and retention mounds may be used for final fill. In general, outlets from settling basins shall be located as remote from the inlet as practicable. Multiple outlets are preferred and shall be separated sufficiently to disperse currents. The height, size and number of outlet structures shall be as shown on the plans. The outlet discharge points shall be protected from scouring and erosion. Waste water return ditches shall be of adequate capacity to discharge the flow from the outlet structures without overrunning the banks of the ditches and shall be protected against erosion and scouring. The invert of the outlet device shall be set at an elevation which will provide sufficient pool capacity to give the retention time necessary to meet water quality standards with the spoil at the maximum fill level. Adjustable weirs may be used which can be elevated as the fill rises, but they shall be set at an elevation which will always give sufficient pool capacity to provide an effluent meeting water quality standards.

XI. Disposal of Spoil in Water

Where the aqueous disposal of spoil material is unavoidable, particular care should be provided to confine the operation within the project area. Spoil piles located in bays, inlets, or other confined water bodies shall be oriented in such a way as to provide minimum obstruction to natural tidal flushing action. Disposal through a submerged discharge pipe or the use of a diaper or enclosure is recommended where lateral drift is a problem. No spoil which contains pollutants in quantities which will cause a violation of the applicable water quality standards shall be disposed of in open water.

Criteria

The decision whether to oppose plans for disposal of dredged spoil in U. S. waters must be made on a case-by-case basis after considering all appropriate factors; including the following:

A. Volume of dredged material.

B. Existing and potential quality and use of the water in the disposal area.

C. Other conditions at the disposal site such as depth and currents.

D. Time of year of disposal (in relation to fish migration and spawning, etc.).

E. Method of disposal and alternatives.

F. Physical, chemical, and biological characteristics of the dredged material.

G. Likely recurrence and total number of disposal requests in a receiving water area.

H. Predicted long and short term effects on receiving water quality.

When concentrations, in sediments, of one or more of the following pollution parameters exceed the limits expressed below, the sediment will be considered polluted in all cases and, therefore, unacceptable for open water disposal.

Sediments in Fresh and Marine Waters	Conc. % (dry wt. basis)
*Volatile Solids	6.0
Chemical Oxygen Demand (C.O.D.)	5.0
Total Kjeldahl Nitrogen	0.10
Oil-Grease	0.15
Mercury	0.0001
Lead	0.005
Zinc	0.005

*When analyzing sediments dredged from marine waters, the following correlation between volatile solids and C.O.D. should be made:

$$T.V.S.\ \%\ (dry) = 1.32 + 0.98(C.O.D.\%)$$

If the results show a significant deviation from this equation, additional samples should be analyzed to insure reliable measurements.

XII. Commercial Sand and Shell Dredging

Commercial sand and shell dredging can be damaging to water supplies, recreational and swimming areas, wildlife, shellfish beds, coral beds and other aquatic biota. In order that commercial sand and shell dredging be carried out with the minimum damage to the environment and water quality values, the EPA recommends that the following guidelines be followed:

A. Sand dredging be prohibited on spawning beds.

B. Shell dredging be prohibited in open shellfish beds.

C. Sand dredging adjacent to coral reefs be done in such a manner that it does not cause damage to the coral. Care be taken not to undermine the edge of the coral reef or cause silting of the coral reef area by lateral drift or silt laden effluent discharges.

D. Sand dredging and screening operations be carried out in such a manner as to prevent the excessive disturbance of silt and other detritus in the watercourse.

E. Where it is necessary to carry on sand dredging operations in streams used for water supply, the dredging operation shall be far enough removed from the intake to allow for complete settling of all solids.

F. Sand be pumped ashore for washing and screening wherever possible.

G. Trailings from washing and screening operations be removed in adequately designed and constructed retention basins or ponds equipped with weirs or by other approved methods which will insure the effective removal of settleable solids.

H. In cases where it is agreed that the dredge is not to pump the sand or the effluent ashore, the effluent discharge pipe be submerged to prevent excessive drift of the silt and to allow it to settle to the general area being dredged.

I. Fans from feeder streams valuable to sport fishing or for fish spawning areas be avoided in dredging operations.

J. Grassy flats and shallow water areas valuable to the fish food chain be avoided in dredging operations.

K. Oil, bilge, garbage or sanitary wastes generated aboard the dredge shall not be discharged to the watercourse. They shall be disposed of in a manner meeting Federal, State and local laws and regulations.

L. Sand dredging shall not be performed where the disturbance of polluted sediments will cause a violation of the water quality standards.

XIII. Dredging Canals or Waterways

In construction projects involving canals and waterways, water quality can frequently be preserved by providing confinement of suspended materials within pools formed within locks, dams, or other flood control structures. In other instances, confinement within a pool can be obtained by the construction of temporary dams or by leaving plugs in the ends of the canal or waterway until excavation has been completed and all sediment has settled out.

XIV. Channelization

Channelization of streams removes the broad flat flood plains, pools, sand and gravel bars, bends and riffles necessary for good fish habitant and food chain organisms indicative of balanced water quality. Spawning areas on shallow river sections are damaged or destroyed with related aquatic biota important to food chain production. Raw banks are exposed to erosion with resultant silting and turbidity. The oxygen regeneration capacity and natural stream purification processes are greatly retarded with a general reduction in water quality values.

XV. Potential Effects of Dredging on Water Quality

The following list is not presented as an all-inclusive summary, but as examples of potential water quality damage which can result from dredging activities.

A. Water Supply

1. Fresh Water Sources

Dredging can add to water treatment costs in the form of sediment removal, taste, odor, and color removal, and conceivably through the removal of toxic residues put insuspension or solution. Furthermore, present water supply treatment methods usually are not designed for the removal of many toxic compounds, which thereby become a hazard to public health. Dredging operations should be kept far enough removed from water intakes so that the water quality is not impaired.

2. Salt Water Sources

Salt water sources are used primarily for industrial cooling water. Where dredging produces sizable quantities of suspended matter, adverse effects in the form of clogged intake screens and heat transfer coils can create a maintenance problem.

B. Bathing, Swimming and Recreation

Damages resulting from dredging in this water-use category relate principally to aesthetic qualities. The presence of high turbidity, scum, sludge, odors, and color which could result from dredging would be aesthetically unacceptable in recreational areas. The public health aspects of water quality damage becomes a problem when toxic, e.g. pesticide compounds are dispersed through disturbance and transport of settled material. In beach nourishment projects where there is a possibility that the sand being dredged is contaminated, tests should be run including fecal coliform count and the results evaluated before allowing the beach to be used.

C. Fish Propagation

Dredging can effect a change in pH or dissolved oxygen as a result of disturbing anaerobic sediments. This action can be detrimental to fish and other aquatic life. Instances have been reported of damage to fish from long-term exposure in highly turbid waters. The potential for exposure to toxic sediments is a possibility in any dredging activity. Perhaps the greatest amount of damage to fish propagation results in damage to members of the fish food chain. Increased color or turbidity can reduce the growth of plankton necessary to the fish food cycle. Siltation can destroy valuable bottom fauna.

D. Shellfish

Studies have shown that a pH less than 7.5 may be detrimental to shellfish growth. Dredging conceivably could effect a lowering of pH as a result of disturbance of acidic deposits. Dredging can also expose a greater amount of deleterious material to the "straining" action of shellfish ingestion. Large amounts of suspended material not needed as food by shellfish can competitively eliminate food material, thus starving the shellfish. The free-swimming larve stage can be caused to settle prematurely in the presence of large concentrations of suspended solids. There is also a great hazard in burying the sedentary adult shellfish form as a result of settling of dredged material. The concentration of heavy metals by shellfish has been well documented and may lead to adverse effects if industrial sludges containing them are resuspended. Copper concentrations can cause greening of the flesh which would adversely affect marketing.

E. Bottom Fauna and Flora

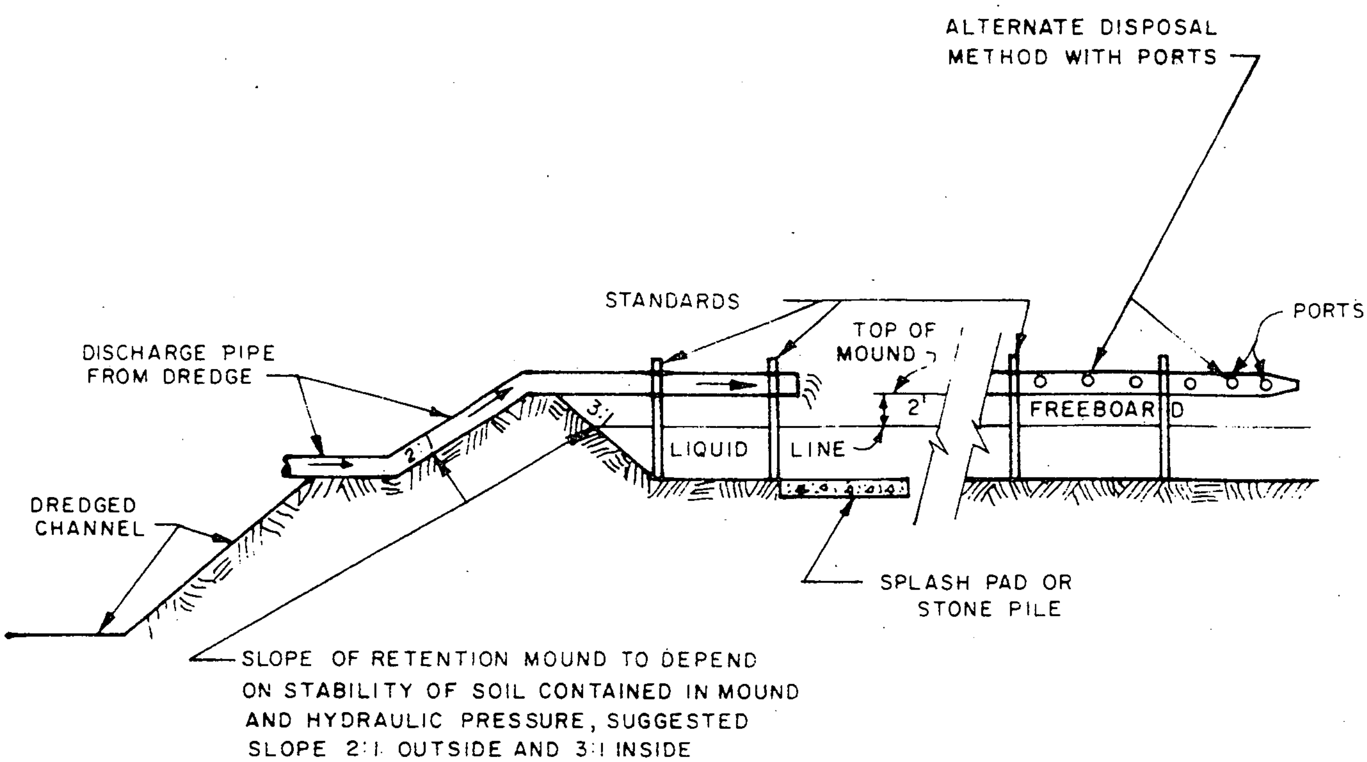
Dredging frequently exposes sterile clays and silts with poor reproductive capacity and growth capabilities. Marine vegetation and organisms necessary to maintain a balanced water quality cannot be sustained in the environment created by low fertility soils because of the physical and/or chemical characteristics of the materials exposed. The increased depth caused by dredging and/or silt, color, turbidity or lack of sufficient sunlight will also eliminate certain types of aquatic vegetation and benthic organisms with a resultant degradation in water quality.

F. Agricultural Water Supply

The resuspending of colloidal and other material in irrigation waters could detrimentally affect soil infiltration rates and damage irrigation equipment through abrasive action. There is also a problem of maintenance in canals related to the deposition of dredged material. Resuspension of contaminated or toxic sludges can poison cattle or fresh vegetable crops used for human consumption

XVI. General Construction including Piers, Bulkheads, Wharves, Submarine Pipelines, Cables, Jetties, Bridges, Dams, Flood Control Structures, etc.

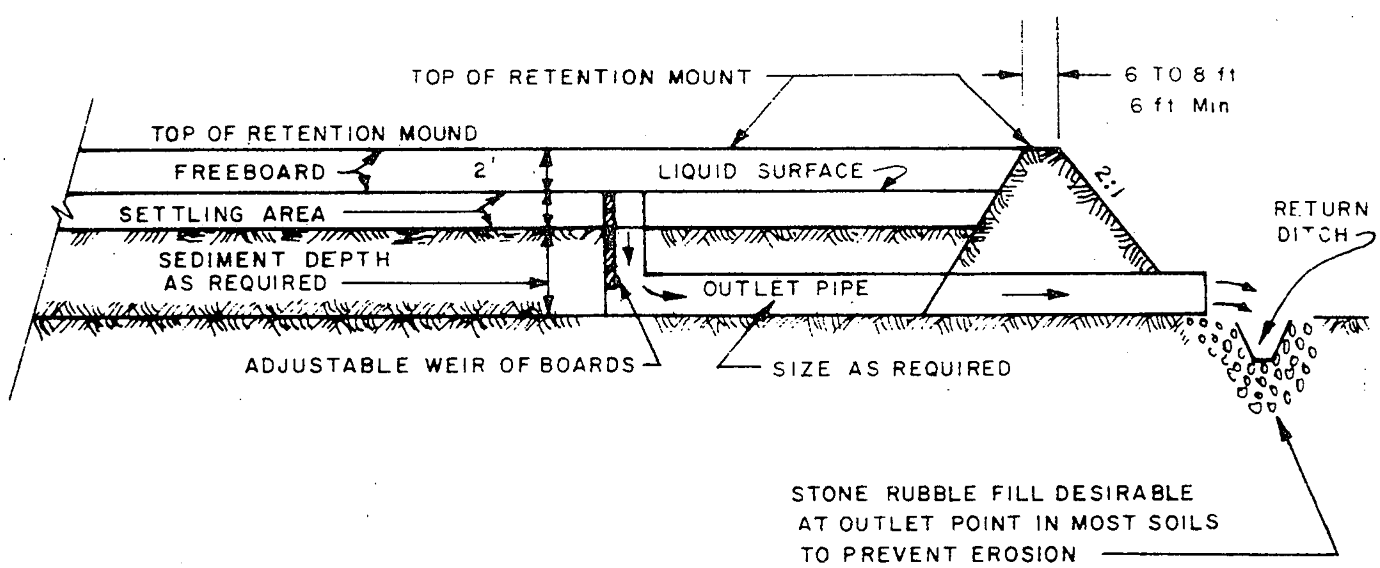
In general the same conditions attributed to dredging apply to the construction of these facilities.



SECTION A – A (INLET)

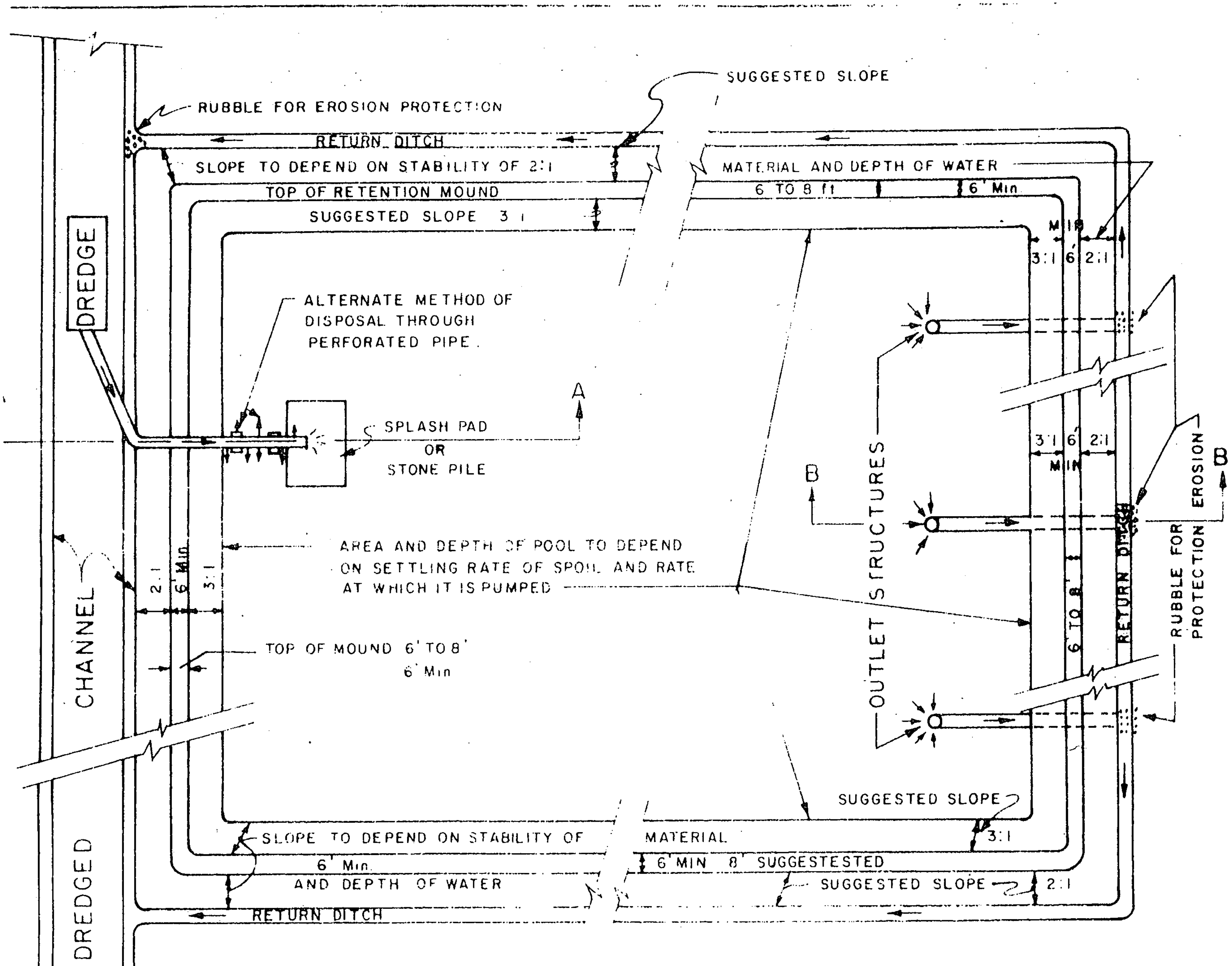
(NO SCALE)

NOTE: PLACE OUTLETS AT OPPOSITE END OF POND FROM INLET.



SECTION B – B (OUTLET)

(NO SCALE)



TYPICAL SPOIL SETTLING POND

(NO SCALE)